Review of Whangamarino Wetland vegetation response to the willow control programme (1999 – 2008)

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K.A. Bodmin
P.D. Champion

NIWA contact/Corresponding author

K.A. Bodmin

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National Institute of Water & Atmospheric Research Ltd
Gate 10, Silverdale Road, Hamilton
P O Box 11115, Hamilton, New Zealand
Phone +64-7-856 7026, Fax +64-7-856 0151
www.niwa.co.nz

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Reviewed by:

F Matheson

Fleur Matheson

Approved for release by:

Mary de Winton

Formatting checked

A. Bartley

Executive Summary

Whangamarino Wetland is one of three nationally important wetlands in the Arawai Kakariki Restoration Programme administered by the Department of Conservation (DOC). DOC has made a considerable investment in aerial control of *Salix fragilis* (crack willow) and *Salix cinerea* (grey willow) over the last ten years, targeting sites where these species have invaded peat bog, sedgeland and riverine areas south of the Whangamarino River. However, the size and ecological impact of willow in Whangamarino Wetland still remains a significant issue. DOC contracted NIWA to undertake a review of the willow control programme in Whangamarino Wetland over the ten year period 1999 – 2008.

Meetings were held with key current and past Waikato Area Office staff of the DOC to gather information on aerial treatment dates, rates of herbicide used and some historical information on wetland vegetation. Site visits were undertaken on 21 May, 2 and 16 June 2009 to sample different wetland vegetation types. Vegetation plots established in 1999 were re-located where possible and new plots established in more recently treated areas. Species presence and percent cover was recorded for each vegetation plot in both treated and untreated areas. Vegetation plots sampled prior to and post aerial spraying provided detailed information on changes to wetland vegetation over time. Vegetation maps of Whangamarino Wetland (1942, 1963, 1977, 1993, 2002 and 2008) were used to determine broad scale changes in willow distribution and areas of willow expansion over time. PRIMER (version 6) was used to conduct a cluster analysis of vegetation for treated and untreated vegetation plot data from 1999, 2006 and 2009. Vegetation types were selected at the 20% similarity margin and used to describe vegetation communities within the Whangamarino Wetland. The contribution individual species made to each vegetation type, and the average similarity within the vegetation type, were calculated using SIMPER (similarity percentage).

Aerial treatment of willow was undertaken by boom spraying of glyphosate at a rate of 9 L / ha from 1999 – 2008. Treatment of *S. fragilis* with glyphosate was very effective with death and collapse of *S. fragilis* forest along the Whangamarino River. Increased water levels since 2000 have waterlogged much of the habitat area previously occupied by *S. fragilis* which was likely to have prevented re-establishment. Vegetation in this area has changed from *S. fragilis* to aquatic vegetation dominated by the native *Persicaria decipiens* and the exotic *Ludwigia peploides* subsp. *montevidensis*. Treatment of *S. cinerea* dominated vegetation with glyphosate resulted in good control although *S. cinerea* had extensively reinvaded treated areas. Considerable non-target damage occurred where aerial boom spraying was used on individual or scattered *S. cinerea* trees, particularly amongst peat bog or fen vegetation. A single 3ha trial of triclopyr triethylene amine (Garlon® 360) was undertaken on 28th February 2008 at a rate of 11 L / ha with poor control due to application late in the season and no surfactant or penetrant was used.

Multivariate statistical analysis (using PRIMER) of vegetation plot data was undertaken on all species present and conducted again with records of both willow species excluded. Results showed there was little difference in the vegetation types after the exclusion of willow data, indicating that willow did not affect vegetation type. Three main wetland types were recognised: fen; periodically inundated swamp (marsh); and semi-permanently inundated swamp. Fen vegetation was characterised by *S. cinerea*, *Osmunda regalis* and *Coprosma tenuicaulis*. Periodically inundated swamp vegetation was comprised of two vegetation types: the first vegetation type was identified by the presence of *Persicaria strigosa*, *P. hydropiper* and *Carex gaudichaudiana*; the second vegetation type was dominated by the invasive species *Bidens frondosa* and the exotic *P. hydropiper*. The flora representative of the semi-permanently inundated swamp vegetation was *P. decipiens* and *Ludwigia peploides* subsp. *montevidensis*. Interestingly, there was a shift in vegetation composition between 1999 and 2009 from periodically inundated species to aquatic species, regardless of whether willow control had occurred. The movement of both treated and untreated plots to a more aquatic composition indicates that there was a change in vegetation regardless of herbicide treatment, and this change was probably related to the response of vegetation to the altered hydrological regime.

Whangamarino Wetland vegetation maps showed broad scale changes in willow distribution and area over time. *Salix fragilis* steadily expanded from 313 ha in 1942 to 825 ha in 1993 when all available riverine habitat was virtually occupied by this species. Expansion of *S. fragilis* largely occurred along the Maramarua and the Whangamarino Rivers and within 500m of the river margins. From 1993 to 2002 *S. fragilis* declined from 825 ha to 550 ha as a result of aerial spraying willow by DOC. Where *S. fragilis* was killed or controlled, the vegetation was replaced by herbaceous vegetation, mostly dominated by the native *Persicaria decipiens* or exotic species. *Salix cinerea* has significantly expanded in Whangamarino Wetland from 36 ha in 1942 to become the dominant willow type covering 1,654 ha in 2002. The expansion of *S. cinerea* has largely occurred on the margins of the wetland, behind the *S. fragilis* river band, in the Reao Arm and along the causeway between Meremere and the Kopuku mine. *Salix cinerea* has not significantly expanded into the raised bog domes, but was present on the margins of fen areas dominated by *Leptospermum scoparium*. *Salix cinerea* would detrimentally modify habitats that support endangered species and rare vegetation community types, such as the *Carex* sedgeland.

When willow control results are compared with management plan priorities and objectives, the value of pursuing a continued widespread *S. cinerea* control programme is questioned as the long-term success is highly unlikely. However, DOC should select and prioritise high value sites within the Whangamarino Wetland at risk of, or in the early stages of, willow invasion. Control should use highly selective methods such as cut and paint, drill and fill or single nozzle spot spraying. Boom spraying is only seen as appropriate when dense canopies of willow occur. *Carex gaudichaudiana* or *C. subdola* sedgeland were identified as key biological values. Protection of this vegetation type has not been achieved due to non-target herbicide damage, an increase in water levels and grazing. A planned monitoring programme should be undertaken pre and post weed control to ensure management actions can be measured and modified to achieve the desired objectives.

1. Introduction

Whangamarino Wetland is one of three nationally important wetlands in the Arawai Kakariki Restoration Programme co-ordinated by the Department of Conservation (DOC). One of the key management objectives for this wetland is to limit weed invasion into raised peat bog and indigenous sedgeland vegetation, and to eradicate weeds from identified areas where indigenous vegetation has the potential to regenerate. DOC has made a considerable investment over the last ten years in aerial control of *Salix fragilis* (crack willow) along riverine areas and *Salix cinerea* (grey willow), targeting invasion into peat bog and sedgeland areas. However, the size and ecological impact of willow in Whangamarino Wetland remains a significant issue.

Before investing in future willow management, it is important to review past willow management. DOC contracted NIWA to undertake a review of the willow control programme in Whangamarino Wetland over the ten year period 1999 – 2008. The review has been split into two associated reports. This report provides:

- an overview of Whangamarino Wetland;
- a summary of previous botanical reports;
- results of vegetation surveys in the willow control area with both treated and untreated vegetation;
- the ecology of willow in Whangamarino Wetland;
- historical changes in distribution of willow;
- an analysis of vegetation types;
- the effect of willow control on wetland vegetation;
- predicted future invasion of willow;
- evaluation of whether the willow control programme has met the goals of the Site Led Weed Management Plan (Reeves, 2001) and other recommendations from subsequent reports; and
- recommendations for future action.

The associated report (Champion & Bodmin, *in prep.*) investigates the impact of nutrients, hydrology, grazing, sediments and other factors on willow and other vegetation communities within Whangamarino Wetland with recommendations for future management.

1.1 Whangamarino Wetland

Whangamarino Wetland lies on the flood plains of the lower Waikato River and is the second largest swamp and bog complex that remains in the North Island of New Zealand (Cromarty, 1996). The Crown is the largest landowner with 4,640 ha in the Whangamarino Wetland Management Reserve and Whangamarino Government Purpose Reserve administered by the Department of Conservation (DOC); the remaining 2,400 ha is freehold land and land administered by Auckland/Waikato Fish and Game Council (Lands and Survey, 1983; Reeves, 2001).

The surrounding catchment is 48,900 ha of rolling and higher hill country which drains into the wetland (Waikato Valley Authority, 1981). The original 10,320 ha wetland has been modified and drained to 6,970 ha (Cromarty, 1996). Land use within the catchment includes pastoral farming of sheep, beef, cattle, pigs and goats, horticulture, viticulture, a quarry on Swan Road and an open cast coal mine at Kopuku with a causeway that connected the mine to the former Meremere Power Station (Waikato Valley Authority, 1981; Cromarty, 1996). Areas of Crown land deemed suitable for grazing are leased although damage to the wetland by stray stock has been noted as a considerable portion of conservation land is not fenced (Cromarty, 1996; Champion, 2003).

The Whangamarino Wetland is comprised of four peat bogs surrounded by more fertile, semi-mineralised and mineralised zones. Soil fertility is lowest in the centre of the raised bogs fed by rain water, with acidic conditions and low nutrients limiting the diversity of plants present. High soil fertility and nutrient rich waters feed the margins of several rivers and streams that flow through the wetland with high productivity and biodiversity for both vegetation and fauna (Waikato Valley Authority, 1981; Clarkson & Stanway, 1994). Whangamarino Wetland was evaluated for agriculture or horticulture development but was instead retained for flood control purposes and other social, economic, cultural and environmental values (Lands and Survey, 1983).

The hydrology of Whangamarino Wetland has been extensively modified since 1961 by the Lower Waikato and Waipa Flood Protection Scheme (Waikato Valley Authority, 1981). Stopbanks and flood gates were constructed upstream of the wetland at Lake Waikare. This involved using Lake Waikare as a storage area for river water when flooding is anticipated from the Waikato River. Water is discharged to Whangamarino Wetland via the Pungarehu Canal (Waikato Valley Authority, 1981). The Waikato River was also dredged and it base level was significantly lowered, and a control structure was also installed at its confluence with the Whangamarino River to prevent back flows into the wetland during flood events (Waikato Valley Authority, 1981). As a result of these modifications, average summer levels of water in the Whangamarino Wetland decreased by up to 1.5 m from 1964 to 1990. A weir was installed on the lower Whangamarino River to raise minimum water levels of the wetland although structural issues required the weir to be reinstated in 2000. Whilst minimum water levels have been increased, low water levels in summer have been constrained and variation in water levels reduced such that DOC is now investigating an ecohydrology model to determine the ecological implications of the altered hydrological regime (Sinclair Knight Merz (SKM), 2010).

Whangamarino Wetland is recognised nationally and internationally (as a Ramsar site) for its significant conservation values. This extensive, lowland freshwater wetland contains peat bog, fen and swamp wetland types, open areas of water and riverine areas. This variety of habitat supports a wide range of flora and fauna species. The Waikato Valley Authority (1981) identified 238 plant species, of which 59% were indigenous. The wetland contains 12 threatened plant species, including the only known population of the orchid *Anzybas carsei* (Wildlands Consultants Ltd, 2009a). Willows were identified as a current threat to *Myriophyllum robustum* and *Cyclosorus interruptus* (Reeves, 2001; Wildlands Consultants Ltd, 2009a). Whangamarino Wetland is also an important habitat for 56 bird species (Ogle & Cheyne, 1981), including rare or threatened species such as Australasian bittern (*Botaurus poiciloptilus*) and large populations of waterfowl; 23 fish species including the endangered black mudfish, *Neochanna diversus*, and invertebrates (Cromarty, 1996; Reeves, 1994).

Introduced mammals include deer (the subject of a recent DOC control programme, K. Hutchinson, pers. comm), possums, ferrets, stoats, weasels, cats, rats, rabbit, sheep and cattle (Cromarty, 1996; Ogle & Cheyne, 1981). The wetland is extensively used for recreational waterfowl hunting, predominantly ducks and swans. Other activities include fishing for eels, mullet and the pest fish koi carp; boating; bird watching; photography and nature appreciation (Cromarty, 1996; Reeves, 1994). Many of these values are under threat from the expansion of willow which would overtop existing vegetation, alter the structure and composition of wetlands thereby changing the available habitat for many species and reducing access for recreational activities.

2. Previous reports

Previous reports on aspects of the Whangamarino Wetland vegetation are summarised in section 2.1 with reports specific to willow invasion summarised in section 2.2 to 2.4. The Whangamarino Wetland 2008 vegetation map produced by Wildlands Consultants Ltd (2009b) was in draft form at the time of this work. The GIS shape files were available but there was no associated report.

2.1 Whangamarino Wetland vegetation communities

Historical information on Whangamarino Wetland vegetation is limited, although a series of vegetation maps were produced from aerial photographs from 1942 to 1993 (Reeves 1994; Reeves & Haskew 2003). The first published vegetation map and complete species list was produced as part of the Waikato Valley Authority's wider study on Whangamarino Wetland in 1981. The study identified 238 plant species (141 indigenous, 97 introduced) and recognised 22 different vegetation types clustered into three main groups: *Salix* dominated; *Leptospermum scoparium*-reed dominated and marginal vegetation. Remnant stands of *Dacrycarpus dacrydioides* were found on the margins of the Maramarua River and other scattered sites. The report concluded that *D. dacrydioides* was historically widespread, covering up to one third of the swamp area, based on the extensive areas with timber layers in peat soil profiles and stumps, trunks or roots found when water levels are low.

The vegetation communities at Whangamarino Wetland, namely peat bog, fen or swamp, are strongly linked to the soil type and hydrological regime. The acidic, low nutrient, peat bog areas have low species diversity but almost all species are indigenous (Reeves 1994). Vegetation is dominated by sedges (*Baumea* species and *Schoenus brevifolius*), the restiad *E. minus*, the shrub *L. scoparium* and the fern *Gleichenia dicarpa* (Waikato Valley Authority, 1981).

Peat bogs are surrounded by less acidic, semi-mineralised swamp areas, also known as fen areas, since the Johnson & Gerbeaux (2004) wetland classification system. These areas receive some nutrients and organic matter from periodic floods which allows them to support peat bog species as well as mineralised swamp species. The fens adjacent to peat bogs were characterised by tall, dense stands of *L. scoparium* (Waikato Valley Authority, 1981), followed by areas of *S. cinerea* associated with sedges (*Baumea* species and *Carex* species), *L. scoparium*, *Cordyline australis*, *Phormium tenax* and *Coprosma* species (Reeves, 1994).

Swamp areas occur on the margins of the wetland and are also associated with the floodplains of the Whangamarino and Maramarua Rivers and Reao Stream. These areas receive high nutrient and organic matter inputs from waterways or regular floods and can be permanently flooded or summer-dry (Ogle & Cheyne, 1981). Swamp areas support high species diversity but also a high number of introduced species and are characterised by a diverse range of plant communities. Dominant species include *S. fragilis*, *S. cinerea*, native sedges (*Carex* species and *Eleocharis* species), herbaceous vegetation (*Persicaria* species, *Ludwigia peploides* subsp. *montevidensis* and *Ranunculus flammula*) and introduced grasses (Reeves, 1994; Waikato Valley Authority, 1981).

Open waterways appear turbid and tea stained from dissolved organic carbon. Submerged vegetation in flowing waters was dominated by the introduced species *Egeria densa* and *Ceratophyllum demersum* with margins fringed by mats of introduced *L. peploides* subsp. *montevidensis* and *Myriophyllum aquaticum.* Permanently still open water bodies were dominated by several native submerged species (*Nitella* species, *Myriophyllum propinquum* and *Potamogeton* species) with semi-emergent, marginal vegetation dominated by *Ludwigia* species, *Typha orientalis*, *Eleocharis* species and the introduced grass *Glyceria maxima.* The free floating *Azolla* species, *Lemna minor*, *Landoltia punctata* and *Wolffia australiana* occurred in wind sheltered waters (Cromarty, 1996; Reeves, 1994; Waikato Valley Authority, 1981).

2.2 Whangamarino River northern bank transects (Champion, 2006)

Three transects were sampled on the northern bank of the Whangamarino River, near the confluence with the Reao Stream in 2006 as part of a wider study on *Osmunda regalis* in the Lower Waikato. Each 2 m wide belt transect was partitioned into different vegetation types, with the percent cover and height of component species recorded for each type. The vegetation was dominated by the introduced weed species *O. regalis* and *S. cinerea* with native species, *L. scoparium,* contributing to the canopy with a native subcanopy of *Baumea rubiginosa* and *G. dicarpa*. Champion (2006) concluded that *O. regalis* had wide ecological amplitude across mineralised and peat soils. This introduced fern also occurred as a significant or dominant part of the understorey of *S. cinerea* or *L. scoparium* vegetation and colonised disturbed peatland, but did not appear to invade unmodified, restiad bog vegetation or eutrophic, riverine wetlands dominated by *S. fragilis*, or the introduced aquatic reed grasses *G. maxima* and *Phalaris arundinacea*.

2.3 Vegetation monitoring 1993 to 2003 (Reeves, 2003)

Three permanent vegetation transect lines were established along the Whangamarino River in 1993, prior to the construction of a weir in the Whangamarino Wetland. The transect lines incorporated the three different wetland types of Whangamarino Wetland; swamp, fen and peat bog. Plots were established within each transect with species and percentage cover recorded for each plot. The initial rock weir was constructed in April 1994 with transects resurveyed in December 1994 to monitor change in vegetation as a result of increased minimum water levels. The weir was scoured out in April 1995 which reduced minimum water levels. Transects were resurveyed in March 1998, prior to remedial work on the weir, and again in March 2003.

When the weir was in operation, vegetation composition and cover showed an increase in introduced aquatic emergent species (such as *R. flammula*, *Alisma plantago-aquatica* and *M. aquaticum*), a decrease or loss of species that prefer drier conditions (such as *Leontodon taraxicoides*, *Trifolium pratense* and *Crepis capillaris*), an increase of native *Carex gaudichaudiana* and *C. subdola* in the sedgeland area and an increase in invasive weeds that threatened the wetland; *G. maxima*, *P. arundinacea*, *O. regalis* and *S. cinerea*. Once the weir was eroded, aquatic species declined but the invasive species *O. regalis* and *S. cinerea* increased (Reeves, 2003).

An overall comparison of 2003 data with pre-weir data showed cover of native species increased and the number of introduced species declined across all three wetland types. Changes in minimum water levels affected mineralised swamp plots the most, particularly since all plots remained submerged from 2000. Vegetation remained dominated by exotic species but there was an increase in cover of native floating aquatic plants (*Azolla rubra*, *L. minor*, *W. australiana*) and the native *Persicaria decipiens* rather than the sedges that once characterised this area. The permanently wet conditions prevented many annual species from germinating although the conditions may have favoured the introduced aquatic reed grasses *G. maxima* and *P. arundinacea*.

Changes in the fen were similar to those in the swamp. The most notable change was the increase in cover of *O. regalis* in plots exposed to short periods of flooding since the weir instalment, and an increase in cover of *S. cinerea*. The decline in species diversity and loss of all introduced species in peat bog vegetation was attributed to the ongoing recovery of this area from a cool burn fire in 1989 and not to water level changes.

Reeves (2003) recommended monitoring transects at three-yearly intervals to identify vegetation changes that resulted from an altered hydrological regime. To our knowledge, no further monitoring of these transects has occurred.

2.4 Sedge restoration monitoring (Champion annual reports 1999 to 2003)

In 1999, 8 plots were established in the ‘Reao sedgeland area’; that is the area bounded by the Whangamarino River and the Reao Stream (Champion, 1999). Within the area to be treated two plots were established in each of the three following vegetation types: *S. cinerea* in sedgeland; *S. fragilis*; and sedgeland dominated vegetation. An additional two plots were also established in untreated sedgeland. For each plot the species present and percent cover was recorded prior to aerial spraying of willows and at least annually monitored until 2003.

Overall, aerial application of glyphosate in 1999 and follow up applications provided “excellent control of both willow species” with complete collapse of the *S. fragilis* forest within 3 years and only isolated *S. cinerea* trees remained alive (Champion, 2003). Vegetation within the treated areas was impacted by herbicide application with sedge species within the plots in particular reduced in average cover from 50% in 1999 prior to aerial spraying, to 15% in 2000 and had disappeared by 2001 (Champion, 2003). However, a reduction in sedge cover was noted in the untreated plots from 78% in 1999 to 6% in 2003 and vegetation in both the treated and untreated plots altered to become dominated by aquatic species, predominantly the native *P. decipiens* and the introduced *M. aquaticum*, *L. peploides* subsp. *montevidensis, Azolla pinnata* and *Ludwigia palustris* (Champion, 2003).

The change from sedgeland to aquatic emergent vegetation was concluded to be from herbicide damage (treated area) compounded by increased water level following the construction of the Whangamarino weir in 2000 and the impacts of grazing (Champion, 2003). Champion (2003) recommended an altered monitoring programme whereby annual low-level aerial photographs and ground truthing be used to assess changes in wetland vegetation and the extent of the sedgeland.

3. Methods

A holistic approach was taken to evaluate changes in wetland vegetation since the commencement of DOC's aerial spray programme in 1999. This included collating information from a series of vegetation maps.

3.1 Time series vegetation maps

Vegetation maps that covered the entire Whangamarino Wetland showed broad scale changes in willow distribution and area over time. Whangamarino Wetland vegetation maps for 1942, 1963, 1977 and 1993 were created from historical aerial photographs by Reeves (1994), a 2002 vegetation map supplied by DOC and a 2008 vegetation map by Wildlands Consultants Ltd (2009b).

3.2 DOC staff interview

Meetings were held with DOC Waikato Area staff Shannon Patterson and Rachel Kelleher (13 May 2009) and Kevin Hutchinson (30 June 2009). Information gathered from staff included a map of the Whangamarino Wetland with willow areas and aerial treatment dates identified from 1999 – 2008, rates of herbicide used and some historical information on wetland vegetation.

3.3 Previously collected data

An aerial spray monitoring programme was set up as part of the willow control programme from 1999 but ceased in 2003. General vegetation monitoring information was available in previous NIWA reports by Reeves (1994, 2003) and Champion (2003, 2006).

Vegetation monitoring data did not focus on the kill rate of willow but rather the changes in vegetation composition over time at different spatial scales. Vegetation plots sampled prior to and post aerial spraying provided detailed information on changes to treated and untreated vegetation over time.

Raw vegetation plot data from previous NIWA reports (Champion, 1999; Champion, 2006) was used to ascertain vegetation cover prior to aerial spray treatment and was also used in data analysis. Plots established by Champion (1999) were of three different sizes: 2 m * 2 m for *Carex* species; 5 m * 5 m for *S. cinerea* and 10 m * 10 m for *S. fragilis*. For each plot the species present and percent cover were recorded. The three transects sampled by Champion (2006) were 2 m wide belt transects sampled through different vegetation zones. These transects were outside of the area where willow control was undertaken. For each belt transect the vegetation types were discerned and percent cover for each species recorded for each vegetation type.

3.4 Site visits

A helicopter was used on 15 April 2009 to gain an overview of Whangamarino Wetland and the aerially treated willow sites. The helicopter was disembarked at two sites to examine spot treatment of willow, non-target damage and plant regeneration in bog vegetation not otherwise sampled in this study (Fig 1).

Site visits were undertaken on 21 May, 2 and 16 June 2009 at different wetland vegetation types south of the Whangamarino River. Historical locations of 1999 vegetation plots were re-located where possible and new 10 m * 10 m plots established in more recently treated areas. Species presence and percent cover was recorded for each vegetation plot. Vegetation classifications were based on categories used by Reeves & Haskew (2003). Modifications made included distinguishing two subcategories for seasonal adventives and grasses (*P. decipiens* and grassland); and two new categories (swamp coprosma shrubland and herbicide damaged fen). Sites visited are shown in Figure 1.

3.5 Analysis of data

Broad scale changes in willow dominated vegetation at Whangamarino Wetland were examined by overlaying GIS shape files for the 2008 vegetation map (Wildlands Consultants Ltd, 2009b) onto a 2007 aerial photograph (supplied by DOC) and the shape files from a series of vegetation maps (1942, 1963, 1977, 1993) created from historical aerial photographs (Reeves, 1994; Reeves & Haskew, 2003) and shape files for the 2002 vegetation map supplied by DOC. Willow expansion was illustrated by identifying willow occupied areas in a vegetation map, such as 1963, overlaying GIS shape files for the preceding vegetation map (1942) and erasing the common areas occupied by willow.

Changes in vegetation were examined for treated versus untreated plots (a total of 6 plots). The aim was to compare historical data with 2009 data using a paired t-test, sign or rank test. However, the small sample size and variability in the data limited this approach. Descriptive analysis of the change in native/exotic species and abundance of dominant species was therefore utilised.

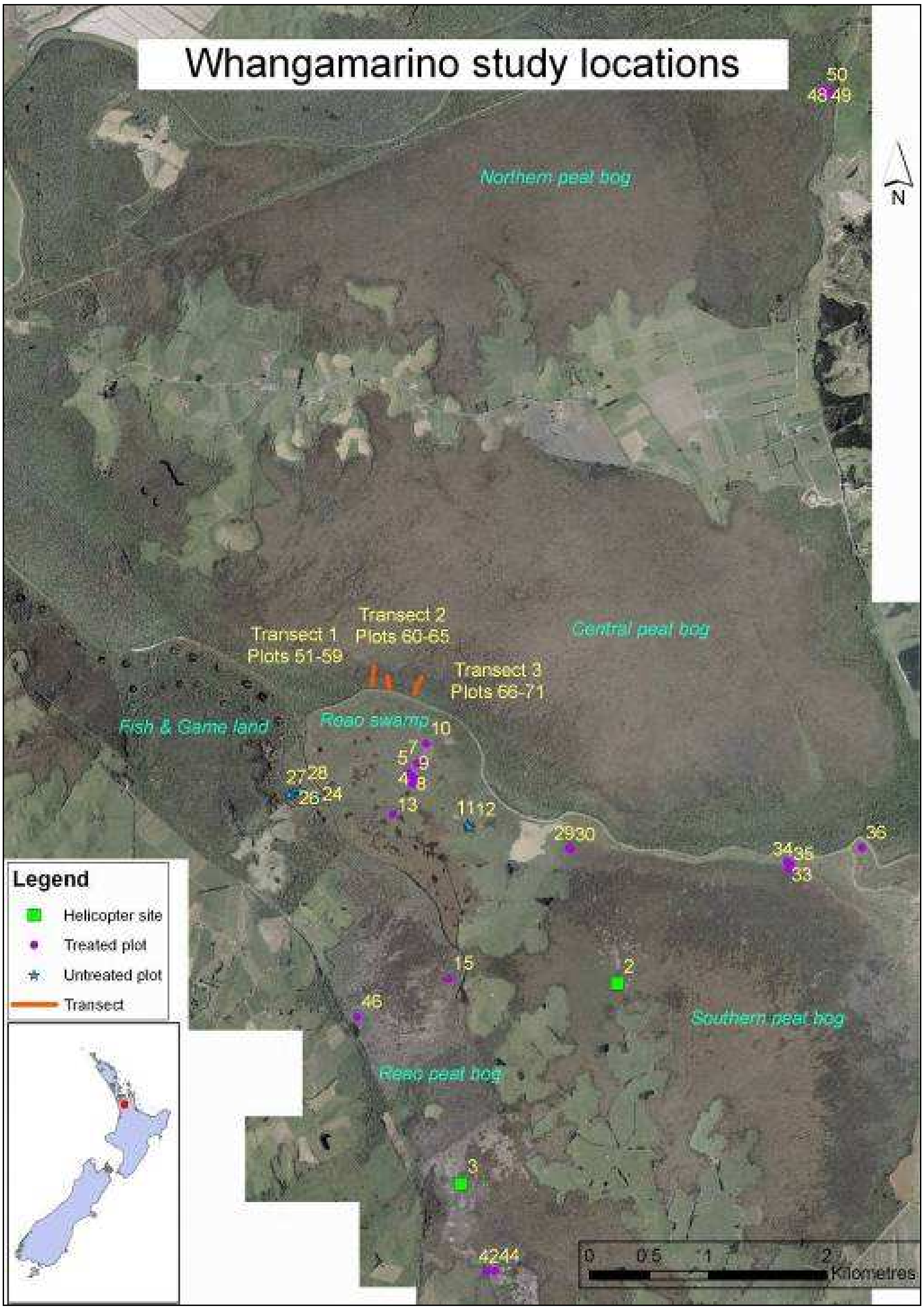

Figure 1: Location of vegetation transects (orange line), vegetation plots (purple circle treated, blue star untreated) and helicopter overview sites (green square) within Whangamarino Wetland in 2009. Historical vegetation plots relocated were plot numbers 4-9, 11, 12, and 51-71. All other plot numbers were vegetation plots established in 2009.

The multivariate statistics software program PRIMER (Clarke & Gorley, 2006) was used to conduct a cluster analysis based on Bray-Curtis similarity for treated and untreated vegetation plot data from 1999, 2006 and 2009. Two analyses were conducted; the first contained percent cover for all species; the second excluded willow data to determine the effect of willow on the vegetation composition of Whangamarino Wetland. The results of these analyses were presented as two dendrograms. Vegetation types were selected at the 20% similarity margin and used to describe vegetation communities within Whangamarino Wetland. The contribution individual species made to each vegetation type (community), and the average similarity within that vegetation type, was calculated using SIMPER (similarity percentage).

4. Results

The results section contains six parts: aerial spray programme (section 4.1); site descriptions for untreated and treated vegetation plots visited in 2009 (section 4.2); vegetation descriptions for helicopter accessed locations of treated sites (section 4.3); a time series of vegetation maps that show the distribution of increases in willow area from 1942 to 2008 (section 4.4); and PRIMER analysis of vegetation changes using vegetation plot data from 1999, 2006 and 2009 (section 4.5). All photographs in this section were taken in April (aerial), May or June (ground based) of 2009.

4.1 Aerial spray programme for *Salix* species

Figure 2 illustrates the areas and years where the DOC has undertaken aerial treatment of willow dominated vegetation in Whangamarino Wetland from 1999 through to 2007. Both *S. fragilis* and *S. cinerea* were aerially sprayed by helicopter. From 1999 to 2007 all treatments used glyphosate at a rate of 9 L / ha. On 28th February 2008 there was a single trial on a 3 ha site of willow adjacent to Coalfields Road where Garlon® 360 (active ingredient is triclopyr triethylene amine) was used at a rate of 11 L / ha. No further willow control has occurred since February 2008 and the results of this report will help inform the future control programme.

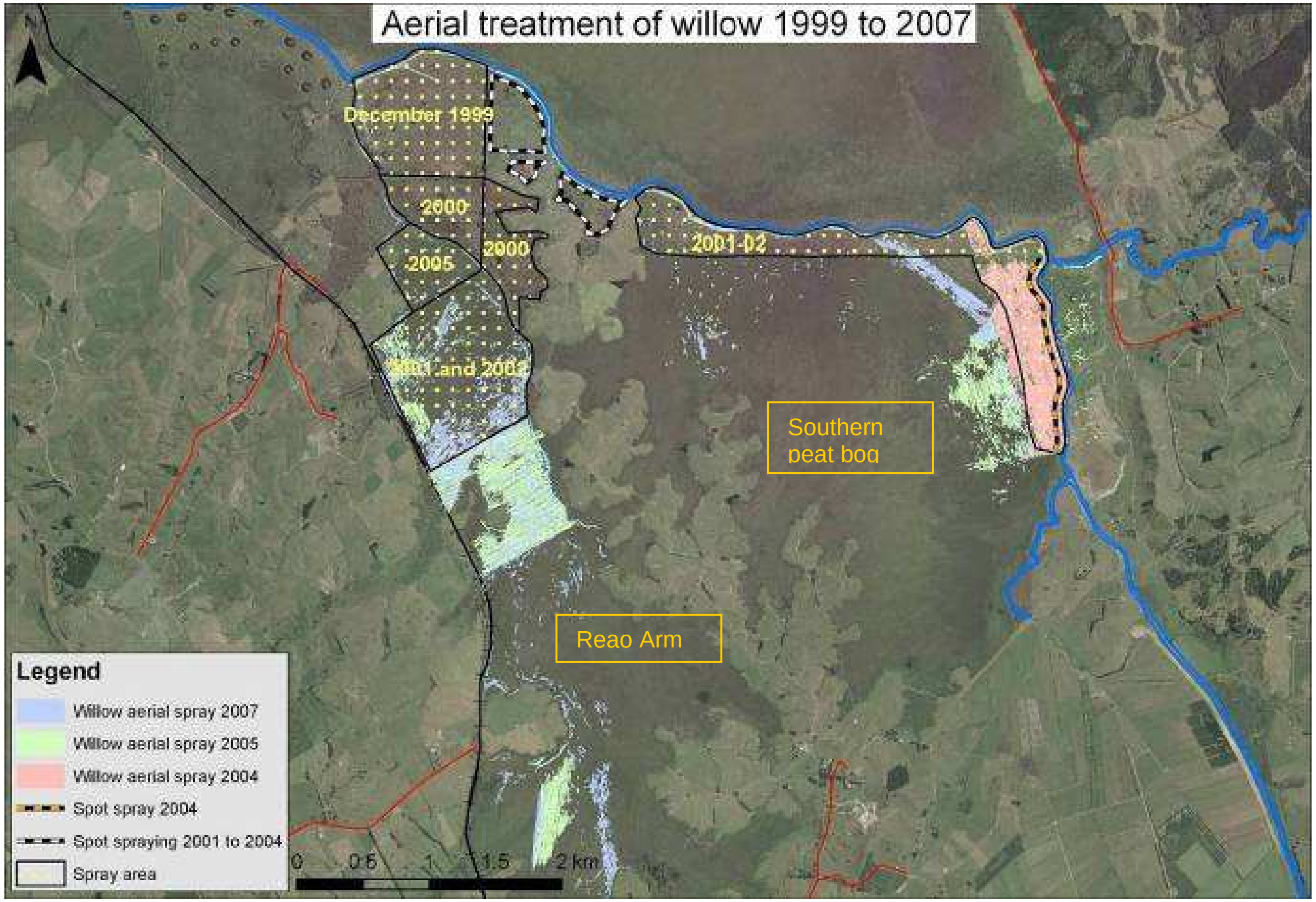

Figure 2: Aerial treatment of willows by the Department of Conservation within Whangamarino Wetland from 1999 to 2007. Flight paths for aerial spraying are shown for 2004, 2005 and 2007.

Figures 3 – 6 illustrate effective aerial application of glyphosate on *S. cinerea* with no damage to immediately adjacent or understorey vegetation. Figure 7 illustrates effective aerial application of glyphosate on *S. fragilis* with complete collapse of the forest. Control of *S. cinerea* by aerial application of triclopyr triethylene amine was patchy with live *S. cinerea* and winter die-back of *O. regalis* visible through standing dead *S. cinerea* (Figure 8).

Regrowth and reinvasion of *S. cinerea* 2 to 4 years after aerial treatment with glyphosate was evident in both the *Carex* sedgeland and fen areas (Figures 9 & 10) with extensive damage to non-target species in fen and bog areas (Figures 11 & 12).

Figure 3: A clear line of dead *Salix cinerea* is evident from aerial treatment. The relatively sharp line between dead and live *S. cinerea* indicates little spray drift occurred.

Figure 4: A clump of dead *Salix cinerea* (white trees) from aerial treatment with glyphosate. Vegetation immediately adjacent to *S. cinerea* remained unaffected.

Figure 5: Dead *Salix cinerea* (white trees) indicate effective aerial treatment with a healthy understorey of *Carex secta* visible.

Figure 6: Dead *Salix cinerea* (white trees) indicate effective aerial treatment with glyphosate. The green understorey visible was healthy fen vegetation with some reinvasion of *S. cinerea* since the 2005 treatment.

Figure 7: Effective aerial application of glyphosate on *Salix fragilis* with complete collapse of the forest (right) with untreated *S. fragilis* (left) on the Whangamarino River.

Figure 8: Winter die-back of the introduced *Osmunda regalis* (red-brown understorey vegetation) was visible through patchy control of *Salix cinerea* by aerial application of triclopyr triethylene amine.

Figure 9: Aerial treatment of *Salix cinerea* (background) with glyphosate was undertaken about 2005, however, live trees and regrowth is evident. The foreground was an untreated area on the Reao Arm and an example of the *Carex subdola* sedgeland under threat from *S. cinerea* invasion.

Figure 10: Reinvasion of *Salix cinerea* (fen area, Reao Arm) approximately 4 years after aerial treatment with glyphosate.

Figure 11: Extensive damage or death of non-target species *Empodisma minus* and *Leptospermum scoparium* (brown and grey vegetation) surround the target *Salix cinerea* (white dead tree, indicated by a pink arrow) in a bog area after aerial treatment with glyphosate in 2007.

Figure 12: Aerial treatment of *Salix cinerea* (white dead trees) also killed the surrounding *Leptospermum scoparium* and created an opening in the vegetation canopy area after aerial treatment with glyphosate in 2005 or 2007.

4.2 2009 site descriptions for untreated and treated areas

Vegetation types have been separated into treated and untreated areas and summarised below, with full descriptions, including percent cover of species recorded in each plot, found in Appendix 1.

Three different vegetation types were identified from six plots sampled in untreated areas of Whangamarino Wetland (Table 1). Seasonal adventives and grasses were dominated by the native herb *P. decipiens* and the exotic herb *L. peploides* var. *montevidensis* (Fig. 13). The sedgeland was dominated by the native *C. subdola* (Fig. 14) and the shrubland was dominated by the exotic *S. cinerea* with an understorey of the native *P. decipiens* (Fig. 15).

The areas where willow control occurred were treated with either triclopyr triethylene amine (plots 48 – 50) or glyphosate (all other plots listed). Four different vegetation types were identified from 21 plots sampled in areas where control of willow occurred in Whangamarino Wetland (Table 2).

The seasonal adventives and grasses vegetation type had four dominant species that occupied different parts of the wetland. The exotic herb *Apium nodiflorum* only occurred at one site at the end of Black Road, east of the railway line, where it was a monoculture (Fig. 16). The area west of Pungarehu Canal was frequently dominated by the exotic herb *Bidens frondosa*, an annual herb dead at the time of survey, associated with high covers of the native herb *Persicaria hydropiper* (Fig. 17) with smaller areas dominated by the exotic grass *P. arundinacea* (Fig. 18). The wetter areas were dominated by the native herb *P. decipiens* and to a much lesser extent the exotic herb *L. peploides* var. *montevidensis* (Fig. 19).

The sedgeland vegetation type had three dominant species that occupied different parts of the wetland. The margins of the Northern peat bog near Coalfields Road were dominated by the native *Baumea arthrophylla*, in association with the native *Coprosma tenuicaulis* and the exotic *S. cinerea* (Fig. 20). Swamp areas to the south of Whangamarino River were dominated by very high covers of the native *Bolboschoenus fluviatilis* (Fig. 21) or the native *Carex secta* (Fig. 22).

The shrubland vegetation type had two dominant species that occupied different parts of the wetland. The native *C. tenuicaulis* dominated parts of the shrubland on the margins of the Reao and Southern peat bogs in association with *L. scoparium* and *B. rubiginosa* (Figs. 23 & 24). The margins of the Northern peat bog near Coalfields Road were dominated by the exotic *S. cinerea* in association with the exotic *O. regalis* in winter die back at the time of survey.

The herbicide damaged fen margins (Appendix 1, 9.2.7) were dominated by open areas of ponded water, dead vegetation from aerial treatment, and a highly diverse but low cover of rushes, grasses, sedges and herb species (referred to as 'swamp meadow' by Reeves, 1999). The native grass *Isachne globosa* and introduced rush *Juncus bulbosus* had the highest vegetation cover of 8% each (Fig. 25). The herbicide damaged fen margins were not included in Table 2 as the cover abundance of plant species did meet the 15% cover threshold.

Table 1: Vegetation types based on average cover abundance (≥15%, rounded to the nearest whole number) in untreated areas. * = exotic species.

Species	Vegetation type and average cover abundance (%)			Plot numbers	Photograph (Figure)	Appendix 1 reference
	Seasonal adventives & grasses	Sedgeland	Shrubland			
Carex subdola		68		24, 28	14	9.1.2
* *Ludwigia peploides var. montevidensis*	26					
* *Myriophyllum aquaticum*			15			
Persicaria decipiens	37		35	11, 12	13	9.1.1
* *Salix cinerea*			40	26, 27	15	9.1.3

Table 2: Vegetation types based on average cover abundance (≥15%, rounded to the nearest whole number) in areas where willow control had occurred. * = exotic species.

Species	Vegetation type and average cover abundance (%)									Plot numbers	Photograph (Figure)	Appendix 1 reference
	Seasonal adventives & grasses				Sedgeland			Shrubland				
	1	2	3	4	1	2	3	1	2			
* *Apium nodiflorum*	95									46	16	9.2.1
Baumea arthrophylla					50					50	20	9.2.4
Baumea rubiginosa								20		15, 29, 30		9.2.5
* *Bidens frondosa* (dead)		53								34, 35	17	9.2.1
Bolboschoenus fluviatilis						95				10	21	9.2.4
Carex secta							50			44	22	9.2.4
Coprosma tenuicaulis					25					50		9.2.4
								57		15, 29, 30	23, 24	9.2.5
* *Ludwigia peploides* var. *montevidensis*				18						4 – 9, 13, 36		9.2.3

Species	**Vegetation type and average cover abundance (%)**									**Plot numbers**	**Photograph (Figure)**	**Appendix 1 reference**
	Seasonal adventives & grasses				**Sedgeland**			**Shrubland**				
	1	**2**	**3**	**4**	**1**	**2**	**3**	**1**	**2**			
Leptospermum scoparium								28		15, 29, 30	23, 24	9.2.5
* *Osmunda regalis* (dead)									70	48, 49		9.2.6
Persicaria decipiens				68						4 – 9, 13, 36	13, 19	9.2.3
* *Persicaria hydropiper*		40								34, 35	17	9.2.1
* *Phalaris arundinacea*			90							33	18	9.2.2
* *Salix cinerea*					20					50	20	9.2.4
									90	48, 49		9.2.6

Figure 13: The native swamp willow weed *Persicaria decipiens* was the dominant species in a sprawling emergent herb area with water approximately 0.6 m deep.

Figure 14: *Carex subdola* was the dominant species in a native sedgeland interspersed with the introduced willow weed *Persicaria strigosa*.

Figure 15: The introduced species *Salix cinerea* (deciduous in autumn / winter) and *Persicaria decipiens* were the dominant species in these untreated plots.

Figure 16: The introduced emergent herb *Apium nodiflorum* was the dominant species in the treated plot 46 with dead crack willow stems still evident.

Figure 17: The introduced emergent herbs *Bidens frondosa* (in seasonal dieback) and *Persicaria hydropiper* were the dominant species in the treated plots 34 and 35.

Figure 18: The introduced grass *Phalaris arundinacea* dominated wetland in plot 33.

Figure 19: The native emergent herb *Persicaria decipiens* was the dominant species in the treated plots 4 - 9.

Figure 20: The native sedge *Baumea arthrophylla* dominated wetland of plot 50 under a canopy of dead willow.

Figure 21: The native sedge *Bolboschoenus fluviatilis* dominated wetland (midground) was a dense sward of vegetation.

Figure 22: The native sedge *Carex secta* dominated wetland of plot 40.

Figure 23: Dense native shrub vegetation dominated by *Leptospermum scoparium* and *Coprosma tenuicaulis* in plot 30.

Figure 24: Dense native shrub vegetation dominated by *Coprosma tenuicaulis* in plot 15.

Figure 25: A matrix of swamp meadow species and open water. The dead vegetation includes willow (centre) but also lower stature native manuka and sedges.

4.3 Site descriptions for helicopter accessed locations

Helicopter access allowed investigation of aerially treated locations in the Southern and Reao peat bogs. No plots were established, but vegetative descriptions of the treated sites and surrounding areas were made.

4.3.1 Southern peat bog

Helicopter access allowed investigation of an aerially sprayed site in the southern peat bog (Site 2, Fig. 1). The site, treated in 2007, was an extensive area of dead native vegetation surrounding the target *S. cinerea* (Fig. 26). *G. dicarpa* and *E. minus*, which previously dominated the site, had approximately 1% regrowth present. Adjacent vegetation surrounding the treated site was dominated by 1.5 – 2 m tall *L. scoparium*, *C. tenuicaulis* and *P. tenax* with native ferns *Blechnum novae-zelandiae*, *Histiopteris incisa* and *Hypolepis distans*, native herbs *Lobelia anceps*, *Dianella haematica*, *Nertera scapanioides*, the native rush *Juncus planifolius* and introduced herbs *B. frondosa*, *Senecio bipinnatisectus*, *Erechtites valerianifolia*, *Epilobium ciliatum*, *Cirsium arvense*, the introduced rush *Juncus effusus* var. *effusus* and seedlings of the introduced *S. cinerea* (Fig. 27 & 28).

Figure 26: Southern peat bog site treated in 2007 dominated by dead native non-target species *Empodisma minus* and *Gleichenia dicarpa* vegetation with a small amount of regrowth of both species present.

Figures 27 & 28: Live vegetation surrounding the 2007 treated site was dominated by *Leptospermum scoparium* (top) and *Coprosma tenuicaulis* (bottom).

4.3.2 Reao peat bog

Helicopter access was used to investigate an aerially sprayed site in the Reao peat bog area (Site 5, Fig. 1). The site, treated in 2007, had some non-target damage to vegetation surrounding *S. cinerea* and degradation of exposed peat (Fig. 29). Vegetation surrounding the treated site was dominated by the native sedge *Baumea teretifolia* with native herbs *Hydrocotyle pterocarpa*, *Eleocharis gracilis*, *Triglochin striata*, *N. scapanioides*, native ferns *Pteridium esculentum H. incisa*, *Hypolepis distans* and *B. novae-zelandiae*, the native rush *J. planifolius*, native sedges *B. rubiginosa* and *Carex virgata*, native flax *P. tenax* the introduced herbs *E. ciliatum* and the introduced fern *O. regalis* (Fig. 30 & 31). Seedlings of the introduced *S. cinerea* had colonised the treated site along with seedlings of the native shrub species *C. tenuicaulis* and seedlings and saplings of *L. scoparium*.

Figure 29: Dead non-target vegetation treated in 2007 at the Reao peat bog with degradation of exposed peat (dark areas), seedlings of the introduced *Salix cinerea* and native seedlings *Leptospermum scoparium* and *Coprosma tenuicaulis*.

Figure 30: Ground cover native herbs *Hydrocotyle pterocarpa* (round leaf) and *Triglochin striata* (green and red stems) in the open areas of the Reao peat bog site treated in 2007.

Figure 31: The introduced fern *Osmunda regalis* (pink arrow) established amongst *Baumea teretifolia* and dead vegetation of the Reao peat bog site treated in 2007.

4.4 Vegetation maps and willow spread from 1942 to 2008

Maps depicting *S. fragilis* and *S. cinerea* dominated vegetation are presented in Appendix 2. Figures 32 – 36 illustrate those areas where willow dominated vegetation had expanded (areas of willow contraction are not shown) in Whangamarino Wetland from 1942 through to 2008. Table 3 presents the number of hectares occupied by willow while Figure 37 illustrates the changes in area occupied by *S. fragilis, S. cinerea* and total willow dominated vegetation from 1942 to 2008. The category 'open willow over seasonal adventives and grasses' was not included in Figure 37 as this vegetation type was interpreted as herbaceous with scattered willow present, but no longer a significant influence on other vegetation. The hectares for the 'open willow over seasonal adventives and grasses' were included in the total number of willow hectares in Figure 37. The 1999 area for *S. fragilis* was not available but estimated to be the same area as 1992, prior to the commencement of aerial spraying.

From 1942 to 1993 *S. fragilis* steadily expanded in Whangamarino Wetland from 313 ha to 825 ha. The expansion of *S. fragilis* willow largely occurred along both the Maramarua and the Whangamarino Rivers, within 500m of the river margins. The most rapid expansion period was from 1963 to 1977. From 1993 to 2008 the rate of *S. fragilis* spread declined. During this period the extent of *S. fragilis* increased along the Maramarua River, downstream of its confluence with the Whangamarino River, and on the western margin of Pungarehu Stream. From 1993 to 2002 there has been a decline in *S. fragilis* willow from 825 ha to 550 ha following the instigation of aerial spraying for willow control by DOC.

From 1942 to 2008 *S. cinerea* has significantly expanded in Whangamarino Wetland from 36 ha to become the dominant willow type covering 1,654 ha in 2002. The expansion of *S. cinerea* has largely occurred on the margins of the wetland, the northern sides of the Whangamarino and Maramarua Rivers behind the *S. fragilis* band, along the Reao Arm between the railway line and the Reao Stream, and along the causeway between Meremere and the Kopuku mine. The periods of most rapid increase were from 1963 to 1977 and from 1993 to 2002.

Further decline (102 ha) in total willow area occurred from 2002 to 2008 however the reduction in hectares of either *S. fragilis* or *S. cinerea* over this period is difficult to identify as selected areas of both *S. fragilis* and *S. cinerea* have been amalgamated into a new vegetation category 'open willow over seasonal adventives and grasses' used in the 2008 vegetation map (Wildlands Consultants Ltd, 2009b).

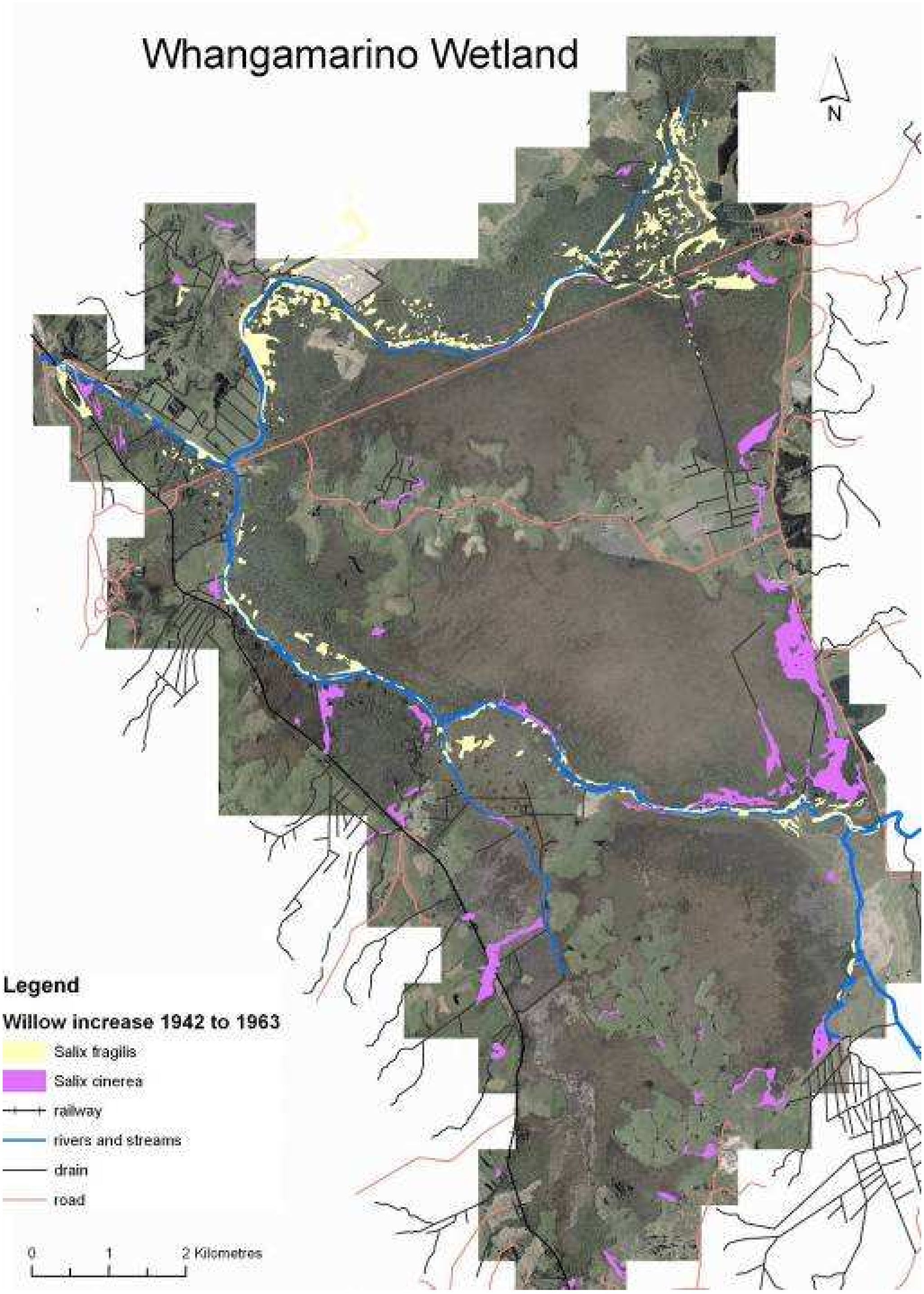

Figure 32: Areas within Whangamarino Wetland where willow dominated vegetation expanded from 1942 to 1963.

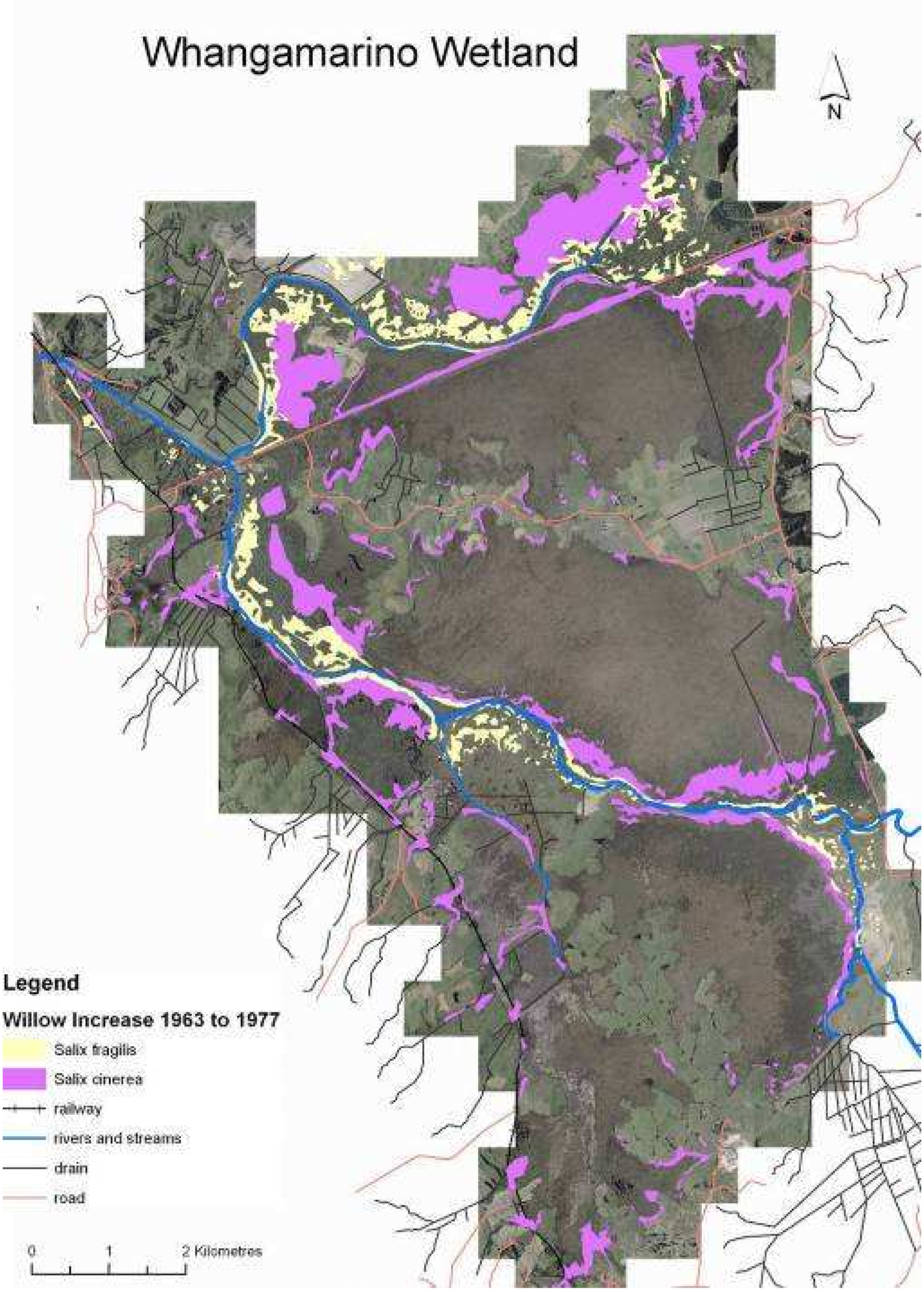

Figure 33: Areas within Whangamarino Wetland where willow dominated vegetation expanded from 1963 to 1977.

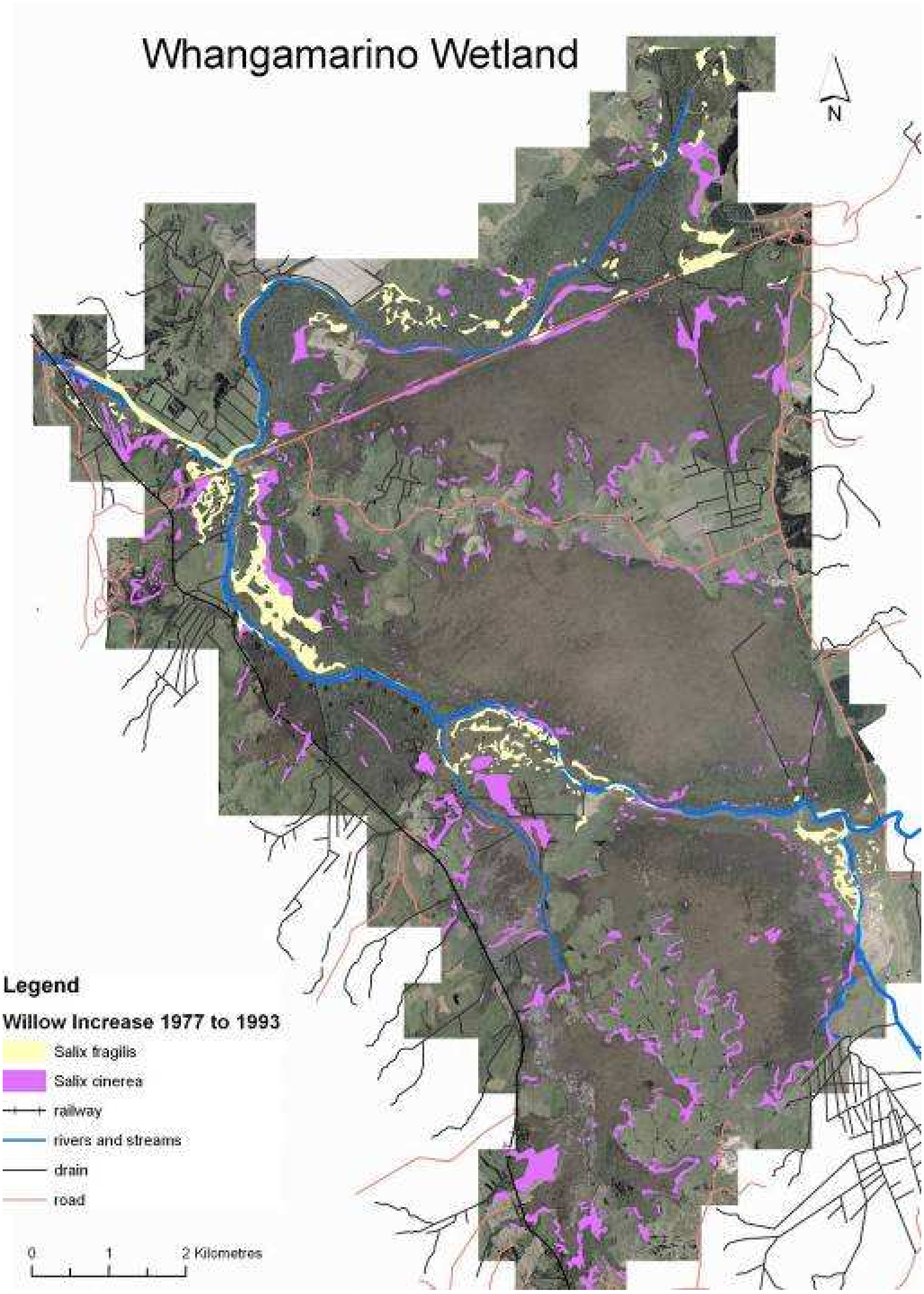

Figure 34: Areas within Whangamarino Wetland where willow dominated vegetation expanded from 1977 to 1993.

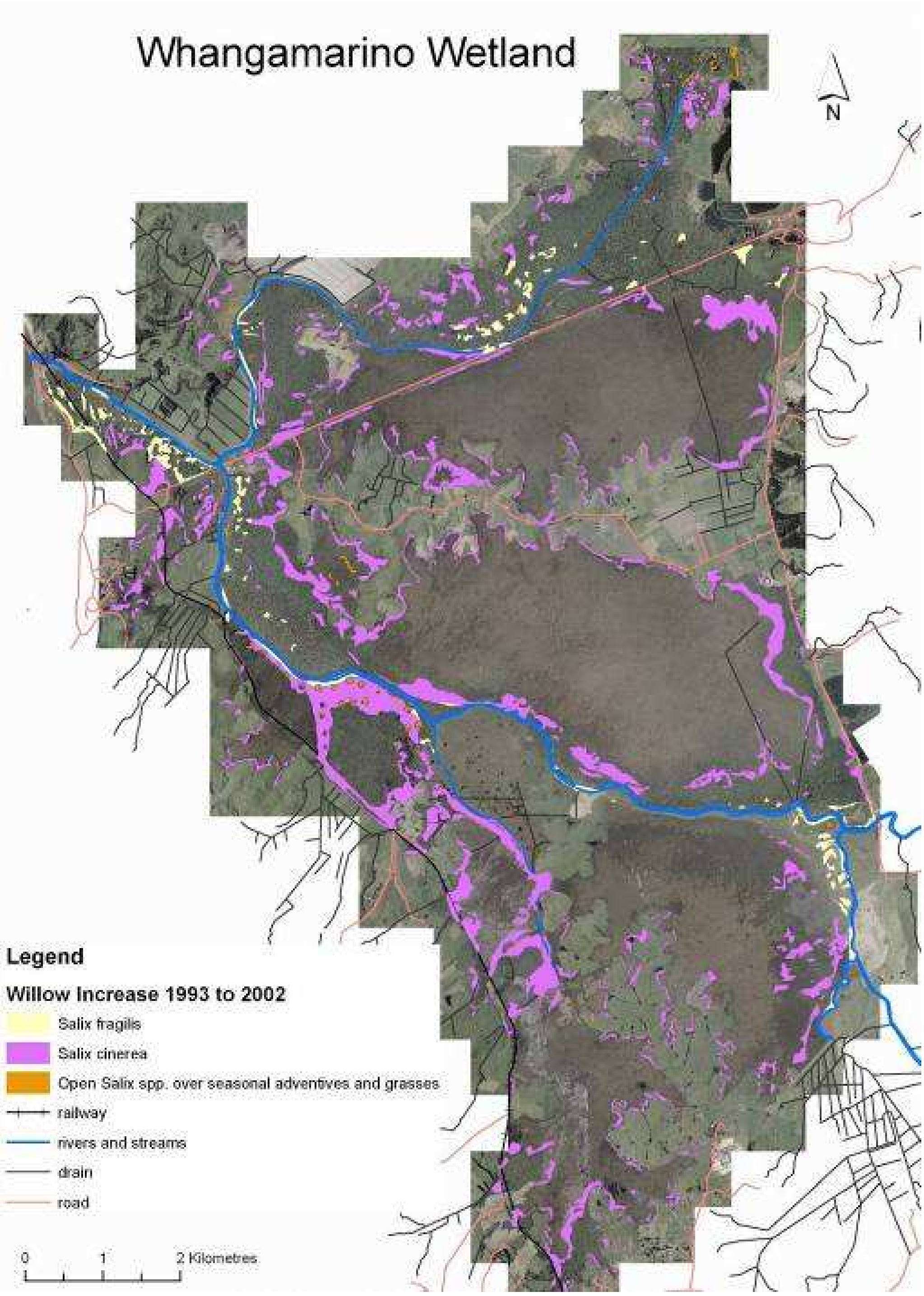

Figure 35: Areas within Whangamarino Wetland where willow dominated vegetation expanded from 1993 to 2002.

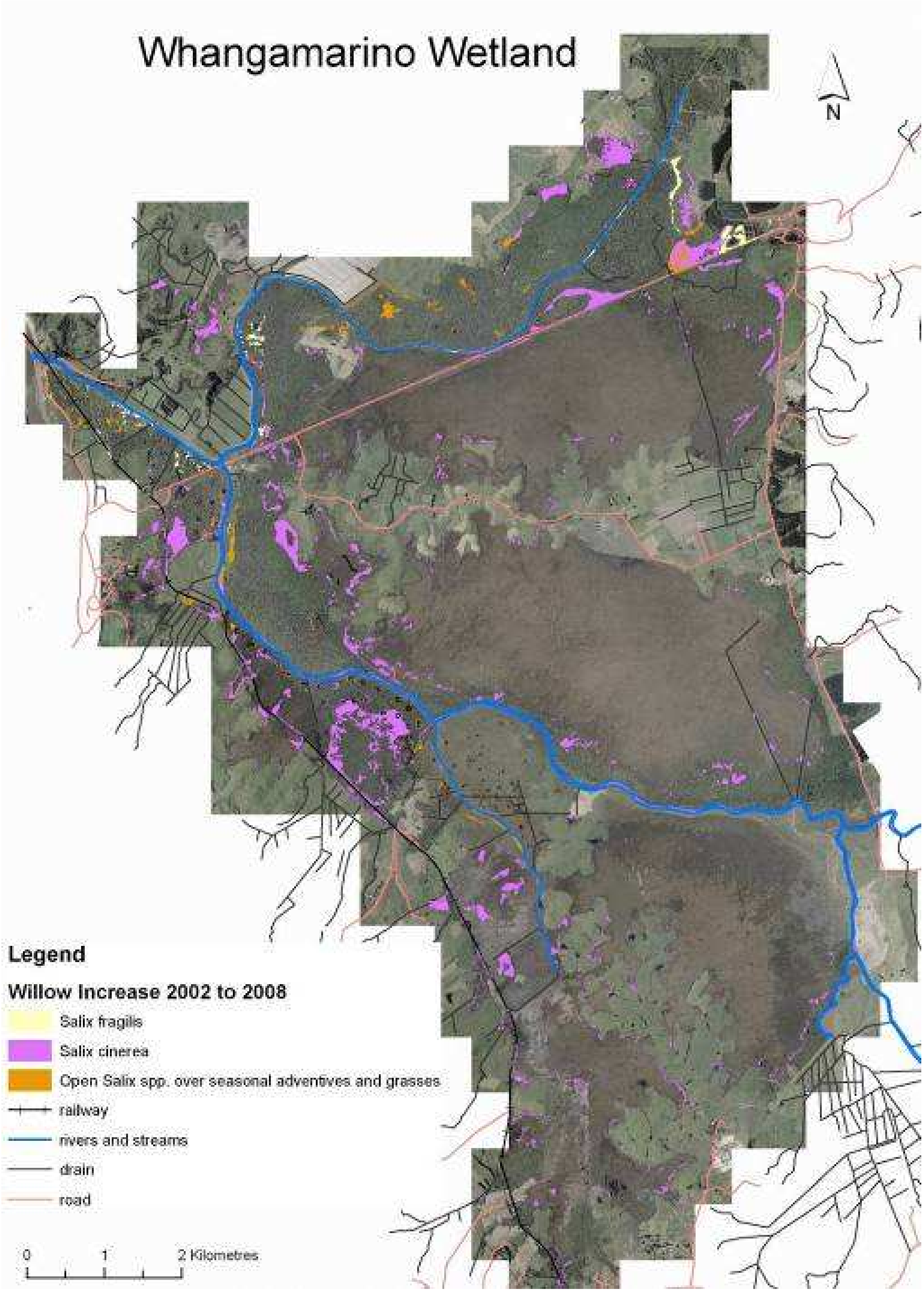

Figure 36: Areas within Whangamarino Wetland where willow dominated vegetation expanded from 2002 to 2008.

Table 3: Hectares occupied by willow in Whangamarino Wetland from 1942 to 2008.

Year	Crack willow (ha)	Grey willow (ha)	Open willow (ha)	Willow (ha)
1942[+]	313	36		350
1963[+]	435	247		682
1977[+]	670	1,108		1,777
1993[+]	825	1,207		2,032
2002[#]	550	1,654	12	2,216
2008[^]	120	1,472	522	2,114

[+] Reeves (1994); Reeves & Haskew (2003).
[#] NIWA (2002).
[^] Wildlands Consultants Ltd (2009b).

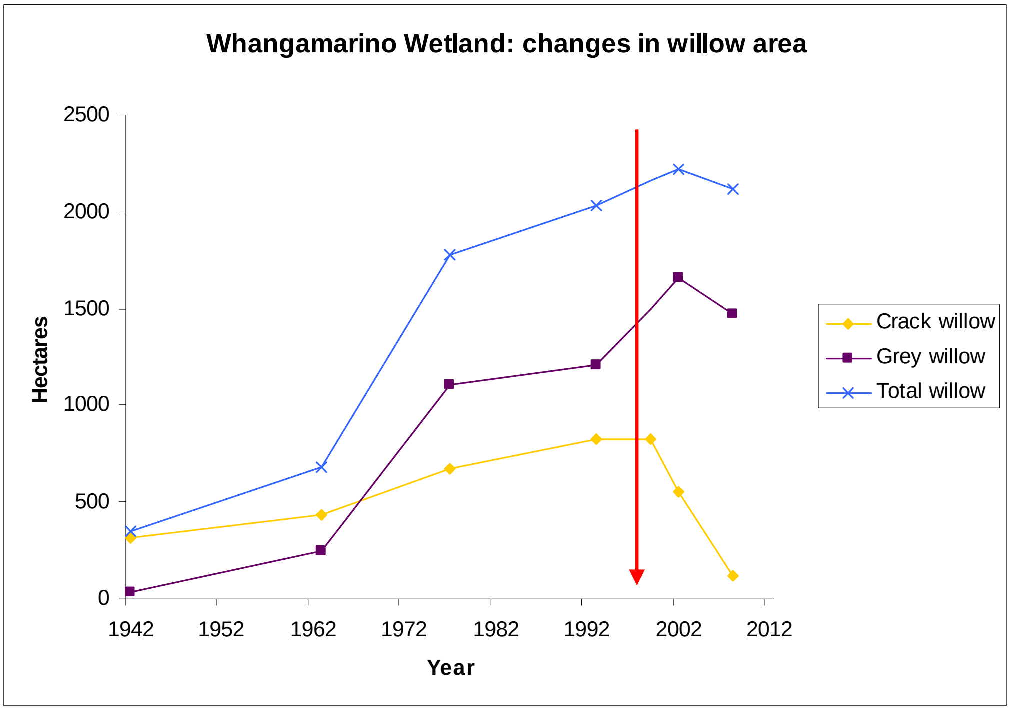

Figure 37: Changes in willow area (hectares) at Whangamarino Wetland from 1942 to 2008 for *Salix fragilis*, *S. cinerea* and total willow area. Commencement of aerial treatment programme for willow is indicated by the red arrow.

4.5 Vegetation types based on PRIMER results

Descriptive accounts of vegetation types, such as those presented in Section 4.3, were based on the structural class and dominant plant species. Applications such as PRIMER can be used to determine vegetation types based on a statistical analysis of species composition (Clarke & Gorley, 2006). That is, vegetation plots of similar species composition were grouped together and described as a vegetation type or community.

Two cluster analyses were conducted using PRIMER; the first contained percent cover for all species; the second excluded willow cover to determine if willow had an overarching effect on the composition of a vegetation community. Vegetation plots established and surveyed in 1999 were resurveyed in 2009. The 1999 vegetation plots were designated with an "a" (plots 4a – 12a) and the 2009 vegetation plots with the plot number (plots 4 – 12).

4.5.1 Willow cover included

Dendrograms of all vegetation plots were produced using PRIMER to calculate dissimilarity coefficients. Division of the dendrogram at the 20% similarity level yielded six separate vegetation types (A – F) when percent cover for all species was used (Fig. 38). Table 4 presents the contribution individual species made to each vegetation type, and the average similarity of plots within each vegetation type.

Three main vegetation types were recognised and correspond to three wetland types: semi-permanently inundated swamp; periodically inundated swamp (or marsh); and fen. Each of these wetland types was characterised by the following species:

- the semi-permanently inundated swamp vegetation was characterised by the semi-aquatic species *P. decipiens* and *L. peploides* subsp. *montevidensis* (vegetation type A, 15 plots);

- the periodically inundated swamp (or marsh) vegetation was characterised by *Persicaria strigosa*, *P. hydropiper* and *C. gaudichaudiana* (vegetation type C, 8 plots) and a smaller group characterised by (dead) *B. frondosa* and *P. hydropiper* (vegetation type B, 3 plots);

- the fen vegetation was characterised by *S. cinerea*, *O. regalis* (either dead or alive), *C. tenuicaulis* and *L. scoparium* (vegetation type F, 27 plots).

Vegetation type D was characterised by *A. nodiflorum* and vegetation type E by *C. secta* and herbicide damaged fen. These vegetation types contained only one and two plots respectively and were not considered further.

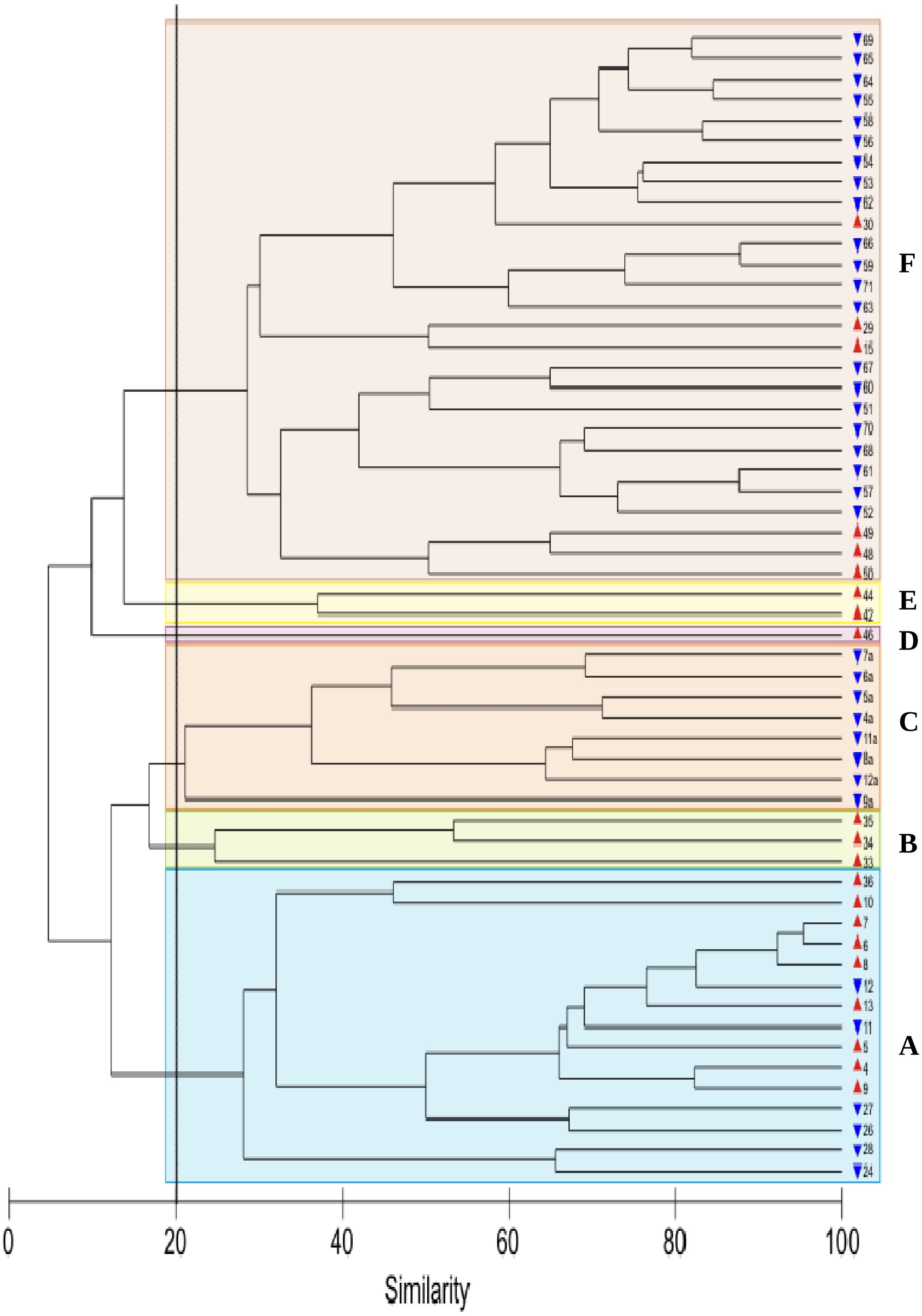

Figure 38: Dendrogram of vegetation types (A – F) based on Bray-Curtis dissimilarity co-efficient calculations. Treated plots are marked with a red triangle ( ), untreated plots with an inverted blue triangle ( ). For an explanation of plot numbers see Section 3.1 and 3.2.

Table 4: Individual species contributions made to each cluster of vegetation types, and their similarity within each cluster calculated using SIMPER (PRIMER), with willow % cover included. * denotes a species is exotic. Cluster D was omitted as there were less than 2 samples. Cluster E was omitted as there was a low average abundance and average similarity and by many species. Percentage dissimilarity values between clusters were: a:f – 95.65%; a:b – 91.57%; f:b – 91.69%; a:e – 95.54%; f:e – 86.27%; b:e – 92.59%; a:d – 100%; f:d – 90.24%; b:d – 92.69%; e:d – 88.16%; a:c – 86.42%; f:c – 95.96%; b:c – 83.32%; e:c – 94.28%; d:c – 100%.

Species	Vegetation Group A		Vegetation Group B		Vegetation Group C		Vegetation Group F	
	Contribution %	Average similarity	Contribution %	Average similarity	Contribution %	Average similarity	Contribution %	Average similarity
* *Bidens frondosa* (dead)			36.67	12.53				
Carex gaudichaudiana					13.71	5.40		
Coprosma tenuicaulis							16.96	6.60
Leptospermum scoparium							13.45	5.23
* *Ludwigia peploides subsp. montevidensis*	20.64	10.02						
* *Osmunda regalis*							17.97	6.99
Persicaria decipiens	59.15	28.72						
* *Persicaria hydropiper*			22.16	7.57	16.62	6.55		
* *Persicaria strigosa*			15.77	5.39	35.39	13.94		
* *Salix cinerea*							24.07	9.37

4.5.2 Willow cover excluded

The second PRIMER analysis excluded willow cover to determine if willow had an effect on vegetation community clusters. A dendrogram of all vegetation plots with willow percent cover excluded was produced using PRIMER to calculate dissimilarity coefficients (Fig. 39). Division of the dendrogram at the 20% similarity level yielded nine separate vegetation types (A – I). Table 5 presents the contribution individual species made to each vegetation type, and the average similarity of plots within each vegetation type. Vegetation types B, C and H could not be analysed in this way as each comprised of a single vegetation plot (see Section 4.2 and 4.3).

When willow covers were excluded from the cluster analysis there were minor changes in the composition of each vegetation type and three additional vegetation types recognised:

- native sedge swamp dominated by *Eleocharis acuta* (plot 9a);
- fen characterised by dead exotic *O. regalis* and the native shrub *C. tenuicaulis* (triclopyr triethylene amine treated plots 48 – 50); and
- native swamp sedge dominated by *C. subdola* (plots 51, 60 and 67).

4.5.3 Influence of willow on PRIMER vegetation types

The separation of the fen vegetation type dominated by dead *O. regalis* (plots 48 – 50) when willow cover was excluded was an artefact of survey time as these plots were sampled later in the season when this introduced fern was in winter dieback (vegetation type E, Fig. 39 and Table 5).

High *S. cinerea* cover grouped plots 51, 60 and 67 in with other fen plots (vegetation type F, Fig. 38). However, when willow cover was excluded, these plots were separated out from the fen vegetation type (vegetation type F, Fig. 39 and Table 5). All of these plots were located at the start of the 2006 transects near the Whangamarino River and reflect a swamp influence with high covers of the native sedge *C. subdola* with other swamp and fen species present.

Overall the analysis of plot data excluding willow did not distinguish any significantly different vegetation types.

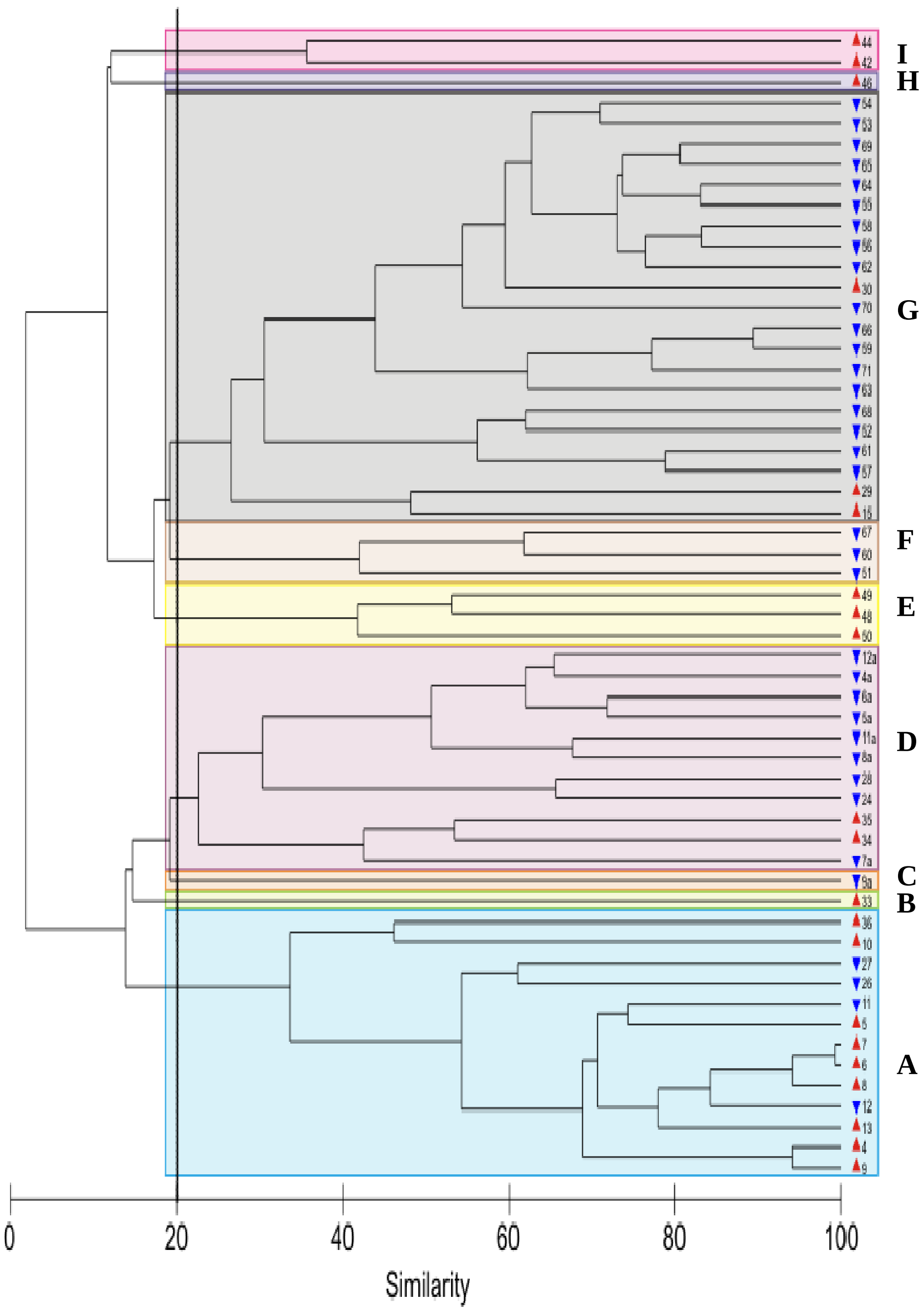

Figure 39: Dendrogram of vegetation types based on Bray-Curtis dissimilarity co-efficient calculations with willow % cover excluded. Treated plots are marked with a red triangle (▲), untreated plots with an inverted blue triangle (▼). For an explanation of plot numbers see Section 4.2 and 4.3.

Table 5: Individual species contributions made to each cluster of vegetation types, and their similarity within each cluster calculated using SIMPER (PRIMER), with willow % cover excluded. * denotes a species is exotic. Cluster B, C and H were omitted as there were less than 2 samples. Cluster I was omitted as there was a low average abundance and average similarity and by many species. Percentage dissimilarity values between clusters were: a:g – 99.83%; a:b – 96.34%; g:b – 95.55%; a:d – 84.34%; g:d – 98.15%; b:d – 84.84%; a:i – 96.70%; g:i – 87.93%; b:i – 97.01%; d:i – 94.56%; a:h – 100%; g:h – 89.48%; b:h – 92.38%; d:h – 98.67%; i:h – 87.95%; a:e – 99.88%; g:e – 82.13%; b:e – 91.53%;d:e – 98.33%; i:e – 85.04%; h:e – 86.59%; a:c – 97.89%; g:c – 99.57%; b:c – 91.72%; d:c – 80.82%; i:c – 93.03%; h:c – 100%; e:c – 98.15%; a:f – 98.61%; g:f – 80.84%; b:f – 82.52%; d:f – 89.76%; i:f – 91.16%; h:f – 90.19%; e:f – 87.96%; c:f – 98.23

Species	**Vegetation Group A**		**Vegetation Group D**		**Vegetation Group E**		**Vegetation Group F**		**Vegetation Group G**	
	Contribution %	**Average similarity**	**Contribution %**	**Average similarity**	**Contribution %**	**Average similarity**	**Contribution %**	**Average similarity**	**Contribution %**	**Average similarity**
Carex subdola							37.62	18.24		
Coprosma tenuicaulis					16.69	7.58	21.26	10.31	16.3	7.15
Leptospermum scoparium									20.58	9.03
* *Ludwigia peploides subsp. montevidensis*	21.03	12.16								
* *Osmunda regalis*					49.96	22.7			26.05	11.43
Persicaria decipiens	64.75	37.43	2.55	13.53						
* *Persicaria hydropiper*			22.24	7.95						
* *Persicaria strigosa*			37.84	13.53						

5. Discussion

5.1 Ecological range of willow in Whangamarino Wetland

S. fragilis is widespread throughout New Zealand, grows up to 25 m tall and inhabits flowing water systems, such as stream and river banks, lake margins or where water levels are only periodically flooded and oxygen rich (Champion, 1986). Of the wetland types in New Zealand, *S. fragilis* is most prolific in swamps. The majority of *S. fragilis* trees in New Zealand are male clones. The main method of dispersal is via vegetative spread, that is, branches breaking off that sprout new roots and shoots (Cremer et al., 1995). Within Whangamarino Wetland, *S. fragilis* was predominantly found along river margins and their floodplains and swamp areas (Fig. 40 – 45, Appendix 2).

Whilst *S. cinerea* is less widespread throughout New Zealand, it tends to be locally abundant and particularly prolific in the Waikato, Bay of Plenty and lowland Canterbury, although it has moved into higher altitudes such as Ashburton Basin (pers. obs.). *S. cinerea* has a wider habitat range than *S. fragilis*, able to tolerate more acidic soils and anaerobic conditions. Once established, *S. cinerea* can also tolerate permanently waterlogged areas (Waikato Valley Authority, 1981; Eser & Rosen, 2000). *S. cinerea* is a shrub that can grow up to 10 m tall but typically is 1-4 m tall. It inhabits standing water systems or damp soils, such as lake margins, swamps, fens and peat bogs with mesotrophic conditions (Waikato Valley Authority, 1981). Both male and female plants of *S. cinerea* were introduced to New Zealand and the species freely reproduces sexually with the main method of spread via wind dispersal of seed in late spring, usually November. Vegetative spread is also possible from stem fragments. Within Whangamarino Wetland, *S. cinerea* was predominantly found in less fertile swamp and fen areas in association with *L. scoparium* or *C. tenuicaulis*, behind the river band of *S. fragilis* or along the wetland margins adjacent to pasture on higher ground (Fig. 40 – 45, Appendix 2).

The ability to shoot and root quickly in or near water coupled with rapid growth rates mean both willow can aggressively invade favoured habitat within fen and swamp wetlands. Impacts include blocked waterways, overtopped vegetation, altered vegetation structure and altered wetland function. Greenwood (1986) noted that if the significant expansion of *S. cinerea* and *S. fragilis* within Whangamarino Wetland continued unabated, willow would detrimentally modify habitats that supported endangered species and rare vegetation community types, such as the *Carex* sedgeland.

The basis for the willow aerial treatment programme was most likely the combination of DOC observation that "grey willow is able to establish in more acidic areas of the wetland" and required control "to ensure the long term integrity of the peat bogs" (Greenwood, 1986) and Reeves (1994) vegetation maps that illustrated a massive reduction in sedgeland area from 2,778 ha in 1942 to 26 ha in 1993 largely attributed to willow invasion.

5.2 History of willow invasion

Up to 1999, *S. fragilis* and *S. cinerea* invaded Whangamarino Wetland with little control undertaken and any control measures were limited to ground based treatment. From 1999 aerial treatment of *S. fragilis* and *S. cinerea* commenced. The changes in distribution within Whangamarino Wetland over this time can be examined for *S. fragilis* and *S. cinerea* separately.

5.2.1 Changes in *Salix fragilis* distribution 1942 to 2008

The slow but steady rate of spread of *S. fragilis* in Whangamarino Wetland appeared to have levelled off around 1993 (Fig. 37) when all available riverine habitat was virtually occupied by this species. From 2002 to 2008 there has been a decrease in *S. fragilis* within the aerial treatment zone. Within the remainder of the Whangamarino Wetland, only a small increase in *S. fragilis* was mapped primarily at the northeastern end between the causeway and the Maramarua River.

There has been a significant reduction in the total area of *S. fragilis* dominated vegetation in the Whangamarino Wetland from a peak of 850 ha in 1993 to 120 ha in 2008 (Fig. 37, Fig. 43 & 45 in Appendix 2). Much of this reduction in area can be attributed to control with glyphosate, essentially removing *S. fragilis* from treated areas (Fig. 7). The complete collapse of *S. fragilis* forests along the Whangamarino River has improved navigation and is likely to have increased water flow in the river. The increased water levels since 2000 have also waterlogged much of the habitat area previously occupied by *S. fragilis* and would now be unsuitable habitat for establishment of this species.

The remaining reduction in *S. fragilis* area was due to a new vegetation type 'open willow over seasonal adventives and grasses' recognised in the 2002 and 2008 vegetation maps as areas presumably no longer dominated by *S. fragilis*, but with *S. fragilis* or *S. cinerea* present.

5.2.2 Changes in *Salix cinerea* distribution 1942 to 2008

The rapid expansion of *S. cinerea* from 1963 to 1977 (Fig. 33) has a similar trajectory to the exponential growth phase of the typical species invasion curve. A decline in water levels or increase in nutrients were the most likely factors that altered the wetland habitat and facilitated the rapid expansion of *S. cinerea* (Reeves, 1994). The rate of *S. cinerea* expansion appeared to flatten out from 1977 to 1993 and then enter a second period of rapid expansion from 1993 to 2002 (Fig. 37). However, Reeves (1994) noted that 300 ha of *S. cinerea* were converted to pasture between 1977 and 1993. If this area of pasture conversion is taken into account, then there would be no dip in the exponential expansion of *S. cinerea*.

From 1993 – 2008 *S. cinerea* continued to spread in fen and swamp areas (Fig. 35 & 36) with no saturation of habitat yet apparent. Vegetation types invaded by *S. cinerea* included *Carex* sedgeland (swamp); *L. scoparium* dominated vegetation (fen); and sedges and *E. minus* where these were adjacent to invaded *L. scoparium* (bog margins) (Reeves, 1994). Of particular concern was the expansion of *S. cinerea* into the largest remaining sedgeland area at the northwest end of the Reao Stream, owned by Waikato Fish and Game. Whilst *S. cinerea* has expanded into this area, there appears to be an anomaly in the 1993 vegetation map. The vegetation on the west and north margins of the Fish & Game land were identified by Reeves (1994) as *S. cinerea* in 1977 and in 2002, but as seasonal adventives and grasses in 1993. It is recommended that the 1993 aerial photograph be re-examined to determine the vegetation type.

Despite the commencement of the aerial willow control programme in 1999, *S. cinerea* dominated vegetation in Whangamarino Wetland continued to increase to a peak of 1,654 ha in 2002 (Fig. 37). From 2004 there was a change to the aerial treatment programme from boom spot spraying to larger, continuous tracts sprayed well into the fen and bog areas. Overall, this change in method and target area resulted in a slight decline in *S. cinerea* total area from 1,654 ha in 2002 to 1,472 ha in 2008 although considerable non-target damage occurred.

As with *S. fragilis*, the new vegetation type 'open willow over seasonal adventives and grasses' had 522 ha in 2008 which contained an unknown proportion of *S. cinerea*, presumably no longer dominated by *S. cinerea*, but with *S. cinerea* or *S. fragilis* present.

5.3 Vegetation monitoring

Changes to vegetation communities can be examined through the vegetation plot data, vegetation maps and field observations to determine the impact of willow on vegetation communities and herbicide impacts on willow and non-target species.

5.3.1 Changes in vegetation type

The change of vegetation in both treated and untreated plots to a more aquatic composition indicated that there has been a change in vegetation regardless of herbicide treatment. For example, vegetation that was periodically inundated swamp in 1999 (plots 4a – 12a) had changed to semi-permanently inundated swamp in 2009 (plots 4 – 12) regardless of herbicide treatment. This was also reported by Champion (2003) and Reeves (2003). The variation in water levels (particularly prolonged periods of high water) make it unlikely for willow to invade those areas where it has been controlled, unless a very dry period lowers levels enough for *S. cinerea* to establish. However, the increased water levels also make it unlikely for *C. subdola* and *C. gaudichaudiana* to re-establish, resulting in the loss of the *Carex* sedgeland that was to be protected.

A similar change in vegetation from sedges to *Persicaria* species was noted after aerial spraying of willow in December 1986 (Greenwood, 1986). A small aerial spray trial on *S. fragilis* was undertaken in the northern part of Whangamarino Wetland, adjacent to the Maramarua River. This area had been impacted by grazing but also contained a significant area of sedges. Greenwood (1986) observed that the aerial spray effectively killed the *S. fragilis* but 7 years after herbicide application the vegetation had changed to *Persicaria* species, and did not return to the sedges and grasses present prior to the spraying. The influence of grazing, water levels and other factors is examined in more detail in Champion & Bodmin (*in prep*.).

5.3.2 Impact of herbicide on willow

Aerial boom spraying has been most effective where there was a closed canopy of the target *Salix* species that ensured good herbicide coverage and limited damage to understorey species. Champion (2003) reported excellent control of *S. fragilis* within the aerial treatment zone. The lack of reinvasion was still evident in 2009 with an absence of *S. fragilis* in any of the 2009 vegetation plot surveys (Fig. 7) although the waterlogged habitat would now be unsuitable for re-invasion of this species.

Good control of *S. cinerea* was achieved with glyphosate but areas of dense regrowth were seen from the helicopter flight over the treated areas (Fig. 9 & 10) and seedlings were found in all plots monitored. Without intensive follow up it is likely that vegetation will revert to *S. cinerea* dominated vegetation.

Garlon control of *S. cinerea* was very poor and patchy but no surfactant or penetrant was used and the application was very late in the season, 28th February 2008 (Chris Berry, DOC, pers. comm.). Evaluation of other Garlon trials has shown major regrowth and future use for aerial treatment cannot be recommended at this time (NIWA unpublished data).

5.3.3 Impact of herbicide on non-target species

Major impacts on non-target species were evident in areas where aerial boom spraying had been used on individual trees or scattered trees amongst native vegetation. Damage was most evident in areas where individual *S. cinerea* trees were targeted for control amidst otherwise intact native peat bog or fen vegetation (Fig. 11 & 12). The impact of this control method was death or severe damage of surrounding non-target species, usually *E. minus* and *G. dicarpa* (Fig. 26) or *L. scoparium* (Fig. 12). The aerial overview of Whangamarino Wetland and examination of sites showed large areas of dead *L. scoparium* around the target *S. cinerea* tree. This probably indicates the use of a boom spray that resulted in significant overspray or *L. scoparium* was mistakenly identified as *S. cinerea*. In fen areas, spray damage was evident to *S. cinerea* and *L. scoparium* trees but *C. tenuicaulis* had little if any damage, or had re-grown in treated areas. Champion (2003) reported the invasion of *O. regalis* into such areas and seedlings or plants were evident in the 2009 survey (Fig. 31).

The spray damage to peat bog vegetation can be regarded as similar to fire damage, as both destroy vegetation. Systemic herbicides, such as glyphosate, can be analogous to a hot burn as both kill rhizome and root material in most species. *Empodisma minus* recolonisation after fire events has been estimated at 5.5 to 15 years (Clarkson, 1997; Clarkson & Stanway, 1994) with timeframes dependent on the time and intensity of the fire and hydrological and vegetation characteristics of the site prior to the burn. However, herbicide treatment is unlikely to cause a short-term elevated spike of soil nutrient levels, as fire does with ash enrichment (Clarkson, 1997), and does not leave a bare surface but a dense layer of dead vegetation.

A site visit to two of these herbicide damaged bog areas 2 – 4 years after treatment showed colonisation by short-lived annuals but also *S. cinerea*, *O. regalis* and *L. scoparium* seedlings (Fig. 29). Damage to the substrate was also evident, in the form of peat decomposition, with collapse of the surface when walked on. The long-term prognosis for these herbicide damaged bog areas is localised invasion of *S. cinerea*, stunted in height due to limited nutrient availability, and the possible creation of pools where peat degradation has occurred.

In swamp areas, extensive damage was noted to the sedge (*C. gaudichaudiana* and *E. acuta*) dominated vegetation (Champion, 2003). By 2001, vegetation cover had severely declined in all but one of the treated plots with a corresponding increase in turbid water or areas of free-floating aquatic plants such as the introduced fern *A. pinnata* (Champion, 2003). By 2003, vegetation had recovered and was dominated by emergent herbs and free-floating aquatic species (Champion, 2003). Although sedge species had disappeared 2 years after herbicide application in the treated plots they had also declined in the untreated plots probably as a consequence of the increased minimum water level from the construction of the Whangamarino weir in 2000 and cattle grazing (Champion, 2003). Over the course of the monitoring period, 1999 – 2003, Champion (2003) also noted sapling grey willow had become more evident within the untreated site. The trend of vegetation changing to more aquatic species continued with 2009 monitoring.

5.4 Potential for future increase in willow

S. fragilis has virtually reached the limit of invasion into currently available habitat, although the potential exists for *S. fragilis* to recolonise those riverine reaches where it has been eliminated by the current willow control programme. Any further habitat expansion is most likely to occur along the riverine and floodplain areas within Whangamarino Wetland in response to inflow changes (such as nutrient, sediment, water flows) or alteration of the hydrological regime.

S. cinerea is expected to re-establish in those treated areas unless continued control is undertaken. Many of the areas treated for *S. fragilis* are also prone to *S. cinerea* invasion. Reinvasion can occur from seed sources both within Whangamarino Wetland and outside of the wetland, particularly from the populations in the west, with seed blown in by the prevailing westerly winds. Therefore, any control of this species in Whangamarino Wetland, regardless of how effective it may be, is most unlikely to prevent re-establishment from seed.

The wetland area west of the Reao Stream and immediately north of the aerial treatment zone, owned by Fish & Game, has been identified as the only extensive area of *C. subdola* and *C. gaudichaudiana* sedgeland that remains (Reeves, 2001). *S.*

cinerea has become denser and has steadily encroached into the sedgeland area with a corresponding decline in density and potential loss of native species since 1993 (Fig. 35 & 36; Reeves, 1994). In the absence of active management, this open sedgeland area is likely to be overtopped by *S. cinerea* in the near future.

S. cinerea has the potential to overtop and severely impact populations of two of the 12 threatened plants in Whangamarino Wetland; the aquatic *Myriophyllum robustum* and the fern *Cyclosorus interruptus* (Reeves, 2001; Wildlands Consultants Ltd, 2009a).

S. fragilis poses little threat to peat bog areas (low pH), static open water areas or low flow water bodies (low oxygen) and most fen areas (low nutrient). *S. cinerea* poses no immediate threat to intact peat bog areas (low pH, low nutrient and dense vegetation), notably the interiors of the northern and central peat bogs, both of which are ombrogenous (raised) bogs. However, fen zones may be vulnerable to further expansion of *S. cinerea* where the canopy is less dense. In the long-term there is potential for degradation of these peat bog and fen areas due to other factors, such as nutrient enrichment, which may facilitate invasion of *S. cinerea*.

The peat bog areas adjacent to Pungarehu Canal and the Southern Bog are not solely ombrogenous, they receive nutrient rich waters from Lake Waikare which makes the wetland susceptible to a change in state from bog to fen to swamp and thus vulnerable to invasion by *S. cinerea*.

Ongoing environmental changes to Whangamarino Wetland (nutrient input, sediment input, surrounding land use changes, water flows, water levels and grazing) are reflected in changes to the wetland vegetation and may lead to invasion of *S. cinerea* and other introduced species. These linkages and the impact on the effectiveness of willow control are examined in the associated Whangamarino Future Willow Management Report (Champion & Bodmin, *in prep.*).

5.5 Willow control and Site Led Weed Management Plan objectives (2001)

NIWA (Reeves, 2001) was commissioned by DOC to produce a site-led weed management plan for those areas of the Whangamarino Wetland under the Department’s management. The purpose of the plan was to protect identified values and ecological processes of Whangamarino Wetland from the effects of pest plants. The key biological values identified in the plan were the indigenous peat bogs, their fen margins, the remaining areas of *Carex* sedgeland located in swamps and threatened plant species which were all located within peat bog or fen areas.

Reeves (2001) identified five weeds, including both *S. fragilis* and *S. cinerea*, as the greatest threat to biological values and ecosystem processes. Weed management actions, control and monitoring were identified and prioritised for each of the identified key values. The management plan was designed with an operation timeframe of 5 years. A recent review has seen the action plan updated (DOC, 2010) however, the willow treatment programme will be evaluated based on the actions and priorities outlined within the 2001 management plan for *S. fragilis* and *S. cinerea* as this guided the actions of the willow programme.

5.5.1 Northern and central peat bogs

Recommendations for the northern and central peat bogs were to monitor whether *S. cinerea* was invading these wetlands, based on aerial photographs of wetland vegetation every 5 years. No control of *S. cinerea* was recommended. *S. fragilis* was not identified as posing a threat to these peat bog areas. These recommendations were rated as a low priority.

An evaluation of willow management within the Northern and Central peat bog areas is beyond the scope of this report. However, DOC did have the Whangamarino Wetland vegetation mapped in 2008 by Wildlands Consultants Ltd (2009b) which enabled broad scale changes in willow distribution to be examined which showed *S. cinerea* has continued to spread in the fen margins of both peat bogs.

5.5.2 Southern peat bog

Recommendations for the southern peat bog were to undertake a control trial of *S. cinerea* using aerial application of herbicide with a single spray nozzle; to conduct the treatment in January to minimise *S. cinerea* invasion by seed; to conduct follow up treatment in year 2; and monitor for *S. cinerea* reinvasion to year 5. Control of *S. cinerea* was only to occur if the vegetation canopy was not opened up as this would facilitate further *S. cinerea* invasion. These recommendations were rated as a medium priority.

Aerial control of willow has occurred in the Southern peat bog with spot spraying on the northern and eastern margins from 2001 – 2004, although the delivery method was boom spray rather than a single spray nozzle. In 2004, 2005 and 2007 larger, continuous tracts of *S. cinerea* were sprayed on the eastern margin with boom spot spraying well into the fen area.

The control trial of *S. cinerea*, the use of a single spray nozzle in aerial application of herbicide and a programme to monitor canopy damage or *S. cinerea* reinvasion was never formally established for the Southern peat bog. Aerial boom spray application of herbicide has controlled *S. cinerea* but has also caused extensive non-target damage, opened the vegetation canopy and facilitated reinvasion of *S. cinerea*.

5.5.3 Reao Arm peat bog and threatened plants

The Reao Arm peat bog, that is the wetland south of Wattle Road and west of the Reao Stream, had the greatest invasion of *S. cinerea* into the bog proper, most probably due to mesotrophic conditions. This area of the Whangamarino Wetland also supported a high number of threatened plants found within the wetland complex with the potential for *S. cinerea* to invade and detrimentally alter the habitat particularly for *M. robustum* and *C. interruptus*. Recommendations were to use a single spray nozzle to spot spray and eradicate *S. cinerea* from the core area of the Reao Arm. The treatment and monitoring methods outlined for the Southern peat bog were to be used. These recommendations were rated as a high priority.

Aerial control of willow has occurred in the Reao Arm peat bog with spot spraying at the northern end in 2001 and 2002, although the delivery method was boom spray rather than a single spray nozzle. In 2005 and 2007 larger, continuous tracts of *S. cinerea* were boom sprayed in the north, a smaller area in the south and western margin, with boom spot spraying in the centre of the bog.

The treatment methods outlined for the Southern peat bog were not followed and a monitoring programme was never formally established. Aerial boom spray application of herbicide has controlled *S. cinerea* but has also caused extensive non-target damage, opened the vegetation canopy and facilitated reinvasion of *S. cinerea*.

5.5.4 Reao Arm swamp

S. fragilis and *S. cinerea* both threaten the few remaining areas of *Carex* sedgeland in the Reao Arm swamp. Control was carried out in 1999 and 2000 in order to protect the largest sedgeland areas. The sedgeland area was expected to remain the dominant vegetation with an increase in species that preferred higher water levels throughout the year due to the weir installation. Recommendations were to continue monitoring the permanent quadrats as per Champion (2001) with annual surveillance for any pest plant invasion. These recommendations were rated as medium priority.

Some aerial spot spraying of willow occurred from 2001 to 2004 and annual monitoring of the vegetation quadrats was undertaken in 2002 and 2003. Champion (2003) stated that despite excellent willow control, the sedgeland area had gone with vegetation in the area altered to more aquatic species as a result of non-target herbicide damage to the sedgeland, an increase in water levels and grazing. There was also a significant decline in sedge species in a nearby sedgeland (Fish & Game land) that had not been treated with herbicide. Champion (2003) concluded that increased minimum water levels and livestock grazing potentially threatened the long-term survival of sedge-dominated vegetation.

From 2003 Champion recommended an altered treatment programme: aerial boom spray to occur only when there is a dense canopy of willow; control isolated *S. cinerea* by cut and paint or drill and inject methods; use annual aerial photography with ground truthing to monitor wetland vegetation change; and to exclude cattle from the untreated sedgeland area.

None of the 2003 recommendations appear to have been implemented. No further control of *S. cinerea* has occurred since 2004 either by aerial or ground based treatment methods. Vegetation change in this area has not been monitored on an annual basis using low level aerial photographs or ground based methods. Cattle have not been excluded from the untreated sedgeland area.

6. Recommendations

Recommendations from the review of the DOC willow control programme are:

- The value of pursuing a continued widespread *S. cinerea* control programme is questioned as its long-term success is highly unlikely.

- DOC should select and prioritise high-value sites within the Whangamarino Wetland at risk of, or in the early stages of, willow invasion and manage willow to prevent their impact in such sites. These high value sites include areas that support threatened species and declining vegetation types, for example, sedgeland.

- Protection of the largest remaining sedgeland area may now be confounded by land tenure as it is owned by Fish & Game. The continuous spread of *S. cinerea* has reduced the open sedgeland area with the potential for this to be lost if there is no intervention. Discussion with Fish & Game is recommended over management of the site with DOC to control willow and sensitive management of the sedgeland by Fish & Game.

- It is recommended that highly selective control methods are used in such high value sites, such as cut and paint, drill and fill or single nozzle spot spraying.

- This report has highlighted the need for a planned monitoring programme to be undertaken pre and post treatment to ensure management actions can be measured and modified to achieve the desired objectives.

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9. Appendix 1

9.1 2009 site descriptions for untreated areas

9.1.1 Seasonal adventives and grasses – *Persicaria decipiens*

The wetland south of the causeway between the Reao Stream and the Whangamarino River, adjacent to the northern end of the Lloyd's farmland (Plots 11 & 12, Fig. 1), was dominated by sprawling emergent herbs and open water approximately 0.6 m deep during the site visit (Fig. 13). The native swamp willow weed *P. decipiens* (60% and 20% cover in plots 11 and 12 respectively) and introduced water primrose *L. peploides* subsp. *montevidensis* (6% and 45% cover) were the main species with patches of open water (20% and 31% cover). Clumps of the native sedge *C. gaudichaudiana* (10% and 1% cover) were found on slightly raised areas. Low covers of the introduced *M. aquaticum* (2% and 2% cover), *P. strigosa* (2% and 0% cover) and *S. cinerea* (0% and 1% cover) were also found.

9.1.2 Reao Stream *Carex* sedgeland

The wetland immediately to the west of the Reao Stream and north of the causeway between the Reao Stream and the Whangamarino River (Plots 24 & 28, Fig. 1) was a native sedgeland (Fig. 14). *C. subdola* was the main sedge species with 50% and 85% cover (plots 24 and 28 respectively) with some *C. gaudichaudiana* (5% cover, plot 24). Sprawling emergent species present were the introduced *P. strigosa* (15% and 8% cover), *M. aquaticum* (10% and 0% cover) and the native *P. decipiens* (10% and 1% cover). Low covers were also found for the introduced species reed canary grass *P. arundinacea* (5% and 2% cover), *L. peploides* subsp. *montevidensis* (3% and 1% cover), open water (1% and 0% cover), *B. frondosa* (1% and 0% cover), *L. punctata* (0% and 1% cover) and the native bamboo spike sedge *Eleocharis sphacelata* (0% and 1% cover).

9.1.3 Grey willow shrubland

North of the causeway between the Reao Stream and the Whangamarino River and to the west of the Reao Stream sedgeland (Plots 26 & 27, Fig. 1) was a grey willow / willow weed wetland (Fig. 15). The invasive grey willow *S. cinerea* (50% and 30% cover) and the native *P. decipiens* (30% and 40% cover) were the main species with sprawling emergent introduced herbs *M. aquaticum* (25% and 5% cover), *L. peploides* subsp. *montevidensis* (15% and 2% cover) and *P. strigosa* (15% and 1% cover) and the floating introduced fern *A. pinnata* (4% and 10% cover). Low covers were also found for the native sedge *C. subdola* (8% cover, plot 26), open water (7% cover, plot 27), the native free floating *L. minor* (1% and 1% cover), and the introduced species *Paspalum distichum* (1% cover, plot 26), *B. frondosa* (1% cover, plot 27), *Juncus articulatus* (1% cover, plot 27), *L. punctata* (1% cover, plot 27), and *C. gaudichaudiana* (1% cover, plot 27).

9.2 2009 site descriptions for treated areas

9.2.1 Seasonal adventives and grasses – periodically inundated

Emergent herb dominated vegetation was found in three different areas. The first area was south of the causeway between the Reao Stream and the Whangamarino River, and adjacent to the northern end of the Lloyd's farmland (Plot 13, Fig. 1). This wetland was dominated by sprawling emergent herbs; the introduced *L. peploides* subsp. *montevidensis* (70% cover) and the native *P. decipiens* (30% cover). Covers of 1% or less were found for introduced species; the herbs dead *B. frondosa* (in seasonal dieback), *L. punctata* and *L. palustris* and the aquatic emergent *M. aquaticum*.

The second area of emergent herb vegetation was at the end of Black Road, on the east side of the North Island Main Trunk railway line (Plot 46, Fig. 1). The introduced emergent herb *A. nodiflorum* was the main species in this area (95% cover) (Fig. 16). Low covers of 1% or less were found for the native shrub *C. tenuicaulis*, the native sedge *C. secta*, native monocots *C. australis* and *P. tenax*, native ferns *H. incisa* and *Hypolepis ambigua* and the introduced herb *Galium palustre*.

The third area was south of the Whangamarino River and to the west of the Pungarehu Stream (Plots 34 & 35, Fig. 1). The introduced emergent herbs *B. frondosa* (55% and 50% cover respectively) and *P. hydropiper* (50% and 30% cover) were the dominant species in this area (Fig. 17). Plot 34 only had three other species present, the introduced grasses *P. arundinacea* (2% cover) and *Agrostis stolonifera* (1% cover) and the introduced herb *P. strigosa* (1% cover). Plot 35 was much more diverse with low covers for the native shrub *C. tenuicaulis* (8% cover), and 2% cover for each of the native sedges *C. virgata* and *Carex maorica* and the native cabbage tree *C. australis*. Covers of 1% or less were found for native species; the herbs *Calystegia sepium* and *Centella uniflora* and the moss *Stokesiella praelonga*. Introduced species with covers of 1% or less were the herbs *G. palustre*, *P. strigosa* and *S. bipinnatisectus*, the grass *Holcus lanatus*, the shrub *Rubus fruticosus* agg. and the sedge *Carex scoparia*.

9.2.2 Seasonal adventives and grasses – grassland – semi-permanently inundated

On the south side of the Whangamarino River, approximately 1 km west of the Pungarehu Stream (Plot 33, Fig. 1) was wetland dominated by the introduced grass *P. arundinacea* (90% cover) (Fig. 18). The native species present were the sedge *C. virgata* (5% cover) and cabbage tree *C. australis* (2% cover). Covers of 1% or less were recorded for the introduced herbs *B. frondosa* (in seasonal dieback) and *P. strigosa* and grey willow *S. cinerea*.

9.2.3 Seasonal adventives and grasses – *Persicaria decipiens* – semi-permanently inundated

P. decipiens dominated vegetation was found in two different areas: the first was north of the causeway between the Reao Stream and the Whangamarino River and to the west of the Whangamarino River (Plots 4 – 9, Fig. 1); the second was on the south side of the Whangamarino River, to the west of the Pungarehu Stream confluence with the Whangamarino River (Plot 36, Fig. 1). The native *P. decipiens* was the main species in both of these areas (73% average cover) (Fig. 19).

Plots 4 – 9 also had open water (12.3% average cover) and the sprawling emergent introduced herbs *L. peploides* subsp. *montevidensis* (12.5% average cover) and *M. aquaticum* (2.8% average cover). *S. cinerea* was found in plots 4 and 5 (both 5% cover) and plot 7 (1% cover). Low covers of 1% were found for the introduced species *P. distichum* (plot 4), *L. palustris* and *P. strigosa* (plot 5).

Plot 36 also had the introduced herb *B. frondosa* (8% cover), the native sedge *B. fluviatilis* (5% cover) and the introduced herb *Persicaria punctata* (1% cover).

9.2.4 Sedgeland

At the end of Paddy Road, on the east side of the North Island Main Trunk railway line (Plot 44, Fig. 1), was a wetland dominated by the native sedge *C. secta* (50% cover) (Fig. 22). Open water was recorded at 12% cover. Low covers were recorded for the introduced herb *E. ciliatum* (5% cover), the native sedge *B. arthrophylla* (3% cover) and the introduced herb *Hypochaeris radicata* (2% cover). Covers of 1% or less were recorded for the native herbs *Hydrocotyle novae-zelandiae*, *H. pterocarpa*, *P. decipiens*, *Pseudognaphalium luteoalbum*, *Senecio hispidulus*; native shrubs *Coprosma robusta*, *C. tenuicaulis* and *L. scoparium*; native sedges *B. rubiginosa* and *Schoenus maschalinus*; other native monocots *P. tenax* and *T. orientalis*; native ferns *B. novae-zelandiae* and *H. incisa*; native rush *J. planifolius* and the native moss

Sphagnum cristatum. Covers of 1% or less were recorded for the introduced herbs *Cerastium fontanum*, *Cirsium vulgare*, *Conyza sumatrensis*, *Helminthotheca echoides*, *L. taraxacoides*, *L. palustris*, *Senecio silvaticus* and *Stellaria media*; introduced rushes *Juncus acuminatus* and *J. articulatus*, the introduced shrub *R. fruticosus* agg., and the introduced willow *S. cinerea*.

The native sedge *B. arthrophylla* (50% cover) (Fig. 20) dominated the wetland to the west of Coalfields Road and south of the Kopuku Stream (Plot 50, Fig. 1) with the native shrub *C. tenuicaulis* (25% cover), the introduced willow *S. cinerea* (20% cover) and winter dieback vegetation of the introduced fern *O. regalis* (10% cover). A cover of 2% was recorded for each of the native fern *G. dicarpa* and the native shrub *L. scoparium*. Covers of 1% or less were recorded for native species the fern *B. novae-zelandiae*, the sedge *C. virgata* and the flax *P. tenax*.

The wetland on the south side of the Whangamarino River, approximately 1 km to the east of the confluence with the Reao Stream was dominated by the native sedge *B. fluviatilis* (95% cover) (Fig. 21) with 5% cover of the native herb *P. decipiens* (Plot 10, Fig. 1).

9.2.5 Swamp coprosma shrubland - fen

On the south side of the Whangamarino River, halfway between the Reao and Pungarehu Streams (Plots 29 & 30, Fig. 1) was a native shrub dominated wetland (Fig. 23). *C. tenuicaulis* (70% and 40% cover) and *L. scoparium* (15% and 40% cover) were the dominant species with a *B. rubiginosa* sedge understorey (40% cover) in plot 30. Low covers of native species were found in plot 29 for the sedge *C. gaudichaudiana* (5% cover), the herb *Sparganium subglobosum* (5% cover), the sedge *C. maorica* (2% cover) and the introduced herb *Lotus pedunculatus* (2% cover). Covers of 1% or less were recorded in plots 29 and 30 for the native fern *B. novae-zelandiae*, the native sedge *C. virgata*, the native cabbage tree *C. australis*, the introduced fern *O. regalis* and the introduced grey willow *S. cinerea*. Plot 29 had covers of 1% or less for the native species: *Baumea tenax*, *C. uniflora*, *E. acuta*, *H. pterocarpa*, *Juncus edgariae*, *P. tenax* and *S. cristatum*; and introduced species *B. frondosa* (deceased), *C. scoparia* and *P. strigosa*. Plot 30 had covers of 1% or less for the native species *H. novae-zelandiae*, *Leptostigma setulosa* and the introduced blackberry *R. fruticosus* agg.

The second native shrub dominated wetland was on the west side of the Reao Stream (Plot 15, Fig. 1) about 3 km south of its confluence with the Whangamarino River. *C. tenuicaulis* (60% cover) was the dominant species (Fig. 24) with open water (32%

cover). Covers of 1% or less were recorded for native species the sedges *B. teretifolia* and *C. maorica*, the herb *C. uniflora*, the shrub *L. scoparium* and the moss *S. cristatum*. Introduced species with a cover of 1% or less were the fern *O. regalis*, the shrub *R. fruticosus* agg. and the grey willow *S. cinerea*.

9.2.6 Grey willow shrubland

The wetland west of Coalfields Road and south of the Kopuku Stream (Plots 48 & 49, Fig. 1) was dominated by exotic invasive species. *S. cinerea* (average cover 90%) was the dominant shrub with an understorey of the exotic fern *O. regalis* (70% and 90% cover). Low covers of native species were found in both plots for the native fern *B. novae-zelandiae* (2% and 1% cover) and the native shrub *C. tenuicaulis* (5% and 1% covers). Covers of 1% or less were recorded in both plots for the native sedge *B. arthrophylla* and the native shrub *Coprosma* x *cunninghamii*. Low covers were recorded for the native sedge *C. virgata* (8% cover) in plot 48 and *Coprosma propinqua* (4% cover) in plot 49. Low covers of 1% or less were recorded in plot 48 for the native species *B. tenax, C. australis, I. globosa* and *P. tenax*; and the exotic species *A. stolonifera, Cortaderia selloana, G. palustre, J. articulatus* and *R. flammula*. In plot 49 cover of 1% or less was recorded for the native *Myrsine australis*.

9.2.7 Herbicide damaged fen

At the end of Paddy Road, on the east side of the North Island Main Trunk railway line was wetland vegetation on the east of farmland grazed by Ron Ashford (Plot 42, Fig. 1). This had areas of open water (22% cover) with a highly diverse, low cover, range of swamp meadow species (Fig. 25). The native grass *I. globosa* and introduced rush *J. bulbosus* had the highest vegetation cover of 8% each. The native sedges *E. gracilis* and *E. acuta*, the native flax *P. tenax* and the introduced grass *H. lanatus* each had a cover of 5%. The introduced herbs *C. capillaries, H. radicata* and *L. taraxacoides* each had a cover of 3% and the introduced herb *S. bipinnatisectus* a cover of 2%.

Low covers of 1% or less were found for native species: the herbs C. uniflora, Euchiton involucratum, H. pterocarpa, Lobelia angulata, S. hispidulus and S. subglobosum; sedges B. teretefolia, C. virgata and E. sphacelata; shrubs C. robusta, C. tenuicaulis and L. scoparium; fern B. novae-zelandiae; free floating L. minor and the rush J. planifolius. Low covers of 1% or less were found for introduced species: the herbs C. vulgare, C. sumatrensis, E. ciliatum, G. palustre, L. pedunculatus, L. palustris, Lycopus europaeus, P. strigosa, R. flammula, Sonchus asper, S. oleraceus and S. media; rushes J. effusus var. effusus and J. articulatus; the grass A. stolonifera and the willow S. cinerea.

10. Appendix 2

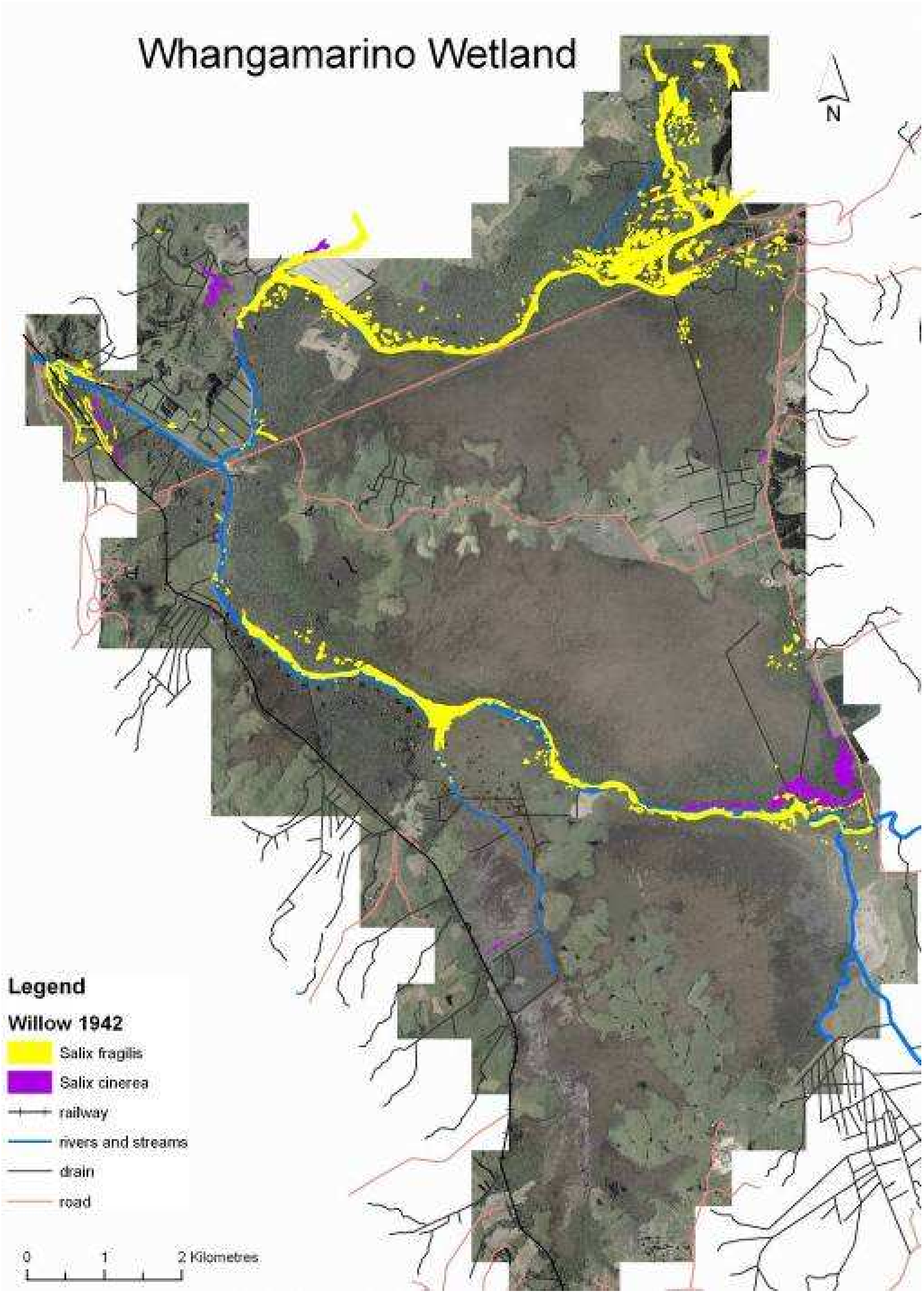

Figure 40: Areas within Whangamarino Wetland dominated by *Salix fragilis* (crack willow) and *Salix cinerea* (grey willow) vegetation in 1942.

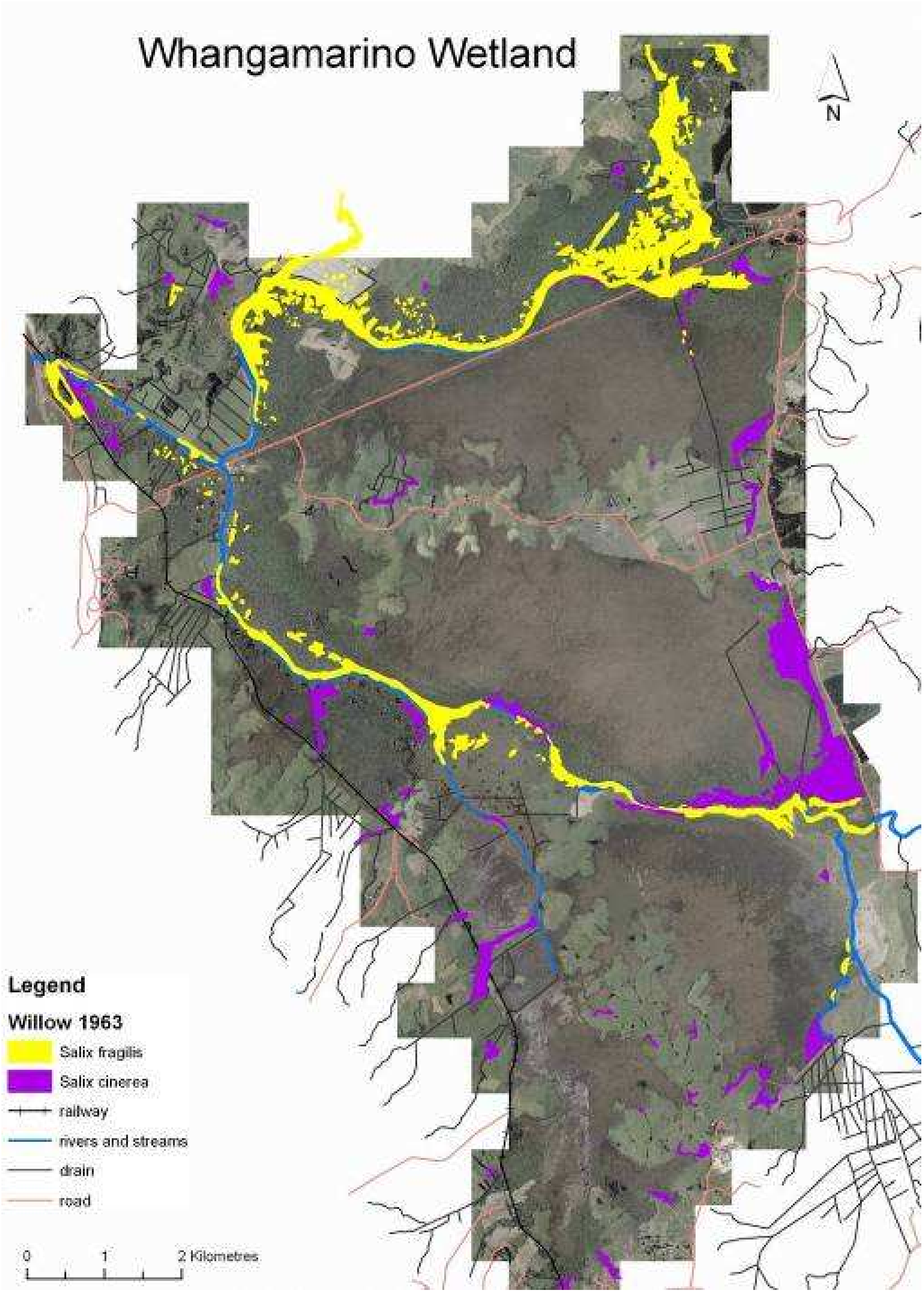

Figure 41: Areas within Whangamarino Wetland dominated by *Salix fragilis* (crack willow) and *Salix cinerea* (grey willow) vegetation in 1963.

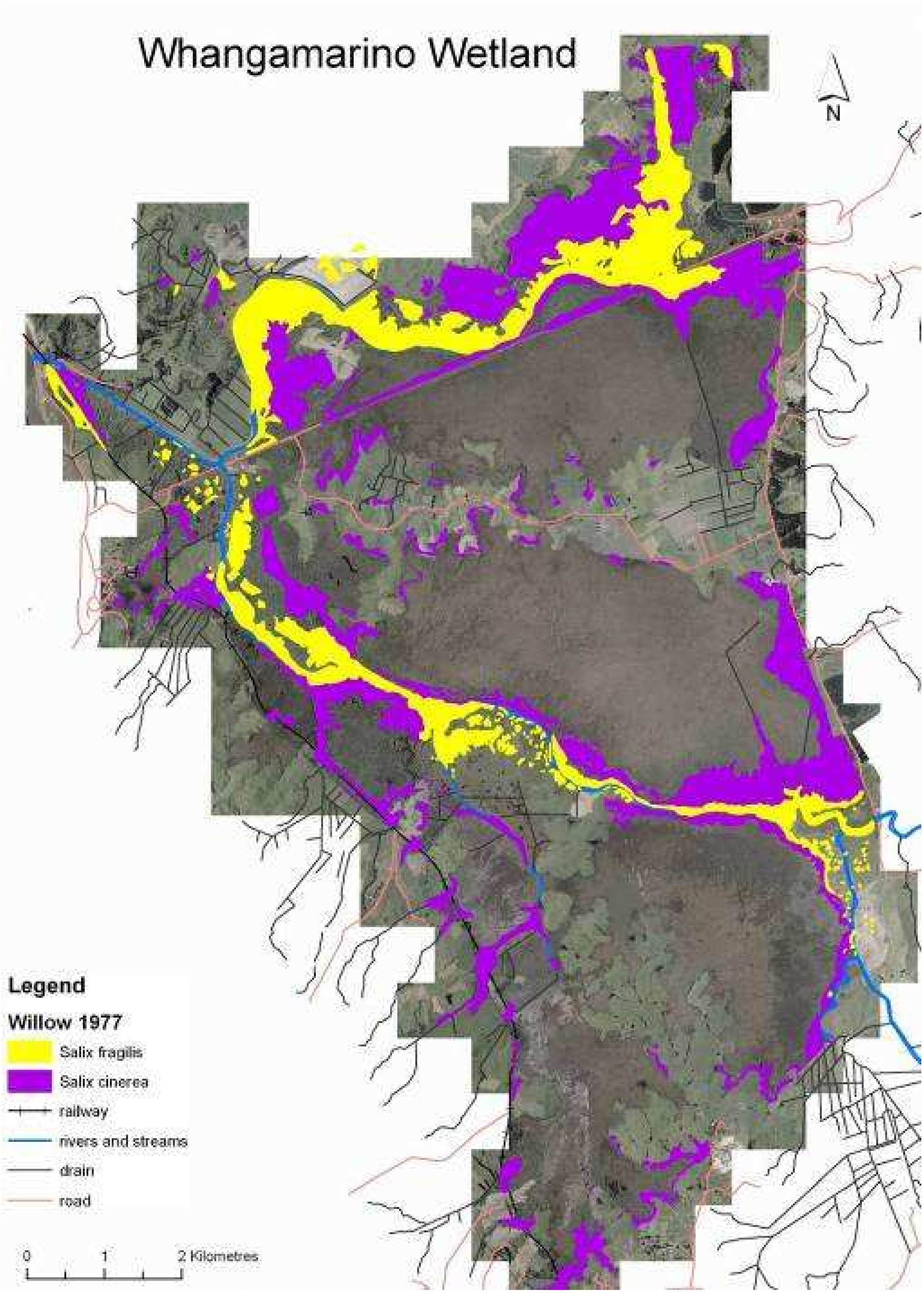

Figure 42: Areas within Whangamarino Wetland dominated by *Salix fragilis* (crack willow) and *Salix cinerea* (grey willow) vegetation in 1977.

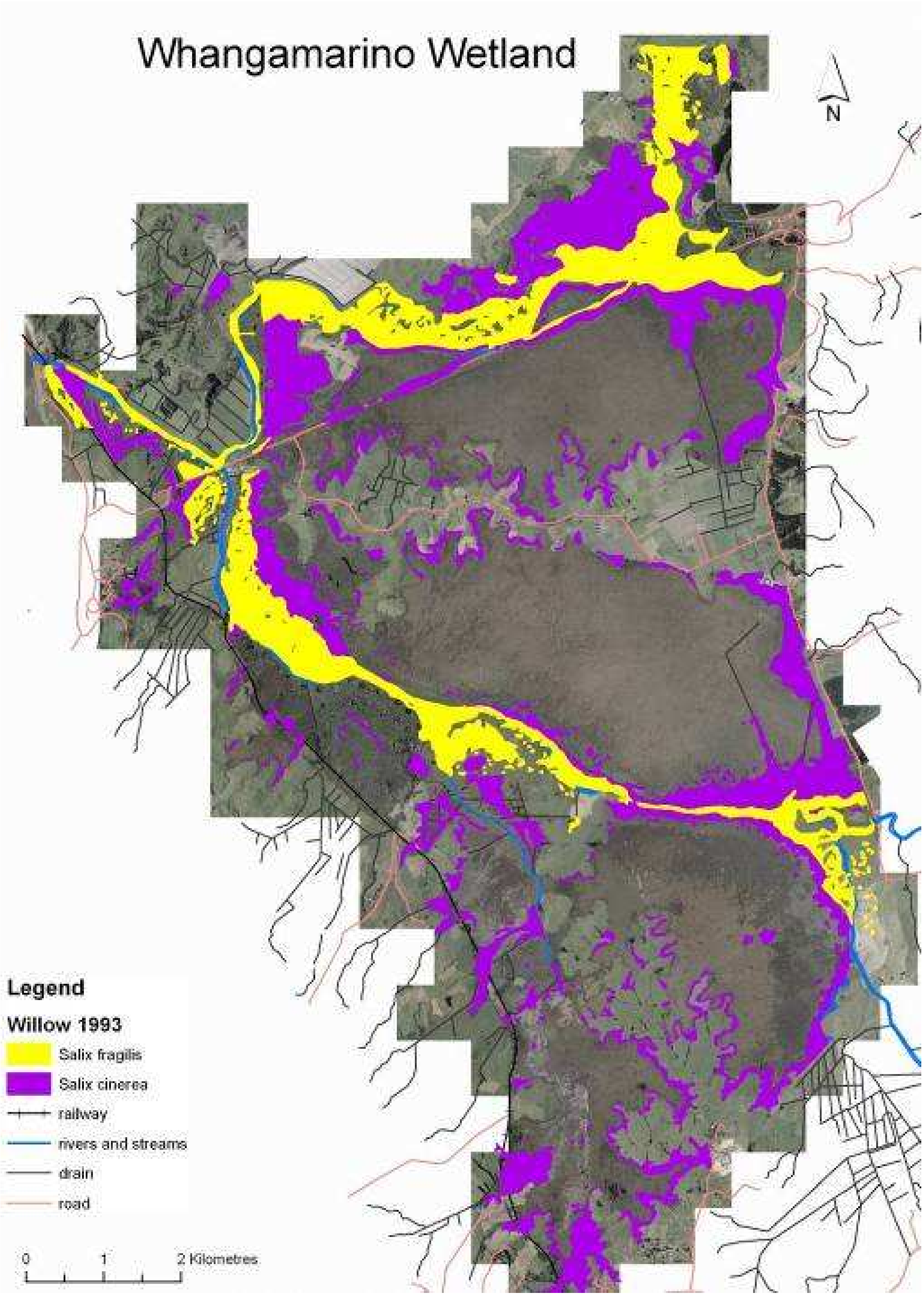

Figure 43: Areas within Whangamarino Wetland dominated by *Salix fragilis* (crack willow) and *Salix cinerea* (grey willow) vegetation in 1993.

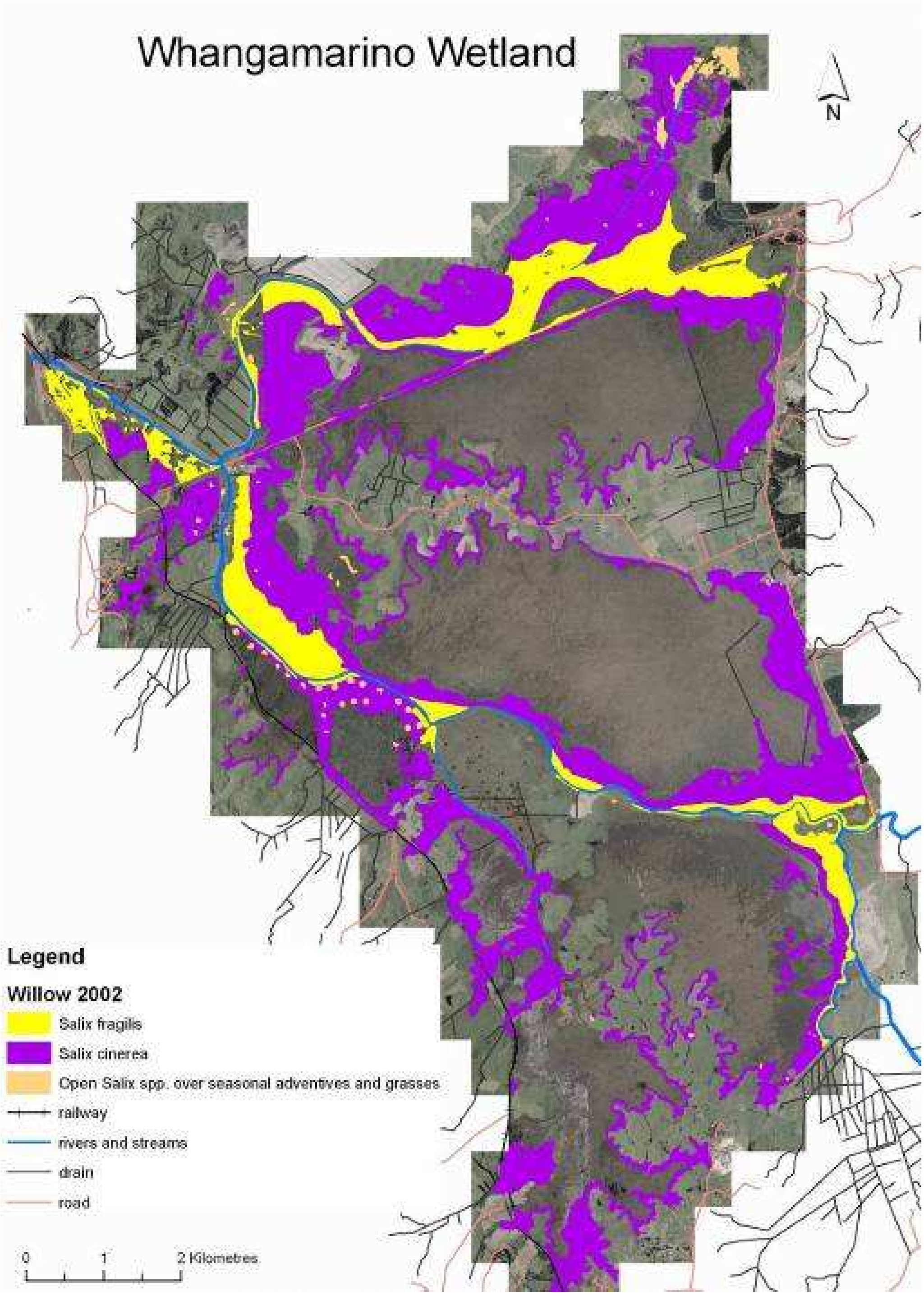

Figure 44: Areas within Whangamarino Wetland dominated by *Salix fragilis* (crack willow) and *Salix cinerea* (grey willow) vegetation in 2002.

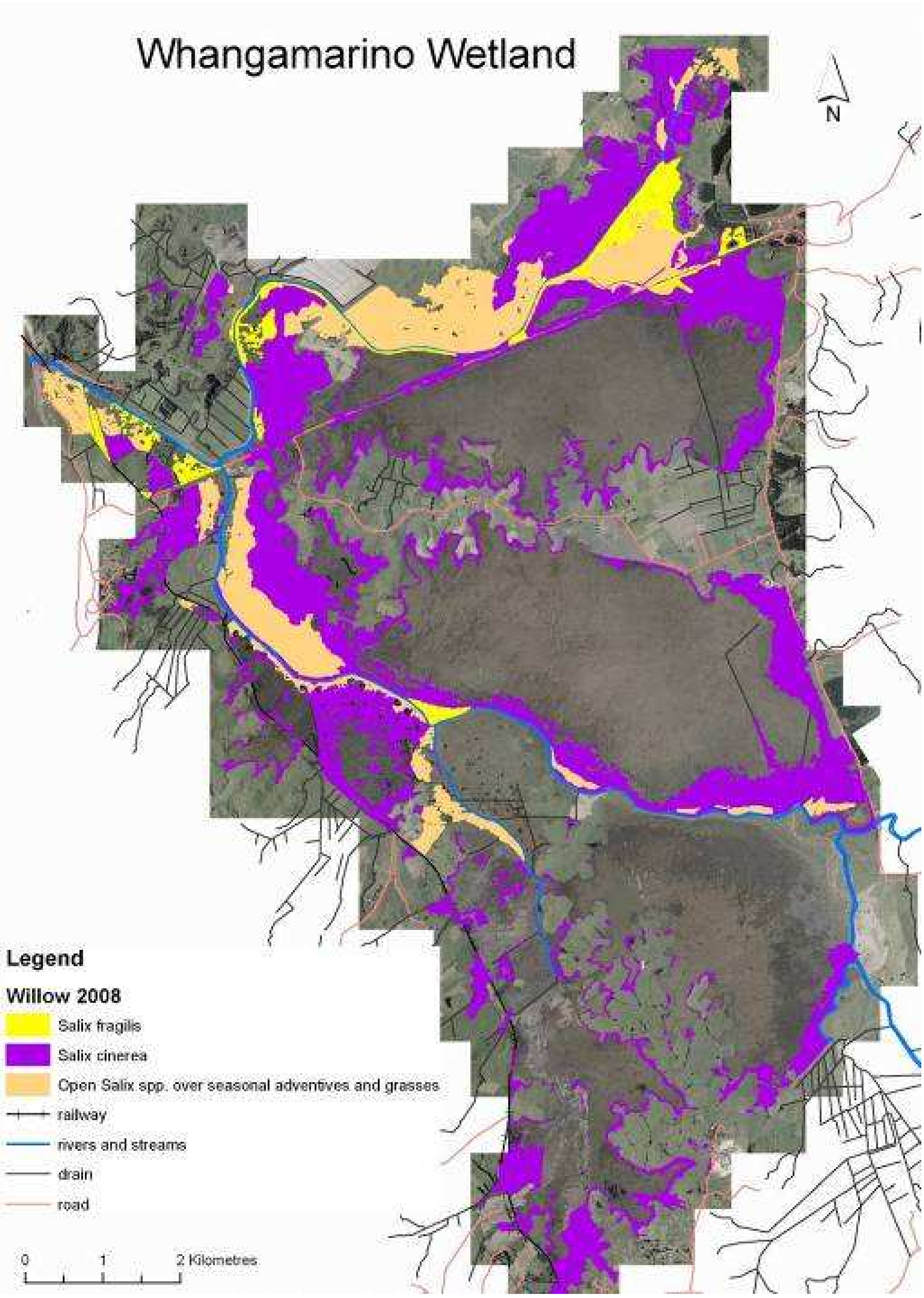

Figure 45: Areas within Whangamarino Wetland dominated by *Salix fragilis* (crack willow) and *Salix cinerea* (grey willow) vegetation in 2008.