Ohau Loop Phase 1

Existing Status and Recommendations for Improvement

Manaaki Taha Moana

Manaaki Taha Moana: Enhancing Coastal Ecosystems for Iwi

MTM Report No. 5
November 2011

ŌHAU LOOP PHASE 1: EXISTING STATUS AND RECOMMENDATIONS FOR IMPROVEMENT

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Manaaki Taha Moana: Enhancing Coastal Ecosystems for Iwi and Hapū

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Mihi

Te ngākau pūaroha ki ngā ōhākī
‘E kore koe e ngaro- te kākano i ruia mai i Rangiātea
Puritia! Puritia! Puritia!

E ngā atua Māori, mō ōu whakaaro whānui mā a tātou, tēnā koutou.

E ngā mana, e ngā reo, e ngā iwi o te motu, tēnā koutou.
E ngā matāwaka, whītiki! Whītiki! Whītiki!
Te hunga ora ki te hunga ora, te hunga mate ki te hunga mate.

E kui mā, e koro mā a Tūkorehe, kia koutou kua ū mai nei ki tēnei mahi nui, ki te atawhai, ki te manaaki i ngā taonga i tukua mai e ngā tūpuna o te takiwā nei a Tahamata, Kuku, tēnā koutou.
E whaea mā, e matua mā, e ngā whānaunga katoa, e hoa mā, e kohikohi ana, e mahi tonu ana me te kaupapa nui mō Te Taiao.

Ko te tūmanako kia whakawhānuitia i ōu mātou tirohanga i roto i te whakatakotoranga kaupapa nei.

Nō reira, tēnā koutou, tēnā koutou, tēnā koutou katoa.

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Palmerston North
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EXECUTIVE SUMMARY

Manaaki Taha Moana (MTM) is a Ministry for Science and Innovation funded research programme that aims to assist iwi to maintain and enhance coastal ecosystems of cultural significance.

Once a highly valued gathering area for *mahinga kai*[1], the Ōhau Loop (known as 'the Loop') was part of a meandering tidal section of the Ōhau River. Flood protection works on the lower Ōhau River in 1972 saw this 3.5 km meander cut off from the main flow. Today the Loop is surrounded by intensive dairy farming and has poor water quality, degraded biodiversity, and an abundance of aquatic weeds. It is proposed that the Loop be targeted for rehabilitation through the MTM programme.

This study had two objectives:

1. To assess the existing ecological state of the Loop before any rehabilitation measures are carried out.
2. To provide recommendations on ecological rehabilitation and further research options for the Loop and adjacent ecosystems, such as the coastal foreshore, the estuary and nearby wetlands.

Fish population, sediment depth, water quality, hydrology, and habitat quality were measured over a four day period in October 2011.

Channel modification and changes in land-use have had a severe impact on the morphology and ecology of the Ōhau Loop. Cessation of flow though the Loop has resulted in an accumulation of approximately 104,000 m^3 of fine sediment. Much of this sediment is high in *E. coli* bacteria, indicating that contaminants have settled out in the stagnant waters and are stored in the sediment.

Water quality in the Loop ranged from good to poor. Surface water quality analyses showed that the Ōhau River and Kuku Stream had higher nitrate-N concentrations than the Loop. Water from a site close to a dairy shed showed the highest nutrient concentrations, likely due to a (now discontinued) long-term discharge of dairy effluent nearby. Dissolved oxygen (DO) saturation recorded at this site showed all measurements to be in breach of the ANZECC >80% saturation guideline. At night the average DO saturation across all sites was 26% and the lowest individual reading was 0.7%.

Fish species richness was much lower in the Loop than in the adjacent reach of the Ōhau River (known as 'the cut'). Native fish found in the Loop included longfin eel, common bully and adult inanga. One exotic species (rudd) was found. The following species were found outside the Loop: black flounder, common smelt, grey mullet, brown trout, common bully, giant bully, inanga, longfin eel, shortfin eel and freshwater shrimp. In addition, an unidentified

[1] Definitions for Māori terms can be found in the glossary.

species of whitebait were also recorded. With the exception of rudd, these fish species are representative of tidal lowland communities and all but giant bully and rudd have been recorded previously in the Ōhau River.

The 3.2 km long Loop is highly segmented by farm tracks with culverts that are generally not conducive to fish passage. Willows have proliferated in some sections, forming a continuous bed of roots across the channel. Due to the uneven distribution of fine sediment deposits, bed height elevations through the loop showed no clear downward trend between the upper and lower Loop sections.

There was no evidence of tidal surface flow into the Loop, so water inflow is likely to be predominantly via shallow groundwater and direct rainfall. More field work is needed to confirm this.

Low DO saturation and the lack of fish passage are considered to be the most limiting factors to the re-establishment of species of interest to iwi. Removing accumulated sediment and organic matter, establishing vegetation for shade to inhibit further growth of algae and hornwort, and restoring flow would all help to improve oxygen levels and fish passage. Whilst ammonia was high in the vicinity of the dairy shed (site 5), levels elsewhere were normal. This may change as temperature in the Loop increases over summer, so more monitoring is advised. Turbidity and pH records were generally within recommended guidelines, except at site 5 which had slightly increased turbidity values.

Preliminary recommendations include the removal of accumulated fine sediments from the Loop and the re-connection of adjacent lagoons to form a continuous channel connected by fish-friendly culverts. The flood gate at the bottom of the Loop should be retrofitted or replaced to enable better fish passage. An as yet unspecified flow should be diverted from the Ōhau River into the top of the Loop to alleviate poor water quality. Further study is required to calculate the flow required for contaminant dilution whilst maintaining flood protection to property and livestock. More suitable riparian fencing and planting native species would also benefit the ecosystem services of the Loop by providing shade, habitat and filtering sediments from farm runoff.

Before final recommendations can be made with regard to augmenting the flow in the Loop and ecosystem rehabilitation, the condition of the Loop should be assessed during the summer period, when water quality is likely to be at its worst.

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GLOSSARY

Term	Definition
°C	Degrees Celsius
ANZECC	Australia and New Zealand Environment and Conservation Council
cfu	Colony forming units
cm	Centimetre
DO	Dissolved oxygen
DRP	Dissolved reactive phosphorus
FRST	Foundation for Research Science and Technology (now called MSI)
g/m^3	Grams per cubic metre
GIS	Geographical Information System
GPS	Global Positioning System
K	Potassium
km	Kilometre
m	Metre or Metres
m/s	Metres per second
m^3/s	Cubic metres per second
MfE	Ministry for the Environment
mg/L	Milligrams per Litre (parts per million)
mL	Millilitre
mm	millimetres
MPN	Most probable number
N	Nitrogen
n	Sample number
NIWA	National Institute of Water and Atmospheric Science
NO_3	Nitrate
NTU	Nephelometric turbidity unit
O	Oxygen
P	Phosphorus
µS/cm	MicroSiemens per centimetre
TN	Total nitrogen
TP	Total phosphorus
hapū	subtribe
iwi	tribe
kaitiaki	guardian, protector
kaumātua	elders
mahinga kai	indigenous freshwater species that have traditionally been used as food, tools, or other resources
mana	authority, respect, prestige
pā	fortified village
rohe	boundary, tribal area
tāngata whenua	people of the land
taonga	treasure
urupā	cemetery
wāhi tapu	sacred place
whānau	extended family, family group

1. INTRODUCTION

1.1. Background to the Manaaki Taha Moana (MTM) Project

This report on the Ōhau River Loop is one in a series of reports and other outputs from the research programme “Enhancing Coastal Ecosystems for Iwi: Manaaki Taha Moana” (MAUX0907), funded by the Ministry for Science and Innovation. Manaaki Taha Moana (MTM) is a six-year programme, running from October 2009 to September 2015. One of the two MTM case study areas is the rohe of Ngāti Raukawa ki te Tonga (and other iwi affiliates including Ngāti Tukorehe, Ngāti Wehiwehi and neighbouring tribe Muaūpoko) which includes the stretch of coast between the Waitohu and Hokio Streams. The second case study area is Tauranga harbour. The MTM programme builds upon previous research by Ecological Economics Research New Zealand (EERNZ) with Ngāti Raukawa, “Ecosystem Services Benefits in Terrestrial Ecosystems for Iwi” (MAUX0502).

1.1.1. MTM personnel

Professor Murray Patterson of EERNZ at Massey University is the Science Leader of MTM (m.g.patterson@massey.ac.nz). Several organisations are contracted to deliver the research:

- Waka Taiao Ltd with support of Manaaki Awanui Trust in the Tauranga moana case study
- Te Reo a Taiao Ngāti Raukawa Environmental Resource Unit (Taiao Raukawa) and Dr Huhana Smith in the Horowhenua coast case study
- WakaDigital Ltd
- Cawthron Institute
- Massey University.

The research team also engages with local communities and end-users through a variety of means. The MTM programme website is: http://www.mtm.ac.nz and readers are encouraged to visit this website to read more about the research programme.

1.1.2. MTM research aims and approaches

The central research question of MTM is, “How can we best enhance and restore the value and resilience of coastal ecosystems and their services, so that this makes a positive contribution to iwi identity, survival and welfare in the case study regions?” Thus, our research aims to restore and enhance coastal ecosystems and their services of importance to iwi and hapū, through a better knowledge of these ecosystems and the degradation processes that affect them.

We utilise both western science and mātauranga Māori knowledge to assist iwi/hapū to evaluate and define preferred options for enhancing/restoring coastal ecosystems. This evaluation of options is also assisted by the development of innovative Information Technology and decision support tools (such as, for example, simulation modelling, interactive mapping, 3D depiction) by WakaDigital Ltd. Action plans will be produced for improving coastal ecosystems in each rohe.

The research team works closely with iwi and hapū in the case study regions to develop tools and approaches to facilitate the uptake of this knowledge and its practical implementation. Mechanisms will also be put in place to facilitate uptake amongst other iwi throughout NZ. The key features of this research are that it is: cross-cultural; interdisciplinary; applied/problem solving; technologically innovative; and integrates the ecological, environmental, cultural and social factors associated with coastal restoration.

The initial research activities for the first phase of MTM focussed on Objective 1 - 'Building Up a Knowledge Base of Coastal Ecosystems and their Services', in both case study regions, resulting in the following report for the Horowhenua region: State of Ecological/Cultural Landscape Decline of the Horowhenua Coastline Between Hokio and Waitohu Streams, which can be found on the following internet address: http://www.mtm.ac.nz/pdf/StateofHorowhenuaCoastFINAL3.pdf.

This 'stocktake' helped to inform the research team about what knowledge gaps exist regarding the state of the coastal ecosystems and their services in our case study areas, and what the most critical areas are for on-going investigation.

1.2. Background to the Ōhau Loop study

The main coastal issue for tāngata whenua in the Horowhenua is a lack of mahinga kai, the inability to harvest from places that were once abundant food sources. The degradation and depletion of various coastal species and the pollution of waterways that help to sustain them has had significant negative impact on the wellbeing/mana of local iwi and hapū. Iwi are particularly interested in the restoration of coastal shellfish fisheries and the systems that maintain their health.

Once abundant with flounder, mullet and whitebait, the Ōhau Loop (the Loop) was part of a tidal lowland meandering section of the Ōhau River that was hydrologically linked with important local coastal, estuarine and wetland ecosystems. Revered in recent memory by local kaumātua as an abundant food resource, the Loop has been degraded to now resemble a 'severely nitrified lagoon' (Lucas Associates 1998; Smith 2007).

Flood protection works on the lower Ōhau in 1972-1974 saw this 3.5 km meander 'cut' from the main flow. The remnant lagoon, now known as the Ōhau Loop, is thought to receive tidal flow via culverts from the main river, but this is insufficient to maintain healthy ecosystems. Intensive dairying in the immediate vicinity is also likely to have contributed to the Loop's current state, which is characterised by poor water quality, degraded biodiversity, lack of habitat for indigenous species and proliferation of hornwort (an invasive exotic floating weed). Local iwi and the affiliated Tahamata Farming Incorporation have made considerable efforts to improve the Loop, but these have been insufficient to restore mahinga kai. In 1998, a report recommended reinstating a greater portion of flow through this river remnant (Lucas Associates, 1998).

In close collaboration with local tāngata whenua, a study to identify restoration options for the Ōhau Loop was selected as a priority for the MTM programme.

Figure 1. Aerial view of the Ōhau River flowing from the Tararua Ranges to the Tasman Sea.

1.3. Aim of the study

This report presents the results from Phase 1 of a project to restore aquatic ecosystem functions and services in the Ōhau Loop. It involved a literature review to assess the merits of previous recommendations for rehabilitation; an assessment of the existing ecological state within the Loop and key factors impairing its ecological function; and an assessment of aquatic ecosystem functions and their significance to whānau, hapū and iwi. The research questions include:

- What is the history of the Loop and what recommendations have previous reports made regarding restoration?
- How does the quality of the water in the Loop compare to water in the Ōhau River, Kuku Stream, and to national environmental standards?
- What fish species are currently present in the Ōhau River, adjacent to the Loop, compared to inside the Loop?
- What factors limit fish habitat and passage?

This report addresses these questions and updates the Loop's most comprehensive ecological assessment to date (Lucas Associates 1998) by re-assessing present day fish presence/absence, as well as nutrient loading. This will be carried out with a level of detail that surpasses previous assessments. In addition, this report compares instream habitat, sedimentation, and bed gradient/elevation in the Loop to that in the adjacent Ohau River. Surface water flow in the Loop has been measured to assess the degree of nutrient and sediment flushing.

The report concludes with initial recommendations regarding what could be done to rehabilitate the ecosystem function of the Loop and what further research is required to enhance adjacent ecosystems such as the coastal foreshore, the estuary and nearby wetlands.

Phase 2 will explore the link to coastal ecosystems in more depth by looking at the relationship between the Loop's groundwater flows and adjacent marine ecosystems. This work can be done in collaboration with an MTM study of surf zone habitat and shellfish, due to start in late 2011 and continue into 2012. That study aims to identify factors influencing the health of surf clam populations by studying several sites along the Raukawa coastline, including a site near the Ōhau mouth.

It is possible that rehabilitation initiatives in the Loop may alter the flow of groundwater affecting coastal benthic diatom abundance (food supply) and the size of habitable intertidal areas for toheroa populations. Selection of a coastal monitoring site below the Loop and Ōhau River would therefore provide information on how changes in groundwater flow may affect surf clam population dynamics.

The Phase 2 report will update the Phase 1 report by incorporating the results of water quality monitoring during the summer months (November 2011-March 2012). Final recommendations will then be made with regard to ecosystem rehabilitation and changing the flow within the Loop. Phase 3 will involve on-going monitoring of the Loop using the same key indicators as in Phase 1.

2. THE ŌHAU RIVER LOOP

2.1. Location and physical environment

The Ōhau Loop is approximately 80 km north of Wellington on the west coast of the North Island (Figure 2). Today the Loop essentially forms an artificial oxbow lake, situated on the lowland floodplain of the Ōhau River.

The 200 km^2 catchment of the Ōhau River extends from the coast to the top of the north-south oriented Tararua Ranges, where moisture laden westerly air flows deliver large volumes of rainfall to topographically higher areas. Long-term monitoring of rainfall across the catchment by Horizons Regional Council (Horizons) and National Institute of Water and Atmospheric Research (NIWA) has recorded annual rainfall of between 800 mm on the coast and 2600 mm at the top of the catchment (Horizons Regional Council 2003). Mean annual rainfall across the entire catchment is 1825 mm.

The Ōhau estuary is included in the Foxton Ecological District (Ravine 1992). It lies in a coastal zone characterised by an elongated band of sand dune country with several significant estuaries, wetlands and dune lagoons covering about 1,100 km^2 (Ravine 1992). Dunes are a distinctive feature of the wider region too. “The parabolic and transgressive dune field that extends from Paekakariki to Patea is the largest in New Zealand, extending approximately 200 km north to south and 18 km wide at its widest point (at Rangiotu)” (Hesp 2001; Loader 2003).

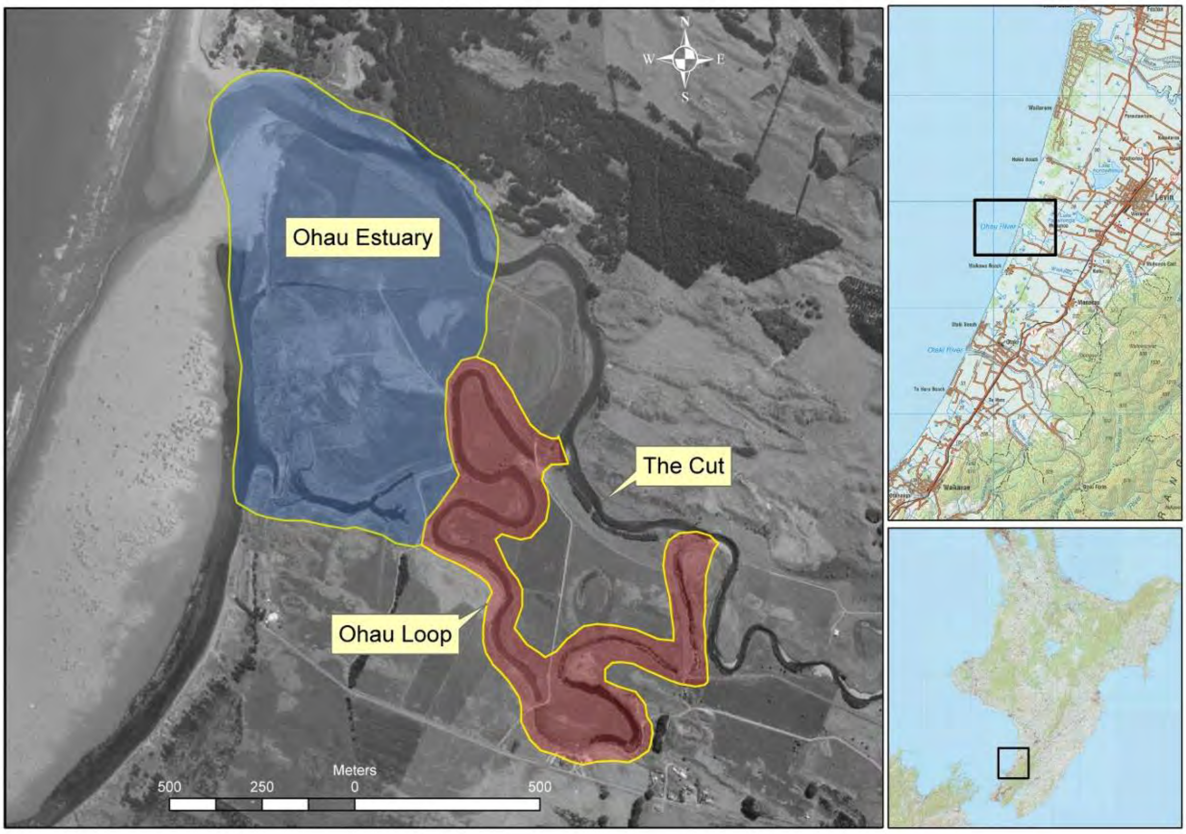


Figure 2. The location of the Ōhau River 'Loop' (pink area), the 'cut', and the Ōhau estuary (blue area). Ōhau estuary boundaries were drawn based on the area delineated by Ravine (1992).

2.2. Significance of the Loop, estuary and river

To Māori, tribal identity and the wellbeing of iwi, hapū and whanau are inextricably intertwined with the natural environment through cultural places, landforms, natural resources and taonga species (Cooper & Brooking 2002; Smith 2007). Traditionally, any ecosystems with particular species and associated habitat qualities were likely to have taonga status in the customary Māori landscape. "A swamp or coastal foreshore ecosystem that possessed such qualities, or a river ecosystem, or a forest, could be considered, with the people it sustained, to be a living being and be termed a taonga (Park 2001)."

> *"These land, sea and water based taonga signified both value and relationships, where natural or cultural 'taonga' in landscape were treasured because of the associations they accumulated"* (Smith 2007).

The value of the Ōhau River and Loop to tangata whenua was appraised in a 2009 report by Treadwell and Associates entitled *'Assessment of the outstanding landscapes and natural features of the Horowhenua coast'.* The report describes the area having noted ancestral landscape value with both wāhi tapu and pā sites, and having 'high' cultural and spiritual significance. "Important Māori expressions of belonging or turangawaewae continue to emphasise ancestral connections and inter-generational responsibilities for lands, rivers, wetlands, healing springs and freshwater springs…" (Treadwell and Associates 2009).

Smith and Cole (2009) mapped culturally significant landscapes in the rohe of Ngāti Raukawa. There are four urupā or other wāhi tapu in close proximity to the Loop (Figure 3). Former pā/occupation sites also line part of the Loop alongside associated cultivation areas. The Ōhau estuary, associated streams, and coastal foreshore north and south of the mouth are significant traditional seafood gathering areas for Māori.

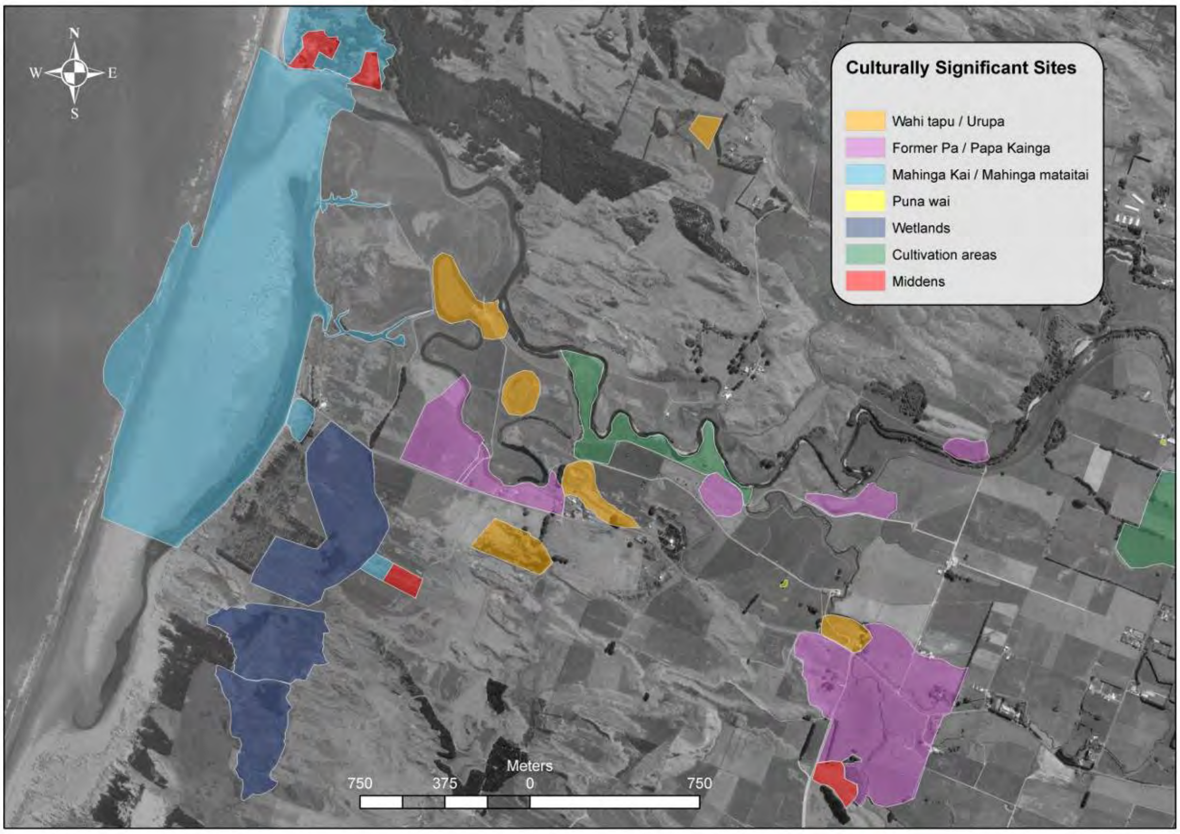


Figure 3. Some areas of cultural significance in the lower Ōhau catchment. Re-drawn using data supplied by Smith and Cole (2009).

The Ōhau estuary (Figure 2) is considered the last major and (albeit arguably) un-modified estuary on the west coast of the Wellington Conservancy and is afforded "a high priority for conservation by the Department of Conservation" (Department of Conservation 1996). Ravine (1992) surveyed the estuary in 1992 when assessing the suitability of wetlands in the district for inclusion in the Department of Conservation's

Protected Natural Areas Programme. The programme aimed to identify and protect a full range of indigenous, biological and landscape features around New Zealand. The 100 hectare estuary was targeted for restoration and protection with ‘Priority 2’ status, citing good examples of estuarine ecosystems, moderate biodiversity, high naturalness, and special wildlife value (Ravine 1992).

The estuary and nearby wetlands are known as habitat for the Weweia (New Zealand Dabchick), Kotuku (White Heron), Kotuku Ngutu-Papa (Royal Spoonbill), and Matuku (Australasian Brown Bittern), and is a breeding ground for the Torea (South Island Pied Oystercatcher) (Ravine 1992; Smith 2007).

The Ōhau River is also highly valued for its scenic and natural character and is considered a ‘better than average’ trout fishery, with important spawning habitat (Horizons Regional Council 2002; 2003). Horizons Regional Council considers the Ōhau River to have “the potential to be an ecological blueprint for a complete ‘green corridor’ from the mountains to the sea” (Horizons Regional Council 2002; Loader 2003).

Monitoring by Horizons Regional Council has indicated that although the Ōhau River is less impacted by human-induced modification than other rivers in the region, water quality, flow, and biological communities below State Highway 1 are in a state of decline (Horizons Regional Council 2003).

3. HISTORIAL DEVELOPMENT OF THE ŌHAU

3.1. Change in land cover and land use

The coastal plain over which the lower Ōhau River runs is a dynamic geophysical environment. The combination of climate change and geological processes over the past 300,000 years have brought about variations in sediment deposition and topography that have largely determined the course of the river after it leaves the Tararua foothills.

Lucas Associates (1998) refers to two early flow pathways for the Ōhau. One meanders north after emerging from the mountains, flowing into the low lying basin where Waipunahau (Lake Horowhenua) now sits. The outlet for this pathway is approximately 7 km north of the existing mouth. The second meanders south to the outlet where the river flows today. A third outlet is evident in historical maps of the area drawn by George Leslie Adkin in the 1930s. Adkin, whose references date back to 1845, produced a map describing former courses of the Ōhau River (Figure 4). The river, according to Adkin, once ran a further 4 km south behind the coastal dunes, to flow out to sea at the same point as the present day Waikawa River (Adkin 1935).

Prior to 1887, lands within the Horowhenua region were still in Māori ownership and the Ōhau catchment was predominantly in its natural state (Horizons Regional Council 2003). At some stage before European settlement, wetlands occupied broad areas of lowland along much of the Kapiti – Horowhenua coastline. Recent GIS analysis mapped the extent of pre-1840 wetland along this section of coast, indicating that almost the entire coastal plain between the Ōhau and Waikawa rivers was once swamp (Figure 5) (Smith & Cole 2009). The floodplain of the Ōhau is likely to have covered a broad span of the coastal plain south of the river channel, similar to that depicted in Figure 5.

In an early account of the area, McDonald (1929) described being told of "several small lakes with no outlet what-so-ever other than evaporation or soakage. … The lower catchment consisted of scrub and smaller swamps, the river traversing wide shingle beds and migrating over much of the land below the current State Highway" (Horizons Regional Council 2003).

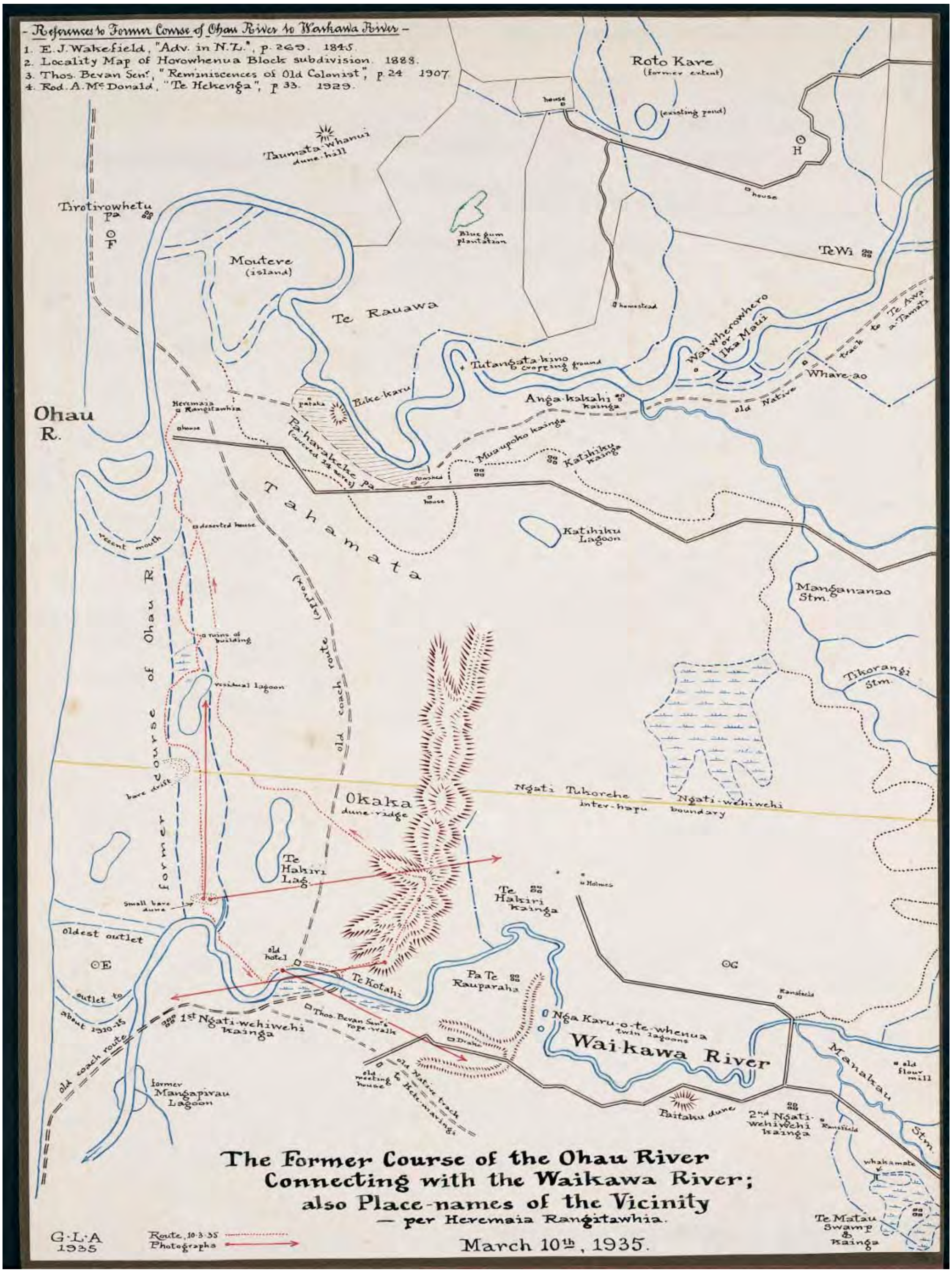


Figure 4. A hand drawn map of the lower Ōhau River and culturally significant features dated 1935. Reproduced with permission from the Alexander Turnbull Library, Wellington.

Figure 5. Approximate pre-1840 wetland extent (blue). Re-drawn from (Smith & Cole 2009).

Due to a range of complex land transactions over an extended period of time, the extensive lowland and valley forests were logged and the river flats were cleared of vegetation to make way for farming. In 1914, the area in Kuku under bush was only one quarter what it had been in 1890 and, by 1963, 91.9% of the land had been cleared (Park 2001). Trees were felled and burnt and the ashes sown in English varieties of grass *e.g.* cocksfoot, clover.

This would have changed the hydrology of the catchment by increasing the volume of surface run-off, the speed of flood flows and the size of flood events. Large areas of contiguous wetland were drained to create pasture for livestock (Lucas Associates 1998). This had the effect of "accelerated obliteration of the beautiful, natural, moisture –conserving water features of our landscape" (Adkin 1948). Early aerial photos (Figure 6) show the meandering section of the lower Ōhau before 'the cut' was constructed. Clearly visible are sediment bars deposited on the inside berms of the meanders. Once the Loop was cut off from the main stem in 1972, there could be no more deposition of larger sediment (*i.e.* cobbles and gravels) or flushing of fine sediment, hence the Loop is now filling with organic detritus and silt from surrounding farmland.

Figure 6. The Ōhau Loop in the 1940s before the cut was made (Smith 2007).

3.2. Flood control efforts

The lower Ōhau was renowned for flooding, as one early anecdote describes: "In a typical year during the late 1940's to 1954, up to a third of the Kidd's one hundred acres, the Saint family farm and flat areas across Ōhau Inland Road (now Kuku Beach Road), and much of the farm between Kidd's and the Ōhau River would flood once to three times a season as backed up in the tide" (Smith 2007; quoting Hon. Douglas Kidd, 6 January 2006). The flood plain is shown in Figure 7.

Between 1940 and 1971 four schemes were proposed to consolidate existing stop-banks and drains and provide for further works to alleviate flooding in the lower reaches (Figure 8). All of the proposed schemes offered some degree of realignment to straighten and shorten the river in the lower reaches in an attempt to speed up flood flows en route to the sea (Smith 2007).

The scheme that was finally constructed in 1972 (proposal D in Figure 8) was the least hydrologically intrusive of the four options. "Completion of the diversion channel, combined with a shift in the position of the river mouth during a flood in 1972, caused an 8 km shortening of the lower river in only six months" (Horizons Regional Council 2002). Consequent changes to the flow led to changes in sediment transport, channel shape, and more problems with bank erosion and flooding. This problem is still apparent today (Horizons Regional Council 2008), yet the mouth of the Ōhau is thought to be more stable due to increased deposition of larger diameter substrate.

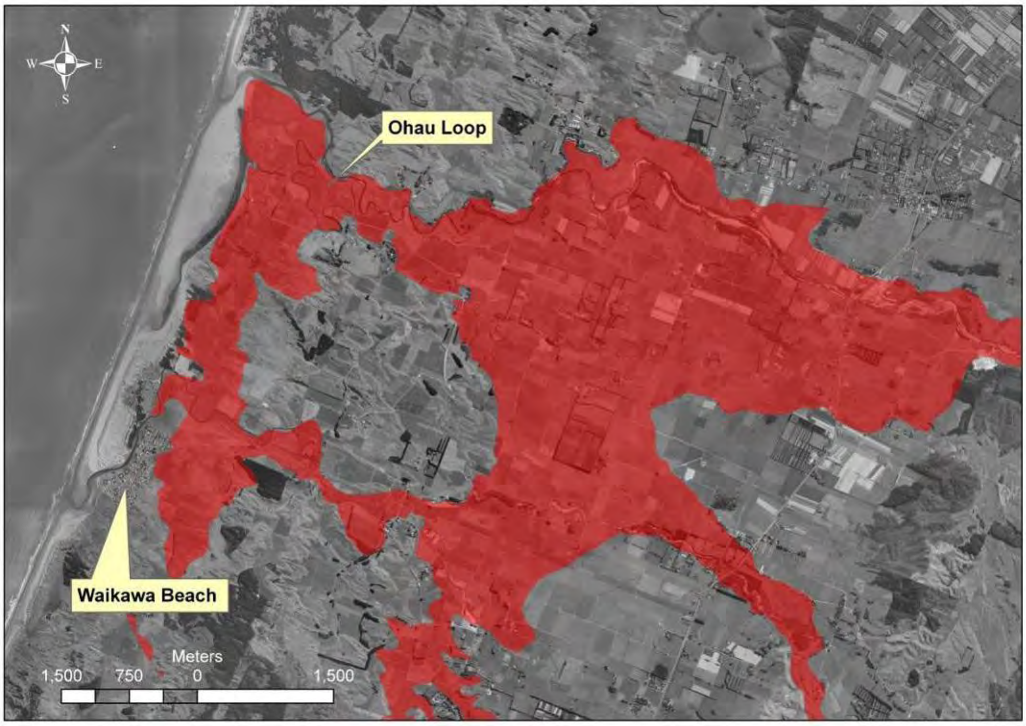


Figure 7. Lower Ōhau River flood plain (re-drawn from Smith & Cole 2009).

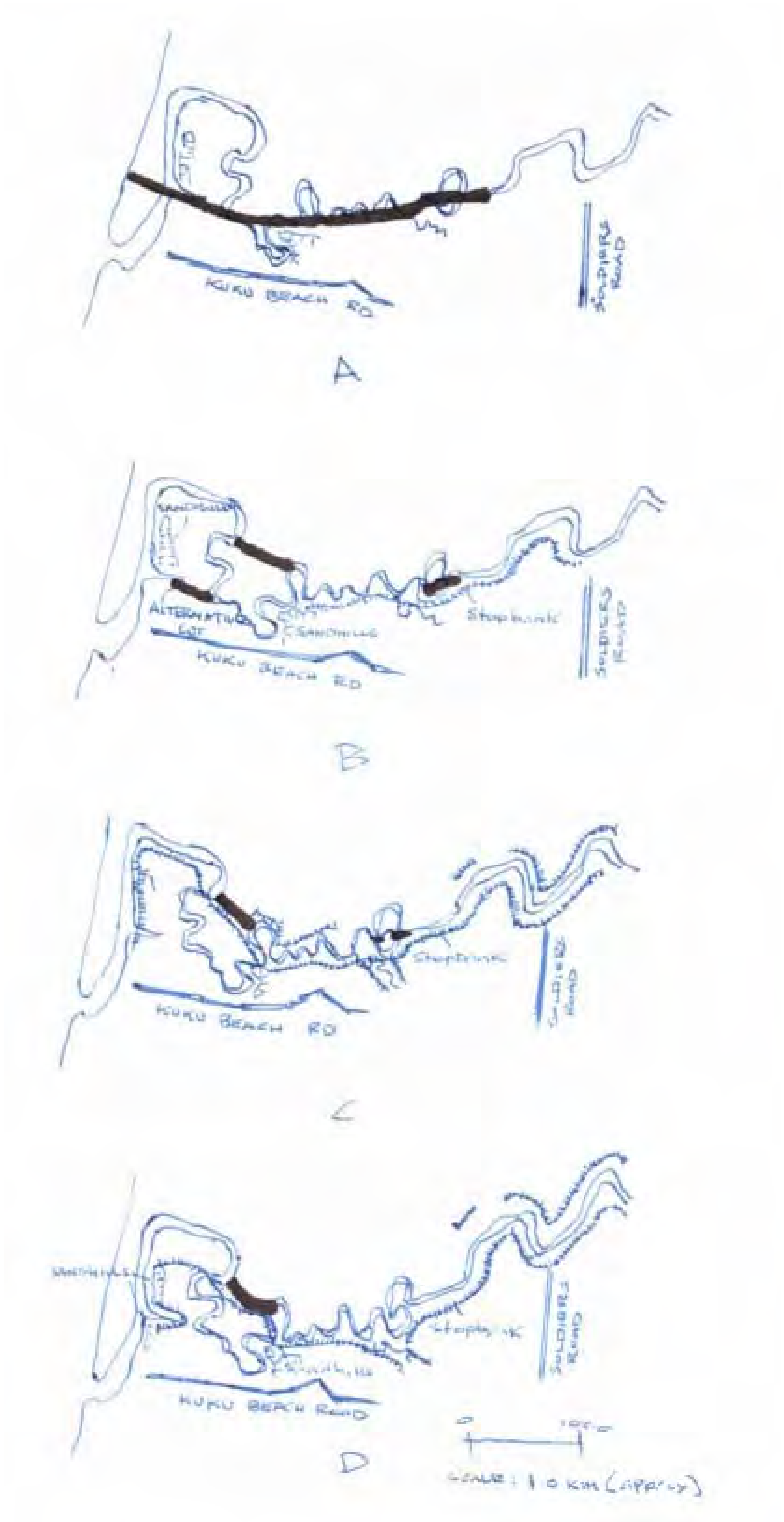


Figure 8. Various proposals for the Ōhau River diversion between 1940 and 1971. Hand-drawn images of Ōhau Loop by original engineer of lower Ōhau River, Edward O'Conner.

Stop-banks constructed along the river below State Highway in the 1970s had a nominal protection standard to cope with a 25 year flood return period. In 2006, following continued problems with flooding, G & E Williams Consultants were commissioned to investigate deposition and sedimentation in the channel below State Highway 1 and to make recommendations on the management of the channel and measures to enhance flood protection. Williams carried out a flood flow frequency analysis for the Ōhau using data from the Rongomatane monitoring site[2] (1978 to 2006), as well as four historic floods in 1940, 1949, 1950 and 1959. Table 1 summarises the flow statistics.

Table 1. Flow statistics for the Ōhau River at Rongomatane (1978-2003), Horizons Regional Council 2003; Williams 2006; NIWA 2011.

Median Flow (m^3/s)	**Mean Annual Low flow (m^3/s)**	**Flood Flows (m^3/s)**			
		2 year return	**5 year return**	**20 year return**	**100 year return**
3.86	1.1	225	325	450	700+

In response to Williams' recommendations, flood protection efforts have since concentrated on maintaining the channel to cope with a 20 year return period. This is achieved by raising the height of the stop-banks; gravel extraction from the main channel bed; widening the main channel to 40 m; lowering the inside berms of the rivers banks; and moving strategic sections of the stop-bank further away from the river (Williams 2006).

The recurring problems with flood damage and erosion below the State Highway reflect the ramifications of the past 120 years of human modification within the catchment. Whilst the council can persist with costly channel maintenance, the problems may remain to some extent whilst the broad natural floodplain beyond the stop-banks is not within the river's reach.

The modern day hydrology within the Loop is described somewhat by Lucas (1998). Whilst the report was predominantly an ecological assessment, Lucas describes the Loop as having little freshwater input and flood gates that are susceptible to being jammed closed so that water flow through the Loop is minimal at best. James and Joy (2007) note similar problems with a jammed floodgate, limiting fish passage as well as water flow. Lucas recommends changes to the hydrological regime within the Loop (described in Section 5).

[2] This site is approximately 3km upstream from the top of the Loop

4. ECOLOGICAL ASSESSMENT IN 1998

In 1998 Lucas Associates was commissioned to produce a preliminary ecological report on the Ōhau Loop to address the issues and opportunities resulting from the cut and associated works. Specific aims included giving advice on the rehabilitation and enhancement of whitebait, eel and depleted indigenous flora of the lower Ōhau.

4.1. Flora

4.1.1. Historical

The lower Ōhau catchment was a forest landscape before European colonisation, with almost continuous forest over plain, terrace and mountain slopes up to the tree line (Lucas Associates 1998). The large block of remnant old-growth native forest at Lake Waiwiri reserve (Papaitonga), 4 km northwest of the Loop, gives a good indication of what pre-European vegetation was likely to have been present around the lower Ōhau. The reserve is the only intact sequence from wetland to mature dry terrace forest in the Wellington and Horowhenua districts. The wetland forest associations of kahikatea/pukatea, tawa and pukatea-tawa-swamp maire are now rare (Department of Conservation 2011b).

Smith and Cole (2009) mapped pre-1840 vegetation in the rohe of Ngāti Raukawa as part of a Foundation for Research, Science and Technology (FRST) funded report called *Ahi Kaa Roa: mapping cultural landscape*. According to this report, the band of lowlands inside the dune-lands parallel to the coast was dominated by kahikatea forest, with matai, tawa and mahoe (Figure 9). The Ōhau Loop lies within this band. The source for the vegetation mapping is unclear, but the description is consistent with a more comprehensive list of 'Past and Potential Indigenous Vegetation' published in Lucas Associates (1998) (see Appendix 5).

Anecdotes gathered by Smith (2007) describe huge piles of stumps and trunks being piled up by bulldozers as the swamps were drained. "There was an extensive range of native species including the extremely hot burning heavy black maire (swamp maire)" (Smith 2007 quoting personal communication with Hon. Douglas Lorimer Kidd, 6 January 2006).

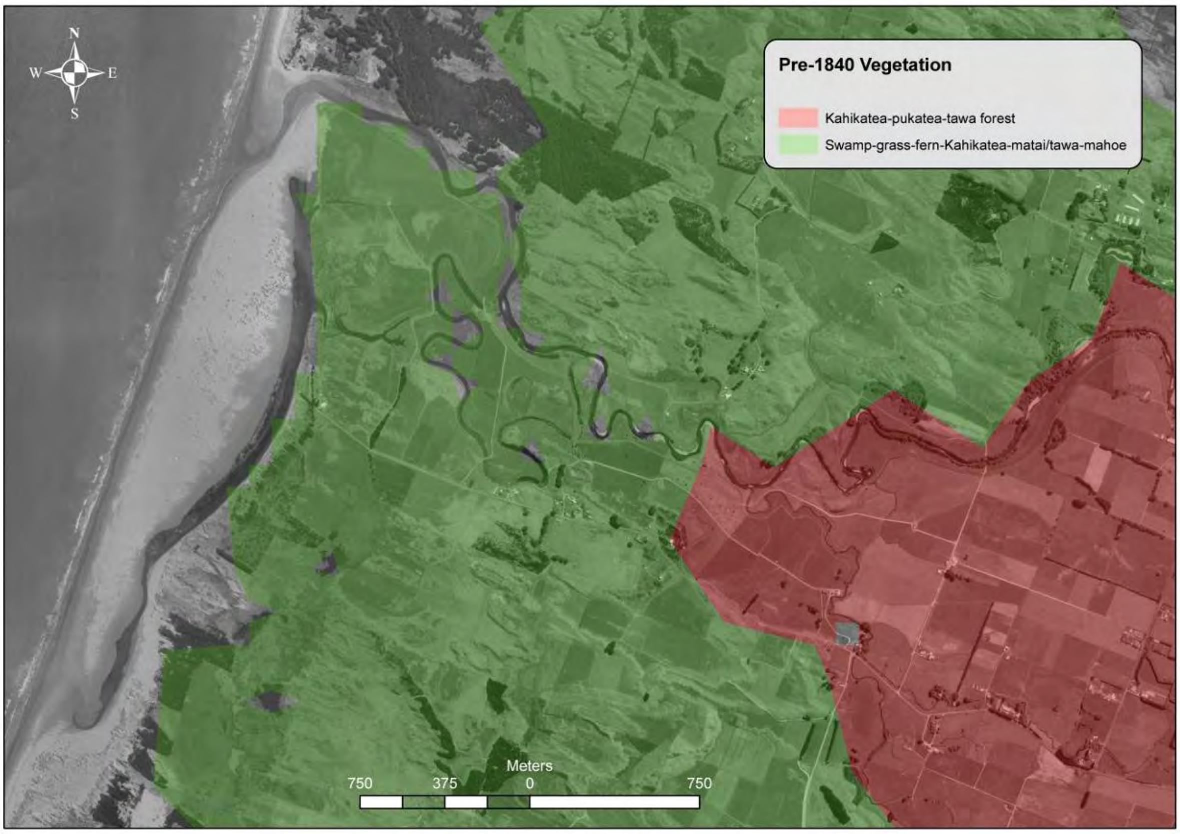


Figure 9. Approximate pre-1840s vegetation around the Loop. Redrawn using data from Smith and Cole (2009).

4.1.2. Present day

As described in Section 3.1, following a series of land transactions over an extended period of time, all or most of the forest on the coastal plain was removed to make way for pastoral farming. Today, riparian vegetation surrounding the Loop is mostly pasture, with a few cabbage trees, flax, toetoe, rushes and willow.

Lucas Associates (1998) included a comprehensive assessment of the (then) current vegetation within the Loop (Table 2). Since this assessment there has been an infestation of hornwort (*Ceratophyllum demersum*), an invasive exotic weed. Kaitiaki from Taiao Raukawa and Nga Whenua Rahui are currently attempting to address this issue via aerial spraying of herbicide, an approach used in nearby Te Hākiri dune wetland.

Table 2. Aquatic, marginal and wetland plants found in the Ōhau Loop.

	Botanical name	Common name	Preferred habitat	Native or introduced
Aquatics	*Ceratophyllum demersum*	Hornwort	Still and flowing freshwater	Introduced
	Potamogeton ochreatus.	Blunt pondweed / manihi	Brackish or fresh, open or slow moving water	Native
	Elodea canadensis.	Canadian pondweed	Freshwater, rooting or drifting	Introduced
Floating plants	*Lemna minor.*	Duckweed	Freshwater	Native
	Azolla filiculoides.	Rotoroto, karerarera	Freshwater, still, fertile ponds and drains	Native
	Rorippa nasturtium aquatica.	Watercress	In seeps and along streams	Introduced
Emergents	*Typha orientalis.*	Raupo, bullrush	Freshwater	Native
	Baumea articulate.	Jointed twig-rush	Ponds and swamps	Native
	Juncus effuses.	Soft rush	Damp ground	Introduced
Marginal	*Apium nodiflorum.*	Water celery, fools watercress	Shallow ponds	Introduced
	Apium prostratum.	Tutae-koau, shore parsley	Saltmarsh	Introduced
	Cotula coronopifolia.	Bachelors button	Brackish	Native
	Paspalum distichum.	Mercer grass	Wet, non-saline soils	Introduced
	Polygnum persicaria.	Willow weed	Damp ground, swamp edges	Introduced
Wetland	*Cyperus eragrostis.*	Umbrella sedge	Damp, and streams	Introduced
	Festuca arundinacea.	Tall fescue grass	Saltmarsh, freshwater	Introduced
	Isolepis prolifer.	Green clubrush	Swampy ground, brackish pool edges	Native
	Juncus maritimus var australiensis.	Searush	Saltmarsh	Native
	Phalaris arundinacea.	Reed canary grass	Shallow pond and stream margins	Introduced
	Salix cinerea.	Grey willow, sallow	In swamps, by rivers	Introduced
	Ramunculus.	Buttercups	Freshwater, pasture	Introduced

A full botanical survey of the Loop was not carried out for the present study in light of the comprehensive assessment carried out by Lucas Associates. However, vegetation was assessed from the perspective of habitat, following Harding *et al.* (2009). Full results of this assessment are tabled in Appendix 3, and summarised below.

As assessed in 2011, the overall quality of riparian habitat in the Loop (sites 4, 5, and 6) was relatively similar, if not slightly better, than in the Ōhau River (sites 3 and 7). Willows along the margin of the Loop provide good habitat for eel and greater shading than what was seen in much of the Ōhau River. This is especially so in the middle and upper reaches of the Loop (around sites 4 and 5), though in some places willows have grown across the stream bed and disrupt or block water flow. Most of the Loop is fenced to livestock and areas inside the fence do not appear to have been grazed. Sites 3 and 7 on the Ōhau River both had sections of absent or substandard fencing, so stock are able to access the river.

Instream vegetative habitat in the Loop was significantly different to that in the Ōhau River. Due to the vastly more unstable flow regime, macrophytes and algae are largely absent in the Ōhau River whilst they're a dominant feature inside the Loop. The entire wetted width at site 4 (in the Loop), for example, was covered in either macrophytes or algae. Sites 5 and 6 had more open water, but the darkly stained water meant assessing vegetation on the stream bed was impossible. Woody debris and log jams were absent at the Loop sites, but provide intermittent habitat in the Ōhau River.

4.2. Fish species

Lucas Associates (1998) described the Loop as a highly eutrophic closed lagoon with deep sections (>3 m) that are likely to contain stable pools of anaerobic saline water at depth. Noting the "almost complete removal of riparian vegetation", the report suggests that reductions in wildlife in the Loop may have as much to do with the removal of habitat as the loss of flow.

The 1998 report lists fish species present inside and outside the Loop ("outside" being downstream of the seaward end, below the floodgate). Common bully, common shrimp and common smelt were found both in and outside the Loop. Outside the Loop there were also black flounder, inanga, and grey mullet.

The upstream limit of the saline / freshwater interface is an important factor with regard to inanga breeding habitat. Using the presence or absence of *Cotula coronopifolia* (bachelors button), a salt-tolerant native wetland plant species, Lucas estimates the upper limit to be close to the top end of the cut. According to the report, inanga were observed breeding (perhaps laying eggs) in long grass at this site. This suggests that much of the Loop would also provide good breeding habitat for inanga, though none were found, perhaps due to lack of access.

Fish passage was described as minimal (at best) and the lack of flow as insufficient to hold open the flood gate most of the time. James and Joy (2009) also looked at fish passage in the Loop. They thought it was nearly impossible for fish to enter the Loop through the flood gate at times of low flow, again because flow would be insufficient to keep the gate open. They also noted that the channel was choked with macrophytes and the water was not flowing. Lack of maintenance has resulted in the flood gate jamming with logs from the Ōhau River (Lucas 1998) and overgrown vegetation (James and Joy 2009).

The report describes anecdotal evidence of dairy shed effluent being discharged into the Loop for 'tens of decades'. This, and fertiliser runoff from surrounding farmland, has increased nutrient loading to the now static water body. The shed referred to was approximately 200m downstream from the current Tahamata dairy shed, which is currently the only dairy shed operating in the area (Figure 10) (Personal communication with Huhana Smith 22/11/2011).

4.3. Proposed water quality study

A second phase of study was proposed by Lucas Associates, though not carried out. The reason for the proposed study was to establish baseline environmental conditions and to assess the potential for success of any habitat restoration efforts, particularly for eel and inanga fisheries.

Water quality was to be assessed at three sites:

1. from the Loop outlet to the estuary
2. the centre of the Loop, and
3. the upper Loop, where dairy shed effluent was said to have been discharged.

The physical parameters oxygen, temperature, salinity, and water clarity (by secchi disk) were to be monitored in both surface and bottom waters. Biotic sampling was to include algae and zooplankton. There were also plans to investigate the potential for nutrient and saline intrusion in the Loop, as well as monitoring to assess barriers to fish passage.

4.4. Recommendations of 1998 study – flow and re-vegetation

Lucas Associates (1998) recommended that "some water should be diverted into the Loop from nearby sources". These sources include Kuku Stream and spring water flowing from the toe of a nearby dune (upstream from the Loop). There is a letter of support for these recommendations from Gary Williams, a hydro-engineer who has since carried out consultancy for Horizons Regional Council on flood mitigation in the Ōhau River.

Lucas Associates considered that allowing the Ōhau River to flow through the Loop once more was “now not considered a practical option”. The report did not provide explicit reasons for this but mentioned that the river is entrenched whereas the Loop has suffered significant deposition of fine sediment as a result of land use (*i.e.*, implying that the bed of the Loop now has a higher elevation than the river).

The report also recommended “re-opening the channel outlet that was further upstream”, though the location of this channel outlet is unclear. Options for modifications to the bottom end floodgate were detailed, and a reopening of the old channel to the Ōhau (assumed to be the bottom end) was also suggested.

To assist with the re-oxygenation of the water column, Lucas Associates recommended mechanically removing stored sediment and extensive clumps of emergent vegetation and associated nutrients from the Loop (in the vicinity of the dairy shed disposal site) with a drag-line. A detailed riparian planting plan was given for a 10-20 m buffer around the Loop.

5. ECO-HYDROLOGY OF THE ŌHAU LOOP 2011

This study updates and significantly extends the assessment done by Lucas Associates (1998) by examining the morphology, hydrology, water quality and fish species of the Ōhau Loop in order to provide a more robust basis for considering possible interventions to restore some of the Loop's lost ecological and cultural value.

No macroinvertebrate sampling was conducted during our study owing to heavy rainfall and subsequent high flows in the Ōhau River prior to the field sampling period, which is likely to have affected species composition and abundance.

5.1. Substrate and sediment volume analysis

The present study followed current best practice for stream habitat assessments in New Zealand wadeable streams as described by Harding *et al.* (2009); relevant protocols are presented in Appendix 2. To compare the current state of habitat in the Loop to that in the Ōhau River, substrate characteristics were measured at sites 3, 4, 5a, 6, and 7 (Figure 10). Characteristics measured include particle size, embeddedness, compactness, the degree of channel scouring/deposition, and the depth of fine sediments. Fine sediment depth was measured using a 2.5 m wading rod pushed into the fine sediment to the approximate depth of the original river bed. Five depths were measured in each of 10 cross-sections along a 100 m reach.

Table 3 displays the results of this analysis. Note that site 5a is 200m downstream from site 5, where water quality was measured. The water at site 5 was too deep to allow us to carry out the substrate assessments.

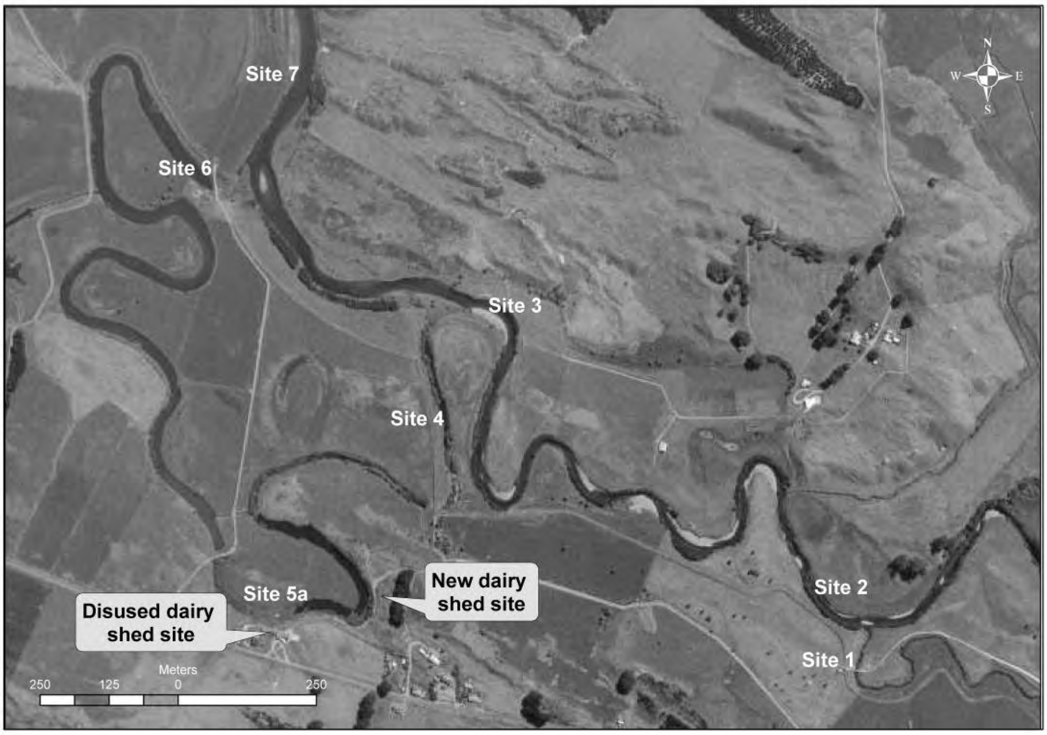


Figure 10. Study sites used for substrate analysis.

Table 3. Results of sediment properties survey.

	Site 3	Site 4	Site 5a	Site 6	Site 7
Mean wetted width (m)	25.3	14.3	19.7	38.6	36
Mean grain size (mm)	27.1	1.2	0	0	13.2
Min/max grain size (mm)	Silt to 128mm	Silt to 32mm	Silt only	Silt only	Silt to 64mm
Mean fine sediment depth (m)	0	0.55	2.1	1.05	0
Min/max fine sediment depth (m)	0	0 to 1.25	1.08 to >2.5	0.1 to 1.7	0
Approximate volume of sediment in the reach (m^3)	0	798	4,137	4,053	0
Embeddedness and compactness[3]	2	Deep, soft silt, no flow	Deep, soft silt, no flow	Deep, soft silt, no flow	1
Depositional and scouring (cm)	400	Deep, soft silt, no flow	Deep, soft silt, no flow	Deep, soft silt, no flow	0

[3] Where 1 is not embedded and loose; and 4 is heavily embedded (>66% of the substrate is buried) and tightly packed.

Substrate particle size in the Ōhau River is significantly larger than in the Loop, where silt was the only substrate found on the bed. Whilst a small amount of fine sediment was found in the Ōhau River, a large volume has accumulated in the Loop. The volume of sediment is highest at site 5, where dairy shed effluent was piped into the lagoon continuously between about 1980 and 2001. A rough estimate of fine sediment volume in the entire Loop was calculated using the data in Table 3 and assigning the following lengths to the upper (site 4), middle (site 5a), and lower (site 6) Loop sections: 800 m, 800 m and 1600 m, respectively. The estimate was approximately 104,000m^3 of fine sediment. Compared to the volume of an Olympic swimming pool (2,500 m^3) this seems like a lot of fine sediment. However, in perspective, the amount of sediment that is being transported by a similar size river (*e.g.* the Ōtaki River) during a two year flood (225 cumecs) with maximum sediment concentrations of 4000 g/m^3, would be approximately 78,000 m^3 of sediment if the flood stayed at this level for one day.

5.2. Bed gradient analysis

Stream bed height was measured with a 5600 Series Trimble Total Station at 83 locations along the 3.2 km Ōhau Loop, and selected parts of the Ōhau River (site 7, Figure 12A) using one of the first order Wellington Vertical Datum LINZ benchmarks (*i.e.*, 2.087 m or 1.647 m New Zealand Vertical Datum 2009).

The survey was split up into four sections: Loop upstream, Loop middle, Loop lower and Loop-Ōhau confluence (Figure 12B).

Bed height elevations showed no clear downward trend between the Loop upstream and the Loop lower sections (Figure 12B). Mean bed height was highest in section Loop lower (*i.e.*, 0.790RL) and lowest at the top of the Loop (*i.e.,* Loop upstream = 0.335).

The Loop upstream section included both the highest (2.533 RL) and the lowest (-0.396 RL) bed height measured within the Loop. The upstream end of this section is filled with sediment and no connection exists to the main river. The highest recording (point 21) was in part of the old river bed, which has been filled in at this location and is now a farm track. At location 9 (Figure 12A), bed height was lower than in the Ōhau River main stem (-0.3RL), however, only eleven records were taken for the main stem section, and only from the lower part of the Ōhau River.

The Loop middle section has highly modified riparian vegetation and aquatic habitat. This section had the second highest mean bed elevation recorded within the Loop (*i.e.*, 0.728 RL). This is likely to be due to the long-term discharge of dairy effluents into the Loop by the adjacent dairy sheds situated on the true left. Bed heights at points 41-44 were the highest recorded in this section. This part of the section was completely filled in with sediment and covered with water celery (Figure 11).

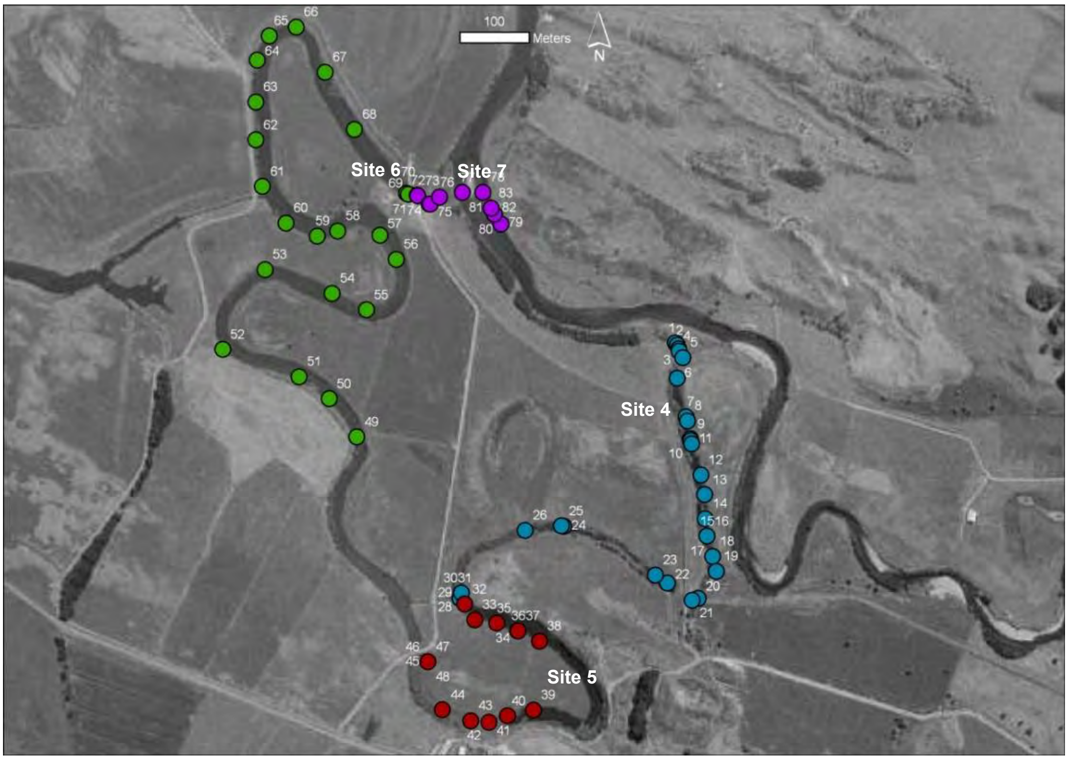
The Loop lower section had the highest mean bed height recorded within the Loop (*i.e.,* 0.790RL), with a range from 0.509RL to 1.222RL. This part of the Loop had consistent water flow and was permanently inundated.

The Loop-Ōhau River confluence section had the second lowest bed height readings and particularly low values at points 78, 79 and 80 (-0.173, -0.297 and -0.3, respectively). No further bed height measurements were made in the Ōhau River because of high wind[4]. Thus more field work is required before precise bed height and gradient descriptions of the Ōhau River can be made.

Figure 11. The once active channel has been filled in with sediment and was covered in water celery at bed height survey points 41-44.

[4] Strong winds meant that the Total Station could no longer hold a steady level.

A



B

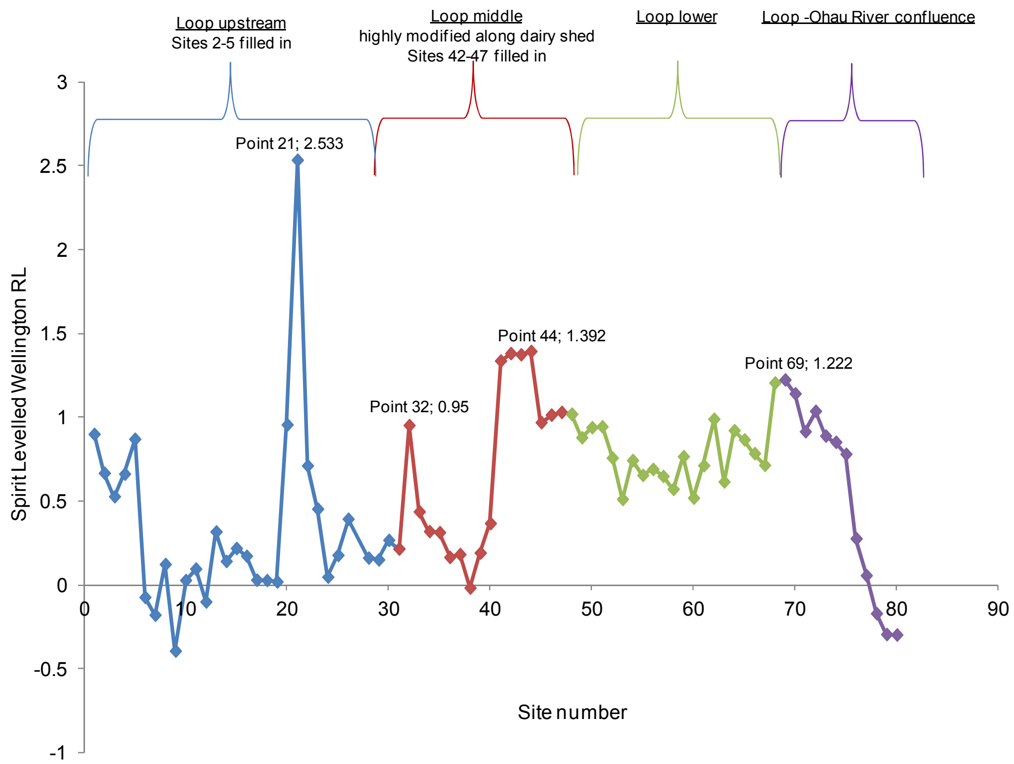


Figure 12. Location of 83 bed height stations (A) and their Right Level elevation (B). Elevations in metres.

5.3. Flows in the Loop

5.3.1. Surface water flow

No detectable surface water flow into the Loop from the Ōhau River was observed over the period of study. The only obvious flow of water within the Loop was at the three locations shown in Figure 13. Water appeared to flow in the same direction irrespective of the tidal conditions. The most significant of these, 'Observed Flow 1' (OF1) was measured immediately upstream of the culvert that drains the Loop's downstream most point (site 6). This water flowed in a 'pre-cut downstream'[5] direction, to join the Ōhau River approximately 50 m below the culvert.

At OF2, a significant flow of water moved in a 'pre-cut upstream'[5] direction, from the site 5 lagoon (adjacent to the dairy shed), via a 200 mm diameter culvert below the farm track. The discharge was not measured, but water flowed constantly in the same direction.

The very small amount of flow observed at OF3 was moving in a 'pre-cut downstream' direction, entering the same lagoon that is fed by flow from OF2.

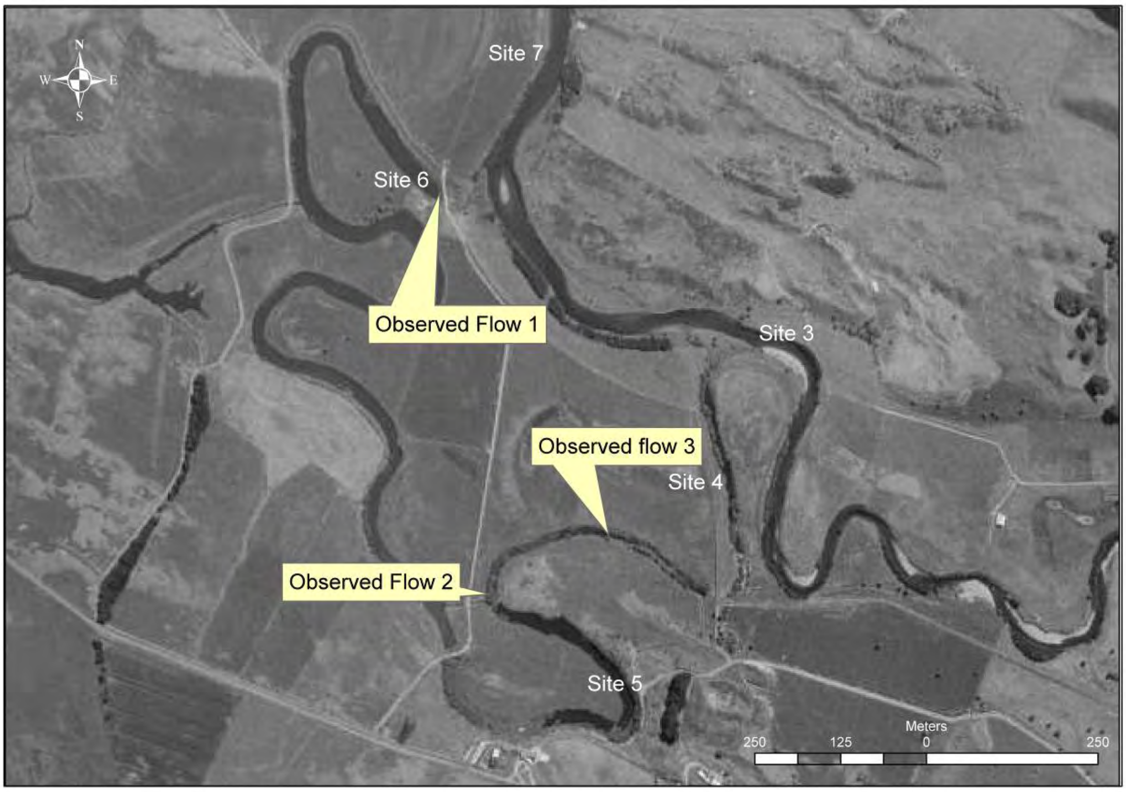


Figure 13. Points on the Loop where surface water flow was observed.

[5] 'Pre-cut downstream' and 'pre-cut upstream': meaning the direction of flow relative to the pre-modified waterway.

5.3.2. Tidal influence on flow

To determine the influence of the tide on flow within the Loop, discharge was measured in the Loop at site 6 (OF1) during high, low, mid incoming and mid outgoing tides (Table 4). Flow was gauged using a Sontek Flow Tracker immediately upstream of the culvert that connects the bottom end of the Loop to the Ōhau River. According to Horizons Regional Council flow records, the Ōhau River was flowing at between 2-3.4 m^3/s at the time the four Loop gaugings were carried out, which is less than the Ōhau River's median flow (3.86 m^3/s). The flow gauging for the mid-incoming tide was carried out two days prior to the other gaugings.

Table 4. Water flow from the Ōhau Loop (site 6) at various tides.

Tide	Date	Discharge (m^3/s)	Mean velocity (m/s)	Mean depth (m)	Cross sectional area (m^2)
Mid outgoing	8/10/2011	0.0329	0.01	0.534	3.388
Low	8/10/2011	0.0537	0.016	0.583	3.382
Mid incoming	6/10/2011	0.0882	0.026	0.608	3.342
High	8/10/2011	0.0352	0.01	0.58	3.422

Water flowed constantly from the Loop into the Ohau River. The fact that the highest discharge occurred on a mid-incoming tide suggests that flow in this section of the Loop is not significantly influenced by tidal movement. Heavy rainfall on 3 October 2011 (31 mm) would have raised the water table significantly in the surrounding land. The higher mean depth for the gauging on 6 October 2011 is likely to reflect this higher water table and subsequent higher discharge on this day, though more data is required to verify this.

5.3.3. Groundwater flow

Given that significant surface water outflow occurs at site 6 on all tides and no surface water inflow was observed, it is likely that most water within the Loop arrived via groundwater inflow or direct rainfall. Monitoring of surface and shallow groundwater levels is necessary to confirm this, but studies done in similar environments have shown that low lying inter-dunal wetlands on the Horowhenua / Kapiti coastal plain are fed largely by shallow groundwater from surrounding dunes (URS 2004; Preece 2005; Allen 2010). Underlying alluvial sediments in the Loop will have high permeability compared to the sand and peat soils of the surrounding land. Following rainfall, water that percolates into the subsoil and shallow groundwater of surrounding land will tend to move laterally and re-surface in the Loop.

Winter (1986) discusses the influence of sand dunes on groundwater level. Water that has percolated through the subsoil tends to mound up higher below the dunes relative to surrounding flatlands. This brings the water table closer to the surface in the inter-dunal depressions adjacent to large dunes (Winter 1986). This may explain why significant flow was observed exiting the lagoon at site 5, as a relatively large dune occupies the area east of the site 5 lagoon (Figure 14).

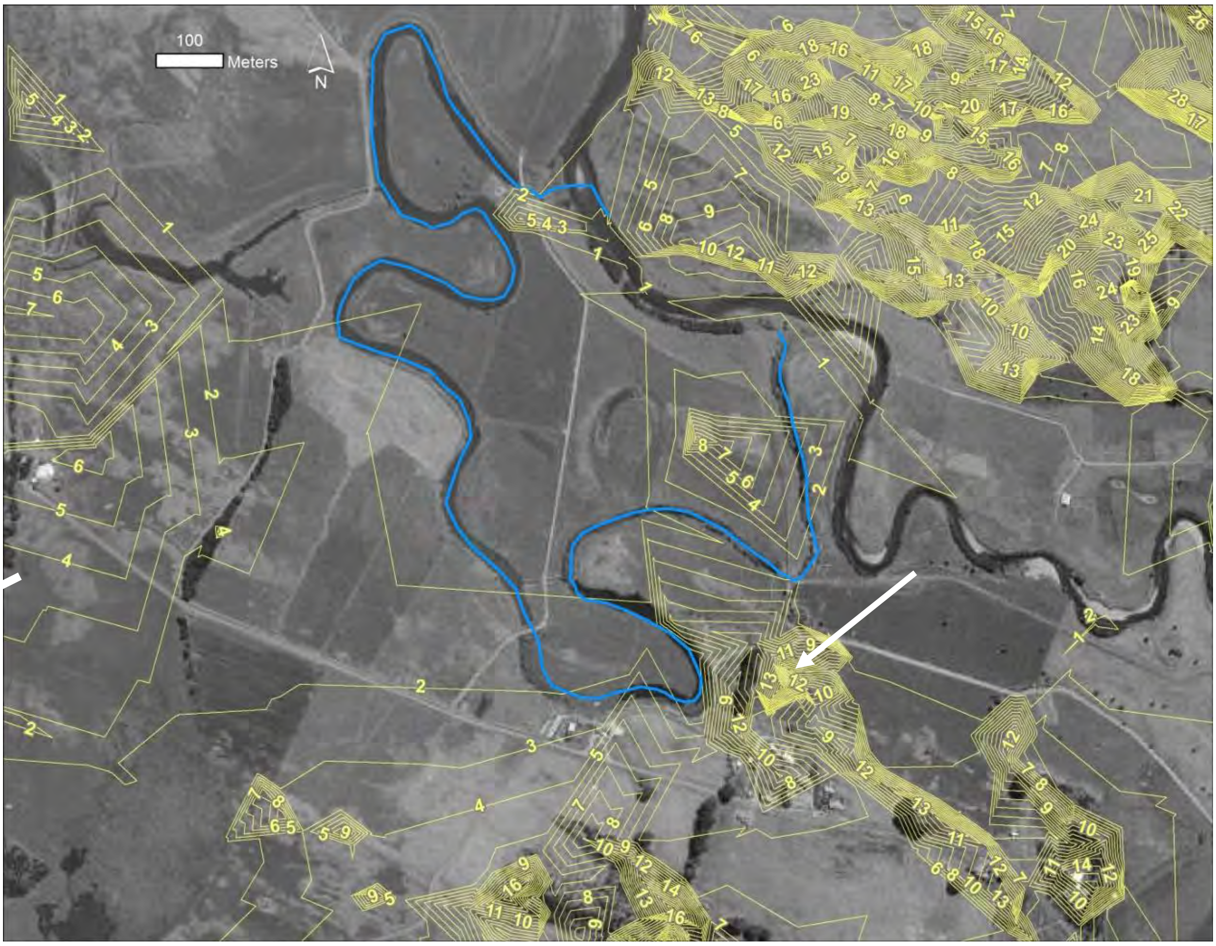


Figure 14. Elevation contours (1 m intervals) for the area surrounding the Loop. The arrow indicates the large dune referred to in the text.

5.4. Water quality

5.4.1. Sampling methods and sites

Spot field measurements of temperature, dissolved oxygen (DO), pH, specific conductivity, and turbidity were made using standard meters (YSI 650QS) at seven sites (Figure 15) and compared to national water quality guidelines (Table 5). Continuous measurements of DO and water temperature were logged from 5-8 October 2011 at four sites within the Loop (at 15 min. intervals) with Zebratech D-

Opto instruments and Hobo pendant temperature loggers. When interpreting water temperature data, it needs to be considered that sampling periods as short as three days cannot accurately represent the water temperature regime at a site, so continuous long-term temperature loggers have been deployed at the seven sites (Figure 15). These loggers will be deployed for a one year period to record seasonal temperature regimes. Data will be downloaded and batteries exchanged in a three month cycle.

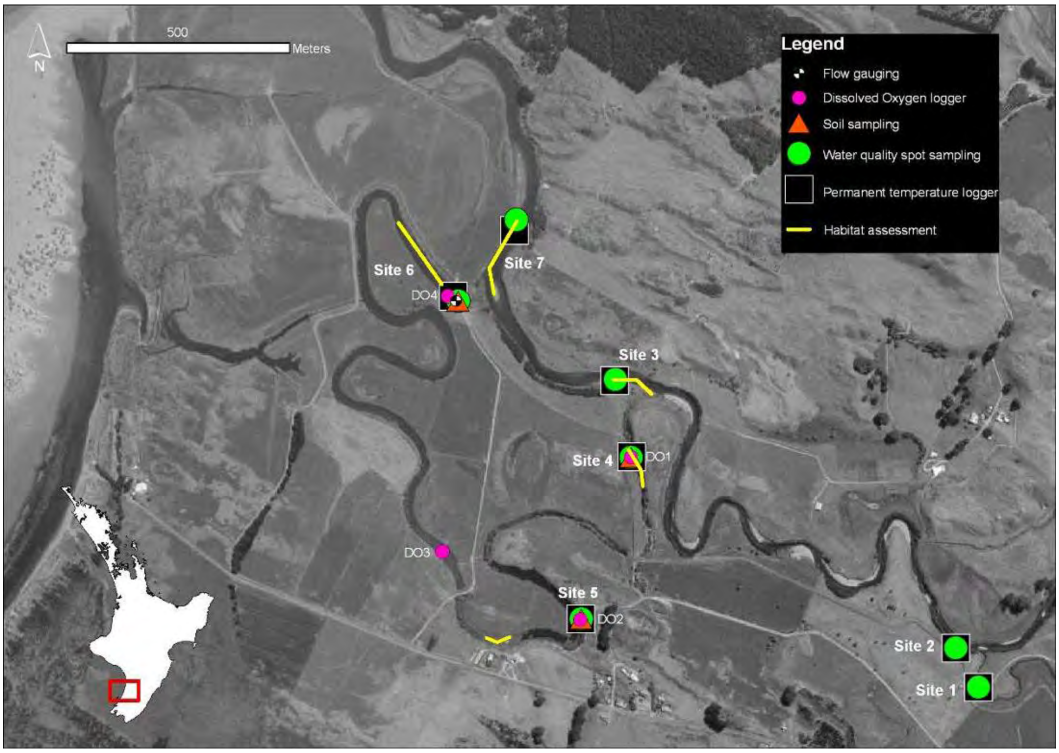


Figure 15. Water quality sampling sites for the Ōhau River and Ōhau Loop for the October 2011 sampling period.

Turbidity was measured with a Hach Model 2100 portable turbidity meter. Water (n=7) and sediment samples (n=3) were collected for laboratory analyses of nitrate nitrogen (NO_3-N), ammoniacal nitrogen (NH_4-N), total nitrogen (TN), total phosphorus (TP) and faecal indicator bacteria (*E. coli*). Samples were transported to the Cawthron Institute's IANZ accredited laboratory in chilly bins (~4°C) for analysis within 24 hours.

Table 5. Water quality parameters measured and their national guidelines.

Parameter	Guideline Value	Purpose of standard or guideline	Reference
Dissolved oxygen (DO)	>80% saturation or >6.5 mg/L	Aquatic ecosystem protection	ANZECC (1992)
pH	>5 and < 9	Aquatic ecosystem protection	ANZECC (2000) Saffran *et al.* (2001)
Water Temperature	≤20°C *	Aquatic ecosystem protection	Cox & Rutherford (2000)
Turbidity	<5.6 NTU for lowland rivers	Contact recreation	ANZECC & ARMCANZ(2000)
Ammoniacal nitrogen (NH_4-N)	<0.02 mg/L for lowland rivers	Aquatic ecosystem protection	ANZECC & ARMCANZ(2000)
Total nitrogen (TN)	<0.614 mg/L	Aquatic ecosystem protection	ANZECC & ARMCANZ(2000)
Nitrate - N	<0.444 mg/L	Aquatic ecosystem protection	ANZECC & ARMCANZ(2000) – amendment 2002
Total phosphorus (TP)	<0.033 mg/L	Aquatic ecosystem protection	ANZECC & ARMCANZ(2000)
E. coli	150 cfu/100mL	Contact recreation (Median)	MfE & MoH (2003)
	<260 cfu/100 mL	Contact recreation Acceptable	
	260-550 cfu/100 mL	Contact recreation Alert	
	>550 cfu/100 mL	Contact recreation Action	
	>1000 cfu/100 mL	Stock drinking water (Median)	ANZECC (1992)

* based on the midpoint of the daily maximum and daily mean.

5.4.2. Dissolved Oxygen saturation

DO saturation at all four sites ranged between 0.74% (site DO2) and 168% (site DO1). The site with the highest daily fluctuation was site DO4 with a minimum-maximum difference of 132.7% (7-8 October 2011).

Dissolved oxygen is fundamental to the survival of aquatic life and the 1992 ANZECC guidelines recommended that dissolved oxygen should not normally be permitted to fall below 6 mg/L or 80-90% saturation (ANZECC 1992). The amount of oxygen required by aquatic animals is quite variable and depends on species, size, activity, water temperature, condition, and the DO concentration itself (Boyd 1990). Thus, some species are more sensitive to low levels of oxygen than others. Concentrations of less than 80% saturation, for instance, are known to adversely affect trout (*i.e.*, feeding and growth) and less than 30% saturation (hypoxic) may result in fish deaths (ANZECC 1992; Dean & Richardson 1999). Dean & Richardson (1999) showed that minimum DO levels for some native fish species such as banded kokopu, torrentfish, common smelt and common bully were similar to those of trout, allowing the minimum DO saturation levels for trout (*i.e.,* 50% saturation) to be used as guidelines for these native fish species (Dean and Richardson 1999). Furthermore, Young (2002) studied the DO tolerance of inanga juveniles and koaro, and showed that all inanga juveniles tested survived three days at 60% saturation and koaro seven days at 50% saturation. However, mortality for both species clearly increased once oxygen saturation dropped below 50% (Young 2002).

At night, DO saturations fell below 60% at all four sites in the Loop (Figure 16), and the average night time DO saturation across all sites was 26%, within a minimum of 0.7%. Minimum DO levels usually occur early in the morning (due to lack of photosynthesis and continued respiration of aquatic organisms). All sites were characterised by extensive macrophyte growth, most of the time covering up to 100% of the water surface. Aquatic plants produce oxygen during day time (photosynthesis) and respire oxygen during night-time (respiration). Large amounts of macrophytes, as found in the Loop, produce oxygen during the day but also consume large amounts of oxygen at night (for respiration), potentially explaining the low DO values measured overnight.

Site DO3 had the lowest DO values recorded, with all measurements breaching the >80% saturation guideline during the sampling period (Table 6). Site DO4 had the highest proportion of DO measurements meeting >80% saturation.

5.4.3. Water temperature in the Ōhau Loop

The main concerns with water temperature are the effects of high temperatures on aquatic life. Some species will tolerate only relatively cool water and may become stressed or die if temperatures become too high. Brown trout is an example of a cool water species. It exhibits optimal growth on maximum rations at about 14°C, ceases feeding and growth at about 19°C and will die once temperatures climb above 25°C for a sustained period (Elliott 1994; Jowett *et al.* 1997). Trout cannot tolerate temperatures above 30°C for even a short period.

The highest overall water temperature recorded was 21.1 °C at site DO4 (13:00; 8 October 2011) and the lowest was 13.4°C at site DO3 (07:30; 6 October 2011,Figure 16).

Table 6. Ranges in daily dissolved oxygen and temperature at four sites in the Ōhau Loop recorded 5-8 October 2011.

Site	Date	DO Max (%)	DO Min (%)	DO Mean (%)	% of measurements < 60%	% of measurements > 80%	Temp Max (°C)	Temp Min (°C)	Temp Mean (°C)
DO1	05/10/11	98.6	46.7	79.5	19	0	15.8	9.5	13.6
	06/10/11	80.0	45.3	61.3	36	1	16.0	13.6	14.7
	07/10/11	88.4	42.1	64.8	47	19	16.1	14.4	15.2
	08/10/11	99.1	40.3	71.4	75	4	17.5	11.2	14.7
DO2	05/10/11	122.8	4.7	80.0	100	0	18.3	9.9	14.7
	06/10/11	56.9	3.1	27.2	100	0	19.7	14.9	16.9
	07/10/11	61.7	0.7	26.7	98	0	18.5	15.8	17.1
	08/10/11	98.8	5.8	49.4	98	2	17.8	11.0	15.7
DO3	05/10/11	108.4	17.0	65.2	100	0	18.4	9.8	13.9
	06/10/11	36.4	11.8	18.7	100	0	16.9	13.4	14.7
	07/10/11	33.9	5.7	15.7	100	0	16.5	13.8	14.8
	08/10/11	99.4	0.8	43.2	100	0	17.3	10.7	14.0
DO4	05/10/11	135.9	74.6	106.2	0	90	19.0	9.4	15.2
	06/10/11	144.6	43.5	87.5	30	47	19.4	14.3	16.6
	07/10/11	167.8	35.1	87.7	36	48	19.3	15.2	17.0
	08/10/11	115.7	31.5	73.2	63	21	21.1	11.2	15.6

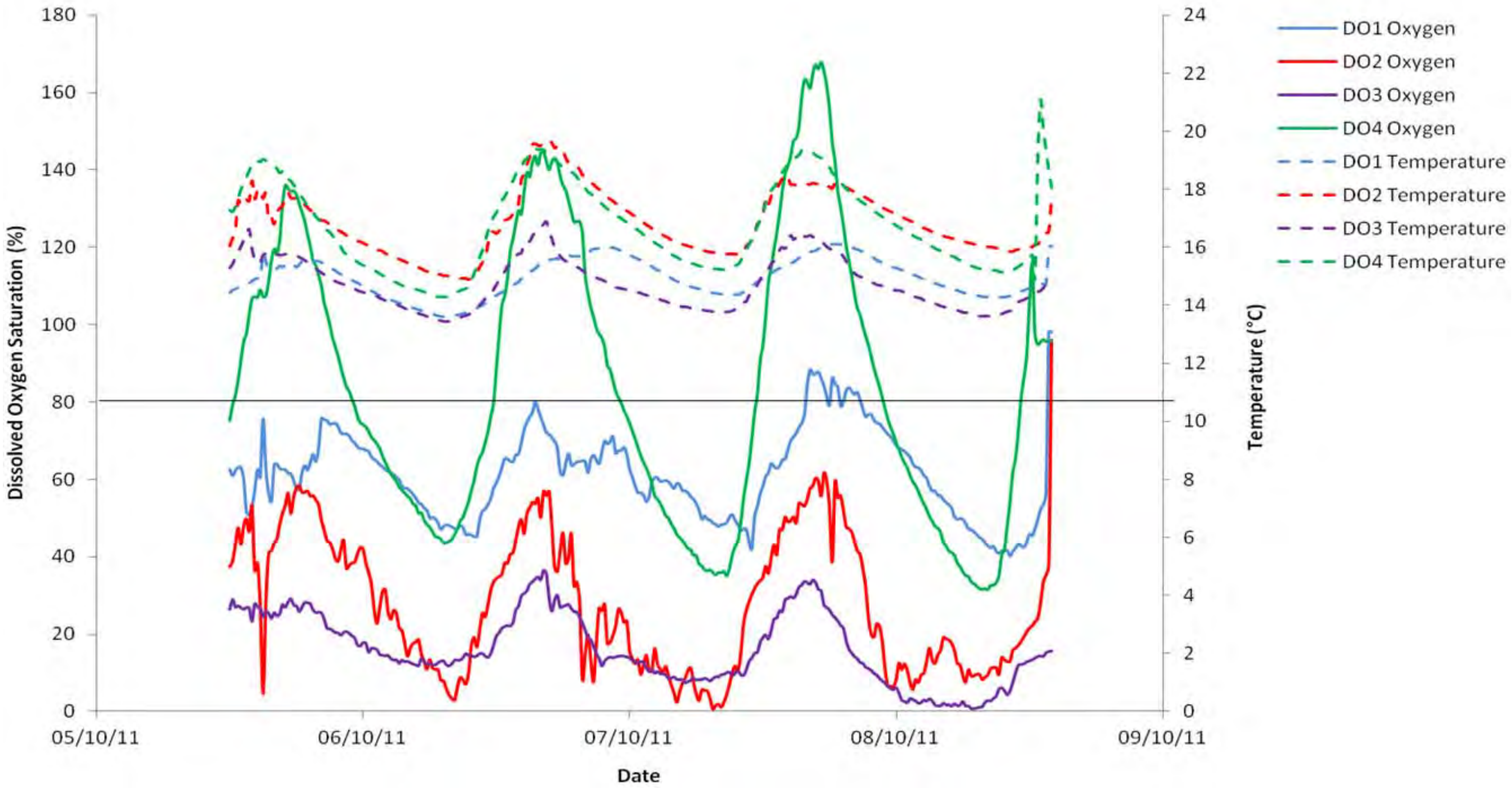


Figure 16. Daily changes in dissolved oxygen saturation at four sites during 5-8 October 2011. The black line represents the recommended minimum (80%) for aquatic ecosystem protection under ANZECC (1992).

Table 7. Water quality spot measurements for surface water and river bed sediment at ten sites. Three water and three sediment samples were taken from within the Loop (sites 4, 5, 6, 'Bottom', 'Mid', and 'Top Loop'); three sites were in the Ōhau River (sites 2, 3 and 7) and one site was in Kuku Stream (site 1). Values exceeding ANZECC water quality guidelines are highlighted in red.

Site	**Type**	**pH**	**Conductivity (µS/cm)**	**Turbidity (NTU)**	**Ammonia-N (g/m^3)**	**Nitrate-N (g/m^3)**	**Total Nitrogen (g/m^3)**	**Total Phosphorus (g/m^3)**	***E. coli* (cfu/100mL)**
1	Water	8.49	149	3.6	0.007	2.3	2.3	0.026	233
2	Water	8.51	105	1.9	0.010	0.92	1.0	0.015	150
3	Water	7.71	101	0.9	0.009	0.75	0.81	0.012	240
4	Water	7.75	140	1.5	<0.005	<0.002	0.42	0.024	140
5	Water	7.07	445	7.4	0.037	0.10	1.4	0.14	200
6	Water	7.54	765	1.7	0.006	<0.002	0.80	0.19	5
7	Water	7.23	1670	0.8	0.017	0.69	0.75	0.012	165

5.4.4. *Comparison of water and sediment quality between the Loop and the Ōhau River*

Comparisons between the Loop, the Ōhau River and Kuku Stream showed that the Loop had comparatively little nitrate-N (*i.e.*, max 0.1 g/m^3), compared to the Ōhau River (*i.e.*, max 0.92 g/m^3). However, Kuku stream had the highest nitrate-N, total nitrogen and *E. coli* concentrations of all of the water samples. Ammonia-N (site 5) and total phosphorus (site 5 and 6) were highest in the Loop and exceeded ANZECC water quality guidelines.

Water quality at the seven sites measured ranged from good to poor, suggesting different sources of water at the various sites. Nutrient measurements were generally within ANZECC recommended water quality guidelines, except for total nitrogen which exceeded guidelines at six of the seven sites and nitrate which exceeded guidelines at four of seven sites. Site 4 (at the top of the Loop) had the best water quality with no measurements exceeding any water quality guidelines and site 5 (in the middle of the Loop, close to the dairy sheds) had the poorest, with three of the five parameters measured exceeding water quality guidelines (Table 7).

River bed sediment samples taken from the Loop had relatively high counts of bacteria (Bottom Loop and Mid Loop Site 800 MPN/100 mL, Top Loop Site 1700 MPN/100 mL). Turbidity and pH records were generally within recommended guidelines, except site 5 which had slightly increased turbidity values (Table 7).

High nitrate-N concentrations in the Ōhau River and Kuku Stream are likely to be due to high agricultural run-off into these waterways from adjacent farm land. Site 5 had among the highest total nitrogen and total phosphorus concentrations which is not surprising considering the long-term effluent discharge into the Loop at this site. The high levels of bacteria found in the sediment need to be considered during rehabilitation efforts in the Loop. If large volumes of sediment are disturbed then it is likely that high concentrations of fine sediment and *E. coli* will be carried downstream and contaminate filter feeding species such as shellfish in the Ōhau estuary. This will temporarily close the area for shellfish harvesting, but with flushing (from high flows) and time the populations will recover.

6. FRESHWATER FISH IN THE ŌHAU LOOP

This section reviews historical and present-day information on the freshwater fish in the Ōhau River catchment. Specifically, it aims to:

1. Identify fish species historically and currently recorded in the Ōhau catchment.
2. Compare current fish communities between the Ōhau and Ōtaki catchments in terms of the fish species found and their distributions.

6.1. New Zealand's fish species

New Zealand has a reasonably small freshwater fish fauna which is partly due to the country's geographical isolation from other land masses but also due to its geological history with periods of extensive marine submergence, ice ages and glaciations, mountain building and intensive volcanic activity (McDowall 2010).

In total, there are 38 native and 21 introduced freshwater fish species recorded from New Zealand (McDowall 2011). A variety of species were first introduced to New Zealand in the late 1840s (*e.g.,* Atlantic salmon), however, some of them were not successfully established until the late 1860s *(e.g.,* brown trout, perch, goldfish, tench) (McDowall 2000).

6.1.1. Migratory native species

Eighteen of New Zealand's 35 native freshwater fish species are diadromous (*i.e.*, they migrate between the sea and freshwater to complete their life cycle). There are three types of diadromy observed in New Zealand species, amphidromy, catadromy and anadromy.

Amphidromous species spawn in freshwater, but the larvae move to sea to feed almost immediately after hatching, returning a few weeks or months later as small juveniles (McDowall 2007). Most growth occurs in freshwater and adults remain in fresh water or die after spawning. This is the most common form of diadromy in native New Zealand fish. Examples of amphidromous fish species found in the Ōhau River include smelt (*R. retropinna* and *Stokellia anisodon*), common bullies (*Gobiomorphus cotidianus*.), inanga (*Galaxias maculatus*) and torrent fish (*Cheimarrichthys fosteri*) (Table 8).

Catadromous species, such as long and short-fin eels (*Anguilla* spp.), spawn in saltwater but their progeny return to rivers from the sea during spring (Table 8) as transparent glass eels where most of the growth occurs (McDowall 2007). Adult eels return to the sea during autumn up to 80+ years later and swim to their spawning grounds that are believed to be in the Pacific Ocean near Tonga.

Anadromous fish species spawn in freshwater, but their progeny go to sea to feed and grow before returning as adults to spawn. Migration from saltwater to freshwater is undertaken for the purpose of spawning and adults either die or return to saltwater after spawning. The most well-known anadromous fish species found in the Ōhau River is brown trout (*Salmo trutta*) which spawns in freshwater, but which can spend various periods of its life in fresh, estuarine or ocean waters (McDowall 2000).

Table 8. Typical migration schedule for migratory fish species likely to be present in the Ōhau catchment.
■ = Peak ■ =Range; Modified from Hamer (2007).

Species	Direction	Life stage	Summer			Autumn			Winter			Spring		
			Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov
Longfin eel	to estuary	Glass eel								Range	Peak	Peak	Peak	Range
	u/s	Juvenile		Peak	Peak	Peak	Peak							
	d/s	Adult					Range	Range						
Shortfin eel	to estuary	Glass eel	Range								Range	Peak	Peak	Peak
	u/s	Juvenile	Peak	Peak	Peak	Peak								Range
	d/s	Adult			Range	Range	Range				Range	Peak	Peak	
Torrentfish	u/s	Juvenile	Peak	Peak	Peak									Peak
	d/s	Larvae			Range	Range	Range	Range						
Common smelt	u/s	Juvenile									Range	Peak	Peak	Range
	d/s	Larvae				Range	Range	Range	Range					
Inanga	u/s	Juvenile						Range	Range	Range	Peak	Peak	Peak	Range
	d/s	Larvae	Range	Range	Peak	Peak	Peak	Range	Range			Range	Range	Range
Koaro	u/s	Juvenile										Peak	Peak	Range
	d/s	Larvae						Range	Peak	Peak				
Giant Kokopu	u/s	Juvenile	Peak										Peak	Peak
	d/s	Larvae						Range	Peak	Peak	Range			
Banded Kokopu	u/s	Juvenile									Range	Peak	Peak	Range
	d/s	Larvae						Range	Range	Range				
Shortjaw Kokopu	u/s	Juvenile										Range	Range	Range
	d/s	Larvae						Range	Peak/Range					
Common bully	u/s	Juvenile	Peak	Peak	Peak								Range	Range
	d/s	Larvae											Range	Range
Bluegill bully	u/s	Juvenile	Peak											Peak
	d/s	Larvae	Range	Range	Range							Range	Range	Range
Redfin bully	u/s	Juvenile	Peak											Peak
	d/s	Larvae									Peak	Peak	Peak	Peak
Brown trout	u/s	Adult				Peak	Peak	Peak	Peak					
	d/s	Juvenile										Peak	Peak	Peak
Lamprey	u/s	Adult							Peak	Peak	Peak	Peak		
	d/s	Juvenile					Range	Range	Range	Range	Range	Range		

6.1.2. Non-migratory native species

Twenty of the 38 native freshwater fish species are non-migratory, which means they do not undertake any migrations between the sea and freshwater. However, non-migratory species may travel reasonable distances within freshwater systems, for instance between lakes and/or different rivers (Rowe & Chisnall 1997; Baker *et al.* 2003). Migratory species are also able to establish 'landlocked' populations in which the sea migration is abandoned and the usually marine life stages occur in lakes (McDowall 2000). This has been recorded when lake outlets have been closed and the species is forced to adjust to a non-migratory life cycle, or where fish species ‘choose’ not to go to sea, but instead complete their life cycle in lakes that remain connected to rivers (*e.g.,* koaro in Lake Wanaka, common smelt and common bully in lakes in the lower Waikato; Rowe et al. 2002; King *et al.* 2003).

6.2. Fish records from the Loop

6.2.1. Historical and anecdotal records

Kaumatua have a shared realisation of the loss and disappearance of the bountiful fish, animal and shellfish supplies, especially since the cut at the mouth of the Ōhau (Lucas Associates 1998).
Early settlers in the lower Ōhau reportedly lived on giant kokopu, and the Loop was renowned for harbouring large eels. “It was the largest eel we ever caught in the Ōhau River….down near the mouth of Kuku Stream. It was enormous…probably near enough to six inches in diameter” (Smith 2007), quoting personal communication with Hon. Douglas Lorimer Kidd, 6 January 2006).

Lucas (1998) lists species that kaumatua have seen harvested in the lower Ōhau, though the exact location is unclear. These include:

- Tuna (Eel)
- Kokopu (adult inanga and whitebait)
- Piharau (Lamprey)
- Mohoao (black flounder) [6]
- Patiki (black flounder)
- Kanae (Grey mullet)
- Aua (Yellow eyed mullet but incorrectly called, herring)
- Kakahi (freshwater mussel)
- Koura (freshwater crayfish)
- Perarau[7] *“soft shell mussel or Māori oyster – harvested from ‘Blind Creek’ which flowed westward from the Loop into the Ōhau estuary”* Lucas (1998).

[6] Lucas Associates (1998) refer to black flounder as Pataki, whereas McDowall (2011) calls black flounder Mohoao owing to common Māori usage in NZ. McDowall uses the term pataki as a generic reference for flounder (*e.g.,* yellowbelly, sand flounder *etc*).

[7] There is no reference to a species called ‘Perarau’ in McDowall (2011). Lucas (1998) may be referring to ‘Peraro’; *Tellina gaimardi* (now called *Peronaea gaimardi*); or *Zenatia acinaces;* common name ‘pipi’*. Zenatia* has a thin shell but not soft; aka Scmitar shell, Otter shell, Peraro, Pipi Roa. Both are clean salt water and sub tidal. Alternatively it may be an undocumented translation for one of the freshwater mussel species *Hyridella menziesi* (Kakahi); or *Cumumerunio websteri (Cook 2010; McDowall 2011)*.

6.2.2. Fish species recorded in previous surveys

Fish species presence/absence data were obtained from the New Zealand Freshwater Fish Database (NZFFD; National Institute of Water and Atmospheric Research (NIWA)), a database that contains information on the distribution of New Zealand's freshwater fish. Data were obtained for the Ōhau Catchment (Catchment number 321.000) between 1964 and 2010 and included all sampling methods and locations, except lakes, ponds and wetlands. Freshwater fish species analyses were grouped as follows:

1. 'Pre-cut' NZFFD (data from 1964 and 1965)
2. 'Post-cut' NZFFD (1990-2010)
3. October 2011 field sampling (5-8 October 2011).

In addition to the data obtained by field sampling, fish distributions were predicted using a spatial database based on Leathwick *et al.* (2008). The model is built around the river network developed originally as the River Environment Classification (REC; Snelder *et al.* 2004) and predicts the probability of presence for each species at all rivers and streams throughout New Zealand.

Due to the reasonably low fish sampling effort in the Ōhau catchment to date, the fish species present in the Ōhau were compared to the adjacent Ōtaki catchment to identify any significant differences in fish species number and/or community composition. This analysis was done digitally only with data derived from the NZFFD.

'Pre-cut'

The New Zealand Freshwater Fish Database (NZFFD) records three fish species from one sampling occasion in 1964 and seven species found on four sampling occasions in 1965 (Table 9). Both of these accounts are from sampling in the upper Ōhau River.

Table 9. Number of fish species and koura recorded in the Ōhau catchment previous to the cut for the years 1964 and 1965. Data derived from the NZFFD.

Common name	Scientific name	1964	1965
Upland bully	*Gobiomorphus breviceps*	1	1
Common bully	*Gobiomorphus cotidianus*	1	
Redfin bully	*Gobiomorphus huttoni*	1	4
Longfin eel	*Anguilla dieffenbachii*	-	3
Koaro	*Galaxias brevipinnis*	-	1
Banded kokopu	*Galaxias fasciatus*	-	2
Shortjaw kokopu	*Galaxias postvectis*	-	2
Brown trout	*Salmo trutta*	-	4
Total number of fish species recorded		**3**	**7**
Koura	*Paranephrops planifrons*	-	2
Total number of records		-	**2**

‘Post-cut’ (to 2010)

In total, there were 126 records at 24 different localities in the Ōhau catchment entered into the NZFFD between 1990 and 2010. There have been 15 fish species recorded in the catchment (Table 10). Longfin eel was the most widespread species, found at 23 of 24 sites surveyed (*i.e.,* 96% of sites), followed by brown trout (18 sites/75%) and redfin bully (14 sites/34%)). Bluegill bully (one site/4.1%), common smelt (one site/4.1%) and Cran’s bully (one site/4.1%) were the least common species.

Table 10. 'Post-cut' fish species and koura recorded from the Ōhau Catchment and their national threat classification (Allibone *et al*. 2010). Data derived from the NZFFD (NIWA) between 1990 and 2010.

Common Name	Scientific Name	Threat Classification	Migratory
Shortfin eel	*Anguilla australis*	Not threatened	Y
Longfin eel	*Anguilla dieffenbachii*	Declining	Y
Torrentfish	*Cheimarrichthys fosteri*	Declining	Y
Koaro	*Galaxias brevipinnis*	Declining	Y
Banded Kokopu	*Galaxias fasciatus*	Not threatened	Y
Inanga	*Galaxias maculatus*	Declining	Y
Shortjaw kokopu	*Galaxias postvectis*	Declining	Y
Lamprey	*Geotria australis*	Declining	Y
Cran's bully	*Gobiomorphus basalis*	Not threatened	N
Upland bully	*Gobiomorphus breviceps*	Not threatened	N
Common bully	*Gobiomorphus cotidianus*	Not threatened	Y
Redfin bully	*Gobiomorphus huttoni*	Declining	Y
Bluegill bully	*Gobiomorphus hubbsi*	Declining	Y
Common smelt	*Retropinna retropinna*	Not threatened	Y
Brown trout	*Salmo trutta*	Introduced and naturalised	Y/N
Koura (freshwater crayfish)*	*Paranephrops planifrons*	Declining	N

*not listed in Allibone *et al.* 2010.

Comparison between fish species recorded in the NZFFD (for the same search criteria: lakes, ponds and wetlands excluded, 1990-2010) for the Ōhau and Ōtaki catchments indicated that the latter has a lower fish species diversity (12 species) than the Ōhau River (16 species). This might be due to lower sampling effort in the Ōtaki (18 sampling localities) compared to 24 localities in the Ōhau (Figure 17). For the Ōhau, the year with the highest sampling effort was 2000 with 54 records, and for the Ōtaki 1998 with 21 records.

Detailed fish distribution maps from the NZFFD for the Ōhau and Ōtaki rivers can be found in Appendix 4.

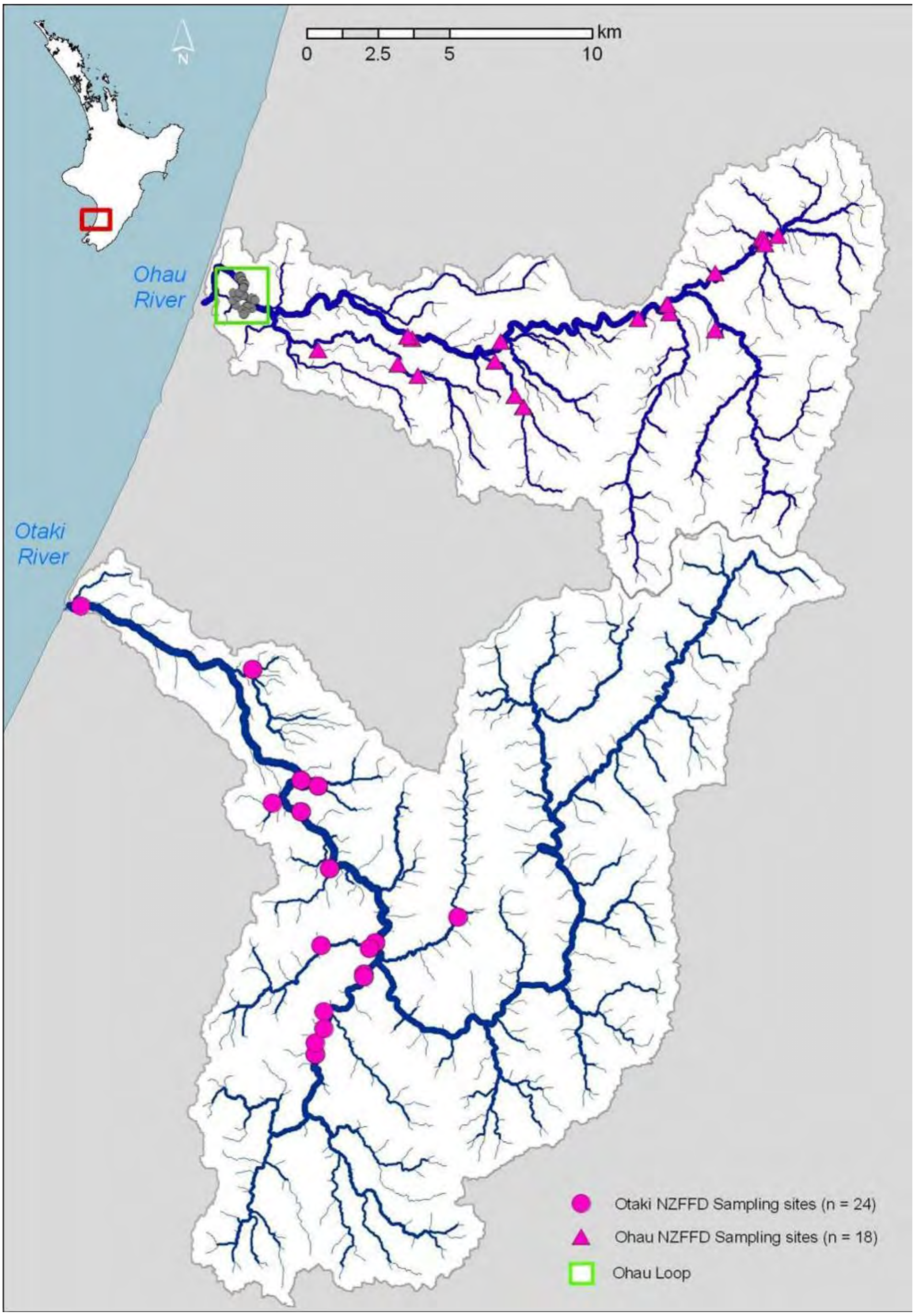


Figure 17. 'Post-cut' fish species records entered in the NZFFD in the Ōhau and Ōtaki catchments between 1990 and 2010.

6.2.3. *October 2011 field sampling*

Field sampling was conducted from 5-8 October 2011 and included night spotlighting, electric fishing and trapping, depending on habitat characteristics. Approximately 100 m long reaches were electric-fished in the Ōhau River at the Loop inlet and outlet (sites 3 and 7). Water depth in the Loop and high salt water influence in the lower Ōhau River (downstream of site 7) meant electric-fishing in these areas was impossible. Instead, marmite-baited minnow traps and fyke nets (hīnaki) were deployed. Spotlight surveys were also conducted in the Ōhau River and Loop from the Ōhau estuary up as far as site 3.

A total of 35 sites were sampled in October 2011 (Figure 18), of which 13 sites had traps deployed (*i.e.,* four minnow traps, nine fyke nets (hinaki), see Figure 18), four sites were electric fished and 18 spotlighted (Figure 18).

There were ten fish species and one crustacean recorded, including common smelt, mullet, brown trout, inanga, longfin and shortfin eels, black flounder, common and giant bully (*Gobiomorphus gobioides*), rudd (*Scardinius erythrophthalmus*) and freshwater shrimp (*Paratya* sp.). No fish were caught in the minnow traps and only longfin eel were caught in fyke nets. With the exception of rudd, these fish species are representative of tidal lowland communities and all but giant bully and rudd have been recorded previously in the Ōhau River.

The giant bully is a large, strongly built, dark coloured fish which is almost always found beneath cover, such as overhanging banks and instream debris. At night, however, it emerges from cover to feed. It can be easily confused with common bully.

Rudd has not been previously recorded in the Ōhau River and must have been released here by humans. The species is known to be widely distributed in the Ōtaki region with its range increasing, owing to illegal releases by coarse fishing enthusiasts. The species is mostly found in still or slow-flowing waters, especially with prolific weed beds such as are found in the Loop. It is mostly carnivorous, feeding on a large variety of aquatic insects but also aquatic plants. The species' fishing value is relatively high (to coarse fish anglers) although it is regarded as essentially inedible (like many of the carp family) and virtually all angling is 'catch and release', as is usual in coarse fishing (McDowall 2000).

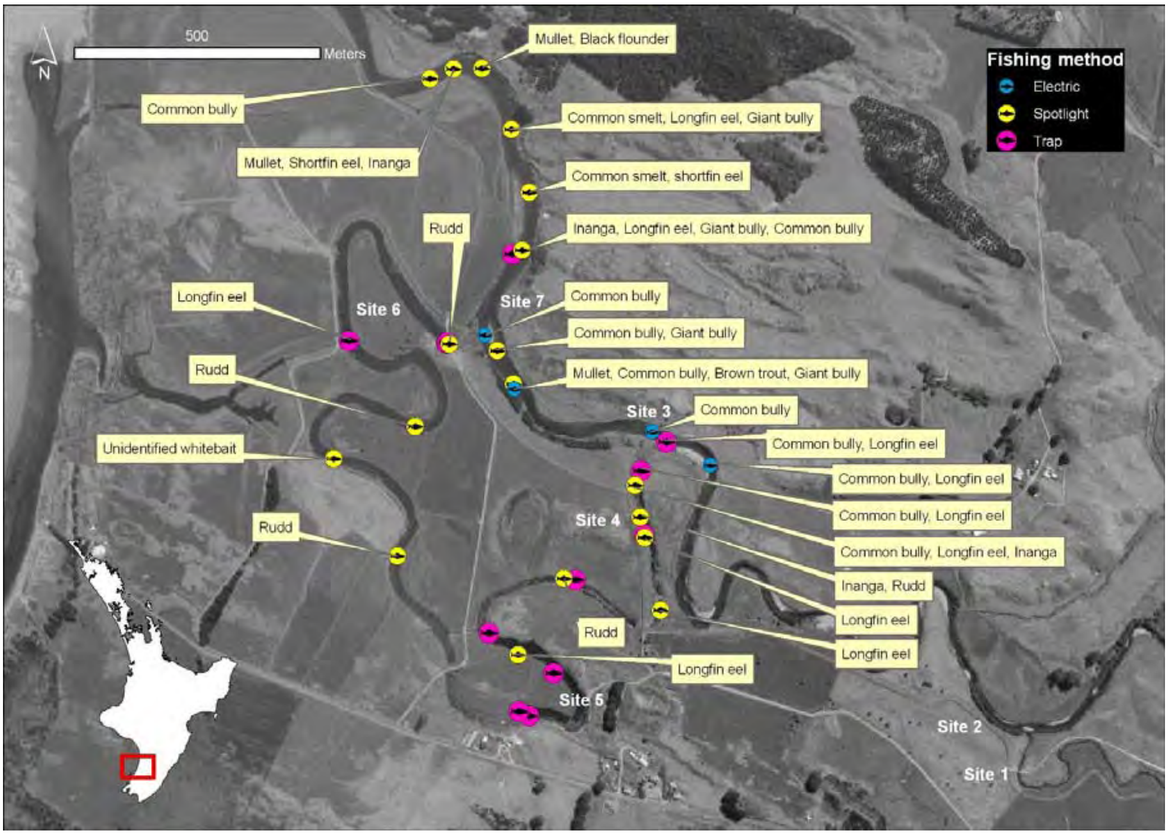


Figure 18. Sampling methods and fish species found in the lower Ōhau River and the Ōhau Loop from 5-8 October 2011

7. DISCUSSION AND RECOMMENDATIONS

Channel modification and changes in land-use over the past 125 years have had a severe impact on the morphology and ecology of the Ōhau Loop. Water quality and habitat quality, in particular, have been strongly affected with fine sediment accumulation being one of the strongest drivers. This was principally caused by the digging of the cut in 1973, which led to a loss of permanent flow through the Loop. Cessation of flow allowed sediment to settle and accumulate. In addition to the loss of flushing capacity in the Loop, intensive dairy farming over the past 35 years has contributed to the build-up of approximately 104,000 m^3 of fine sediment. This is about 2000 truckloads (with a 50 m^3 load capacity).

The main issues contributing to poor water quality and fish habitat and its utilisation within the Loop are:

- sediment accumulation and poor water quality
- lack of fish passage
- lack of riparian vegetation.

Flow and water quality in the Loop

Low DO saturation and the lack of fish passage are considered to be the most limiting factors to re-establishment of species of interest to iwi and hapū. Removing accumulated sediment and organic matter, establishing vegetation for shade to inhibit further growth of algae and hornwort, and restoring flow would all help to improve oxygen levels and fish passage. Whilst ammonia was high in the vicinity of the existing dairy shed, levels elsewhere were not above the recommended concentration. This may change as temperature in the Loop increases over summer, so more monitoring is advised. Poor water quality at site 5 may not be indicative of problems with the existing dairy shed.

Ideally some flood flows would be re-introduced to the Loop for the purpose of flushing sediment, algae and macrophytes. However this could jeopardise past flood mitigation efforts and put valued property, land and livestock at risk. A compromise may be achieved by diverting a small amount of flow through the Loop. It would have to be a sufficient flow to improve the water quality but not so much that it would create flood risk. Adding a flow of high quality water at the top of the Loop should improve the water quality by diluting the existing low DO, high nitrogen and phosphorus in the Loop, and possibly lowering summer water temperatures.

In 2007 a resource consent application was delivered to Horizons by Tahamata Corporation to divert 100 l/s from the Kuku Stream into the Loop. It is understood that this application was withdrawn for financial reasons before consent was granted. This application detailed the culvert and race design that would carry water to the Loop for the sole purpose of improving water quality and fish habitat in the Loop (John Philpott and Associates 2007). The report calculated that 100 l/s would replace the water in the Loop every nine days, and that delivering more than this volume would adversely affect farm drainage.

Whilst this appears to be a good solution, there are problems that would need to be addressed. Firstly, the results outlined in this report show that water from Kuku Stream has high nitrate and *E. coli* concentrations relative to both the Ōhau River and the Loop. Adding this high nutrient water to the Loop may result in macrophyte and algal blooms that would further degrade water quality by reducing DO concentrations. Also, the consent application does not consider what flow is required to dilute existing poor water quality in the Loop. This would need to be addressed as a 100 l/s augmentation flow may prove to be insufficient for attaining desired water quality.

If 100 l/s were delivered, fine sediment would continue to be deposited on the bed and, given the gentle gradient, water will generally flow slower than 0.2-0.3 m/s throughout the Loop. An average velocity of 0.2-0.3 m/s is estimated to be the critical velocity necessary to maintain suspension of fine sediments (Jowett *et al.* 2008). We also anticipate that nuisance growths of long filamentous algae and macrophytes will continue to occur under these conditions, so water quality (DO) may still be too poor for some fish species.

Regardless, diverting a quantity of water from a suitably high quality source remains the best option for rehabilitation of the Loop. Given the high nutrient and *E. coli* concentrations in Kuku Stream, we suggest that diverting water from the Ōhau River is the better option. Topographical surveying will be required to identify a suitable location for the flow diversion, taking account of relative bed and water levels between river and Loop and with the Loop bed levels adjusted for sediment removal. Bed and water level elevation surveying would also be required to accurately assess the maximum flow that the Loop can convey without increasing flood hazard.

Water quality measurements made in this study do not fully represent the Loop's overall condition as they were synoptic spring measurements. Water quality should be monitored again during summer when water quality is expected to be lower. This will ascertain what water quality parameters are critical in the Loop and enable comparison with water from the potential sources of inflow (*i.e.* the Ōhau River and Kuku Stream). These data would be essential for estimating the amount of flow required to dilute current contaminant loads in the Loop.

Water quality in parts of the Loop (especially around site 5) has been degraded by inappropriate dairy shed effluent disposal over a twenty year period. High *E. coli* counts in sediment from the Loop indicate that much of the sediment is likely to contain disease-causing organisms. If these are mobilised into the water column by introducing flow they will make the Loop water unsafe for contact recreation such as swimming, fishing and shellfish harvest in the Ōhau estuary, as well as pose a health risk to domestic livestock. The dairy shed effluent disposal issue has now been addressed, but the problem of polluted sediment remains.

The solution for this is to remove as much accumulated fine sediment as possible, perhaps concentrating efforts on the most polluted areas. Bed height elevations showed no clear downward trend between the upper and lower Loop - in fact, bed height was higher at the top of the Loop than at the bottom. This highlights how modified the system is. The work would aim to grade the bed as close as possible to the original Loop gradient so that when flow is introduced there are few stagnant pools. It would be best if works were carried out in autumn/early winter to avoid the whitebait season, as areas downstream from the Loop are popular with whitebaiters. This would also coincide with winter floods which will help to flush fine sediment deposited on the Ōhau River bed below the Loop outflow culvert as a result of sediment removal efforts within the Loop. The Tahamata farm manager, Troy Hobson, suggested spreading the excavated material onto pasture on the northern side of the farm, which is known to be nutrient deficient. It may be possible to use a suction pump and hose to transport the sediment across the farm, dispensing the need for trucks. It would be important to test the sediment for contaminants before spreading it on pasture.

Flow and water quality alterations have adversely affected ecosystem services in the Loop. Some fish communities deal better with habitat and water quality degradation than others. However in the long-term, if water quality continues to degrade only fish species extremely tolerant to low water quality, such as eels and rudd, will be able to survive in the Loop. Whilst the high abundance of rudd observed in the Loop is a consequence of the suitable habitat and tolerance to low DO, rudd may also contribute to the degradation of water quality. Rudd are known to stir up bottom sediments which, given the polluted nature of the Loop's bed, is likely to reduce DO, increase turbidity, suspended nutrient, and *E. coli* (Department of Conservation 2011a). Conversely, juvenile rudd could be an excellent food source for eel, so their presence in the Loop is not without some value.

Increasing flow, improving water quality and riparian re-vegetation within the Loop will increase the habitat suitability for more sensitive fish species, such as giant and banded kokopu and possibly red-fin bully (provided that suitable substrate for the latter fish species is available), however restoring fish diversity in the Loop to 'pre-cut' conditions is highly unlikely given the current and proposed flow regimes.

Fish passage in the Loop

In its current state, the Loop is not a continuous body of water, so adding flow at the top end is at this stage not possible. Farm tracks have segmented the Loop at five locations, including both ends where the Loop was disconnected from the Ōhau River.

Of the five barriers, only two join adjacent waterways via culverts, neither of which is fish-friendly. Facilitating continuity of flow and fish passage would play a major role in rehabilitating the Loop ecosystem, as 82% (14 out of the 17) of the fish species recorded in the Ōhau River (post 1990) are migratory. Whitebait observed in the lagoon at site 6 arrived either via the site 6 culvert or via Blind Creek, so some fish passage is occurring. It is unclear how whitebait observed in the lagoon at site 4 accessed this area.

Floodgates play an important role in protecting productive farmland and housing during floods and spring tides, but they also hinder the passage of fish such as whitebait (Doehring *et al*. 2011). Re-joining contiguous waterways within the Loop via a series of modern fish-friendly floodgates and culverts would greatly benefit fish access as well as water quality. The current site 6 flood gate appears to be set too high, so that at high tide the water on the Ōhau River side does not reach the culvert. We recommend that flood and tide modelling is undertaken to aid the design of a new fish-friendly floodgate.

Fish-friendly floodgates allow fish passage during high tide and more natural water flow conditions behind the gates, improving water quality and thus enhancing conditions for aquatic organisms. There are several fish-friendly floodgate designs, including one that can be retro-fitted to existing structures (Retrieved 30 October 2011 from http://www.niwa.co.nz/our-science/freshwater/publications/all/wru/2007-23/floodgates). Alternatively, a new fish-friendly flood gate (Figure 19) could be installed at a cost of approximately $3,000.

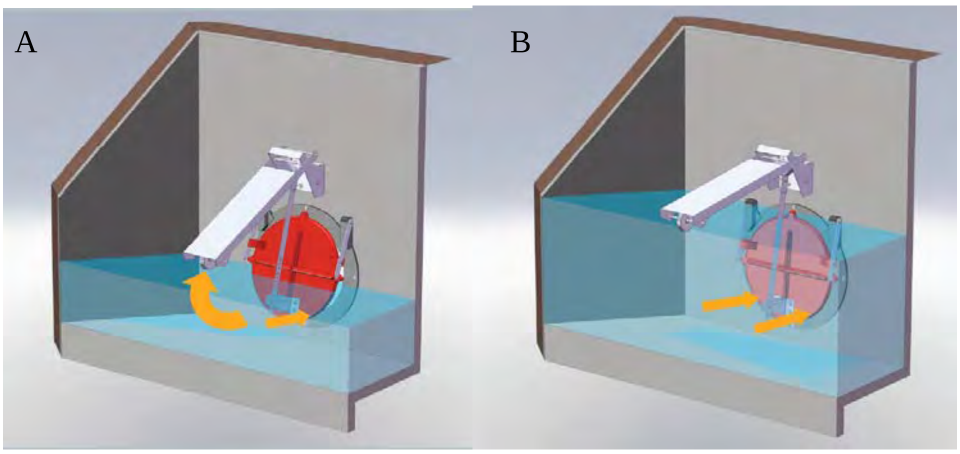


Figure 19. (A) Fish-friendly floodgates delay the closing moment as the water rises, allowing extended access to upstream habitat for migratory fish and (B) hold the flap closed as normal tide gates during high tide.

Riparian vegetation

Although, sediment accumulation and fish passage are the primary issues affecting the ecological health of the Loop, a lack of riparian vegetation and poor habitat is also of concern. Riparian planting is a good way to engage communities and stakeholders instream rehabilitation because the visual results are easily assessed by way of observation as often as desired.

A good starting point for rehabilitation that involves the community would be to create riparian buffer zones by planting native vegetation, such as low growing raupo and harakeke and trees such as kahikatea. These species facilitate de-nitrification and filtration of sediments and contaminants from local runoff. Provided plantings are tall enough relative to width, riparian buffers help to maintain cooler water temperatures by providing shade. Riparian vegetation enhancement in the Loop could also be designed to increase inanga spawning habitat. A rehabilitated Ōhau Loop (with adequate fish passage) represents a potentially ideal spawning habitat for inanga, as it is not subject to floods but will still be subject to tidal influence – with which inanga spawning is associated. Engaging community interest in the project will be more effective if tangible and valued outcomes are highlighted - such as increased whitebait yield.

This introduces a potential area of study in ecological economics. If new inanga spawning habitat is made available throughout the Loop’s 3.2 km by riparian planting such that say 3 m of suitable spawning habitat was gained along each margin, one could estimate the potential value of the Loop for inanga spawning and rearing habitat to contribute to the whitebait fishery. The current market rate for whitebait is approximately $79 per kilo (The Mainland Trader 2011) and it vies with trout fishing as the nation’s most popular freshwater fishery, at least in spring.

Some areas along the Loop have already been replanted. However, it is likely to take at least another five years before these plants will be large enough to provide sufficient shading and effective fish habitat. Lucas Associates (1998) provided a comprehensive list of native species for future planting among their recommendations.

Willow trees have proliferated in some areas of the Loop, where they provide good shade and habitat for eel. However in some places they have grown so thick that the small amount of flow is retarded, accelerating fine sediment deposition. Whilst willows are still planted for flood and erosion control in New Zealand rivers, they are known to be invasive and have a very high rate of evapotranspiration, so will remove significant volumes of water from the Loop during summer. In some areas of New Zealand, introduced willow trees are targeted for removal and replacement with native plant species. Given their current habitat and shading value, it would be a mistake to remove all of the willows in the Loop at the same time. Instead, selective removal and inter-planting with native plant alternatives would help in the short and long term, leaving sufficient time for new plants to become established (*c.* 5-10 years).

Rehabilitation of riparian buffer zones would need to be accompanied by improvements to fencing. Whilst most of the Loop is fenced to keep stock from entering the water, a wider riparian buffer would be more beneficial. The best process for riparian restoration is to first consult with farm managers, as it may not be necessary to retire highly productive land for a broad riparian strip along the entire length of the Loop to achieve similar results.

Finally, good communication and collaboration with farm management and regional authorities is particularly important during the planning stage of the restoration to find workable solutions for all parties involved.

Given that flood control objectives limit the amount of flow that can be diverted into the Loop and that removing all of the accumulated fine sediment is likely to be unsustainable, it is not realistic to expect that the Loop will recover to its former ecological status as described by kaumatua in previous chapters. We can however greatly improve this coastal ecosystem by focusing on improving water quality, full or partial removal of fine sediment, and improved access to habitat for the more tolerant species such as whitebait and eel: mahinga kai that are highly valued by local iwi and hapū. If no action is taken to improve the Loop it will continue to degrade.

Recommendations

- Remove accumulated fine sediment from the Loop, at least partially, particularly in problem areas. The bed should be graded as closely as possible to the original Loop gradient to accommodate plans to introduce flow at the top of the Loop. This should be done in autumn/winter to mitigate the impact on aquatic species and to coincide with winter floods in the Ōhau River which will help flush sediment that reaches the river.
- Excavate areas where farm tracks currently inhibit flow and re-connect the Loop with fish friendly culverts.
- Engineer or retro-fit a fish-friendly flood gate at the downstream end of the Loop to better enable fish passage throughout the Loop. This may require flood and tide modelling to set the flood gate at the correct height.
- Conduct further water quality monitoring to ascertain the concentrations of nutrients in the Loop and in the potential source of flow to be introduced.
- Calculate the augmentation flow that is required for dilution to achieve water quality targets in the Loop.
- Conduct a further topography survey on the Loop to assess the maximum augmentation flow that the Loop and associated farm drainage can receive without increasing flood hazard.

- Once an appropriate augmentation flow is ascertained, engineer a culvert to take water from the Ōhau River. Topographical survey data will be needed to determine a suitable location to divert flow from the Ōhau into the Loop. Bed elevation data from within the Loop should be adjusted for sediment removal.
- Install strategic fencing along riparian margins in collaboration with farm managers.
- Selectively remove willows and establish native vegetation in riparian areas.
- Collaborate with the MTM Raukawa surf clam and surf zone water quality study to explore the link between the Loop and coastal ecosystems in more depth.

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9. APPENDICES

Appendix 1. Field work plan October 2011.

Habitat assessments

Initially at sites 4, 5 and 6, assess the habitat under protocols P2b (hydrology and morphology); P2d (riparian); P3c (instream habitat). If time allows toward the end of the week, complete habitat assessments for sites 1, 2, 3 and 7.

Water quality (Grey highlight indicates training of hapū for monthly data)

Water quality in the Loop vs. outside

1. 14 Temp loggers to run for six months at sites 1-7 (two loggers at each site; one deep and one near surface).
2. Five DO loggers to run for five days at sites 3, 4, 6, and 7. site 6 has two loggers; one deep and one near surface.
3. Spot measurements of pH, temp, salinity/conductivity, turbidity from sites 1-7. Sample these each time a site is visited (two to three times).
4. **Nutrients:** One water sample from sites 1-7 on map. Test for TN, TP NO3N, NH4N, and DRP). Take at same time of day and same tide if possible. Courier to Cawthron.
5. **Faecal bacteria:** One water sample from sites 1-7 on map. Test for *E. coli* and faecal coliforms. Take at same time of day and same tide if possible. Courier to Cawthron.

Macroinvertebrate presence / absence in the Loop vs. outside

1. Kick-net samples from sites 1-7 on map. Use Protocol C1 for the Ōhau River (hard bottomed semi-quantitative); and C2 for the Loop (soft bottomed semi-quantitative). Try to sample from similar habitat (*e.g.* different parts of the same riffle *etc.*). One sample from each site is adequate (but consider taking two and only processing one just in case). Try to sample all sites on the same day (mainly to get all at the same flow).

Substrate in the Loop

1. **Substrate size and composition:** Use Wolman walk to determine average particle size at sites 4, 5, 6 (inside Loop), and possibly sites 3 and 7
2. Bed height analysis (and sediment volume estimate): (ideally low tide) Use a wading rod to determine depth of fine sediments at sites 4, 5, and 6. Cover three habitats if possible (unlikely), so take 10 measurements from each of 10 cross sections in a 100 m representative reach at each site (*i.e.* 100 measurements at each site).
3. **Bed gradient:** (low tide) Use the total station set up in the middle of the Loop to measure the height of the bed and gradient down through the Loop.

Fish presence / absence in the Loop vs. outside

Spot lighting (night, low tide) presence/absence

1. Ōhau River from the estuary to bottom of Loop (2 km)
2. Ōhau Loop – walk the length (3 km)
3. Ōhau River from the bottom of the Loop to Kuku Stream (2 km)
4. Ōhau River from Kuku Stream to the SOE site (1.6 km).

Electric fishing / minnow traps / netting (day, low tide)

1. Ōhau Loop – at sites 4, 5, 6; presence absence or measure lengths.
2. Ōhau River / Kuku stream – at sites 1, 2, 3, and 7.

Flow gauging

Flow inside the Loop: one flow gauging at site 6. Sample four times; high tide, mid outgoing, low tide and mid incoming.

Appendix 2. Habitat assessments.

Selected sampling protocols have been used for this case study and are collated here. These were sourced from Harding *et al.* (2009) (protocols for stream habitat assessment; P2b, hydrology; P2d, riparian; and P3c, instream habitat– hydrology, riparian, and instream habitat).

Habitat assessment: Hydrology and morphology (Protocol P2b)

1. Record site details such as site name, site code as well as the name of the assessor and the date. Establish reach start by marking with a waratah and GPS. Take photos upstream and downstream at reach start.
2. Measure stream wetted width using rangefinder and calculate the site length approximately 20x wetted width. Whilst walking toward the other end of the reach record the meso-habitat length in meters for each meso-habitat encountered. GPS the reach end point and take photos upstream and downstream.
3. Estimate the floodplain shape for the site.
4. Locate three representative channel cross sections in (if present), a run, a riffle and a pool. At each cross section estimate bankfull channel shape, wetted width channel shape, and measure the average width of undercut bank with 1m ruler (no undercut = 0). At least one run cross section should be included and it should be suitable for.
5. Complete a plan diagram (using an aerial photo printout) of the site including photo points, location of cross sections, and the direction of stream flow.

Habitat assessment: Riparian (Protocol P2d)

Conduct this survey along the full length of the sample reach and assess riparian zones on both banks. On the field sheet write your results in the two columns ‘LB’ (left bank), and ‘RB’ (right bank).

1. Assess **shading of water** at the water surface; consider shading at all points across the water surface throughout the reach, so that the influence of banks, bank vegetation, and hill slopes are included in the assessment.
2. Assess the **riparian buffer width** from the stream bank in-land that is managed differently from the rest of the catchment. This riparian buffer (*i.e.* the managed area) may differ in extent to the riparian zone. If there is no difference in management use a width of 30 m.
3. **Buffer intactness** - estimate the percentage of gaps in the riparian vegetation that may reduce the effectiveness of the riparian buffer in providing habitat and interception of contaminant inputs.
4. Assess the riparian **vegetation composition** within the riparian buffer and the remaining area between the stream bank and 30 m in-land. If no buffer is present (*i.e.* no managed riparian vegetation) write ‘NB’ in the space below ‘Buffer’ in the

boxes for LB and RB scores and fill in scores for the whole area to 30 m from the stream bank in space beneath ‘Adjacent land’.

5. Walk the length of the reach and evaluate the typical condition of bank stability of both banks.
6. Assess **livestock access** by the presence of fencing, evidence of riparian vegetation grazing, presence of stock access tracks and other signs of animal access, such as cowpats.
7. **Riparian soil denitrification potential -** along the reach assess soil wetness and presence of subsurface drains (*e.g.*, tile drains instream banks) and open surface drains that enable groundwater to bypass moist riparian soils. Water-logged soils will sink underfoot and often have wetland plants present, such as sedges, flax or raupo.
8. Assess average **land slope** from the stream bank to 30 m landward on each bank. Several measurements should be made initially ‘to get your eye in’ using two survey poles and an inclinometer or builder’s level.
9. Assess the **groundcover** for both the buffer (if present) and adjacent land to 30 m from the stream bank.
10. Use a trowel, soil corer or spade to dig into the riparian soil at three to five locations along each side of the stream to assess the soil texture and **soil drainage** potential *i.e.*, boggy or free draining.
11. Count the number of **rills** that are likely to concentrate surface runoff through the riparian area and hence bypass filtering vegetation and soil infiltration.

Attributes	L	R	Scores 1	Scores 2	Scores 3	Scores 4	Scores 5
Shading of water			Little or no shading	10-25% shading	25-50%	50-80%	>80%
Buffer width			<1 m	1-5 m	5-15 m	15-30 m	>30 m
Buffer intactness			Buffer absent	50-99% gaps	20-50% gaps	1-20% gaps	Completely intact
Vegetation comp. of buffer and/or adjacent land to 30 m from streambank	**Buffer Adjacent**	**Buffer land**	Short grazed pasture grasses to stream edge, or impervious surfaces	Exotic weedy shrubs Gorse, blackberry, broom, or mainly high grasses or low native shrubs 0.3-2 m	Deciduous tree dominated; native shrub dom. (2-5 m); or plantation with <25% cover of >5 m trees; or tussock where natural	Regen. native forest or woodlot evergreens with >25% cover sub-canopy (>5 m) trees but <10% canopy trees (>12 m)	Maturing native forest including >10% cover canopy trees (>12 m); or native wetland or natural tussock veg.
Bank stability			Very low: uncohesive sediments & few roots & >40% recently eroded	Low: uncohesive sediments & few roots/ low veg. cover & >15–40% recently eroded	Moderate: stabilized by geology (e.g. cobbles), veg cover &/or roots & >5–15% recently eroded	High: stabilized by geology (e.g. bedrock), veg. cover &/or roots; & 1-5% recently eroded	Very high: stabilized by geology (e.g. bedrock), veg. cover &/or roots; <1% recently eroded
Livestock access			High: unfenced and unmanaged with active livestock use	Moderate: some livestock access	Limited: Unfenced but with low stocking, bridges, troughs, natural deterrents	Very limited: Temporary fencing of all livestock or naturally v limited access	None: Permanent fencing or no livestock
Riparian soil denitrification potential			Soils dry/firm underfoot <u>or</u> moist-wet but frequent tile drains bypass riparian soils (≥3 per 100 m)	1-30% streambank soils moist but firm <u>or</u> moist-wet with infrequent bypass drains (1-2 per 100 m)	≥30% streambank soils moist but firm underfoot. No drains.	1-30% streambank soils water-logged, soft underfoot with black soil. No drains.	≥30% of streambanks water-logged, surface moist/fluid underfoot. No drains.
Land slope 0-30 m from stream bank			>35°	>20 - 35°	>10 - 20°	>5 - 10°	0 - 5°
Groundcover of buffer and/or adjacent land to 30 m from streambank	**Buffer Adjacent**	**Buffer Land**	Bare	Short/regularly grazed pasture (<3 cm)	Pasture grass/ tussock with bare flow paths or 2-3 cm tree litter layer	Moderate density grass or dense (>3 cm) tree litter layer	High density long grass
Soil drainage			Impervious (e.g. sealed) or extensively pugged and/or compacted soil	Low permeability (e.g. high clay content) or moderately pugged/compacted soil	Low-moderate permeability (e.g. silt / loam) and not pugged/compacted	Mod-high permeability (e.g. sandy loam) & not pugged/compacted	Very high permeability (e.g. pumice / sand) & not pugged/compacted
Rills / Channels			Frequent rills (> 9 per 100 m) or larger channels carry most runoff	Common rills (4-9 per 100 m) or 1-2 larger channels carry some runoff	Infrequent rills (2-3 per 100 m) and no larger channels	Rare rills (1 per 100 m) and no larger channels	None

Figure A2.1. Riparian assessment field protocol (P2d) following Harding *et al.* (2009).

Habitat assessment: Instream habitat (Protocol P3c)

This assessment is made across the bankfull extent of the stream; it includes lower banks, any dry river bed and the wetted width of the stream.

1. Measure six cross-sections including two riffles, two runs and two pools. At each cross-section conduct the following:

- Measure the substrate size of 10 randomly selected particles whilst wading across the stream cross-section, measure the second narrowest axis of each particle.
- For each of the 10 randomly selected particles, note the degree of substrate embeddedness using the 1-4 scale:

Score 1	Score 2	Score 3	Score 4
Not embedded the substrate on top of the bed	Slightly embedded, < 25% of the particle is buried or attached to the surrounding substrate	Firmly embedded, approximately 50% of the substrate is embedded or attached to the surrounding substrate	Heavily embedded, >66% of the substrate is buried

- Substrate compactness - Walk across part of the riverbed and estimate the degree of compactness. Compactness is assessed on a 1- 4 scale.

Score 1	Score 2	Score 3	Score 4
Loose, easily moved substrate	Mostly loose, little compaction	Moderately packed	Tightly packed substrate

- Measure the total amount of depositional or scouring zones across the measuring tape.
- Measure the width of macrophyte beds that intersect the tape. Note if macrophytes are submerged, emergent or marginal.
- Measure the total width of visible algal growths that intersect the tape.
- Measure the total width of visible leaf packs (> 10 cm^2) that intersect the tape.
- Measure the longest axis of any large woody debris (> 20 cm longest axis) that intersects the tape.
- Count the number of significant obstructions to flow such as large boulders and log jams > 0.5 m in size that intersect the tape.
- Measure the amount of wetted stream bed with bank cover referring to overhanging banks or vegetation (< 30 cm above water surface) across the cross section.

2. Repeat these measurements for another nine cross-sections through each site

Appendix 3. Habitat assessment results.

Table A3.1. Reach start and reach end GPS coordinates for three sites in the Loop (sites 4, 5 and 6) and two in the Ōhau River (sites 3 and 7).

GPS Coordinates	Site 3	Site 4	Site 5	Site 6	Site 7
Reach Start	N 6058399 E 2693893	N 6058247 E 2693931	N 6057830 E 2693655	N 6058600 E 2693503	N 6058761 E 2693680
Reach End	N 6058373 E 2693983	N 6058166 E 2693952	N 6057836 E 2693615	N 6058739 E 2693402	N 6058591 E 2693606

Table A3.2. Instream vegetative habitat results within the Loop (sites 4, 5 and 6) and in the Ōhau River (sites 3 and 7).

Instream vegetative habitat	Site 3	Site 4	Site 5	Site 6	Site 7
Macrophytes Submerged (m)	0	4	Too murky to assess	0.6	0
Macrophytes Emergent (m)	0	8		0.4	0
Algae (m)	0	12		0.05	0
Woody debris (m)	0.6	0		0	1
Large boulders & log jams (count)	4	0		0	0

Table A3.3. Riparian habitat results within the Loop (sites 4, 5 and 6) and in the Ōhau River (sites 3 and 7).

Riparian Habitat	Site 3		Site 4		Site 5		Site 6		Site 7	
	True left	True right	True left	True right	True left	True right	True left	True right	True left	True right
Shading of water	1	3	3	4	3	2	1	1	4	1
Buffer width	3	4	2	3	3	2	1	1	4	1
Buffer intactness	2	3	2	3	3	2	1	1	3	1
Vegetation comp of buffer	2	2	2	3	2	2	2	2	3	2
Vegetation comp of adjacent land	1	1	1	1	1	1	1	1	1	1
Bank stability	2	2	1	1	4	4	5	5	4	2
Livestock access	1	5	4	1	5	5	5	5	1	1
Riparian soil de-nitrification potential	1	1	2	2	2	2	2	2	2	2

Riparian Habitat	Site 3		Site 4		Site 5		Site 6		Site 7	
	True left	True right	True left	True right	True left	True right	True left	True right	True left	True right
Land slope	1	3	1	1	2	3	2	3	1	2
Ground cover of buffer	2	1	3	3	3	3	2	2	3	3
Ground cover of adjacent land	2	2	2	2	2	2	2	2	2	2
Soil drainage	5	5	5	5	5	5	5	5	5	5
Rills/Channels	3	2	4	4	5	5	5	5	4	4
Overall score (maximum 5)	2.3		2.5		3		2.7		2.5	

Table A3.4. Wolman Count particle size results within the Loop (sites 4, 5 and 6) and in the Ōhau River (sites 3 and 7).

Wolman Count: Site 3										
Wetted width	**1TL**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10TR**
23.7	32	22.6	16	32	16	2	8	32	32	16
29.2	16	64	16	32	32	32	16	8	2	2
30	128	64	16	16	16	32	2	8	32	64
21.8	16	32	8	32	8	8	32	64	2	32
22.7	32	16	64	32	64	32	32	2	2	32
23.6	64	16	32	16	16	8	2	2	2	2
23.7	64	8	32	16	32	32	2	16	2	16
25.6	64	64	32	32	64	16	2	16	2	0
27.4	64	128	64	32	64	16	4	2	0	0
25.6	64	128	64	32	8	8	2	4	2	2
25.33	54.4	54.26	34.4	27.2	32	18.6	10.2	15.4	7.8	16.6

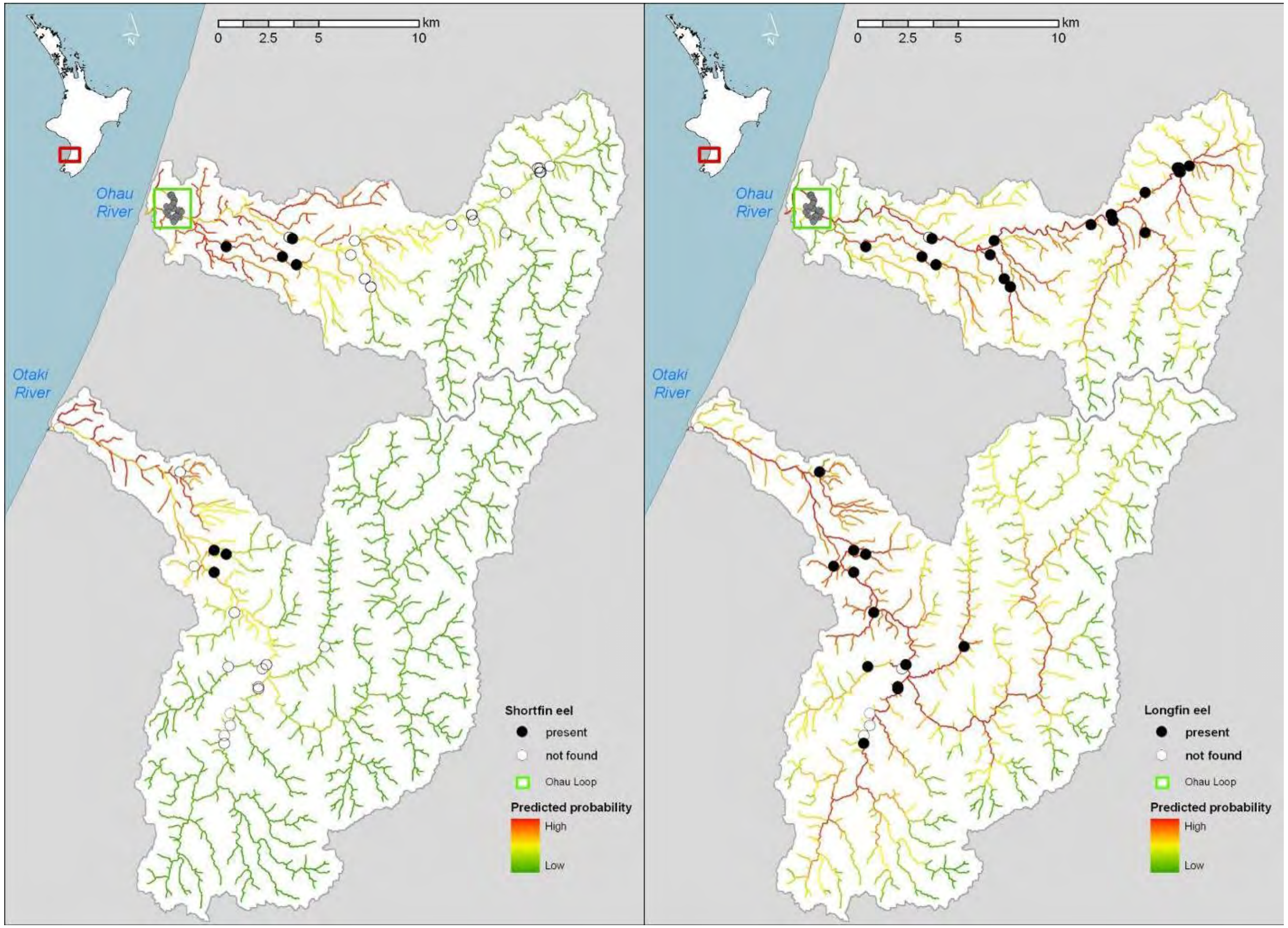
Wolman Count: Site 4										
13.7	0	0	0	0	0	0	0	0	0	0
10.9	0	0	0	0	0	0	0	0	0	0
15.5	0	0	0	0	16	0	0	0	0	0
16.4	0	0	0	0	8	16	16	32	32	0
15.5	0	0	0	0	0	0	0	0	0	0
16.2	0	0	0	0	0	0	0	0	0	0
16.3	0	0	0	0	0	0	0	0	0	0
14.8	0	0	0	0	0	0	0	0	0	0
13.7	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0
14.3	0	0	0	0	2.4	1.6	1.6	3.2	3.2	0

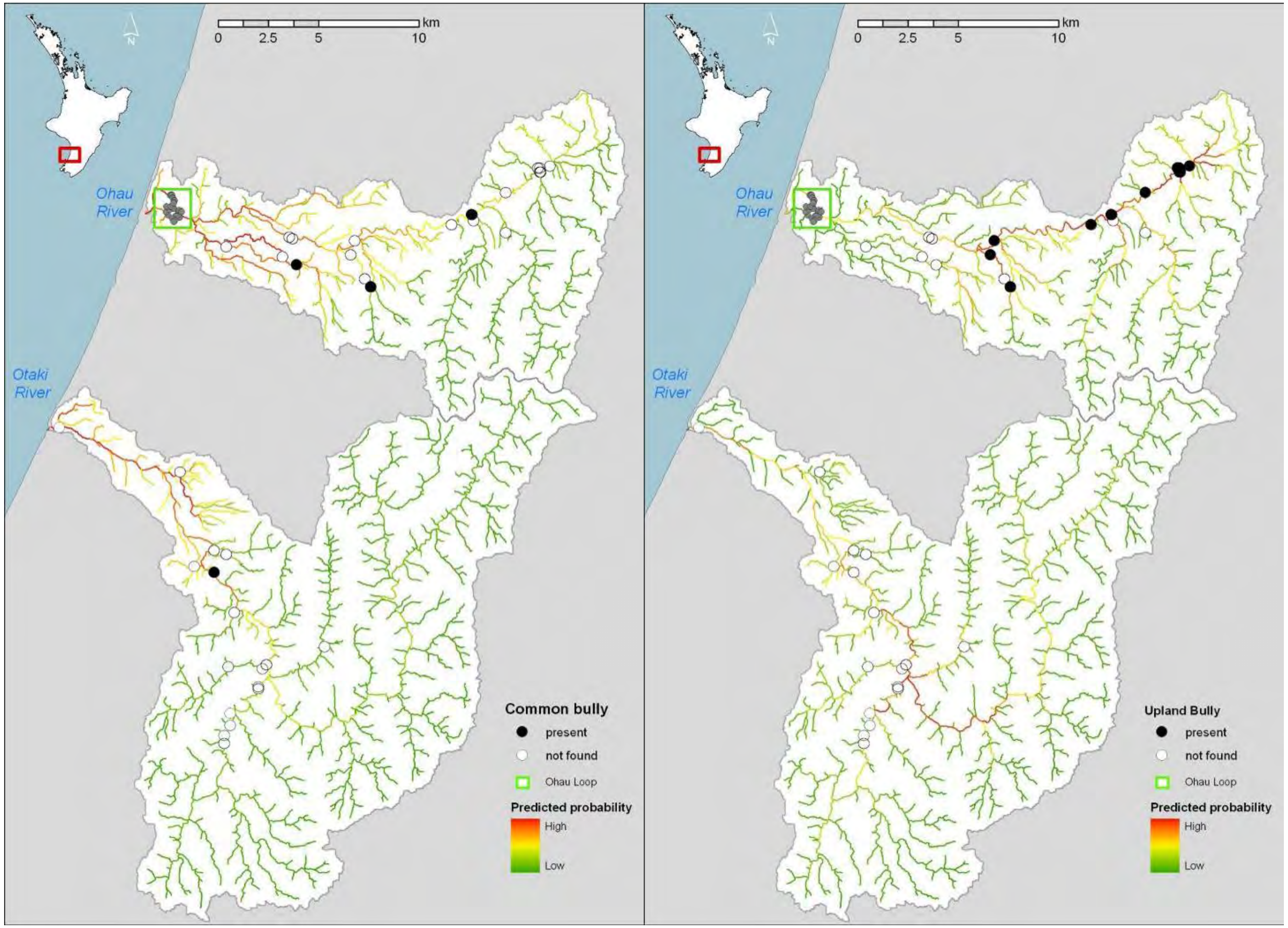
Wolman Count: Site 5										
17.3	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0
20.9	0	0	0	0	0	0	0	0	0	0
19.1	0	0	0	0	0	0	0	0	0	0
19.1	0	0	0	0	0	0	0	0	0	0
20.9	0	0	0	0	0	0	0	0	0	0
18.2	0	0	0	0	0	0	0	0	0	0
20.9	0	0	0	0	0	0	0	0	0	0
19.7	0	0	0	0	0	0	0	0	0	0
21.8	0	0	0	0	0	0	0	0	0	0
19.69	0	0	0	0	0	0	0	0	0	0

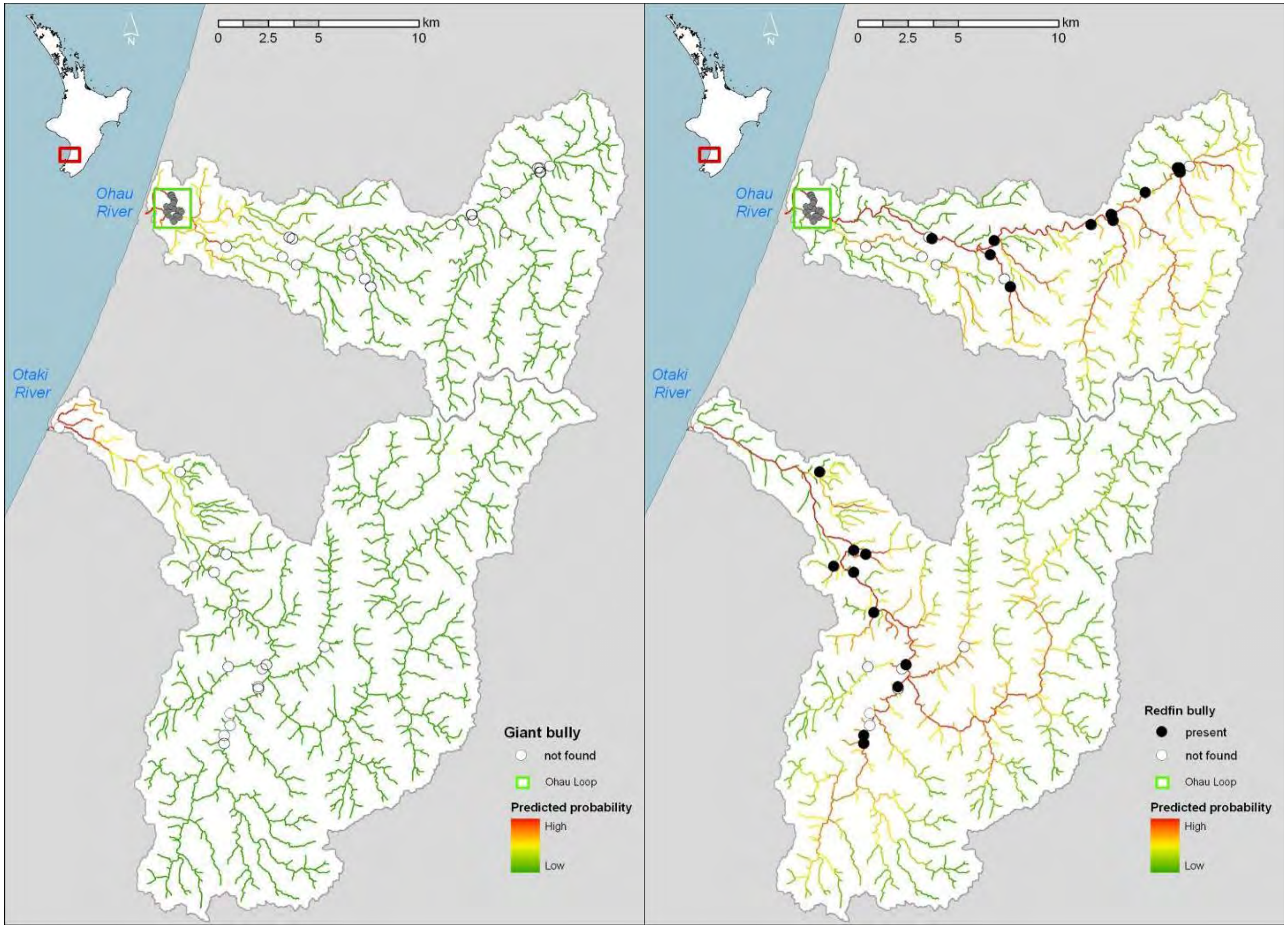
Wolman Count: Site 6										
38	0	0	0	0	0	0	0	0	0	0
40.9	0	0	0	0	0	0	0	0	0	0
41.8	0	0	0	0	0	0	0	0	0	0
39.1	0	0	0	0	0	0	0	0	0	0
40.1	0	0	0	0	0	0	0	0	0	0
41.9	0	0	0	0	0	0	0	0	0	0
40.2	0	0	0	0	0	0	0	0	0	0
37.4	0	0	0	0	0	0	0	0	0	0
38.4	0	0	0	0	0	0	0	0	0	0
28.3	0	0	0	0	0	0	0	0	0	0
38.61	0	0	0	0	0	0	0	0	0	0

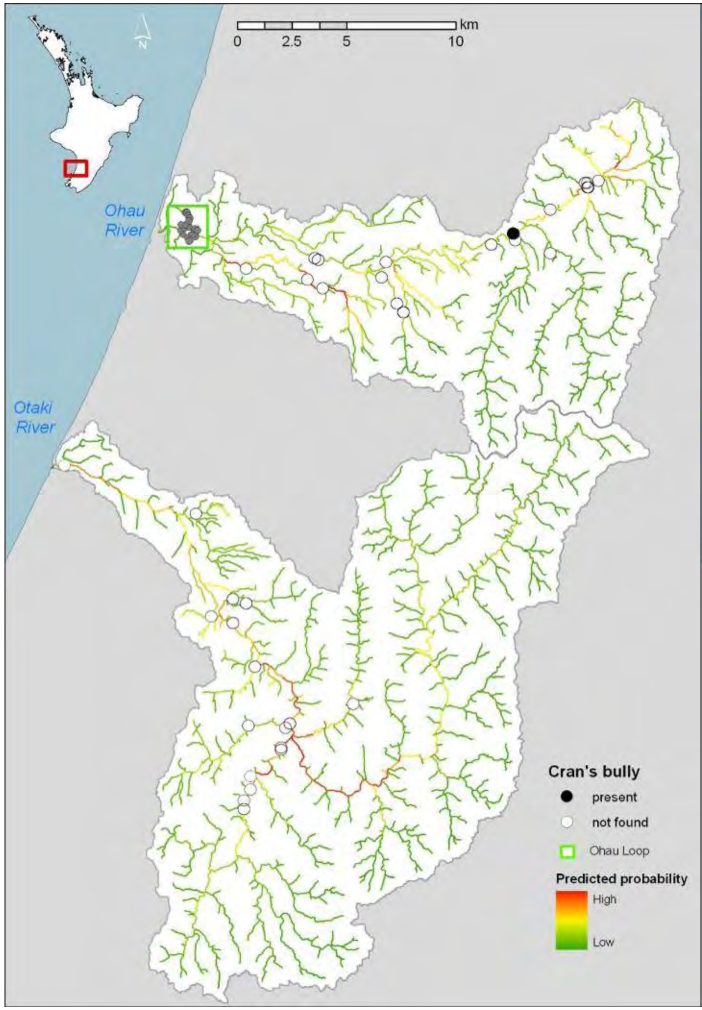
Wolman Count: Site 7										
37.4	0	4	16	8	4	2	2	2	0	0
39.2	0	0	32	16	16	16	8	2	2	0
40.2	0	0	32	32	32	16	4	2	2	0
29	0	0	16	32	32	16	8	2	0	0
23.9	0	0	4	32	16	32	16	4	2	2
23.7	0	0	4	16	32	32	16	32	2	4
30	0	0	8	32	16	2	2	8	32	16
48	0	0	16	64	32	64	64	16	16	32
45.6	0	0	0	32	32	16	16	64	8	32
42.8	0	0	0	8	32	16	16	2	16	8
35.98	0	0.4	12.8	27.2	24.4	21.2	15.2	13.4	8	9.4

Appendix 4. Predicted (*Leathwick et al.* (2008)) and observed (New Zealand Freshwater Fish Database) fish species distribution in the Ōhau River and Ōtaki River catchments. The green square shows the Loop and the sampling sites for the October 2011 field sampling.

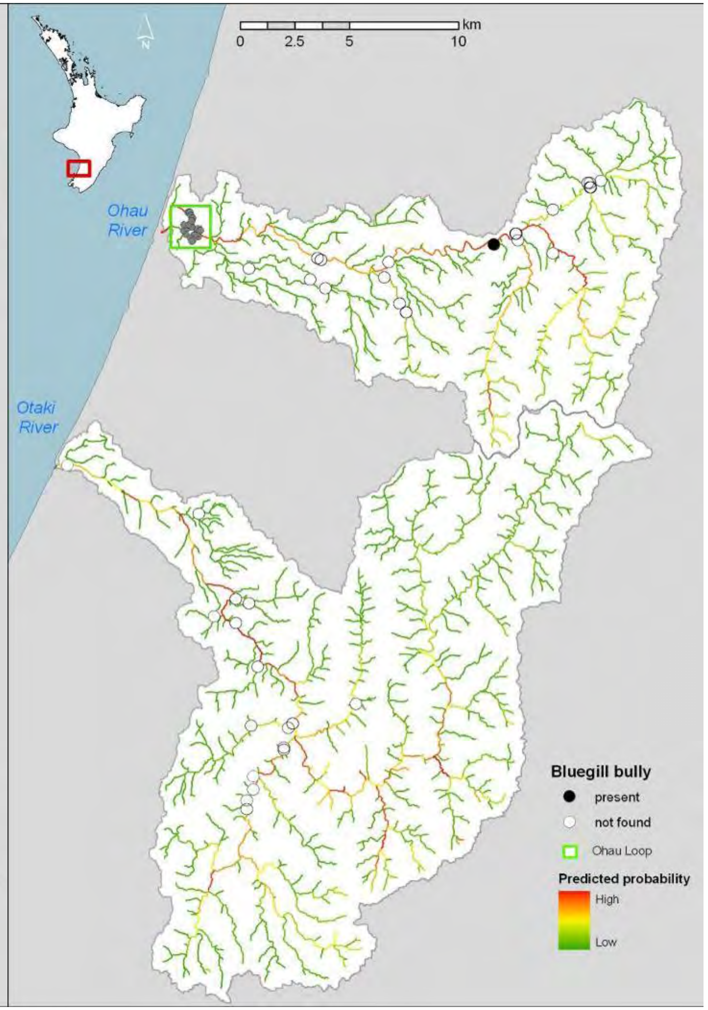



km
0 2.5 5 10
Ohau River
Otaki River
Common bully
present
not found
Ohau Loop
Predicted probability
High
Low
km
0 2.5 5 10
Ohau River
Otaki River
Upland Bully
present
not found
Ohau Loop
Predicted probability
High
Low

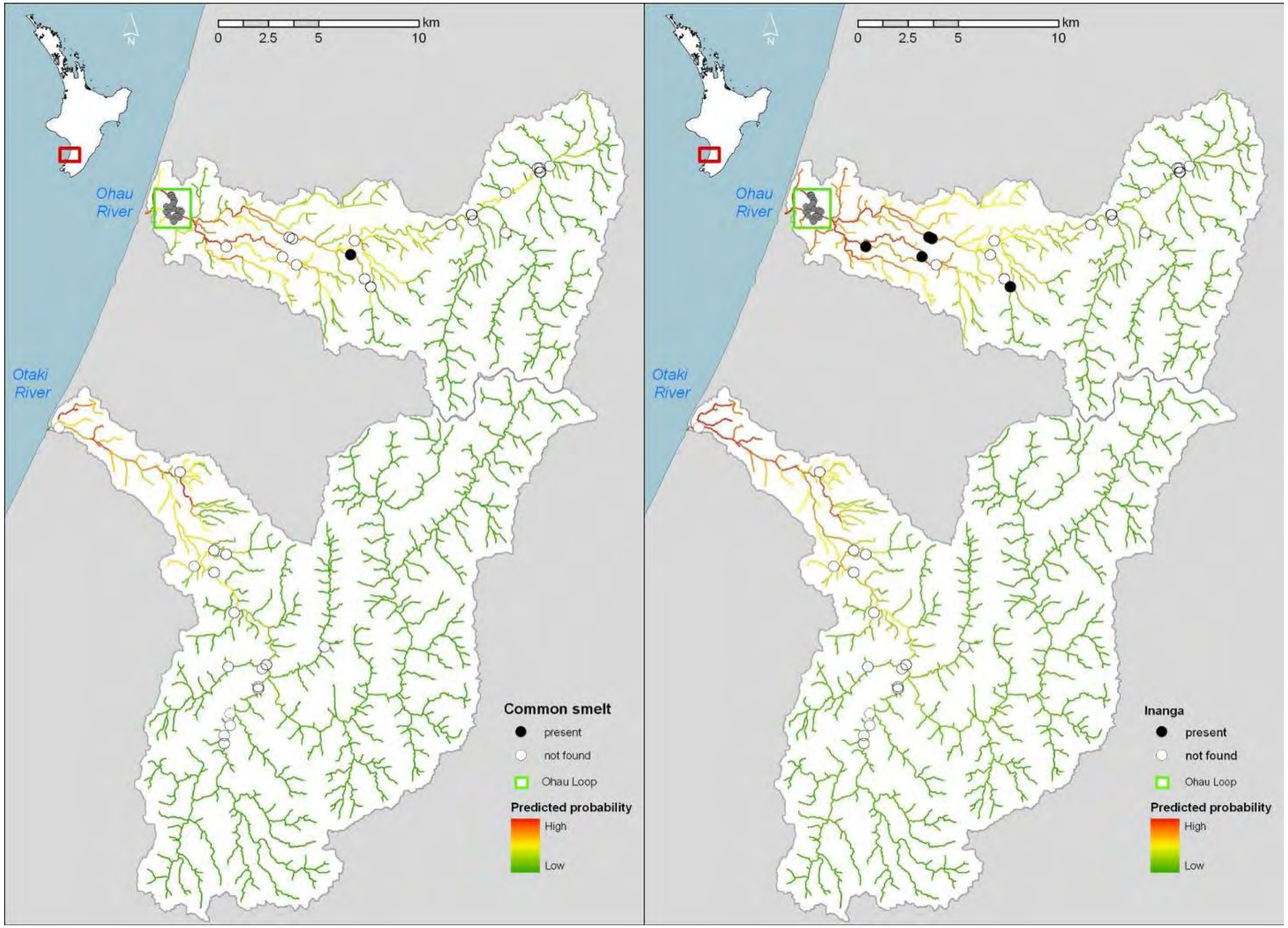

km
0 2.5 5 10
Ohau River
Otaki River
Giant bully
not found
Ohau Loop
Predicted probability
High
Low
Redfin bully
present
not found
Ohau Loop
Predicted probability
High
Low



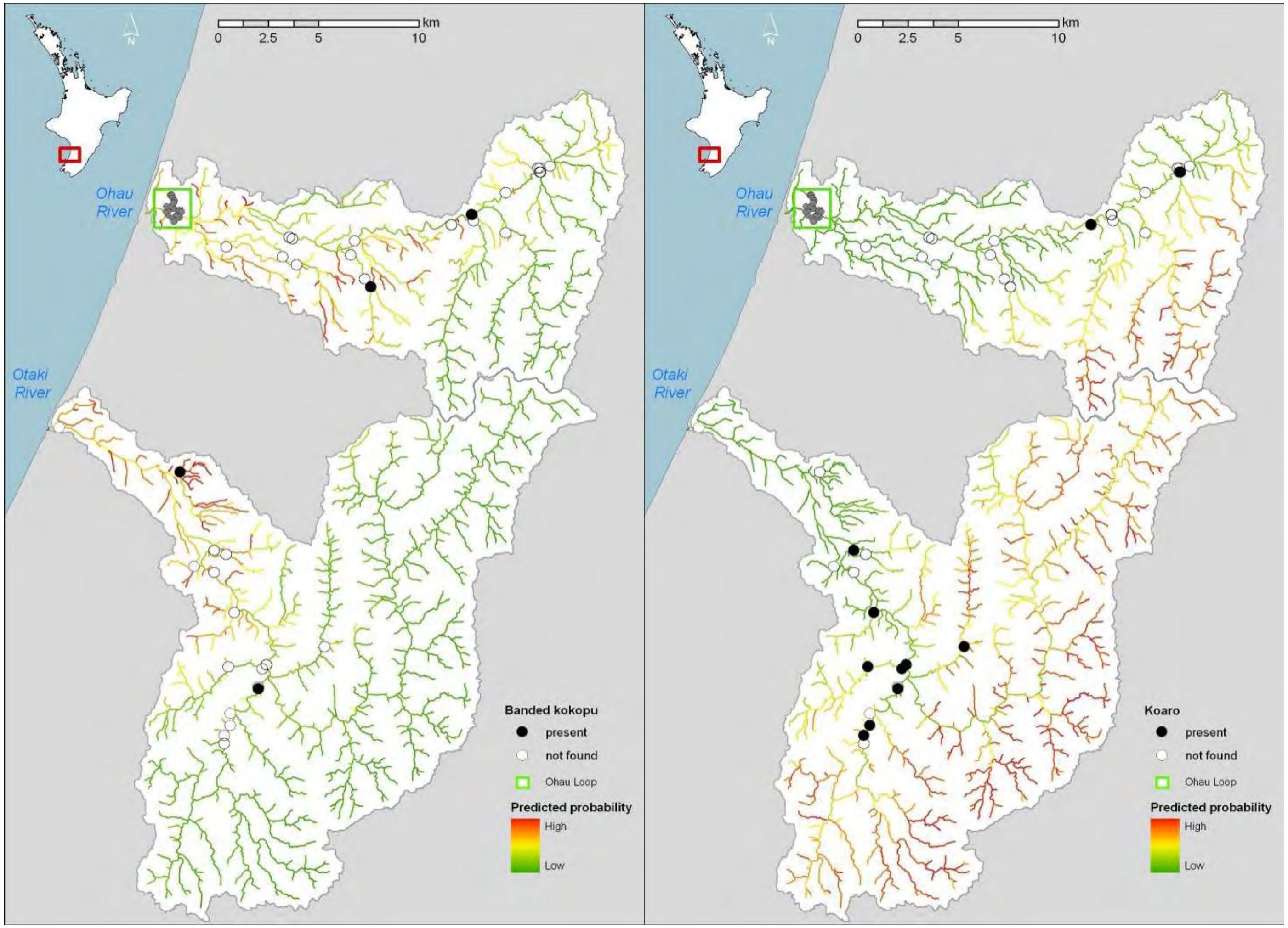
km
0
2.5
5
10
Ohau River
Otaki River
Cran's bully
present
not found
Ohau Loop
Predicted probability
High
Low



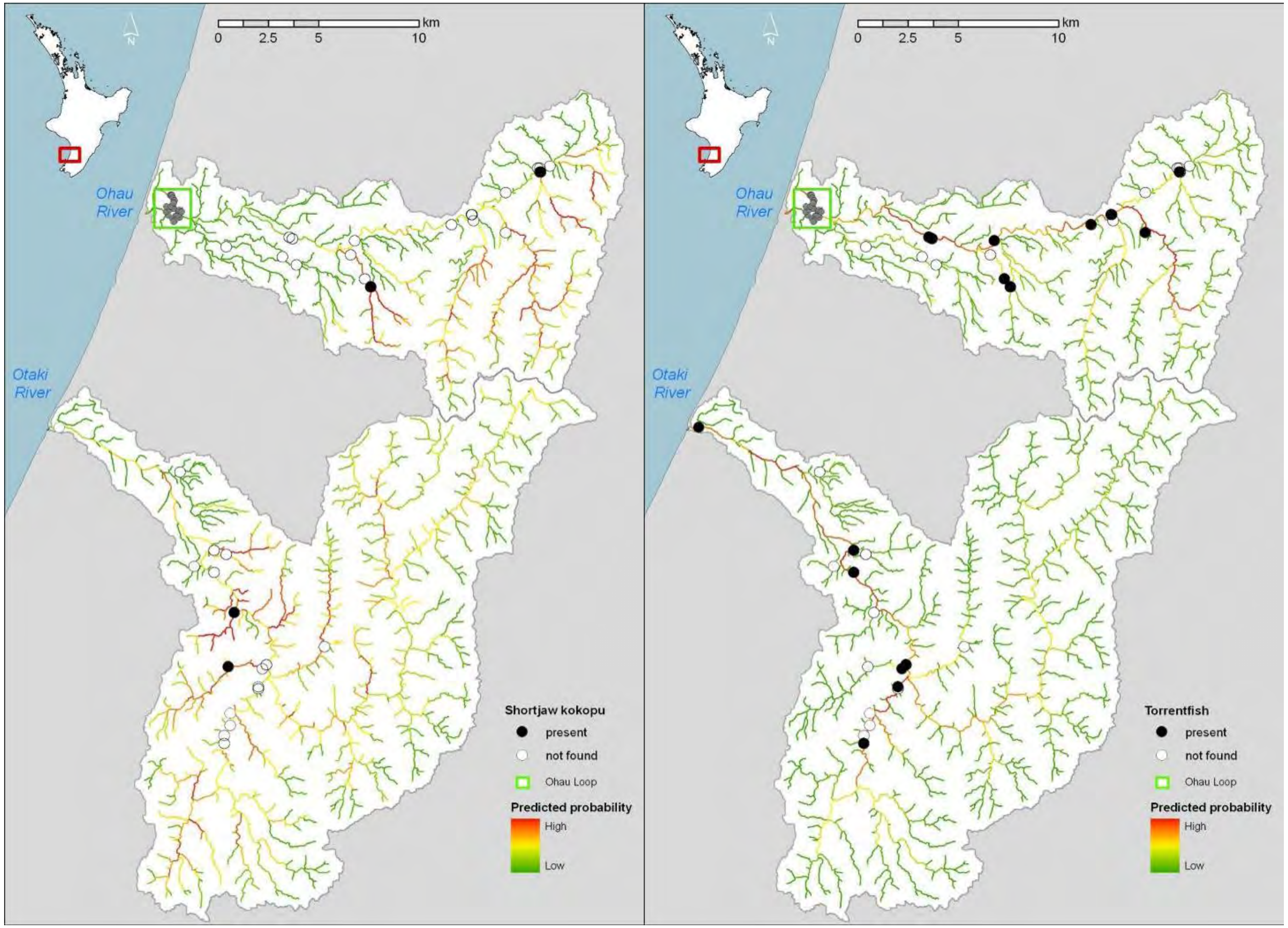
km
0
2.5
5
10
Ohau River
Otaki River
Bluegill bully
present
not found
Ohau Loop
Predicted probability
High
Low

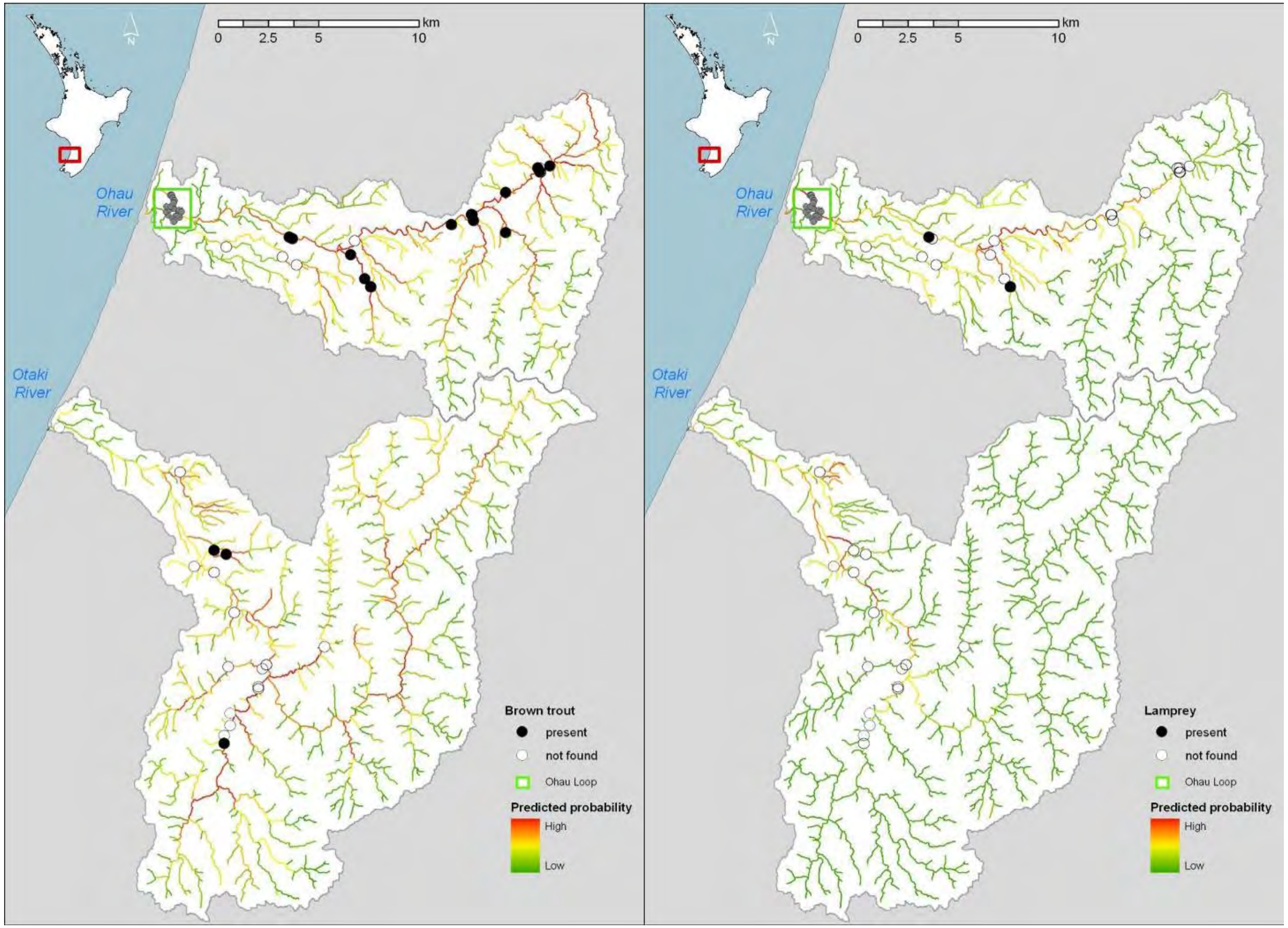


km
0 2.5 5 10
N
Ohau River
Otaki River
Common smelt
present
not found
Ohau Loop
Predicted probability
High
Low
km
0 2.5 5 10
N
Ohau River
Otaki River
Inanga
present
not found
Ohau Loop
Predicted probability
High
Low



km
0
2.5
5
10
Ohau River
Otaki River
Banded kokopu
present
not found
Ohau Loop
Predicted probability
High
Low
Koaro
present
not found
Ohau Loop
Predicted probability
High
Low


km
0 2.5 5 10
Ohau River
Otaki River
Shortjaw kokopu
present
not found
Ohau Loop
Predicted probability
High
Low
km
0 2.5 5 10
Ohau River
Otaki River
Torrentfish
present
not found
Ohau Loop
Predicted probability
High
Low


km
0
2.5
5
10
Ohau River
Otaki River
Brown trout
present
not found
Ohau Loop
Predicted probability
High
Low
km
0
2.5
5
10
Ohau River
Otaki River
Lamprey
present
not found
Ohau Loop
Predicted probability
High
Low

Appendix 5. Past and present indigenous vegetation (Lucas Associates 1998).

Appendix

PAST AND POTENTIAL INDIGENOUS VEGETATION

To establish, shelter is needed to protect many species from saltburn. Hardy species are proposed for first stage plantings. Long-term canopy species © to be carefully and sparsely located, particularly the podocarps.

For native forest restoration, plant densely (@ 1 per sq.m.) with:

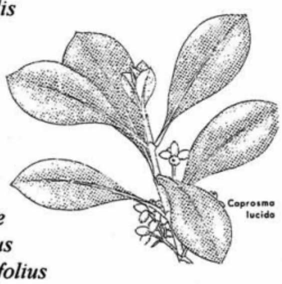
first stage:

TREES

karaka	*Corynocarpus laevigatus*
kohuhu	*Pittosporum tenuifolium*
kowhai	*Sophora microphylla*
manuka	*Leptospermum scoparium*
ngaio	*Myoporum laetum*

SHRUBS & FLAXES

harakeke	*Phormium tenax*
hukihuki	*Coprosma tenuicaulis*
karamu	*Coprosma robusta*
shining karamu	*Coprosma lucida*
three-penny bit shrub	*Coprosma areolata*



second stage:

TREES

ewekuri	*Streblus banksii*
hangehange	*Geniostoma rupestre*
hinau ©	*Elaeocarpus dentatus*
horoeka, lancewood	*Pseudopanax crassifolius*
kahikatea ©	*Dacrycarpus dacrydioides*
kohekohe ©	*Dysoxylum spectabile*
mahoe	*Melicytus ramiflorus*
mapou	*Myrsine asutralis*
matai ©	*Prumnopitys taxifolia*
nikau	*Rhopalostylus sapida*
northern rata ©	*Metrosideros robusta*
oro-oro	*Nestegis montana*
porokaiwhiri ©	*Hedycarya arborea*
pukatea ©	*Laurelia navaezelandiae*
putaputaweta	*Carpodetus serratus*
rimu ©	*Dacrydium cupressinum*
tawa ©	*Beilschmiedia tawa*
titoki©	*Alectryon excelsus*
totara ©	*Podocarpus totara*

SHRUBS

koromiko	*Hebe stricta*
poroporo	*Solanum aviculare*
shrub pseudopanax	*Pseudopanax anomalus*

CLIMBERS & FLAXES

giant astelia	*Astelia grandis*
kiekie	*Freycinetia banksii*

third stage:

FERNS

mamaku	*Cyathea medularis*
maratata	*Phymatosorus pustulatu.*
ponga	*Cyathea dealbata*

CLIMBERS

kareao	*Ripogonum scandens*
kawakawa	*Macropiper excelsum*
white rata vine	*Metrosideros diffusa*