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Swamp kauri resources of Northland

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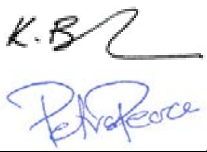	Reviewed by:	Ken Becker Auckland Regional Manager Petra Pearce, Climate Scientist, Auckland
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Executive summary

- We have mapped the distribution of Northland's swamp kauri (subfossil kauri) resources using a multivariate approach of combining soil types, geomorphology and topography, validating potential subfossil kauri terrain using historic information (including interviews from industry operators).

- There are significant relationships between Northland subfossil kauri and specific geomorphic settings. Four basic geomorphic arrangements in Northland hold subfossil kauri within organic sediments. The geomorphic settings are relic fluvial systems, relic coastal barriers that were formerly compartmentalized between rocky headlands, relic aeolian (parabolic and sand wave) dune systems, and composite relic coastal barrier/dune complexes.

- Most subfossil kauri are found in association with organic soils (peats) within the four geomorphic settings we have identified. Those soils may be widespread (and mapped as such) or occur as small patches (identified or not identified) nested within other more dominant soils. At present, there are some limitations to using large-scale soil type maps to unequivocally identify potential subfossil kauri deposits.

- The range of subfossil kauri extraction sites across Northland indicates significant quantities of buried wood may be found in association with more than one soil type, however some soils have a higher potential to preserve subfossil kauri (e.g. organic humic and mesic) than others (e.g. podzol densipan).

- Of the terrain we have identified as potentially holding subfossil kauri from broad-scale GIS mapping, ~21% on average had existing ecological constraints while ~78% was characterised as "ecological constraints unlikely". This indicates a majority of subfossil kauri environments exist within highly modified agricultural landscapes. However, a caveat to this assessment is that some ecological values may not be comprehensively reflected using the predominantly large-scale ecological data sets used in this study. As such, site-level surveys are likely required to determine the further suitability of the range of coverage we have identified in our regional assessment for subfossil kauri extraction.

- Historic subfossil kauri extraction information provided by industry operators about the amount of timber (cubic meters) or tonnes of wood per hectare covered more than 125 Northland sites. Regression equations were developed from that data for the purpose of estimating volumes of Northland's subfossil kauri resource prior to any extraction having taken place. A caveat on this assessment is an inconsistent amount of metadata about wood volumes or tonnage extracted and lack of measurement for the areas of historic subfossil kauri extraction.

- Best estimates from empirical evidence suggest 30-50% of the original pre-extraction subfossil kauri resource of Northland may have been removed to date, leaving anywhere from 50-70% of the resource for assessment, which equates to ~240,000m^3 to 437,000m^3. The conservative minimum estimate of the remaining volume is ~110,000m^3.

- The remaining Northland subfossil kauri resource will need to be assessed for suitability of future extraction and use. As such, the amount of millable timber that is likely to receive permission for extraction with a resource consent and milling statement will be lower than the total estimated amount of remaining resource calculated in this study.
- The paucity of detailed records about historic subfossil kauri extractions, subfossil kauri exports, and current subfossil kauri stockpiles, in addition to data from the national market for subfossil kauri, limit our confidence in calculating remaining subfossil kauri yield and volume of timber within Northland. Many of those shortcomings, along with those related to spatial resolution of soil/topography/geomorphic maps, could be rectified with further work.

1 Purpose of project

1.1 Background

MPI requested that NIWA and Wildland Consultants LTD (hereforth referred to as the Team) develop a methodology and implement it to assess the spatial extent and volume of the buried swamp kauri (hereforth referred to by its scientific name “subfossil kauri”) resource in the Northland region. MPI requires that information to better inform the discussion around management of subfossil kauri resources. Antecedent knowledge for the methodology development comes from NIWA’s experience working with subfossil kauri wood samples and Wildlands work on ecological surveys in subfossil kauri environments. The Team also includes Dr Jonathan Palmer, who is subcontracted to NIWA for his expertise on subfossil kauri.

1.2 Requirements of the project

The scope for the project is to:

- Review current databases, evaluate contemporary landscapes, review historic information (published and unpublished) and acquire personal observations from field staff and subfossil kauri operators, with the intention of identifying physical sites where subfossil kauri was extracted or where it may remain;
- Use remotely sensed and geodetically-based data and analyses (satellite imagery, maps, aerial photos, geologic, soil, vegetation, and natural area maps) to extend and/or extrapolate field-based observations of subfossil kauri to the wider terrain of Northland;
- Identify land tenures in Northland that are most likely to provide conditions for preserving subfossil kauri.

Extensive ground-truthing or field validation of subfossil kauri is considered out of scope for this project, meaning there is a reliance on extant information to achieve the main deliverables.

1.3 Deliverables

The key outcomes of the project are:

- An accurate understanding of Northland areas that are likely to preserve subfossil kauri;
- A spatial representation (i.e. maps, animations etc.) of those areas likely to provide conditions for preserving subfossil kauri;
- A reliable assessment of potential subfossil kauri volumes buried in those areas and confidence intervals for the assessed volumes;
- A final report outlining the methodology established and the results of the assessment.

This is the final report as part of the agreed contract with MPI, and we provide details of our work below.

2 Mapping Northland subfossil kauri

2.1 Methodology

The agreed methodology provided to MPI was to map kauri based on a multi-faceted approach of understanding antecedent geomorphic environments and the soil types that are associated with buried kauri. Our team identified that we would use existing land cover data that are readily available in Geographic Information System (GIS) format and details of historic subfossil kauri extractions from personal relationships with major ancient kauri contractors and businesses in Northland. In addition, we stated that we would make use of existing information about ancient kauri environments (from published presentations or publications that are in preparation) as part of MBIE-funded core science to map the extent of Northland's buried kauri resource. This method is also based, in-part, on *a priori* knowledge of subfossil kauri environments.

Previous research we have undertaken indicates a strong association of the subfossil kauri resource across northern New Zealand to four primary geographic settings (outside of remnant indigenous kauri forest). The buried wood primarily resides in peaty sediments of late Quaternary age that are contained within: a) relic coastal barrier sequences, b) drowned/infilled former river valleys connected to meandering fluvial systems, c) infilled maar (volcanic) craters and associated volcanic products, and d) lakes or palaeolakes in inland basins that formed as a result of migrating dunes/sand waves or abrupt drainage changes (See **Figure 1**). We recognise other geomorphic settings related to subfossil kauri preservation outside of the Northland region, and these are not discussed in this report.

Figure 1. Different types of geomorphic associations of subfossil kauri (three shown here). A) relic coastal barrier sequences (main landform in centre of picture, subfossil kauri to the right in the distance; near Kaimaumau), B) palaeodune lakes (with pile of subfossil kauri in the foreground; near Kai Iwi Lakes), C) stem of a preserved buried kauri surrounded by bluffs of volcanogenic sediment (Manukau Harbour, Auckland).

The methodology is split into three basic phases:

1. Geographic analysis of Northland subfossil kauri environments;
2. Historic subfossil kauri extraction and current subfossil kauri operator information;
3. Future extraction sites and subfossil kauri volumes (including ecological delimiters).

2.2 GIS analysis

During Phase 1, we constructed a multi-layer GIS map including spatial data about physical environmental conditions in Northland that was used for assessment of the subfossil kauri resource. To achieve that we have collated and reviewed all relevant GIS data which included:

- Geological maps;
- Topographic DEM;
- New Zealand Soil Classification maps;
- Land Use Capability (LUC);
- Land Resource Inventory (LRI);
- Land Cover Database (LCDB4.1);
- Northland's wetlands (Northland Regional Council dataset));
- Sites identified and mapped for the Department of Conservation Protected Natural Areas Programme (PNAP);
- Land ownership (private with no protection, private with protection e.g. QEII covenant, Crown land administered by the Department of Conservation)

In the evaluation of different geologic and soil map types, critical differences are obvious for the level of detail of soil subdivision and in the way different surficial geology units are depicted with respect to topography. The Landcare Fundamental Soils classification map appears to provide the greatest differentiation between Quaternary sedimentary deposits and soils of Northland, which we have utilised to determine the extent of Northland subfossil kauri. In addition, the added detail in from this base map helped to test multiple iterations of land cover that potentially contained subfossil kauri as well as statistical/regression models that we worked on to relate soil type (and subsequently refine with geomorphic information) to historic subfossil kauri excavations. Those models are applied to estimate remaining subfossil kauri volume for Northland.

2.3 Historic data

We conducted archive work at The Kauri Museum in Matakohe during the last week of July 2016 and at the Dargaville Museum in mid-August 2016. During those trips, we accessed many different types of written and photo-documentary resources at both museums, including information from subfossil kauri display samples that provide physical evidence about where buried wood has been extracted (**Figure 2**). As such, historic details contained in printed resources at both museums about kauri gum digging (a thriving industry during the colonial era) were obtained. Correspondence on subfossil kauri and kauri gum in the form of books, newspaper articles, gum licenses, gum industry reports, forestry reports, and theses were captured by photography and catalogued. In addition, we photographed historic black and white images and displays of the kauri gum industry, noting metadata about locations of the photos where possible.

One highly useful piece of information was uncovered in a PhD thesis on the kauri gum industry (Smith, 1952). That work was undertaken prior to satellite imagery or access to aerial photography, yet it is remarkable how well some of the richest deposits of kauri gum correspond to areas where we know subfossil kauri was extracted in abundance (**Figure 3**). As such, use of the Smith (1952) kauri gum field map is a useful check on more limited field data we have from modern subfossil kauri extractions (post-1990). We also have an additional map that indicates the land that was set aside as a part of the Kauri-gum Industry Act for 1889-1900 that indicates acreage area and names of reserves that we will also use as a validation source for our mapping.

We also completed interviews of subfossil kauri industry operators that allowed us to obtain information about buried wood yield per hectare (in cubic meters or tonnage). Those interviews have added a layer of data richness beyond what MPI milling statements alone could give in regard to actual wood extracted from subfossil kauri sites. To date, we interviewed Nelson Parker from Nelson's Kaihu Kauri, Milton Randall, NZ Kauri LTD (Gary Beckham), Johnston's Gumdiggers Park (John Johnston) and M & S Subfossil Kauri LTD (Sacha Williams). During the process of this work, Dave Stewart of Ancient Kauri Kingdom passed away, and data from his executors is not currently available. An example of excavator site geographic locations are show in **Figure 4** for the Dargaville-Kaihu region.

Figure 2. Photo of heavy equipment working kauri gum lands and digging up buried wood in the process (note the piece of subfossil kauri being pulled toward the digger driver by the shovel bucket). Other historic photos of the gumfields show in situ subfossil kauri root plates, kauri peg roots, and buried logs. Photo AI 1992/915/116 courtesy of The Kauri Museum in Matakohe.

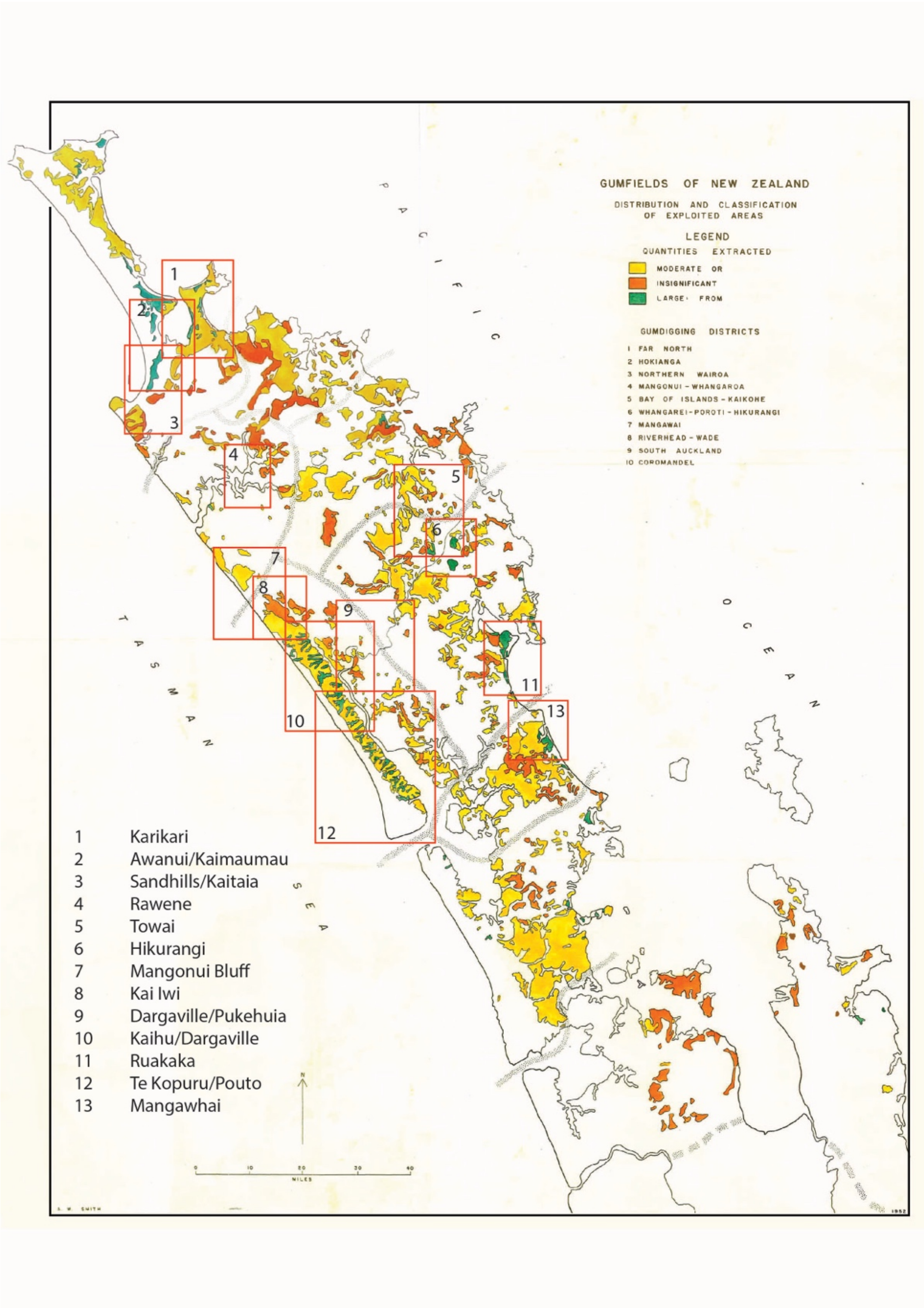

Figure 3. Modified copy of a map contained in A.W. Smith's (1952) PhD thesis on the kauri gum industry. Note that the green shades indicate regions where gum was obtained in large quantities from bogs. Our test examples for soil type and geomorphic mapping cover five distinct regions on this map that are broken into 13 different subregions (noted as red boxes, and listed from north to south in the lower left of the map). Subregion test maps where we interrogated soil type and geomorphology are included in the Appendix.

Figure 4. Google Earth image noting sites in the Dargaville-Kaihu region that have yielded subfossil kauri in recent decades. The star denotes the position of Dargaville. Initial analysis of soil type distribution for this region is shown in Figure 5. Pin colours correspond to the soil map key used in Figure 5.

We also collated all scientific literature on subfossil kauri, and obtained copies of all University of Auckland Tree Ring Laboratory working papers for Northland, which provided additional validation for five sites in the Dargaville-Kaihu region. Those resources are listed in a parallel progress report being prepared for MPI on subfossil kauri scientific values.

2.4 Test domains and soil subtype selection

To evaluate constraining delimiters for Northland subfossil kauri environments based on soil types, we first examined soils that cover lowland environments that subfossil kauri are known to be located within, or which are in close proximity to subfossil kauri sites. This allowed us to eliminate a number of soil types that we have not observed in association with subfossil kauri. In addition, primary comparisons with the Smith (1952) gum field map shows close association between some historic excavation sites and organic lowland soils. We note that some of the richest subfossil kauri deposits that we have accessed for research closely correspond to both humic and mesic organic soil types (**Table 1**).

Table 1. Association of soil types to different lines of field evidence that demonstrate an connection with subfossil kauri for Northland. Soil types are based on the Landcare Fundamental Soils Classification (see Appendix). Slope limits indicate whether topographic data was used to constrain the areal extent for a soil

type. Letters in the field validation and comments columns denote what style of validation has been used: a) evidence from historic subfossil kauri extraction; b) soil type significantly overlaps historic gum digging areas (Smith, 1952) of high and/or moderate yield; c) soil type is arranged in an adjacent fringing ring around known subfossil kauri substrates; d) geomorphic expression suggests subfossil kauri could be preserved; e) further validation required.

Soil type	Soil subtype	Slope limits?	Field validation (example site)	Geomorphic environment	Comments
Organic	*Mesic (OM)* *Humic (OH)*	Total extent	A (Towai) (Lake Ohia) A (Scotty Camp Road)	Fluvial, inland basin, palaeo-lacustrine	B B
Brown	*Sandy (BS)* *Acidic (BA)*	Less than 5 degrees	B, D (Sandhills Road) B	Composite coastal barrier/ aeolian dune	E E
Podzols	*Densipan (ZD)* *Pan (ZX)* *Groundwater-gley (ZG)*	<5 degrees Total extent Total extent	A, C, D (Basin Road) A (Marsden City, Ruakaka) B (Paparore Rd/Kaimaumau)	Relic coastal barrier, relic dune field, relic maar crater	B, E B E
Ultic	*Perch-Gley (UP)*	Less than 5 degrees	A, D (west of Kai Iwi)	Transitional slopes around lowlands, wetland depressions	B, E

For the initial validation of soil type and subfossil kauri environment mapping, we focused on several subregions within Northland to help evaluate our initial selection of soil types and verify the slope limitations placed on some of those soils. The test regions are indicated in **Figure 3** and shown in more detail in the Appendix. An example map is provided for the Kai Iwi / Dargaville sector in **Figure 5**, which allowed for a broad evaluation against subfossil kauri excavation sites. In addition, we noted several soil types containing subfossil kauri have extensive coverages that probably exceed where subfossil kauri may be found. These are discussed in more detail below (see section 3.1.2) and evaluated on a case-by-case basis (see example in **Figure 6**).

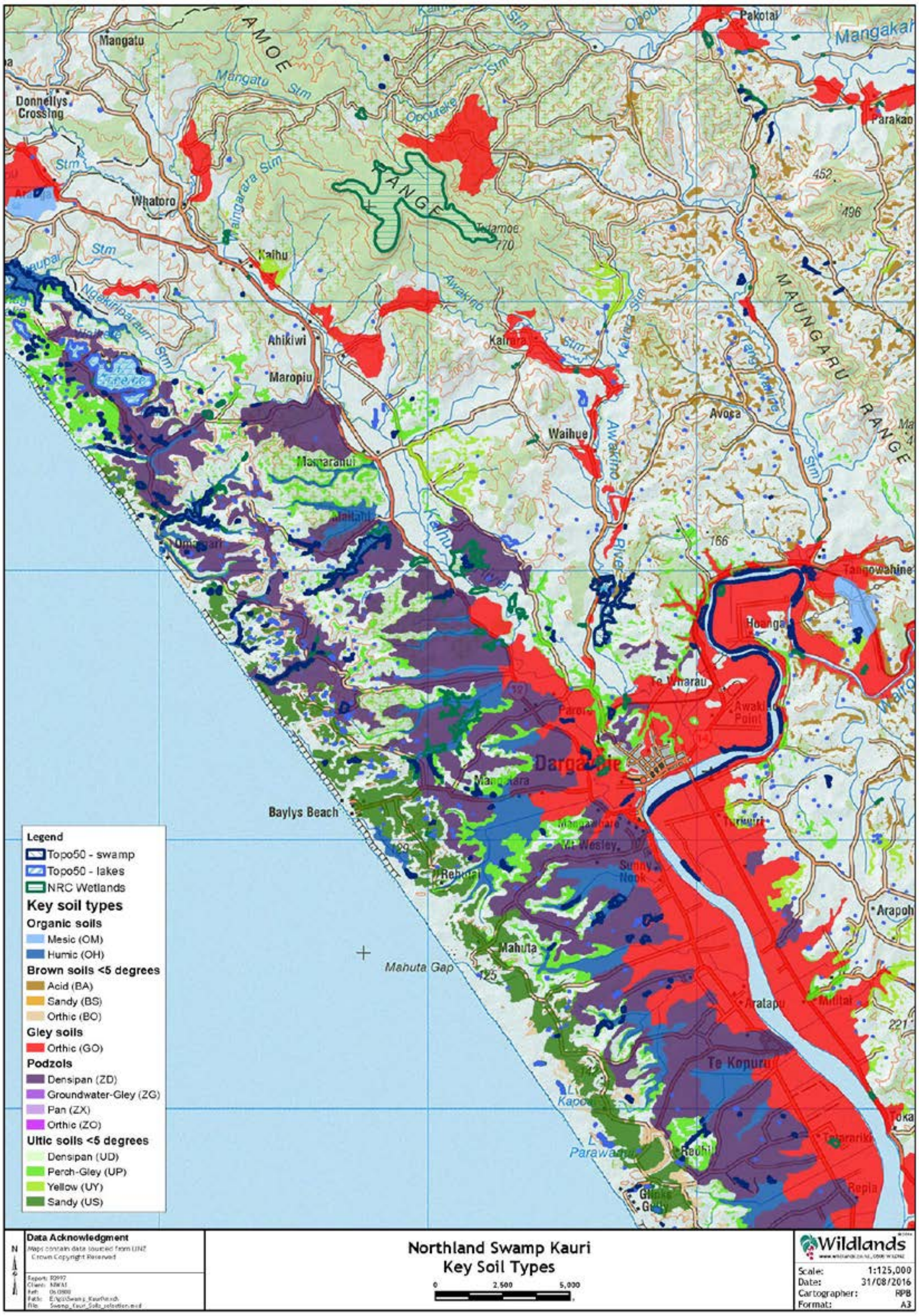

Figure 5. Soil types (preliminary assessment) associated with Northland subfossil kauri for the Kai Iwi Lakes / Dargaville region. Figure 4 has a similar view of this region and shows more than 30 sites that were used to narrow down the soil type selection and place limits on some units. Only perch-gley ultic soils were eventually selected, and limited to slopes <5 degrees. In addition, Brown, Gley and Podzol orthic soils were excluded, as were yellow and sandy Ultic soils. Densipan ZD soils were revised to include coverage only including slopes less than 5 degrees and a fractional percentage of that remaining cover. Refer to Table 1 for details about soil subtypes and the appendix for further details.

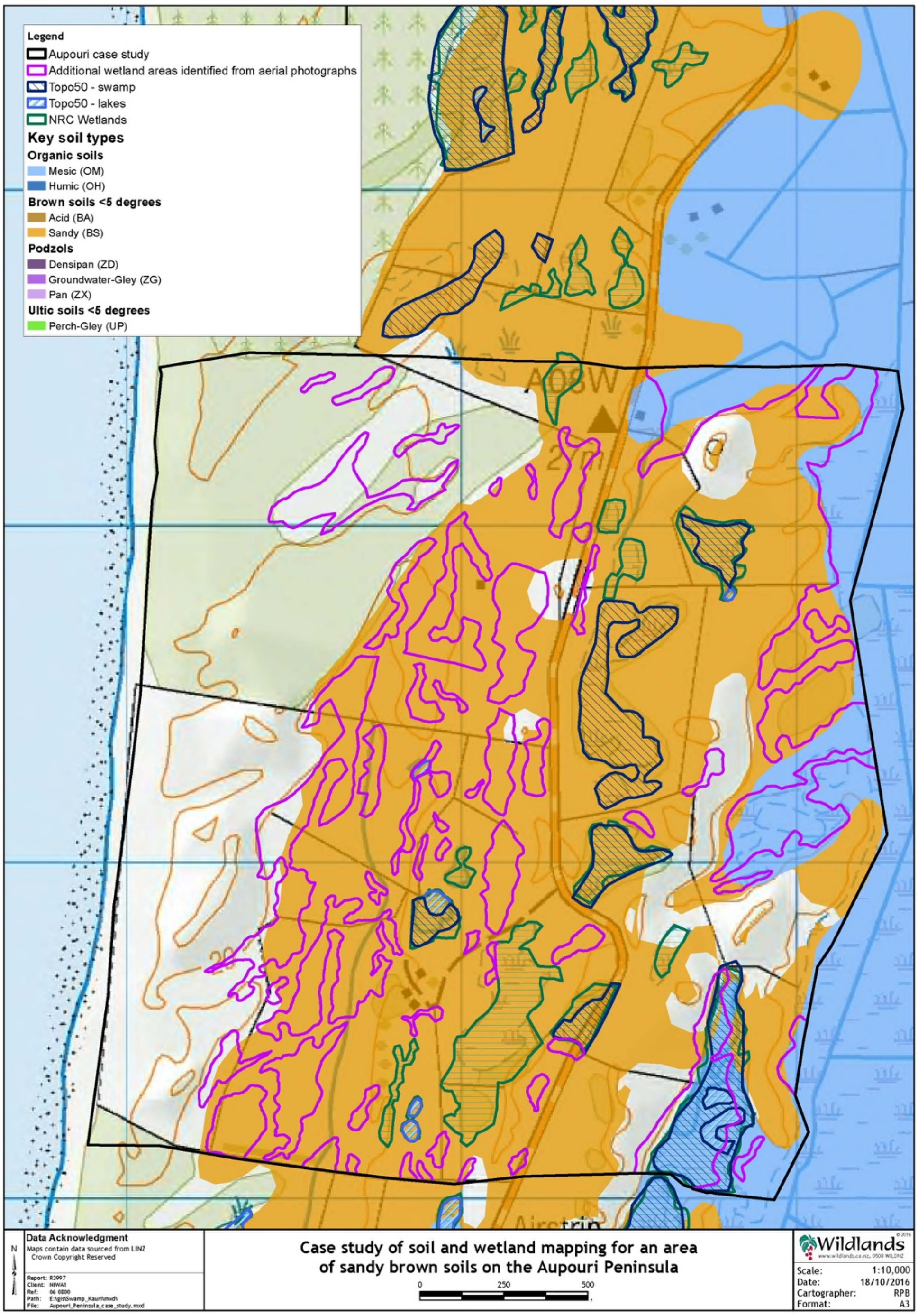

Figure 6. A detailed case study of Brown Sandy soils (BS) near Sandhills Road at the southern end of Aupouri Peninsula, near Kaitaia. There are seven subfossil kauri sites located within the black polygon in this figure, and four of them fall inside the pink polygons which circumscribe additional potential wetlands identified using aerial photography. The total coverage for previously unmapped areas not identified as a wetland or swamp from existing GIS layers (i.e. solely dependent on our high resolution supplementary mapping) within Brown Sands is approximately 20% of the spatial coverage. Similar distributions are noted for Podzol Densipan (ZD) and Ultic Perch-Gley (UP) soils. Refer to Table 1 for details about soil subtypes that are still undergoing evaluation and Appendix for case study maps of ZD and UP type sections.

3 Results

3.1 Physical Geography of Northland subfossil kauri

3.1.1 Field data

The environmental, geological and geomorphic settings that are conducive to subfossil kauri preservation across Northland are variable. Typically, the wood is preserved in anoxic conditions that prevail in lowland bogs or in environmental settings where sediments have sealed the wood off from sub-aerial exposure and decay. This assessment of where Northland subfossil kauri may be located was based on locations of former and current subfossil kauri excavation sites provided by industry operators, MPI milling statements and subfossil kauri tree-ring research publications. An evaluation of how those historic excavation sites are co-located in relation to soil types and with respect to geomorphology was undertaken using multi-variate GIS data. Historic information about Northland kauri gum digging fields that existed from the 19^{th} and early 20^{th} century helped to determine the location of subfossil kauri because both resources are known to have a close association.

Metadata for subfossil kauri excavation sites was variable between industry operators and between different sources of academic information about buried kauri. However, the spatial locations (latitude and longitude) were most commonly known followed by information about extracted timber (in either cubic meters or estimated tonnes), dates of extraction, and occasional notes about the substrate that had been dug. One difficulty that was encountered related to how much surface area at each site had been previously dug over to obtain specific wood volumes/tonnages. Where possible an estimate was provided when asked of each operator, and these estimates are likely to introduce error into yield calculations in this study because they are approximate.

In addition, the depth into the substrate that buried kauri was extracted from varied from site to site and between excavator operator. There is some suggestion that sites in the Far North have subfossil kauri-bearing substrates to depths where consistent extension to the full depth of a 30-ton excavator boom arm (approximately 7m) is required to extract all the wood. Photographic evidence from the Aupouri Peninsula at multiple sites verifies that assertion, though it will not be true of all settings in the Far North. Ground penetrating radar surveys have also indicated some sites that hold kauri have highly variable subsurface depths to the semi-lithified sediments at depth (also known as hard pan). As such, we recognise that multiple unknowns for historic excavations (surface area and depth) place significant caveats on any calculation of subfossil kauri yield. Thus, the results in this study are, at best, a suggestion of the mean yield remaining in Northland (i.e. more or less could be possible; ascribing confidence is difficult because of missing metadata).

3.1.2 Soil maps

A first order comparison of physical geography relationships to kauri excavation sites was undertaken using soil type distribution maps (**see Appendix**). This allowed us to eliminate several pedologic units across Northland from further consideration, resulting in a final set of soil spatial constraints (**Table 1**). Subsequently, the areal extent of the pre-selected soils that potentially hold subfossil kauri deposits were initially cross-validated against extant historic data obtained at The Kauri Museum at Matakohe and the Dargaville Musuem. During the archive work at Matakohe, a PhD thesis that included a map of Northland kauri gumfield yields (Smith, 1952) proved highly enlightening. In addition, locations of historic gum digging operations that showed subfossil kauri trees and root plates within kauri gum environments (from both museums) allowed us to assert that where kauri gum was abundant (and where it was mapped as such) subfossil kauri may also be co-located.

The soil type evaluation with reference to historic gum digging operations illustrates a large majority of buried kauri trees are directly associated with the areas mapped by Smith (1952) where large volumes of kauri gum were extracted. The spatial expression for the large gum volume areas are unequivocally associated with lowland environments that contain humic or mesic organic soil types (OH and OM), or where there is shallowly undulating topography dispersed over relatively flat ground. We note that there is excellent correspondence between these two soil types and locations where many subfossil kauri excavations have historically taken place since the 1980s.

Northland subfossil kauri appear to also be located more broadly within other soil type units, including some podzols (often associated with the distribution of modern kauri), some ultic soils (associated with ephemerally high water tables) and some brown soils. On closer inspection, it appears that subfossil kauri excavation sites that are located in those particular soil zones occur where slopes are <5 degrees. On further inspection, we consider that the fine-grained distribution of OH and OM soils in small pockets as a minority constituent may have not been mapped in sufficient detail, but could exist. In this type of situation, organic soils could be nested within a larger spatial setting where a different soil type is dominant (as with podzols, acidic brown soils, and perch-gley soils). Clearly, the lack of topographic spatial control for those types of potentially small subfossil kauri deposits arises from limited survey model constraints (elevational points referenced to fixed datum which are now being acquired digitally rather than geodetically). This situation places some fundamental limits on the accuracy of the desktop mapping of Northland subfossil kauri we have undertaken, which may hinder (and contribute to underestimates of) an exhaustive and detailed identification of subtle swales and hollows filled with peat (and possibly buried wood).

Nevertheless, an assessment of some particular soil types (podzol densipan, ZD; ultic-gley, UP; and brown sands, BS) using test cases (**see Figure 6 and Appendix**) where small organic soil pockets may exist within more predominant pedologic units shows that approximately 20% of the surface area within those soil types contains terrain that could hold small deposits of subfossil kauri (undulating topography that is typified by a 'wetland-like' local environ). Our field evidence from former extractions suggests this interpretation is highly likely for places like the Aupouri Peninsula. As such, we invoke a percentage limiter, relative to the total hectare coverage for each of those particular soil types, as a way to estimate how much subfossil kauri those unique substrates may hold.

3.1.3 Geomorphology

Four primary geomorphic associations of subfossil kauri (**see Figures 7-10**) are categorized for Northland: relic fluvial environments (RF), relic coastal barrier foredune ridges (RC), relic aeolian dunes (parabolic dunes and sand waves; RD), and composite relic coastal barrier ridges / aeolian dune complexes (CBD) where former coastal margins are superposed or modified by aeolian landforms that developed at a later time. We also recognise there could be an association with in-filled volcanic craters (maars) and palaeolakes that likely exist in the Hikurangi area, but more validation is required to affirm those settings. We define the physical traits of our selected geomorphic settings in **Table 2**. For the purposes of this mapping exercise, the maar setting is negated because they do not constitute a significant percentage of environments where wood has been found and excavated. We also do not consider a separate, marginal type of deposit that may exist along hillslope fringes brought about by landslides. We recognise that by virtue of having the right preservation potential, all swamps and all wetlands in Northland should be included in the total calculation of terrain where subfossil kauri could be found. That particular aspect of the mapping will be discussed further when the minimum estimated remaining yield of Northland subfossil kauri is calculated.

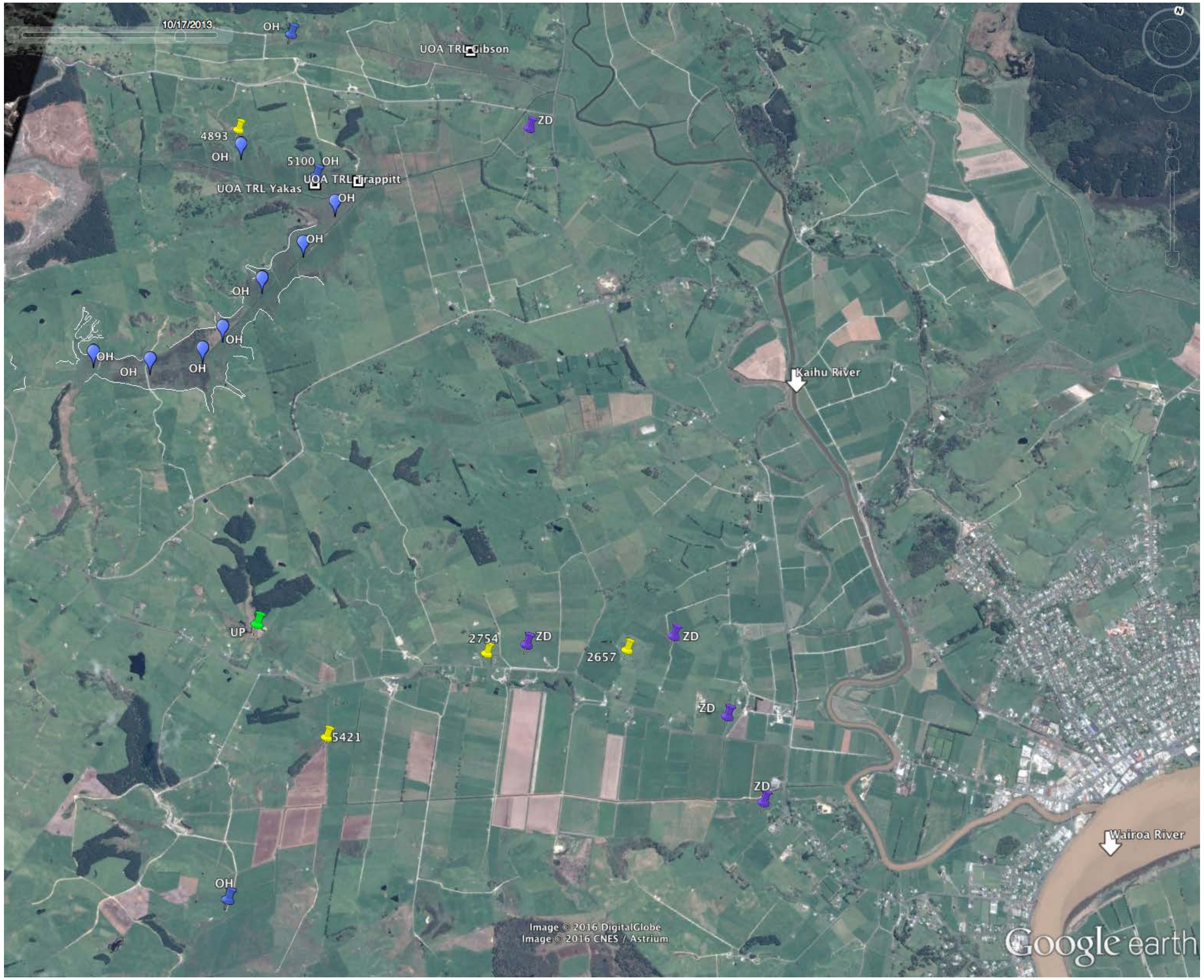

Figure 7. A relic fluvial (RF) subfossil kauri geomorphic settings located near Dargaville, Northland. The white arrow in the lower right corner notes the Wairoa River close to the confluence of the Kaihu River (which flows from north to south). Blue, purple and green pins indicate excavation sites associated with Organic humic (OH), Podzol densipan (ZD) and Ultic perch-gley (UP), respectively. These sites are located in valleys that drain east into the Kaihu.

Figure 8. Relic coastal foredune ridges (RC) subfossil kauri geomorphic setting located at Ruakaka, Northland. Marsden Point refinery is located at the tip of land in the northeast corner of this figure. The contrasting light and dark ridges trending SW-NE represent relic foredune ridges (tan) and interspersed swales now in-filled with organic soil (green). Blue and purple pins indicate subfossil kauri excavation sites associated with Organic mesic (OM) and Podzol pan (ZX) soils, respectively. Information for this region included excavations, RTK GPS surveys, stratigraphic cross sections and ground penetrating radar.

Figure 9. Relic aeolian dune (RD) subfossil kauri geomorphic setting located near Kai Iwi Lakes, Northland. White outlines due west of the lake mark the edges of relic 'boomerang' shaped parabolic dunes/sand waves which can be observed across that area. These sand dunes would have migrated across the landscape, and after they stabilized tens of thousands of years ago, there was a patchwork of sheltered hollows that were then able to be in-filled with both water and/or organic soil, and also colonized by kauri. Green and purple pins indicate subfossil kauri excavation sites associated with Ultic perch-gley (UP) and Podzol Densipan (ZD) soils, respectively. Information for this region included excavations, RTK GPS surveys, stratigraphic cross sections, locations from MPI milling statements and ground penetrating radar.

Figure 10. Composite (CBD) subfossil kauri geomorphic setting located at Sandhills Road, Northland (see Appendix for soil type details for this area, and **Figure 6** for detailed case study mapping). West to east: A vertical red line marks the current coastline backing 90 Mile Beach, followed by a red 'feather edge' line just inland outlining the edge of an aeolian dune complex superposed on the modern coastal barrier (likely Holocene age). Then, the western-most orange 'feather edge' line marks an aeolian dune complex older than the present Holocene sequence and younger than last interglacial epoch. East of that landform and to the west of Sandhills Road (shown as a black line) there are contrasting light and dark N-S trending ridges and interspersed swales that represent relic foredune ridges that are probably last interglacial age. One swale in the centre of the figure next to Sandhills Road contains blue and orange marker pins that indicate where rich subfossil kauri deposits and excavation sites are associated with Organic mesic (OM) and Brown Sand (BS) soils, respectively. East of Sandhills Road to the easternmost orange line marks an old parabolic dune sequence that is of equivalent or older age as the last interglacial relic foredune ridges running parallel to Sandhills Road.

3.1.4 Ecological and land use constraints

For each selected soil type, quantification of the extent of subfossil kauri deposits that are likely to have ecological constraints has been based on:

1. Natural areas mapped by the Department of Conservation, as part of the Protected Natural Area Programme (PNAP), or included in the "Northland wetlands" database held by Northland Regional Council;
2. Extent of lakes and ponds as shown in topographical maps;
3. Indigenous vegetation and or habitats as mapped in LCDB4.1. This database is primarily derived from satellite imagery, supplemented by data from other sources such as wetland layers held by regional councils and topographical maps. For a full explanation of how LCDB4.1 is constructed refer to the appendix. Only parts of LCDB4.1 have been ground-truthed.

The extent of subfossil kauri deposits where ecological constraints are likely is therefore indicative, and field survey of subfossil kauri deposits is required on a case by case basis to determine the resource consent requirements for a specific extraction site.

Conversely, ecological constraints may be present at sites assigned to "ecological constraints unlikely". This is due to the use of satellite imagery to identify indigenous vegetation and habitats, with the associated errors in identification of what occurs at a site, and in the location of polygon boundaries. In addition, whilst the majority of areas assigned to "ecological constraints unlikely" comprise agricultural landscapes, and in particular cropland and grassland, some of these areas will support significant ecological values that are not able to be identified by desk-top analysis. For example, watercourses flowing through subfossil kauri deposits can be of high ecological value regardless of associated vegetation, and may support indigenous freshwater fish species (e.g. *Neochanna diversus*) with "At Risk-Declining" conservation status (Goodman *et al.* 2013).

The intent of this quantification of ecological constraints is to indicate the extent of subfossil kauri deposits that can be extracted henceforth with minimal adverse ecological effects. Preliminary analysis indicates that the majority of subfossil kauri deposits occur within highly modified agricultural landscapes (**Table 2**).

Table 2. Spatial extent of soil types that could hold subfossil kauri in Northland with reference to ecological and land use constraints.

Soil Group			Ecological Constraints		Ecological constraints unlikely		Urban areas and infrastructure		Grand Total
	Geomorphic setting	% of setting	ha	%	ha	%	ha	%	ha
BA	N/A	20	3536.36	17.27	16912.48	82.61	24.40	0.12	20473.24
BS	CBD	20	892.00	13.37	5751.08	86.22	26.90	0.40	6669.98
OH	RF/RB	100	1115.13	20.88	4220.60	79.04	4.37	0.08	5340.10
OM	RF	100	5934.84	28.61	14760.33	71.15	48.83	0.24	20743.99
UP	RD	20	3390.97	21.29	12513.42	78.56	23.88	0.15	15928.26
ZD	RF/RF	20	3879.31	17.64	17852.19	81.20	255.28	1.16	21986.77
ZG	RB	100	208.99	16.35	1069.44	83.65	0.00	0.00	1278.42
ZX	RB	50	2466.01	24.18	7535.79	73.89	196.83	1.93	10198.63
Grand Total			21423.60	20.88	80615.33	78.56	580.48	0.57	102619.40

3.2 Pre-extraction subfossil kauri volume of Northland

3.2.1 Regression equations for pre-extraction subfossil kauri yield

We developed a null hypothesis (**Figure 11**) that there is no significant difference in yield per hectare based on soil type or geomorphic setting for Northland subfossil kauri. Field data from four main subfossil kauri timber operators where known excavation area in hectares and timber yield in cubic meters (and in some cases tonnes converted to an estimated cubic meters) were used to test that hypothesis. Our reasoning for undertaking this test was to increase the objectivity of selecting a statistical or average yield model for estimating the remaining Northland subfossil kauri volume (**Figure 12**).

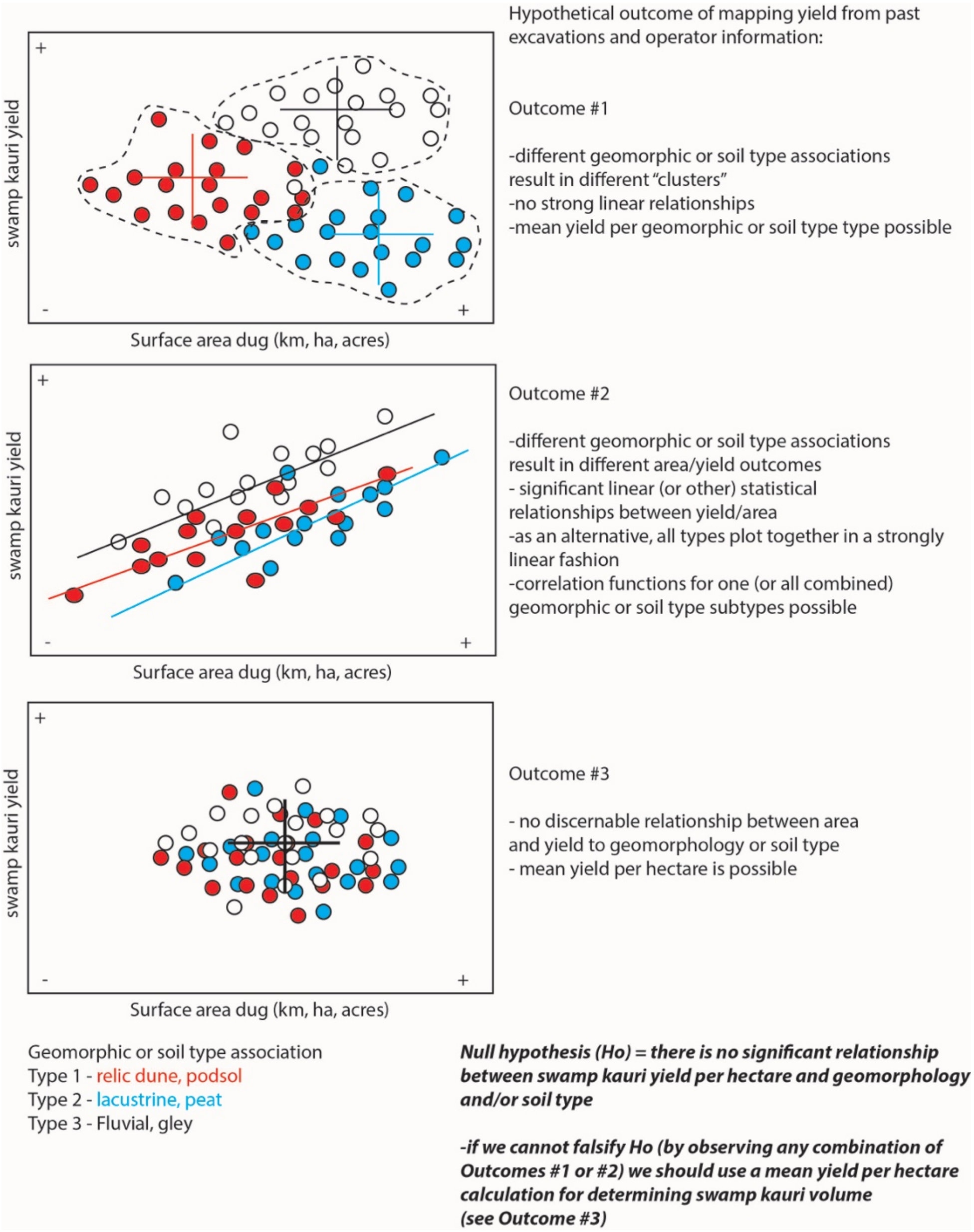

Figure 11. Hypothetical examples of comparing data about yield and hectares dug based on former subfossil kauri extractions.

No significant differences between subfossil kauri yield per hectare and soil type was observed based on the data we gathered from industry operators (i.e. Outcome 3, Figure 11; no significant relationships, not shown). With respect to geomorphic setting, it was equivocal whether discernable differences exist between RF, RC, and RD geomorphic settings and subfossil kauri yield per hectare. While the data and anecdotal accounts hint that there may be differences between these types of settings (**Figure 12**), the limited number of sites categorized as RC and RD prohibit a meaningful separation of those geomorphic sites from RF sites.

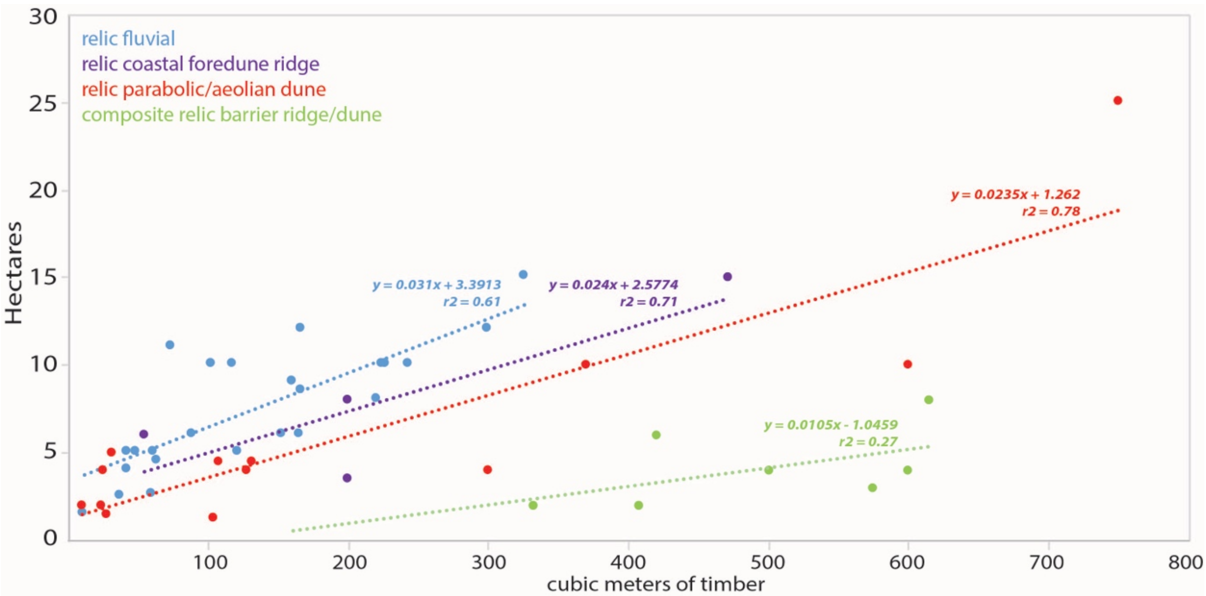

Figure 12. Linear regression models for subfossil kauri yield based on reported cubic meters of timber extracted from four different types of geomorphic settings in Northland, New Zealand. Only the composite relic barrier ridge/dune complex (CBD) geomorphic type can be differentiated from this analysis, suggesting the three other geomorphic types may be concatenated into a single model applied to all three settings.

The relic composite barrier dune complex (CBD) geomorphic setting (**Figure 10**) has anomalously high yields with respect to other geomorphic settings (**Figure 12**) and field data from CBD sites do not overlap any data from the other subfossil kauri geomorphic settings. The higher yield per hectare ratio of CBD relative to RF, RC, and RD geomorphic types relies specifically on a subset of data we gathered for the southern Aupouri Peninsula at Sandhills Road. We have noted that this geomorphic setting occurs in direct association with only brown sand (BS) acidic soils that are distributed along the length of the Aupouri Peninsula. For CBD type of subfossil kauri environments, it appears that the linear-to-sublinear relic foredune ridges that are orientated parallel to 90 Mile Beach (representing former coastline ridges of sand) have been overrun by parabolic dunes that migrated west-to-east onto and across part of the peninsula. The timescales and processes that control the composite geomorphology setting is not discussed here, but what appears to be important is that there are long, deep seams of organic soil hemmed between linear ridges that may have been subsequently protected from natural erosion because they were in more sheltered or protected spots than surrounding areas.

All sites falling into RF, RC, and RD geomorphic categories were concatenated into a single regression (**Figure 13**) that was used to estimate subfossil kauri yield per hectare. It should be noted that while there is a significant linear trend observed in the data, there is also potential to use either a mean or median yield per hectare ratio for calculating subfossil kauri volumes for Northland, which has been suggested by several excavator operators. Because of the association of all soil types (except one) with the concatenated equation, and because GIS analyses allow for rapid acquisition of the number of hectares per soil type, for ease of calculation we utilized the delimited soil type surface area extent to estimate subfossil kauri yields across Northland.

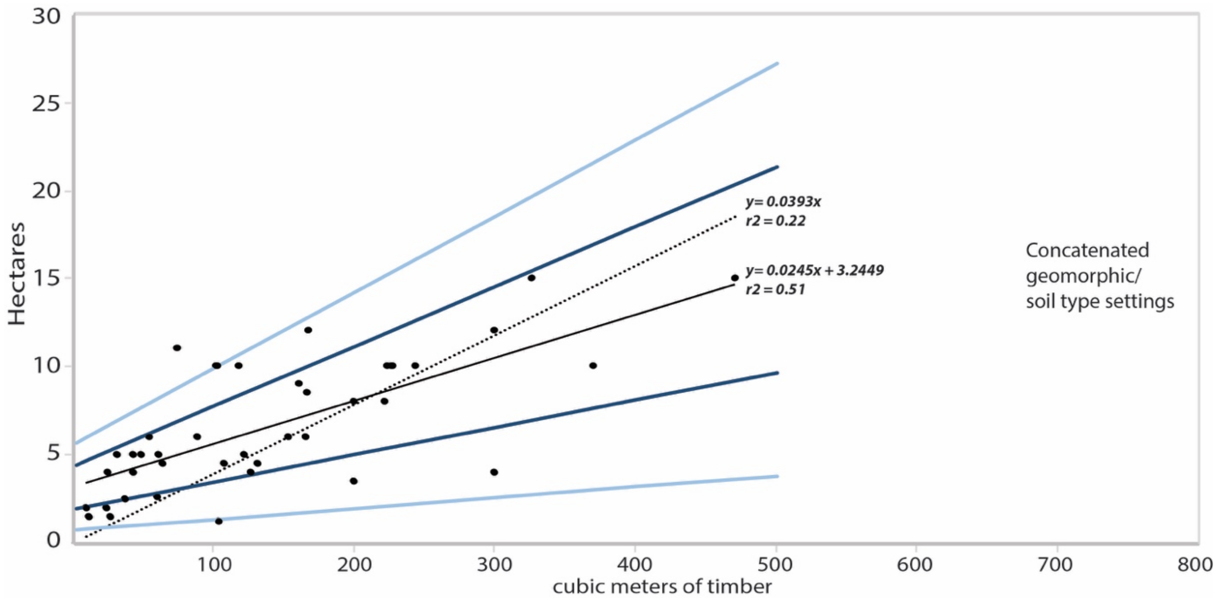

Figure 13. Regression equations using all field data (except from CBD geomorphic settings) that were tested to calculate subfossil kauri yield. Two outlier values have been removed from Figure 12. Dashed regression line is forced through zero, solid black regression is "best fit".

Table 3. Yield of subfossil kauri for Northland (pre-extraction) based on equations in Figures 12 and 13 (using an average site size of 7.18 ha), compared to calculations undertaken using a mean yield of 20m^3 per hectare. ^Equation for composite relic barrier/dune complex in Figure 12 was used for the BS soil type. *Amount used to calculate minimum best estimate. **Amount used prior to extraction for calculation of maximum mean best estimate. $^{\$}$Amount used prior to extraction for calculation of minimum mean best estimate. Spatial distribution maps of these soil types that collectively make up swamp kauri terrain coverage of Northland are found in the Appendix.

Soil Type	Geomorphic setting	% of setting that will yield	Ecological constraints unlikely (ha)	% total terrain without ecological constraints	Yield m3 (regression through origin; Fig. 13)^	Yield m3 (regression best fit; Fig. 13)^	Yield using 20m3/ha ratio
BA	N/A	20	16912.48	82.61	85915.40	75632.61	67649.92
BS	CBD	20	5751.08	86.22	121807.87	121807.87	23004.33
OH	RF/RB	100	4220.59	79.04	107202.99	94372.39	84411.94
OM	RF	100	14760.32	71.15	374912.13	330040.76	295206.57
UP	RD	20	12513.42	78.56	63568.17	55960.01	50053.69
ZD	RF/RF	20	17852.18	81.20	90689.07	79834.95	71408.74
ZG	RB	100	1069.43	83.65	27163.52	23912.45	21388.78
ZX	RB	50	7535.78	73.89	95704.41	84250.02	75357.88
Total			80615.32	78.56			
				With BA	966963.56	865811.07	688481.87
				Without BA	881048.16	790178.46	620831.95
					- 20% after landscape modification		
				With BA	*773570.85*	***692648.86*	*550785.49*
				Without BA	*704838.53*	*$^{\$}$632142.77*	**496665.56*

We applied the regression equations in **Figures 12 and 13** to the total number of hectares that passed our initial ecological delimiting framework and then determined what remaining volume of subfossil kauri could be available for future extraction. Prior to formulating a final estimate of remaining Northland subfossil kauri, we assumed that some of the lowland environments that are associated with subfossil kauri are likely to have been significantly altered (with loss of wood as a result) by human modifications related to pastoral agriculture (i.e. logs and stumps may have simply been ground, cleared and/or burned). As such, we conservatively deducted 20% from our estimated initial starting amount of buried subfossil kauri and categorized that percentage as relating to modification losses prior to any historic subfossil kauri extraction (**Table 3**). We also calculated potential amounts with and without the inclusion of brown acidic (BA) soil types, which still require further validation to determine how much of that type of terrain holds kauri (estimated here conservatively as 20% of total terrain coverage).

The estimates for the initial mean volume of Northland subfossil kauri prior to any excavation (including and excluding BA soil types) ranges from 496,665m^3 to 773,570m^3. We deal with calculations of remaining Northland subfossil kauri volumes based on these figures below.

3.2.2 Post-extraction estimates of remaining Northland subfossil kauri

There are limited data on the amounts of subfossil kauri that have historically been extracted from Northland bogs, however these are required to estimate remaining volumes. As a result, some of these figures have been estimated in order to fully evaluate what the minimum remaining yield could be for Northland. A caveat is that this introduces an unknown level of uncertainty in our calculations, so they should be treated with caution.

We accounted for previously excavated Northland subfossil kauri based on interviews with operators, from milling statements, from MPI export figures and from remotely estimated volumes of large current subfossil kauri stockpiles. We used a multiplier of 20% over the international amount exported (based on MPI data) as a proxy for estimating the amount of subfossil kauri volume that has passed through the national market in recent decades. We also used 1980 as a baseline for the time when the subfossil kauri industry would have begun in earnest, which places a limitation on the historic time period that our previous extraction estimates cover. We based several of our estimated values for past subfossil kauri amounts delivered into the national market on the statement that "on average, a larger proportion is sold into the domestic market or held as inventory for future processing" (MPI, 2016). We then used the maximum and minimum yields from **Table 3** that were calculated using three different methods and subtracted the total minimum estimated subfossil kauri amount removed in historic times to arrive at estimates for remaining Northland subfossil kauri volumes (**Table 4**).

The confidence bounds for the best-fit regression equation in **Figure 13** may also be used along with estimates of historic extraction volumes to gauge the amount of remaining subfossil kauri in Northland. This approach takes into account the variability of subfossil kauri extraction yields from the site data we have access to at present, and the fact that remaining swamp kauri sites are likely to be excavated in a similar way as in past operations (i.e similar site sizes constrained by unique property boundaries). We estimate 632,142m^3 as the pre-extraction, post environmental modification baseline for Northland subfossil kauri (i.e. mean starting volume). However, that amount could be more or less, and the calculation of this volume depends largely on the sites we have extraction data from (which are probably biased towards smaller sites with lower yields; mean site size is just over 7 ha). The 68% confidence bounds associated with that regression equation (16th and 84th percentile) equates to starting pre-extraction/post-modification minimum and maximum volumes of 365,990m^3 and 1,218,969m^3 respectively, inclusive of BA soil types that may contain unknown volumes of subfossil kauri. Using those potential starting volumes, and the estimate of material removed to date (**Table 4**) anywhere from ~110,250 m^3 to ~1,090,141 m^3 of the subfossil kauri resource for Northland may remain today (approximately 30-80% of the original resource). We recognise the upper confidence bound used in our calculations, with an estimate of >1x10^6 m^3 as the initial subfossil kauri resource amount, may be perceived as relatively high and considered skewed by a few rich excavation sites over 10 hectares in size. However, use of restrictive confidence boundaries (68% confidence interval) serves to minimize those outliers in our estimates, and that means potentially 'unbound' (and unrealistic) upper estimates that could be possible for subfossil kauri (on the order of >3x10^6 m^3 using the 95% confidence bound) are excluded in our maximum assessment. In addition, the lower bound we have employed here represents a perspective about the limitations on the remaining subfossil resource that could be used as a "worst case scenario" based on current extraction practices (i.e. specific site sizes that are excavated today will be similar in the future).

Table 4. Estimates of subfossil kauri removed from Northland and mean yield remaining for subfossil wood. Remaining subfossil kauri volume is estimated using pre-extraction total volumes shown in Table 3 (indicated by single and double asterisks) that were calculated using different yield per hectare equations or ratios. Alternative calculations for remaining subfossil kauri in Northland using confidence bounds (shown by # for 16% and ## for 84% confidence intervals, respectively) is discussed in section 3.2.2.

Estimates of extracted/milled timber		m^3	Source
National trade	1980-1999	14400	estimate
	2000-2009	4200	estimate
	2010-2012	1440	estimate
	2013-2015	10800	estimate
International trade	1980-1999	12000	estimate
	2000-2009	3500	estimate
	2010-2012	1200	MPI
	2013-2015	9000	MPI
Kaihu		3300	Nelson Parker
Ancient Kauri Kingdom		20000	Estimate
Milton's Vintage		38400	Milton Randall
Milling statements	1993-2004	12500	MPI-ChCh
Personal use	historic times	25000	estimate
Presently in stock	as of 2016	100000	estimate
		255740	Estimated total resource removed
		Remaining volume:	Comment:
Right: Potential volumes of remaining subfossil kauri in Northland (m^3) yet to be extracted based on a range of pre-extraction volume 'best estimates'.		110250	Conservative minimum estimate; 16% confidence boundary lower limit#
		240925	minimum best estimate *
# *16% confidence bound mean yield, all soil types except BA*		376402	Minimum mean best estimate$
* *20m^3/ha, without BA soil type*			
$ *regression best fit mean yield, all soil types except BA*		436908	Maximum mean best estimate**
** *regression best fit mean yield, all soil types*			
## *84% confidence bound bound mean yield, all soil types*		1090141	Maximum estimate; 84% confidence boundary upper limit##

3.3 Limitations on ability to estimate volumes using this method

3.3.1 Ecological and environmental constraints

Kauri can grow on a wide range of soil types and at altitudes from sea level to about 800 m above sea level (Ecroyd, 1982). Kauri preservation primarily occurs where kauri fall 'in-situ' into substrates that are conducive of preservation (e.g. waterlogged and/or acidic soils). However, kauri preservation can also occur where kauri grow on well-drained soil types but fall into preservation environments (e.g. on hillslopes adjacent to wetlands). In effect, this means that almost any wetland could potentially hold subfossil kauri. Extraction records also show that at some locations, very small wetlands (e.g. less than 1000 m^2) may be rich sources of subfossil kauri. However, while these types of locations could hold preserved wood, they are often protected under the Resource Management Act (RMA) if so ascribed in extant mapping. In addition, as part of site-level surveys via the RMA consenting process (conducted by Northland Regional Council; Forester, personal communication), many unidentified small wetlands would be revealed, and therefore MPI milling statement approval would not be likely as part of existing processes.

Existing wetlands, and former wetlands, are mapped in part by existing GIS layers. Existing wetlands are more likely to be mapped if they are recognised as a natural area with ecological values (e.g. PNAP data) or are large in extent (topographical maps). Some historical wetlands are indicated by the presence of particular soil types (e.g. organic or gley soils); however, soil maps are of low resolution, and rarely include smaller wetland features. In particular, narrow wetland features on valley floors are often omitted from any map layers that include wetland features. There is no fine-scale mapping available of wetland extent (current and historical) for Northland that includes all of the wetlands that may preserve subfossil kauri.

In effect then, wetlands (and soils associated with former wetlands) occur as widespread and common features of the landscapes within which kauri occurs. The extent of these wetlands is underrepresented by existing map layers, particularly for wetlands that have been highly modified by agricultural activities (e.g. drainage and grazing). Further desktop analysis, with ground-truthing, would be required to accurately map the extent of wetlands that may contain subfossil kauri. This secondary analysis would decrease the mapped extent of some subfossil kauri deposits (by limiting a selected soil type to the environments within it which result in preservation) and increase others (e.g. margins of wetlands that fall within the range of kauri, but not within one of the selected subfossil kauri soil types).

3.3.2 Lack of national and international subfossil kauri trade data

The largest source of uncertainty for calculating the remaining volume of Northland subfossil kauri lies in our inability to correctly attribute how much subfossil kauri material has been historically extracted from the ground, in addition to how much has been milled/crafted and sold/distributed on both the domestic and international markets. These are equally important components that dictate how we may determine what amount of the subfossil kauri resource of Northland (and wider northern New Zealand) has been exhausted. As stated by MPI, if someone wishes to extract kauri, but has no intention of milling it, they do not need to apply for a milling statement. However, more detailed information about volumes of wood that are extracted at sites and more precise indications of the total hectares that were dug, in addition to the details about subsurface architecture of subfossil kauri environments, could improve the preliminary calculations produced in this study. Those types of improvements would certainly help in refining the uncertainties about the finite nature of the subfossil kauri resource.

In addition, there is documentation that many stock piles of subfossil kauri currently exist, but some of these can only be scaled remotely to estimate the amount of millable timber in them. Increased understanding of the current stockpiles being held would further reduce the error margin in estimating remaining Northland subfossil kauri volumes. For example we attempted an estimation of stocked subfossil kauri volumes using aerial and oblique photos for three main kauri subfossil timber depots located across Northland. However, the lack of vertical detail about how high subfossil kauri logs were stacked in those storage yards suggests that type of assessment needs to be done by a professional on the ground who is trained at scaling timber.

4 Conclusions

This study has indicated that subfossil kauri exist across a diverse range of geomorphic settings that are underpinned by organic soil types, and other broadly dispersed soil types associated with former kauri forest that contain pockets of organic soils. There are exceptions to those associations, and limitations to identifying subfossil kauri terrains using broadscale GIS mapping. However, field validation from past swamp kauri excavations and subfossil kauri tree ring research suggest good efficacy for using the remote sensing approach and geomorphic/soil type delimiters outlined in this study for indicating the primary extent of swamp kauri terrain across Northland.

Based on the excavation data we have access to at present, anywhere from 30-80% of initial subfossil kauri resources of Northland could have been removed to date (constrained by 68% confidence interval boundaries from empirical evidence). The three best estimate assessments for the remaining Northland subfossil kauri volume (minimum best estimate, minimum mean best estimate and maximum mean best estimate; **Table 4**), each with independent starting baselines for the initial resource amount, suggest 50%-70% of the Northland subfossil kauri resource may remain and could be assessed for future use. However, the estimates of the amount of removed subfossil kauri resource could rise sharply (and amount of remaining source could plummet sharply) if we have underestimated the amounts currently residing in stockpiles or amounts previously excavated (or eliminated during environmental modification) during prehistoric and historic times.

In addition, we have noted that while some areas have been mapped as having no apparent ecological constraints, there are apparent shortcomings to both ecological and soil type mapping using a remote sensing approach. These collective shortcomings suggest the area of land extent that may hold extractable subfossil kauri could be much smaller than what we have indicated, which would further reduce the estimated amount of remaining subfossil kauri in Northland.

Further work to improve the definition of subfossil kauri environments could also provide greater clarity about the subfossil kauri resources of Northland, and in specific cases whether it is feasible or not to extract wood at certain sites. A similar exercise to what is presented in this study could also be applied to Auckland and Waikato, which also have subfossil kauri that compose a significant portion of the national resource. Until a formal assessment is undertaken, it should not be assumed that the same relative percentage of subfossil kauri material remains in regions outside of Northland.

5 Acknowledgements

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MacDonald are thanked for their assistance with archive work at The Kauri Museum. Andrea Hemmins is thanked for assistance at the Dargaville Maritime Museum. Dr Gretel Boswijk is thanked for providing subfossil kauri literature in the form of site reports for the Babylon Coast Region in Dargaville. Petra Pearce, Christian Hyde and John-Mark Woolley at NIWA are thanked for excellent assistance in the archive and field. Roger Bawden is thanked for excellent support for GIS mapping. Chris Turney and Alan Hogg are thanked for discussions on swamp kauri across Northland.

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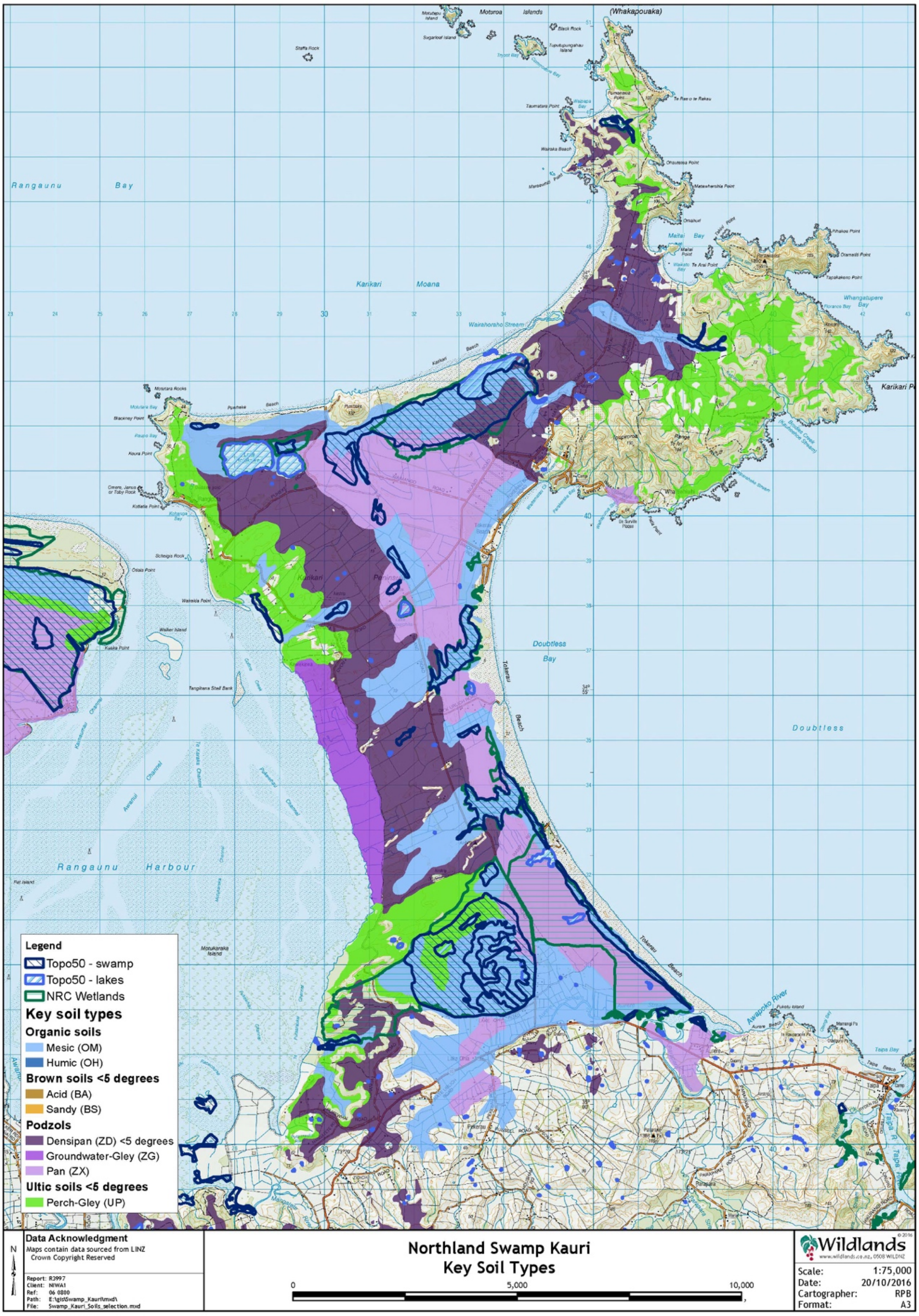
7 Appendix

7.1 Subregion test maps for soils type-subfossil kauri comparisons

Test examples for soil type and geomorphic mapping that cover 13 different subregions (noted as red boxes, and listed from north to south in the lower left of the map in Figure 3) where this study interrogated soil type, geomorphology, and historic swamp kauri excavation details.


Rangaunu Bay
Karikari Moana
Doubtless Bay
Doubtless
Rangaunu Harbour
Legend
Topo50 - swamp
Topo50 - lakes
NRC Wetlands
Key soil types
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Mesic (OM)
Humic (OH)
Brown soils <5 degrees
Acid (BA)
Sandy (BS)
Podzols
Densipan (ZD) <5 degrees
Groundwater-Gley (ZG)
Pan (ZX)
Ultic soils <5 degrees
Perch-Gley (UP)
Data Acknowledgment
Maps contain data sourced from LINZ
Crown Copyright Reserved
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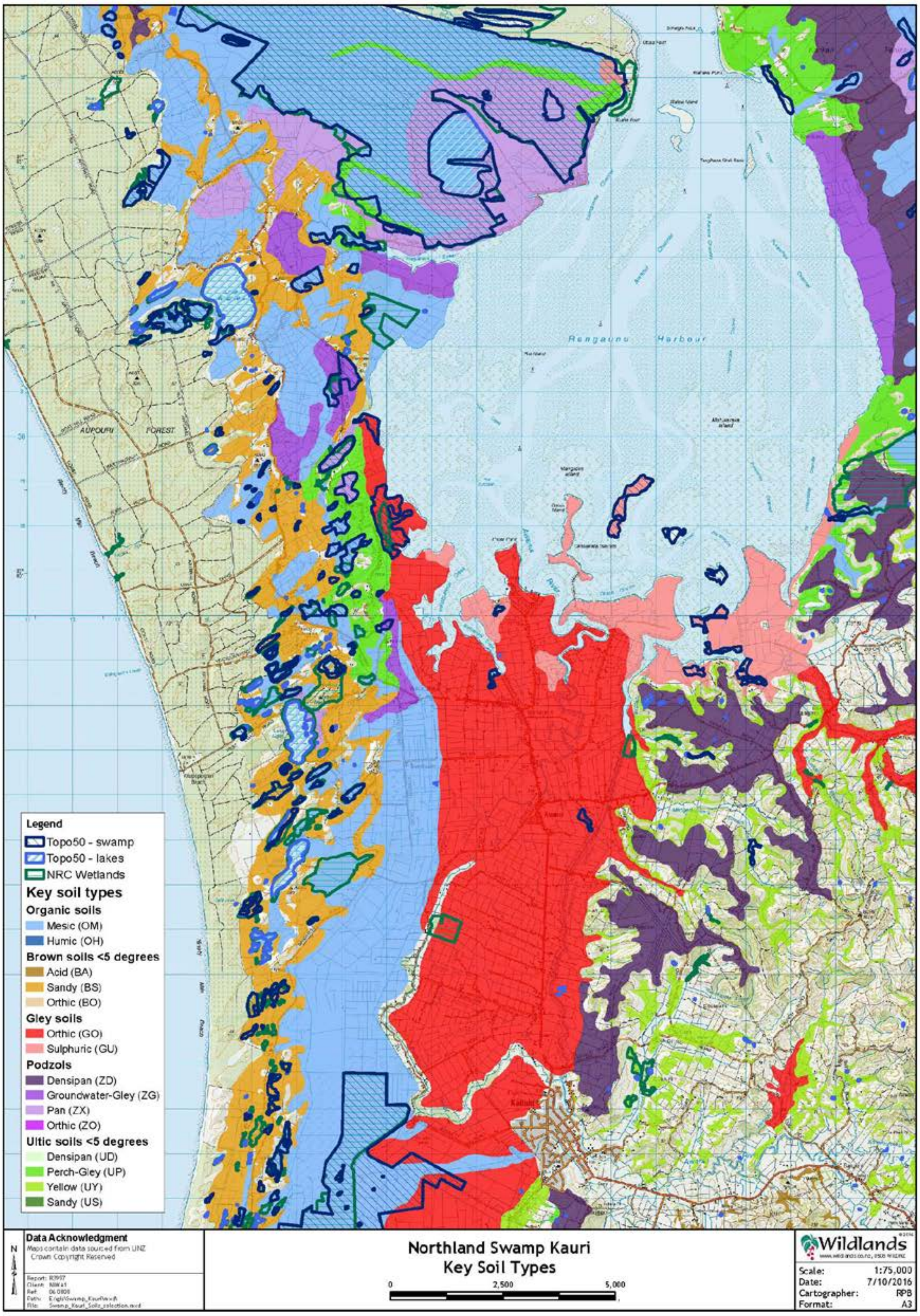
Format: A3


Rangaunu Harbour
AUPOURI FOREST
Legend
Topo50 - swamp
Topo50 - lakes
NRC Wetlands
Key soil types
Organic soils
Mesic (OM)
Humic (OH)
Brown soils <5 degrees
Acid (BA)
Sandy (BS)
Orthic (BO)
Gley soils
Orthic (GO)
Sulphuric (GU)
Podzols
Densipan (ZD)
Groundwater-Gley (ZG)
Pan (ZX)
Orthic (ZO)
Ultic soils <5 degrees
Densipan (UD)
Perch-Gley (UP)
Yellow (UY)
Sandy (US)
N
Data Acknowledgment
Maps contain data sourced from LINZ
Crown Copyright Reserved
Northland Swamp Kauri
Key Soil Types
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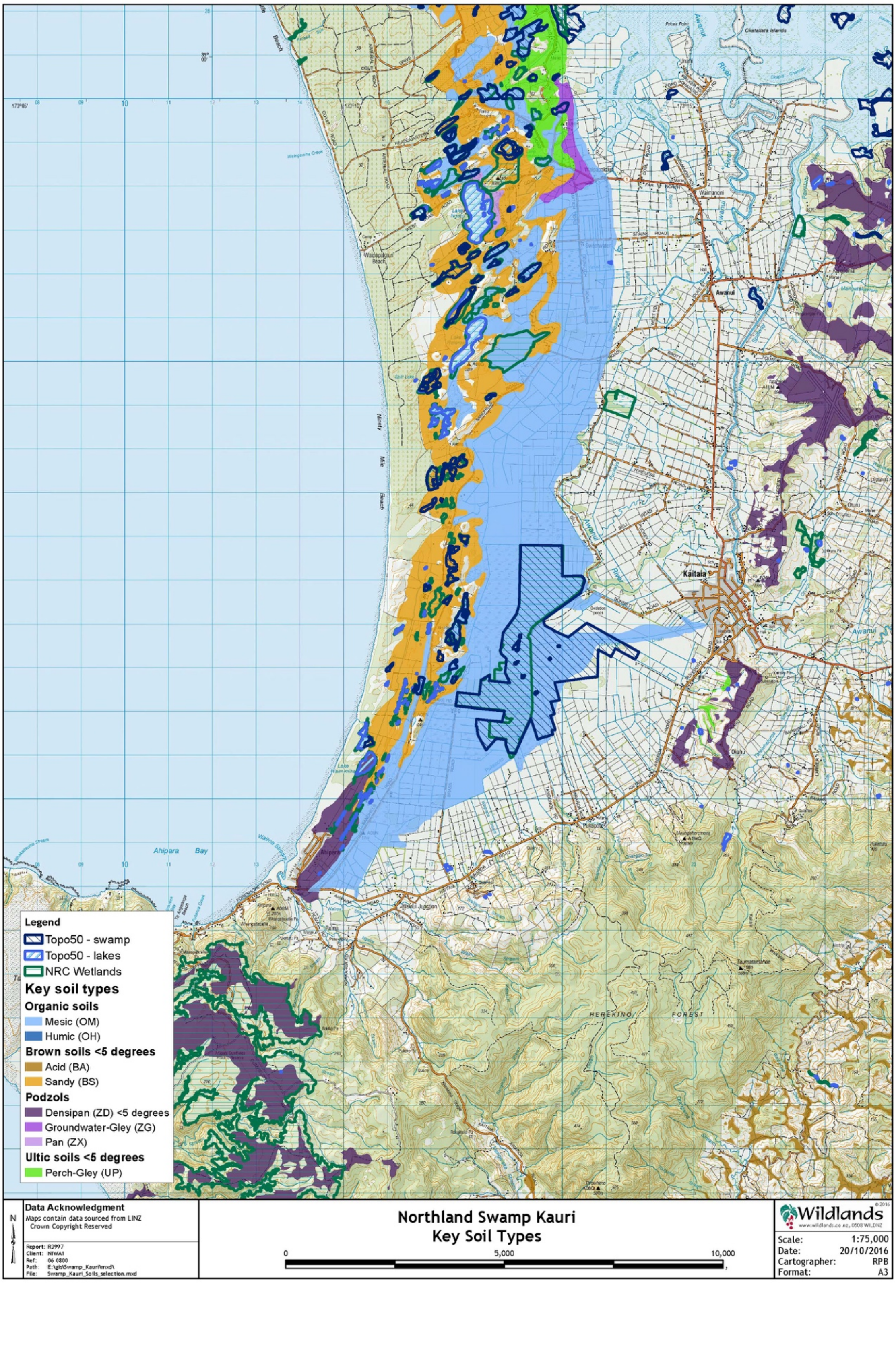
5,000
Wildlands
Scale: 1:75,000
Date: 7/10/2016
Cartographer: RPB
Format: A3


Legend
Topo50 - swamp
Topo50 - lakes
NRC Wetlands
Key soil types
Organic soils
Mesic (OM)
Humic (OH)
Brown soils <5 degrees
Acid (BA)
Sandy (BS)
Podzols
Densipan (ZD) <5 degrees
Groundwater-Gley (ZG)
Pan (ZX)
Ultic soils <5 degrees
Perch-Gley (UP)
Ahipara Bay
Kaitaia
Awanui
N
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Crown Copyright Reserved
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Northland Swamp Kauri
Key Soil Types
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5,000
10,000
© 2016
Wildlands
www.wildlands.co.nz, 0508 WILDNZ
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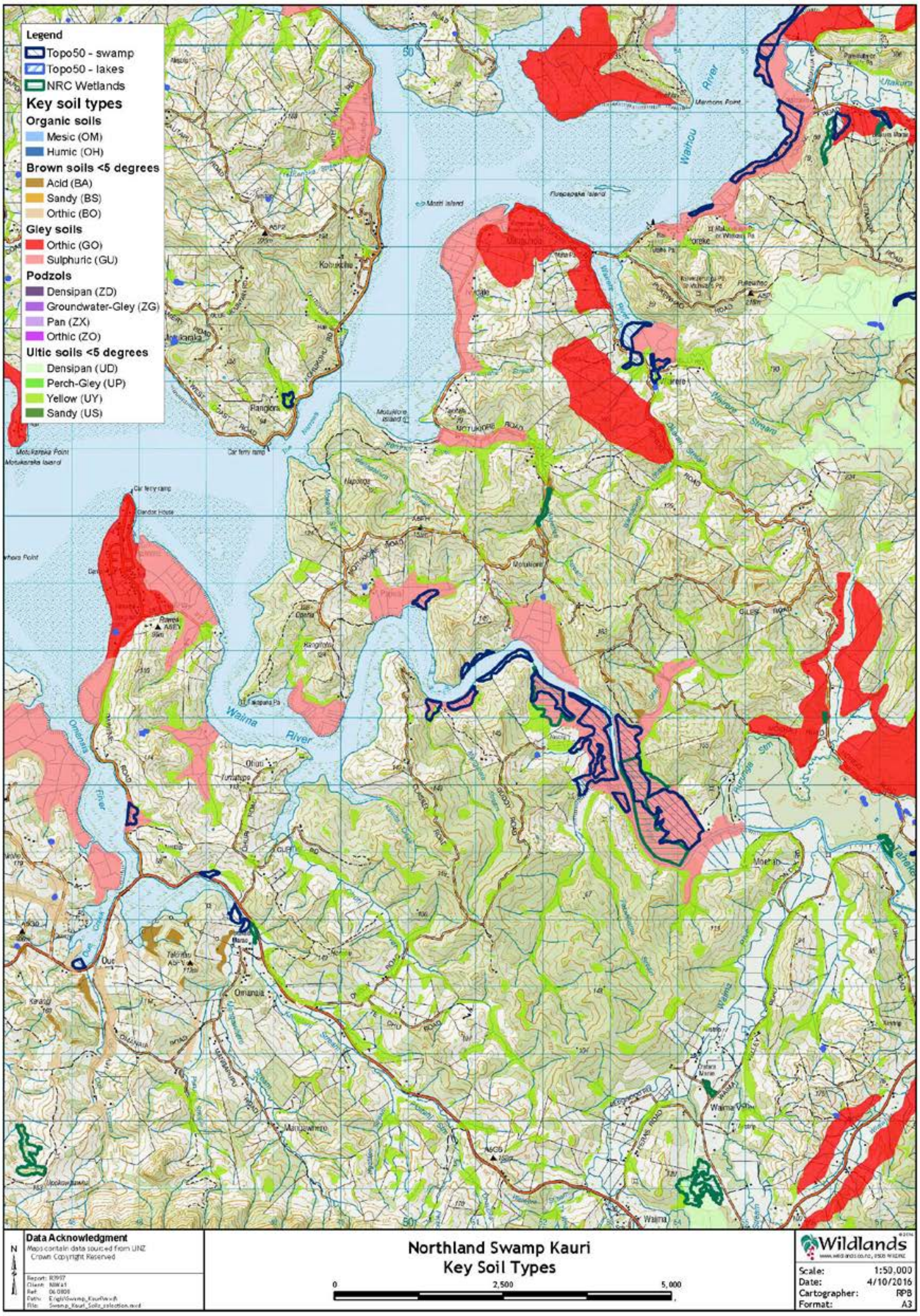

Legend
Topo50 - swamp
Topo50 - lakes
NRC Wetlands
Key soil types
Organic soils
Mesic (OM)
Humic (OH)
Brown soils <5 degrees
Acid (BA)
Sandy (BS)
Orthic (BO)
Gley soils
Orthic (GO)
Sulphuric (GU)
Podzols
Densipan (ZD)
Groundwater-Gley (ZG)
Pan (ZX)
Orthic (ZO)
Ultic soils <5 degrees
Densipan (UD)
Perch-Gley (UP)
Yellow (UY)
Sandy (US)
Waima River
Data Acknowledgment
Maps contain data sourced from LINZ
Crown Copyright Reserved
Northland Swamp Kauri
Key Soil Types
0
2,500
5,000
Wildlands
Scale: 1:50,000
Date: 4/10/2016
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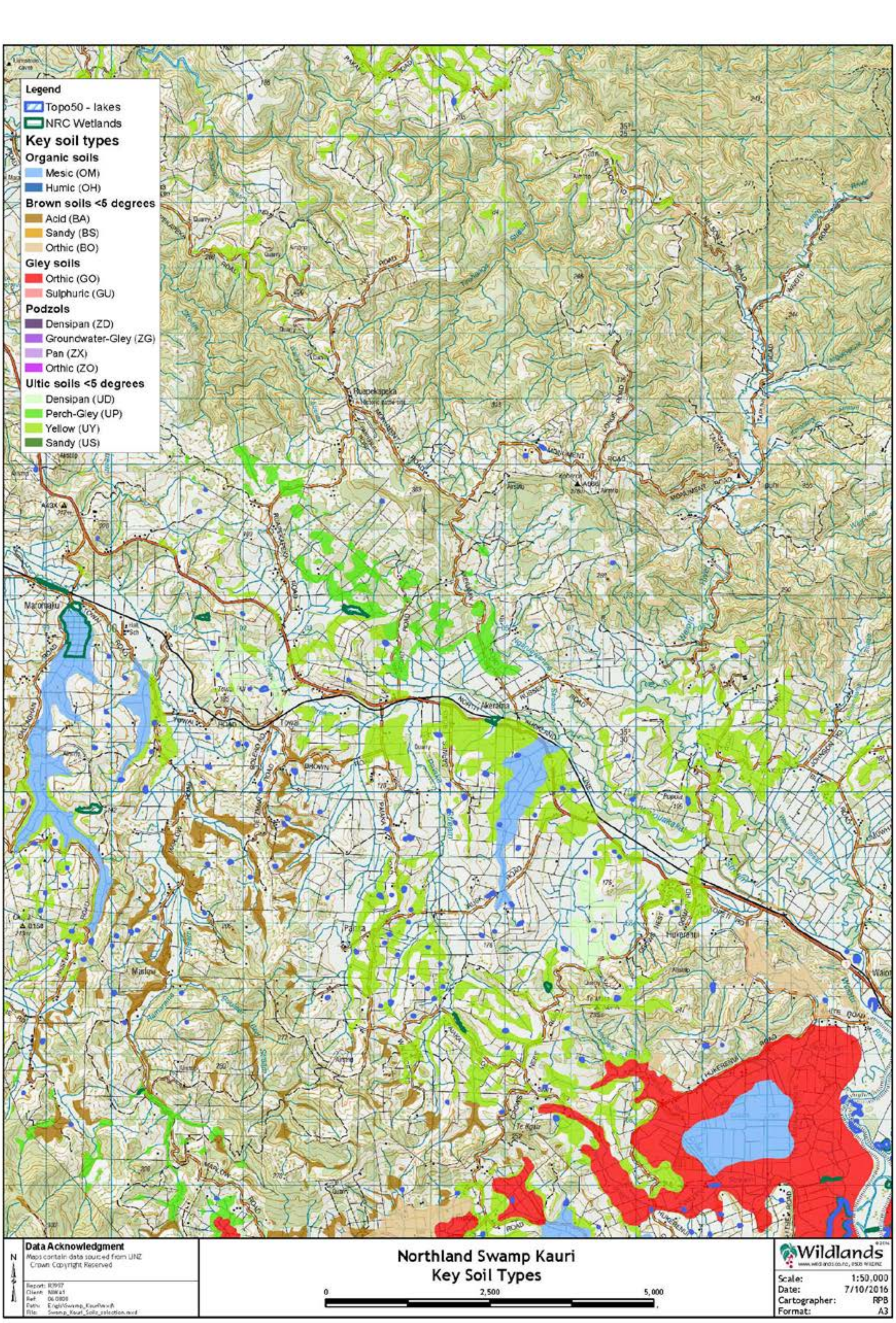
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Topo50 - lakes
NRC Wetlands
Key soil types
Organic soils
Mesic (OM)
Humic (OH)
Brown soils <5 degrees
Acid (BA)
Sandy (BS)
Orthic (BO)
Gley soils
Orthic (GO)
Sulphuric (GU)
Podzols
Densipan (ZD)
Groundwater-Gley (ZG)
Pan (ZX)
Orthic (ZO)
Ultic soils <5 degrees
Densipan (UD)
Perch-Gley (UP)
Yellow (UY)
Sandy (US)
Data Acknowledgment
Maps contain data sourced from LINZ
Crown Copyright Reserved
Northland Swamp Kauri
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Wildlands
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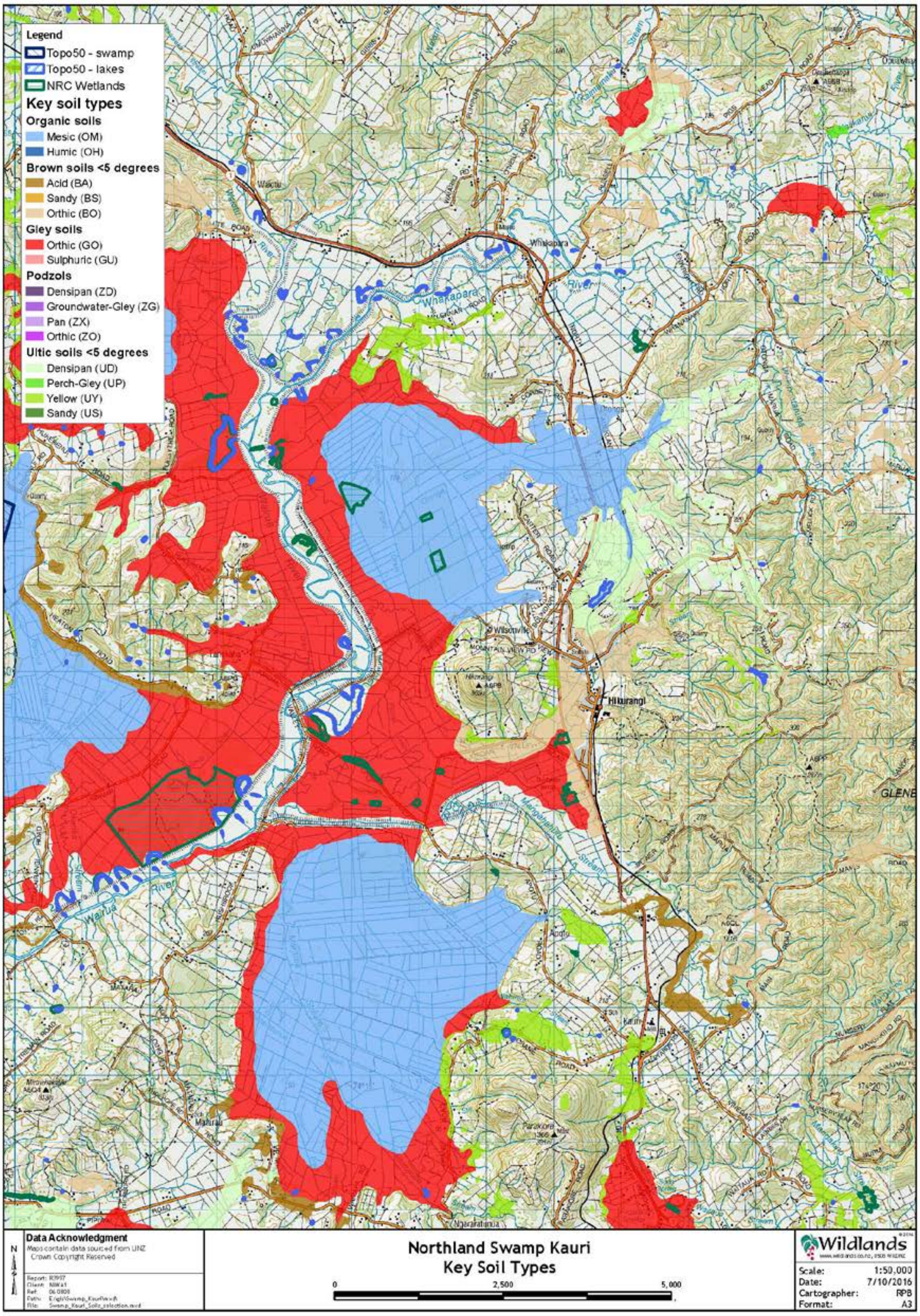
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Topo50 - lakes
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Sulphuric (GU)
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Maps contain data sourced from LINZ
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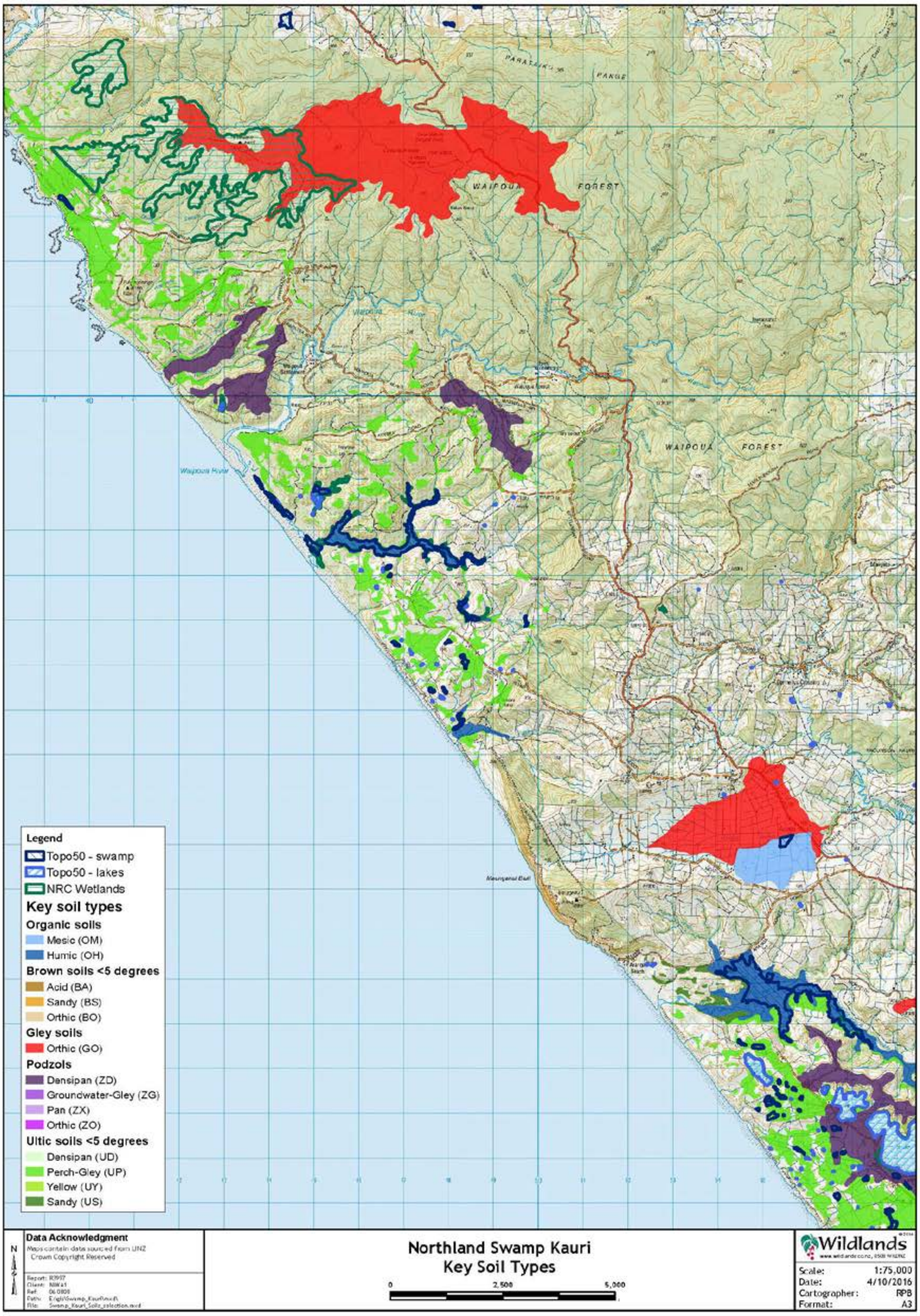
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Podzols
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Groundwater-Gley (ZG)
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Ultic soils <5 degrees
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Perch-Gley (UP)
Yellow (UY)
Sandy (US)
WAIPOUA FOREST
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Maps contain data sourced from LINZ
Crown Copyright Reserved
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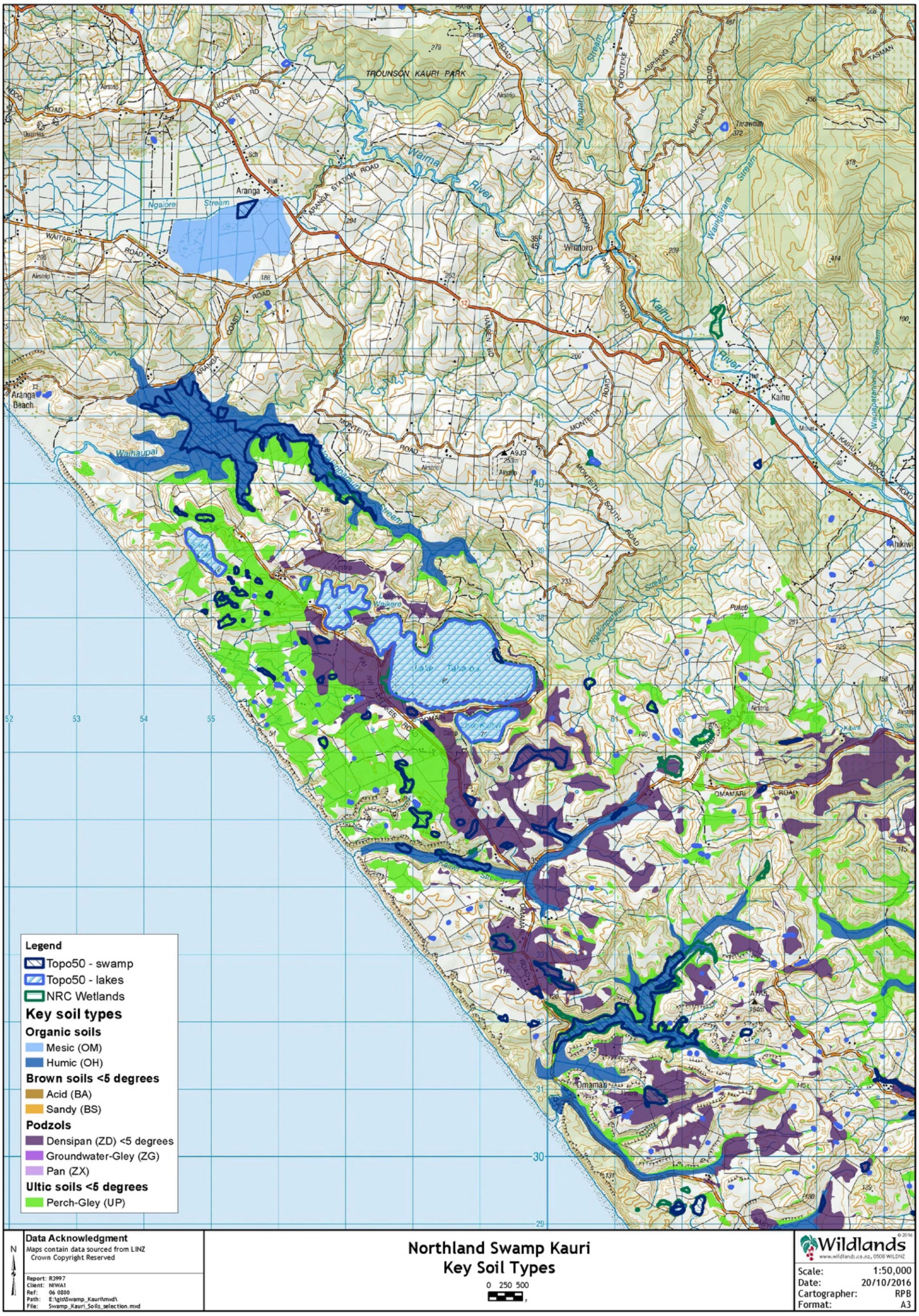
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Topo50 - lakes
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Brown soils <5 degrees
Acid (BA)
Sandy (BS)
Podzols
Densipan (ZD) <5 degrees
Groundwater-Gley (ZG)
Pan (ZX)
Ultic soils <5 degrees
Perch-Gley (UP)
TROUNSON KAURI PARK
Aranga
Aranga Beach
Waihaupai
Whatoro
Kaihu
Omamari
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Maps contain data sourced from LINZ
Crown Copyright Reserved
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www.wildlands.co.nz, 0508 WILDNZ
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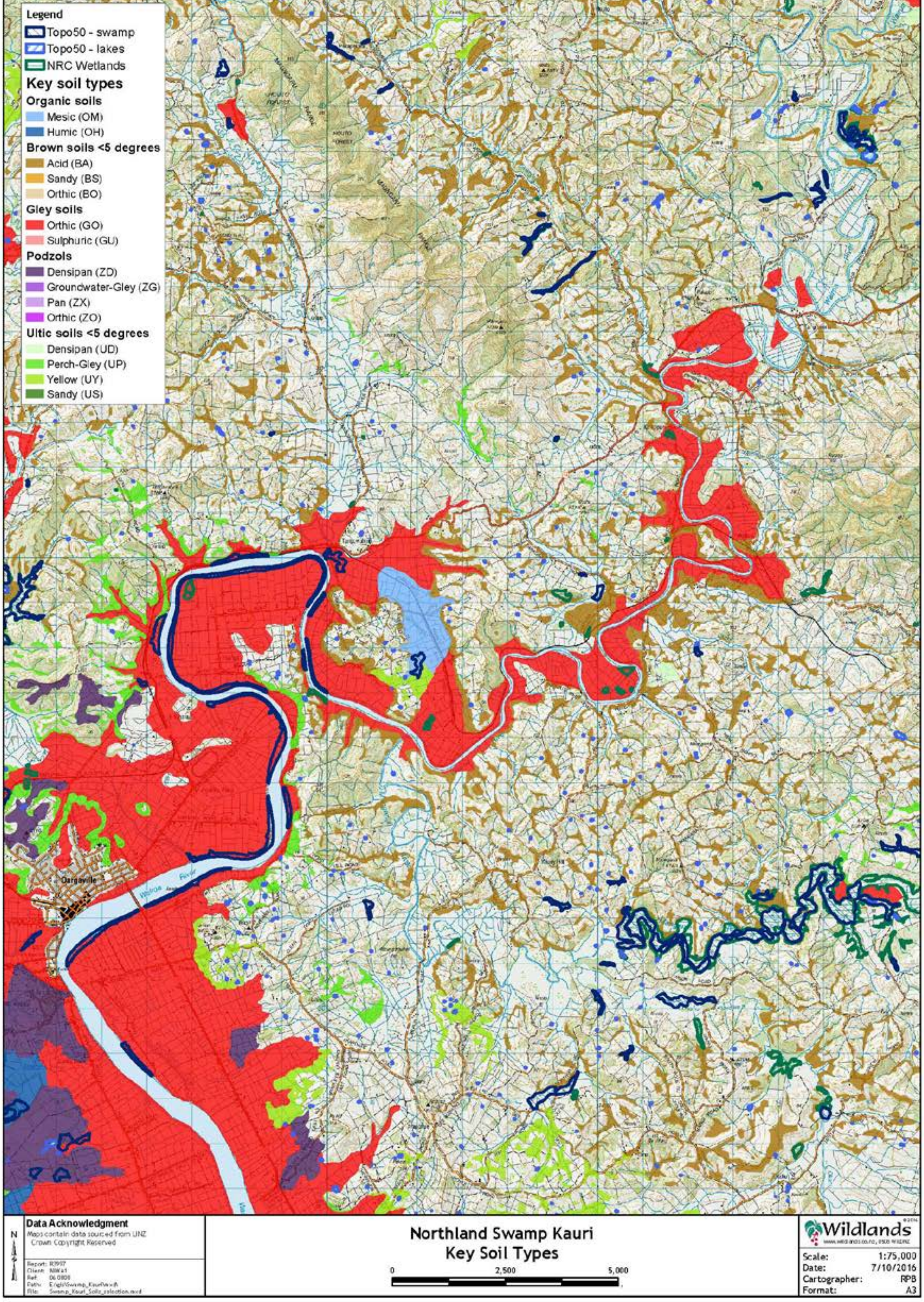
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Topo50 - lakes
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Densipan (ZD)
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Pan (ZX)
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Dargaville
Data Acknowledgment
Maps contain data sourced from LINZ
Crown Copyright Reserved
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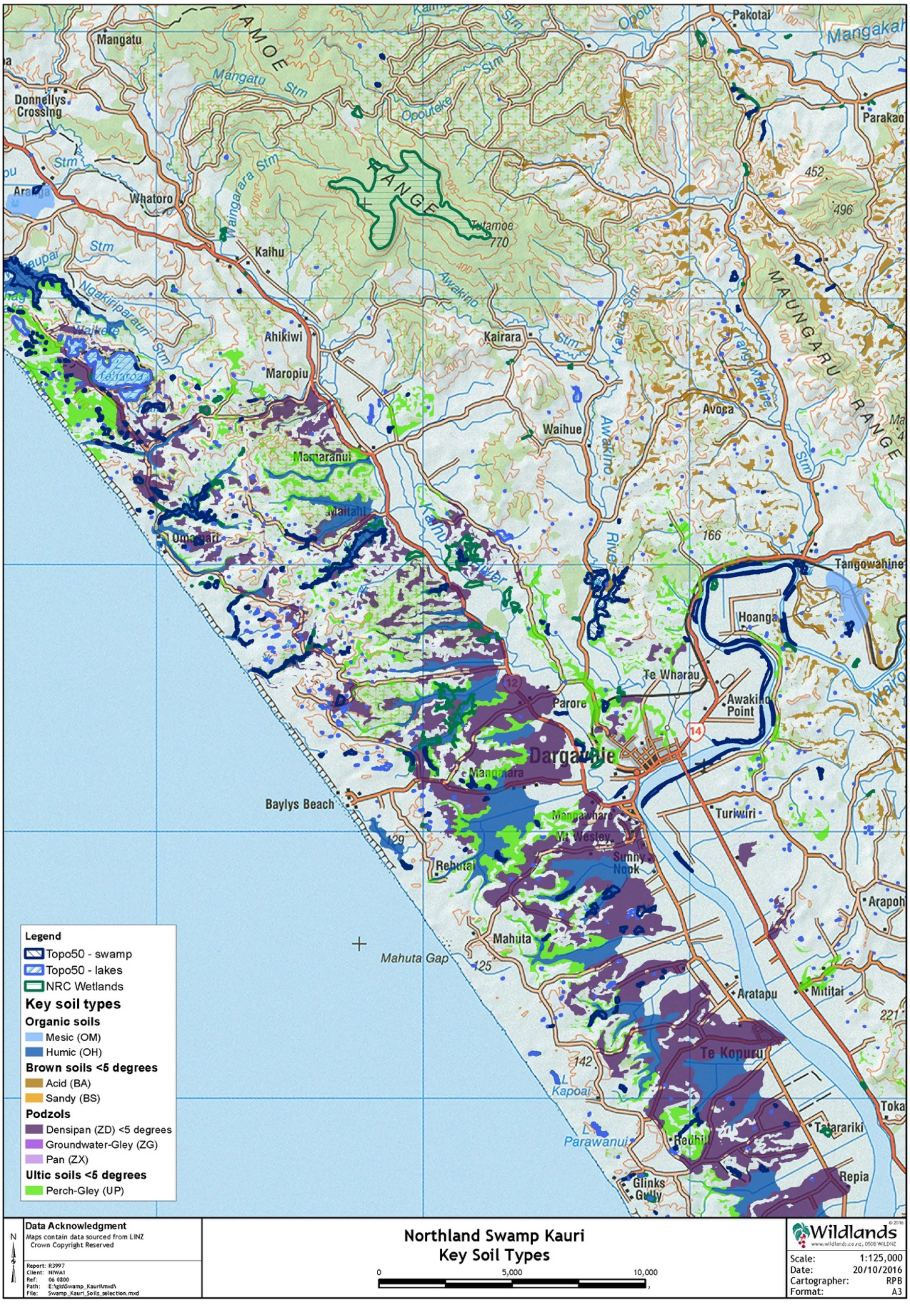
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Groundwater-Gley (ZG)
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Ultic soils <5 degrees
Perch-Gley (UP)
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Maps contain data sourced from LINZ
Crown Copyright Reserved
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www.wildlands.co.nz, 0508 WILDNZ
© 2016
Scale: 1:125,000
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Baylys Beach
Te Kopuru
Mahuta Gap
Kaihu
Aranga
Whatoro
Mangatu
Donnellys Crossing
Ahikiwi
Maropiu
Kairara
Waihue
Avoca
Pakotai
Parakao
Tangowahine
Hoanga
Te Wharau
Awakino Point
Parore
Mangawhare
Mt Wesley
Sunny Nook
Turiwiri
Rehutai
Mahuta
Aratapu
Mititai
Arapohue
Tatarariki
Redhill
Repia
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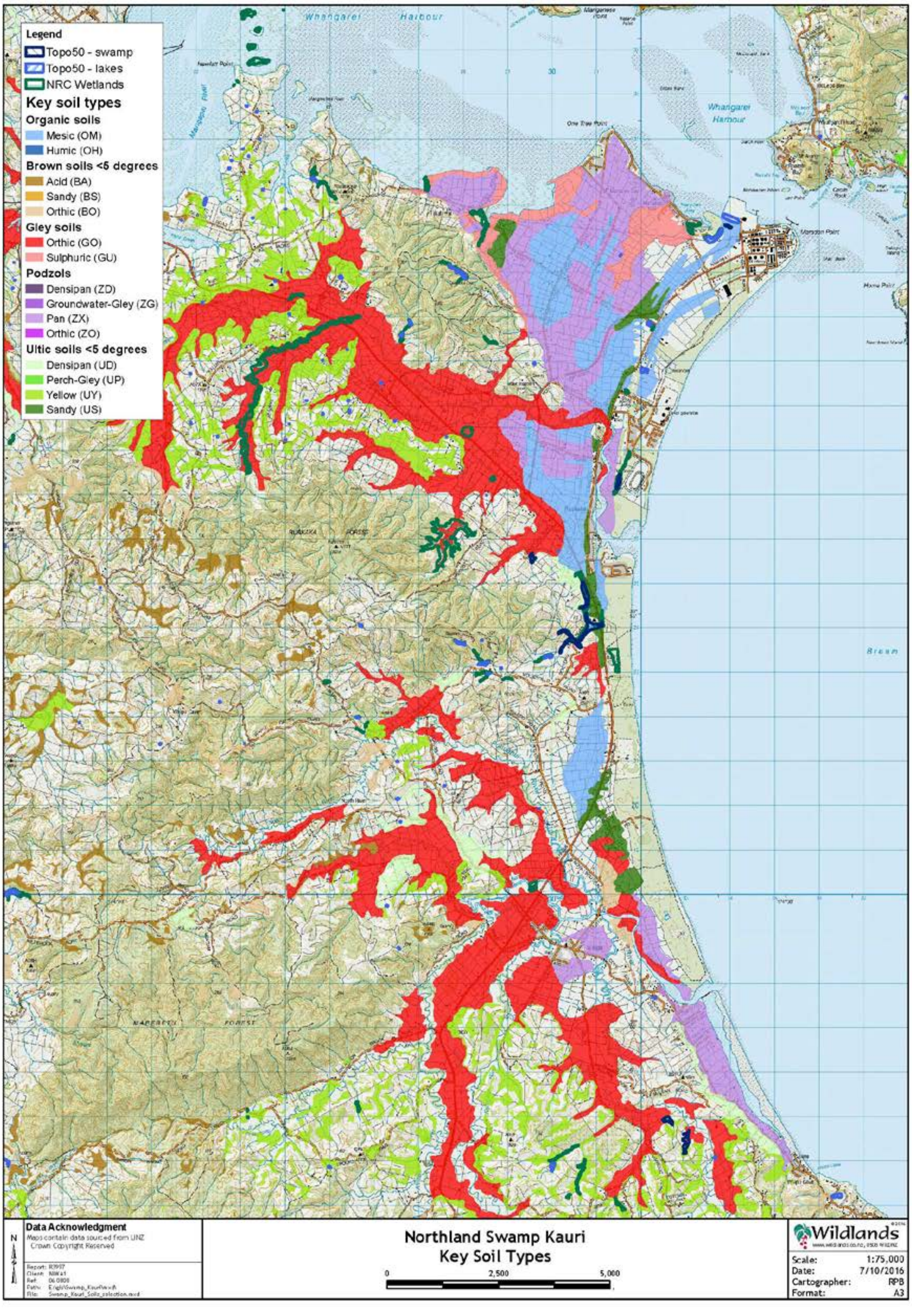
Kapoai
Parawanui
Mamaranui
Omamari
Maitahi
MAUNGARU RANGE
Tutamoe
770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Gley soils
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Sulphuric (GU)
Podzols
Densipan (ZD)
Groundwater-Gley (ZG)
Pan (ZX)
Orthic (ZO)
Ultic soils <5 degrees
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Perch-Gley (UP)
Yellow (UY)
Sandy (US)
Whangarei Harbour
Marsden Point
Data Acknowledgment
Maps contain data sourced from LINZ
Crown Copyright Reserved
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Date: 7/10/2016
Cartographer: RPB
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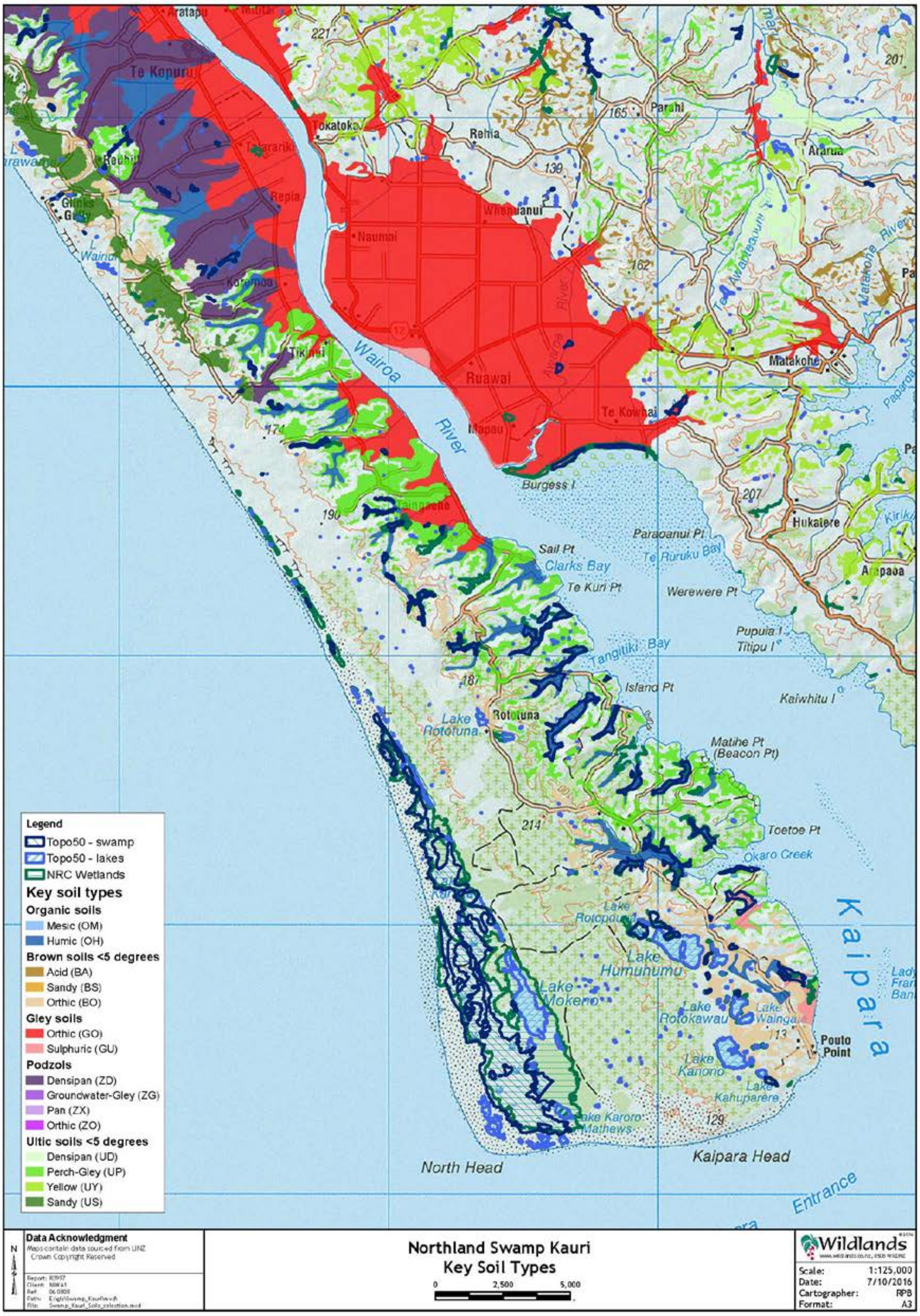
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Topo50 - lakes
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Orthic (BO)
Gley soils
Orthic (GO)
Sulphuric (GU)
Podzols
Densipan (ZD)
Groundwater-Gley (ZG)
Pan (ZX)
Orthic (ZO)
Ultic soils <5 degrees
Densipan (UD)
Perch-Gley (UP)
Yellow (UY)
Sandy (US)
Wairoa River
Ruawai
Te Kopuru
Tokatoka
Naumai
Te Kowhai
Burgess I
Matakohe
Hukatere
Sail Pt
Clarks Bay
Te Kuri Pt
Tangitiki Bay
Island Pt
Lake Rotofuna
Rotoluna
Matihe Pt (Beacon Pt)
Toetoe Pt
Okaro Creek
Lake Humuhumu
Lake Mokeno
Lake Rotokawau
Lake Kanono
Lake Kahuparere
Pouto Point
Kaipara
North Head
Kaipara Head
Entrance
Data Acknowledgment
Maps contain data sourced from LINZ
Crown Copyright Reserved
Northland Swamp Kauri
Key Soil Types
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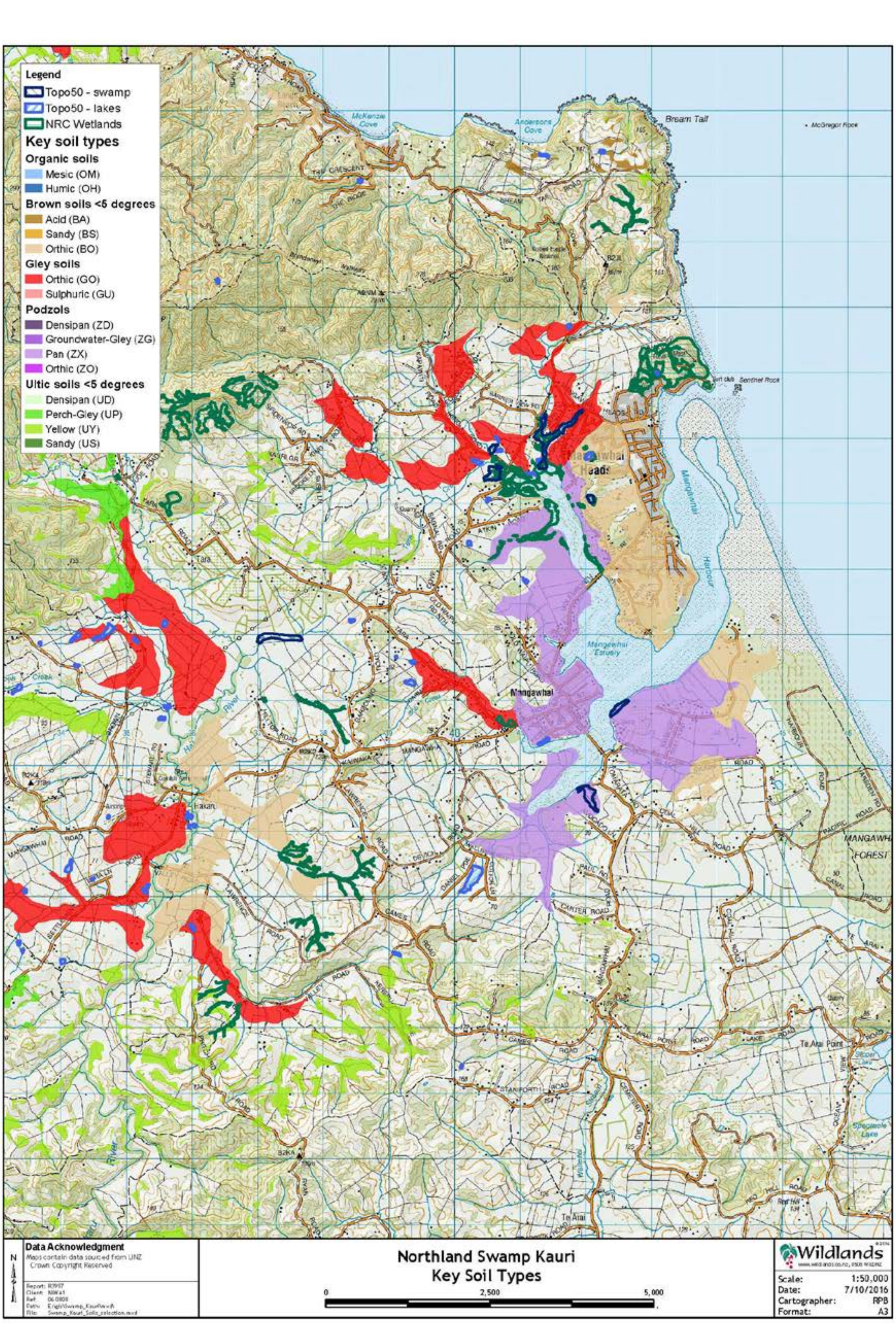
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Topo50 - lakes
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Humic (OH)
Brown soils <5 degrees
Acid (BA)
Sandy (BS)
Orthic (BO)
Gley soils
Orthic (GO)
Sulphuric (GU)
Podzols
Densipan (ZD)
Groundwater-Gley (ZG)
Pan (ZX)
Orthic (ZO)
Ultic soils <5 degrees
Densipan (UD)
Perch-Gley (UP)
Yellow (UY)
Sandy (US)
Bream Tail
Mangawhai
Mangawhai Estuary
Harbour
Te Arai Point
Te Arai
MANGAWHAI FOREST
Data Acknowledgment
Maps contain data sourced from LINZ
Crown Copyright Reserved
Northland Swamp Kauri
Key Soil Types
0
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Date: 7/10/2016
Cartographer: RPB
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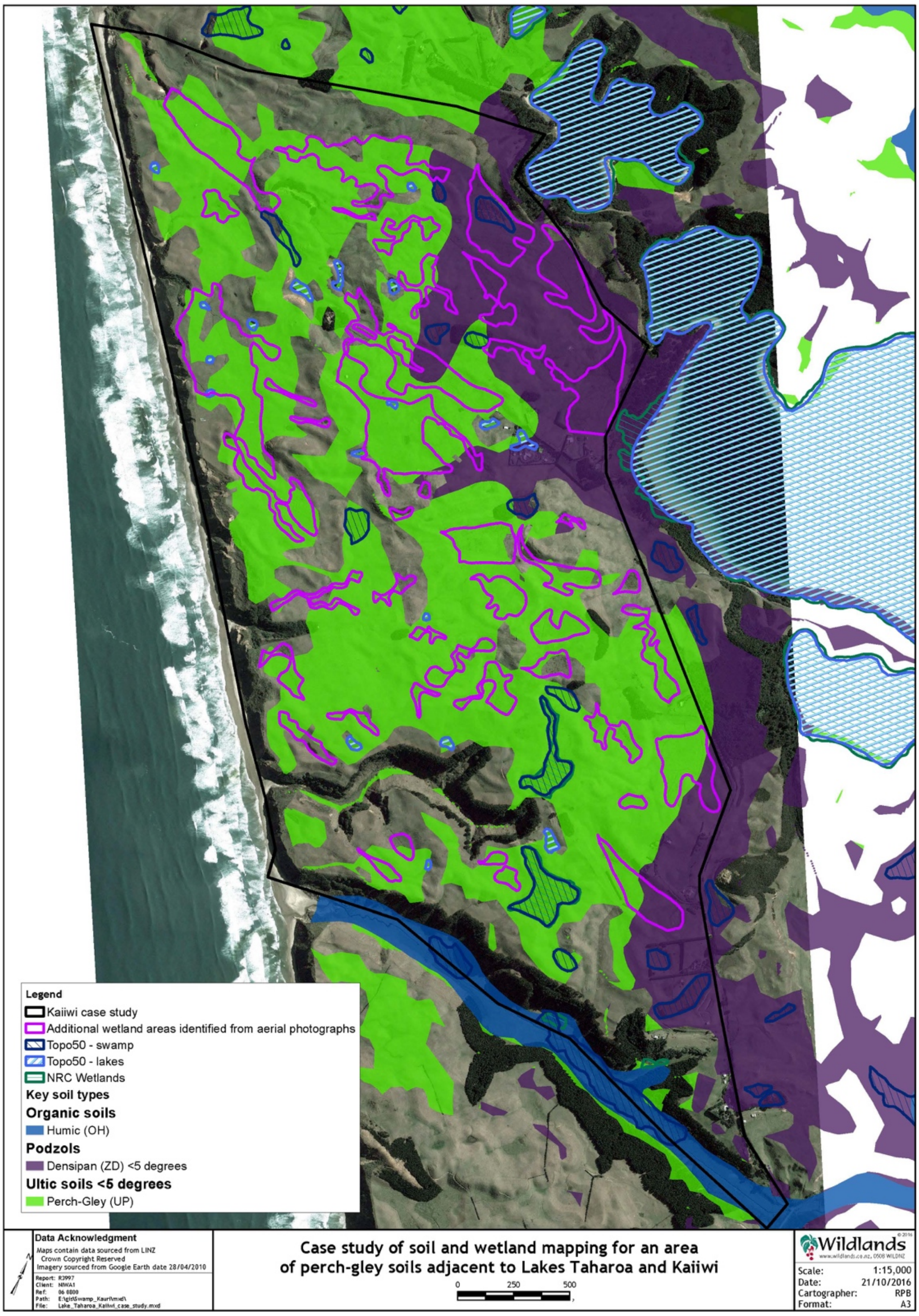
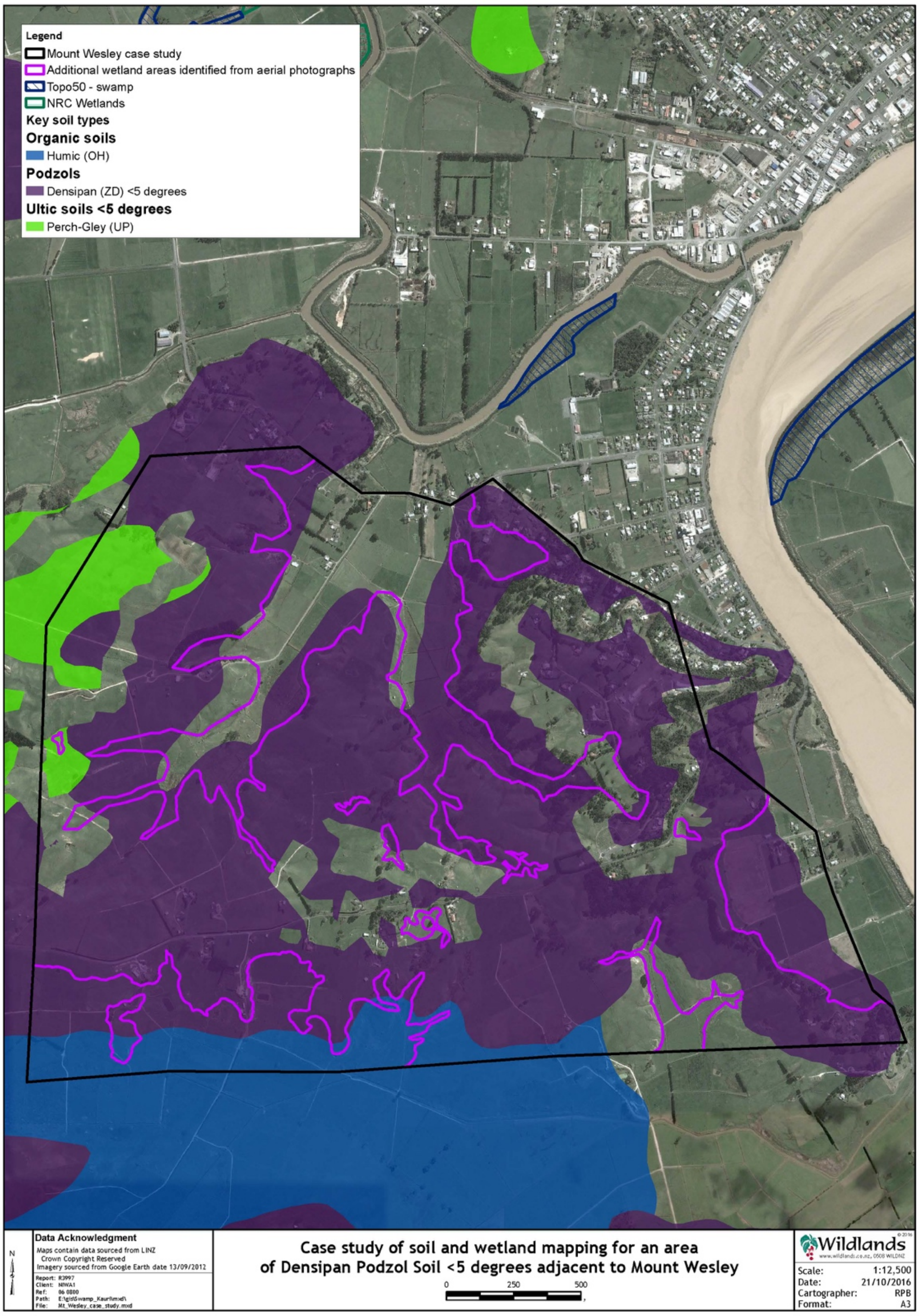
7.2 Case studies of small unidentified wetlands within broader soil types




Legend
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Additional wetland areas identified from aerial photographs
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NRC Wetlands
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Humic (OH)
Podzols
Densipan (ZD) <5 degrees
Ultic soils <5 degrees
Perch-Gley (UP)
N
Data Acknowledgment
Maps contain data sourced from LINZ
Crown Copyright Reserved
Imagery sourced from Google Earth date 13/09/2012
Report: R3997
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Case study of soil and wetland mapping for an area
of Densipan Podzol Soil <5 degrees adjacent to Mount Wesley
0 250 500
Wildlands
www.wildlands.co.nz, 0508 WILDNZ
© 2016
Scale: 1:12,500
Date: 21/10/2016
Cartographer: RPB
Format: A3

7.3 Ecological delimiters

Reference:

Thompson S., Gruner I., and Gapare N. 2003: New Zealand land cover database version 2. Illustrated guide to target classes. Ministry for the Environment, Wellington. (for descriptions)

Land Cover Class Exotic	Description	Area in Northland (ha)	Constraint assessment
Built up	Built-up areas comprise central business districts, suburban dwellings, commercial and industrial areas, and horticultural sites dominated by structures and sealed surfaces (e.g. glasshouses).	7944	Urban areas and infrastructure
Urban Park	Open, typically mown, grassed amenity areas within or associated with built-up areas. The class includes parks with scattered trees, playing fields, cemeteries, airports, golf courses, and river berms. Areas of hard surface, buildings and trees or scrub within urban parkland / open space, that are larger than the MMU are classified separately	1615	Urban areas and infrastructure
Transport Infrastructure	Includes artificial surfaces such as roads, railroads, airport runways and skid sites associated with forest logging, where these features are discernible and exceed the 1 ha MMU.	174	Urban areas and infrastructure
Mines&Dumps	Mines comprise culturally derived bare surfaces such as gravel pits and other open quarries. Dumps are areas used for the surface disposal of solid waste material.	701	Urban areas and infrastructure
Sand&Gravel	Bare surfaces dominated by unconsolidated materials generally finer than coarse gravel (60mm). Typically mapped along sandy seashores and the margins of lagoons and estuaries, lakes and rivers and some areas subject to surficial erosion, soil toxicity and extreme exposure.	14549	Ecological constraints likely
Landslide	Bare surfaces arising from mass-movement erosion generally in mountainlands and steep hill-country.	10	Ecological constraints likely

Gravel&Rock	Bare surfaces dominated by unconsolidated or consolidated materials generally coarser than coarse gravel (60mm). Typically mapped along rocky seashores and rivers, sub-alpine and alpine areas, scree slopes and erosion pavements.	36	Ecological constraints likely
Lake&Pond	Essentially-permanent, open, fresh-water without emerging vegetation including artificial features such as oxidation ponds, amenity, farm and fire ponds and reservoirs as well as natural lakes, ponds and tarns.	4141	Ecological constraints likely
River	Flowing open fresh-water generally more than 30 m wide and without emerging vegetation. It includes artificial features such as canals and channels as well as natural rivers and streams.	2024	Ecological constraints likely
Estuarine	Standing or flowing saline water without emerging vegetation including estuaries, lagoons, and occasionally lakes occurring in saline situations such as inter-dune hollows and coastal depressions.	25349	Ecological constraints likely
Cropland	Land regularly cultivated for the production of cereal, root, and seed crops, hops, vegetables, strawberries and field nurseries, often including intervening grassland, fallow land, and other covers not delineated separately.	3915	Ecological constraints unlikely
Cropland	Land managed for the production of grapes, pip, citrus and stone fruit, nuts, olives, berries, kiwifruit, and other perennial crops. Cultivation for crop renewal is infrequent and irregular but is sometimes practiced for weed control.	5366	Ecological constraints unlikely
Cropland	Exotic sward grassland of good pastoral quality and vigour reflecting relatively high soil fertility and intensive grazing management. Clover species, ryegrass and cocksfoot dominate with lucerne and plantain locally important, but also including	585021	Ecological constraints unlikely

	lower-producing grasses exhibiting vigour in areas of good soil moisture and fertility.		
Low producing grassland*	Exotic sward grassland and indigenous short tussock grassland of poor pastoral quality reflecting lower soil fertility and extensive grazing management or non-agricultural use. Browntop, sweet vernal, danthonia, fescue, and Yorkshire fog dominate, with indigenous short tussocks locally.	19517	Ecological constraints unlikely
Depleted grassland	Areas of very low herbaceous vegetation with exotic grassland/herbfield character and often prominent bare ground degraded by over-grazing, fire, rabbits and weed invasion.	7	Ecological constraints unlikely
Fernland	This class includes areas of dominant bracken fern (*Pteridium esculentum*), umbrella fern (*Gleichenia* sp.), and ring fern (*Paesia scaberula*). The ferns are often associated with shrubs, such as mānuka (*Leptospermum scoparium* agg.) or kānuka (*Kunzea* spp.), as the community represents a successional vegetation type on previously forested land.	160	Ecological constraints likely
Gorse&broom	Commonly associated with low producing exotic grassland on hill country throughout New Zealand, where low site fertility, extensive grazing and fire facilitate the plants' spread and establishment. Gorse (*Ulex europaeus*) and/or broom (*Cytisus scoparius*) will reach heights of 1 - 2m, and are typical of land subject to frequent physical disturbance such as aggrading river beds, road cuttings, and firebreaks.	6824	Ecological constraints unlikely
Mixed exotic shrubland	Communities of introduced shrubs and climbers such as boxthorn, hawthorn, elderberry, blackberry, sweet brier, buddleia, and old man's beard.	2548	Ecological constraints unlikely

Forest-harvested	Predominantly bare ground arising from the harvesting of exotic forest or, less commonly, the clearing of indigenous forest. Replanting of exotic forest (or conversion to a new land use) is not evident and nor is the future use of land cleared of indigenous forest.	11612	Ecological constraints unlikely
Deciduous hardwood	Exotic deciduous woodlands, predominantly of willows or poplars but also of oak, elm, ash or other species. Commonly alongside inland water (or as part of wetlands), or as erosion-control, shelter and amenity plantings.	2294	Ecological constraints unlikely
Exotic forest	Planted or naturalised exotic forest predominantly of radiata pine but including other species such as Douglas fir, cypress, larch, acacia and eucalypts. Production forestry is the main land use in this class with minor areas devoted to massmovement erosion-control and other areas of naturalised (wildling) establishment.	175394	Ecological constraints unlikely
Herbaceous freshwater	Herbaceous wetland communities occurring in freshwater habitats where the water table is above or just below the substrate surface for most of the year. The class includes rush, sedge, restiad, and sphagnum communities and other wetland species, but not flax nor willows which are mapped as flaxland and deciduous hardwoods respectively.	9246	Ecological constraints likely
Herbaceous saline	Areas dominated by herbaceous aquatic vegetation as a component of estuarine or coastal wetlands, i.e. the plants emerge over saline or brackish water or grow in saltwater saturated soils. Most areas of herbaceous saline vegetation are subject to tidal changes in water level	3102	Ecological constraints likely
Flaxland	Areas dominated by lowland flax (*Phormium tenax*). Sites are	147	Ecological constraints likely

	usually moist and often represent parts of wetland systems.		
Mānuka& kānuka	Indigenous shrubland typically found as early successional scrub type on previously forested land with a history of burning to control scrub reversion. Mānuka or kānuka can be dominant, but they also occur in mixtures, with kānuka more common in the North Island.	124077	Ecological constraints likely
Broadleaved indigenous hardwoods	Lowland scrub communities dominated by indigenous mixed broadleaved shrubs such as wineberry, mahoe, five-finger, Pittosporum spp, fuchsia, tutu, titoki and tree ferns. This class is usually indicative of advanced succession toward indigenous forest.	20970	Ecological constraints likely
Grey scrub	Scrub and shrubland comprising small-leaved, often divaricating shrubs such as *Coprosma* spp, *Muehlenbeckia* spp., *Cassinia* spp., and *Parsonsia* spp. These, from a distance, often have a grey appearance.	577	Ecological constraints likely
Indigenous forest	Tall forest dominated by indigenous conifer, broadleaved or beech species.	249077	Ecological constraints likely
Mangrove	Shrubs or small trees of the New Zealand mangrove (*Avicennia marina* subsp. *australascia*) growing in harbours, estuaries, tidal creeks and rivers north of Kawhia on the west coast and Ohiwa on the east coast.	15544	Ecological constraints likely
Grand total		1291940	

7.4 PNAP Criteria

The natural areas described in this report meet at least one of the following criteria:

- They are of predominantly indigenous character, by virtue of physical dominance, species composition.
- They provide habitat for a threatened indigenous plant or animal species.
- They include an indigenous vegetation community or ecological unit, in any condition, that is nationally uncommon or much reduced from its former extent.

The conservation value of these areas was then assessed using a two-level classification of habitat significance based on the PNAP ecological criteria of representativeness, rarity and special features, diversity and pattern, habitat structure and characteristics important for the maintenance of ecosystems (buffer, linkage or corridor, size, and shape).

The highest value areas (Level 1) are those which contain significant vegetation and/or significant habitats of indigenous fauna in terms of the RMA and are defined by the presence of one or more of the following ecological characteristics:

1. Contain or is regularly used by critical, endangered, vulnerable, declining, recovering or naturally uncommon taxa (i.e. species and subspecies), or taxa of indeterminate threatened status nationally.
2. Contain or is regularly used by indigenous or endemic taxa that are threatened, rare, or of local occurrence in Northland or in the Ecological District.
3. Contain the best representative examples in the Ecological District of a particular ecological unit or combination of ecological units.
4. Have high diversity of taxa or habitat types for the Ecological District.
5. Form ecological buffers, linkages or corridors to other areas of significant vegetation or significant habitats of indigenous fauna.
6. Contain habitat types that are rare or threatened in the Ecological District or regionally or nationally.
7. Support good populations of taxa which are endemic to Northland or Northland-Auckland.
8. Are important for indigenous or endemic migratory taxa.

9. Cover a large geographic area relative to other similar habitat types within the Ecological District.

Level 2 sites are natural areas supporting populations of indigenous flora and fauna not identified as meeting the criteria for Level 1. They are sites which:

- contain common indigenous species.
- may be small and isolated from other habitats.
- may contain a high proportion of pest species.
- may be structurally modified e.g. forest understorey grazed.
- have not been surveyed sufficiently to determine whether they meet the criteria for Level 1 sites.

7.5 Soil type descriptions

References:

Landcare Research 2016: Soils portal https://soils.landcareresearch.co.nz/describing-soils/nzsc/soil-order/organic-soils/ (Accessed 5 October 2016).

Soil Order	Soil type	Description
Organic Soils		Organic soils are formed in the partly decomposed remains of wetland plants (peat) or forest litter. Some mineral material may be present but the soil is dominated by organic matter.
	Mesic Organic (OM)	Mesic organic soils are are formed in the partly decomposed remains of wetland plants (peat) or forest litter. Some mineral material may be present but the soil is dominated by organic matter.
	Humic Organic (OH)	Humic organic soils are comprised of strongly decomposed or amorphous peat and occur in wetlands or under forests that produce acid litter in areas of high precipitation.
Brown Soils <5 degrees		Brown soils have a brown or yellow-brown subsoil below a dark grey-brown topsoil and occur in places where summer drought is uncommon and which are not waterlogged in winter and cover c.43% of New Zealand.
	Acid (BA)	Acid brown soils are strongly or extremely acidic .
	Sandy (BS)	Sandy brown soils are dominated by mainly coastal sand or loamy sand .
Podzols		Podzol soils are strongly acid soils that usually have a bleached horizon immediately beneath the topsoil. This horizon is the source of aluminium and iron oxides that have accumulated, in association with organic matter, in an underlying dark or reddish coloured horizon.
	Densipan (ZD)	Densipan Podzol is a high density, pale coloured, pan just beneath the topsoil.
	Groundwater-Gley (ZG)	Groundwater-Gley Podzols are characterised by periodic wetness caused by groundwater table.
	Pan (ZX)	Pan Podzols are cemented pans within the B horizon.
Ultic soils <5 degrees		Ultic Soils are strongly weathered soils that have a well-structured, clay enriched subsoil horizon. An E horizon, which is relatively depleted in clay, frequently occurs immediately beneath the topsoil. The soils are acid and strongly leached, with generally low levels of calcium and other basic cations. They occur in clay or sandy clay material derived by strong alteration of quartz-rich rocks over long periods of time.
	Perch-Gley(UP)	Perch-Gley Ultic soils experience periodic wetness caused by a perched water table.

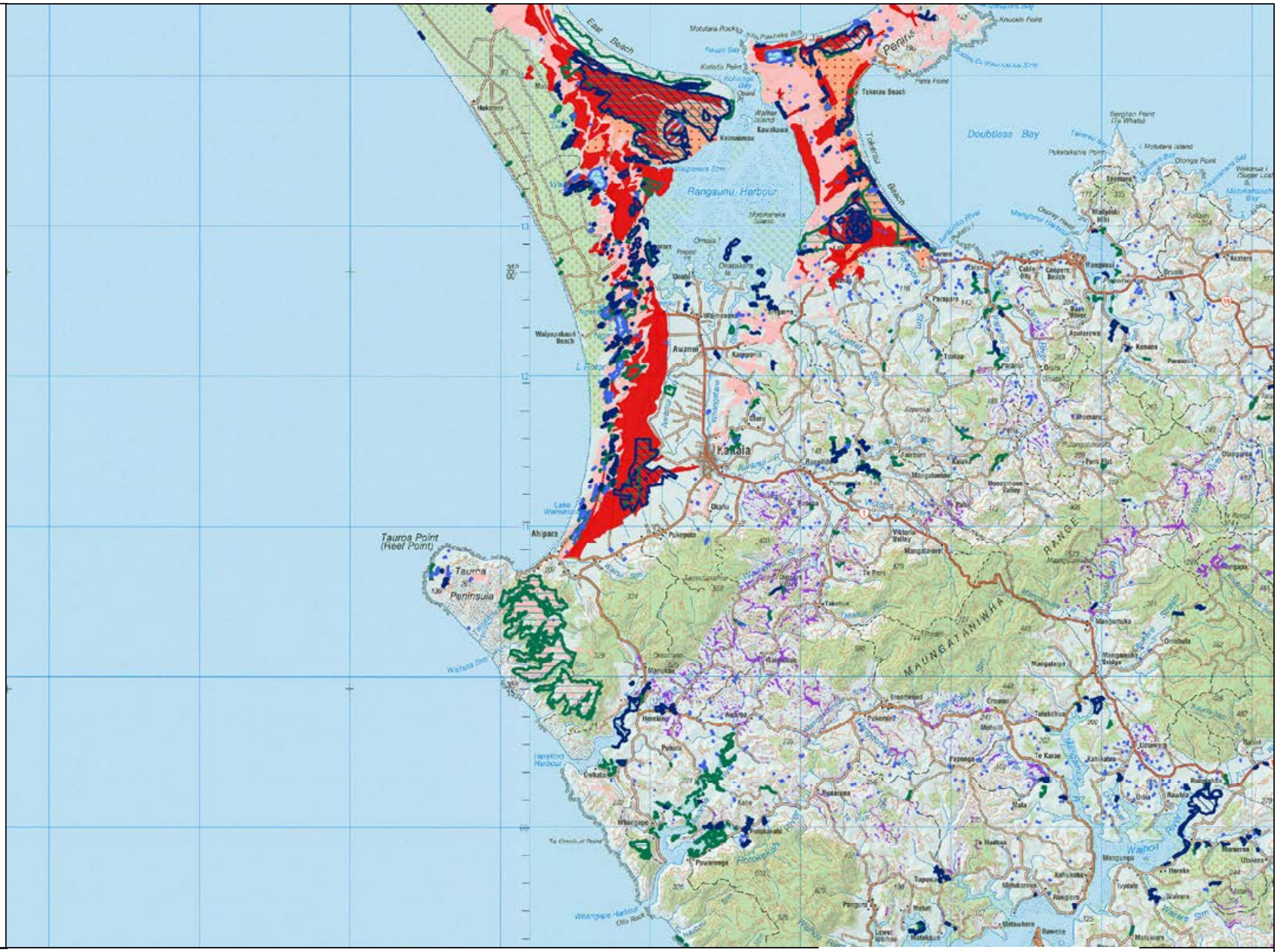
7.6 Swamp kauri terrain spatial coverage for Northland

Maps indicating the spatial extent of different types of swamp kauri terrain for Northland (see Table 2). Percentages indicate the amount of the terrain where swamp kauri could be preserved, but are not indicative of site suitability, permission to extract or total subfossil wood volumes that might be extracted at any given site.

Digital versions of these maps may be obtained from MPI on request.

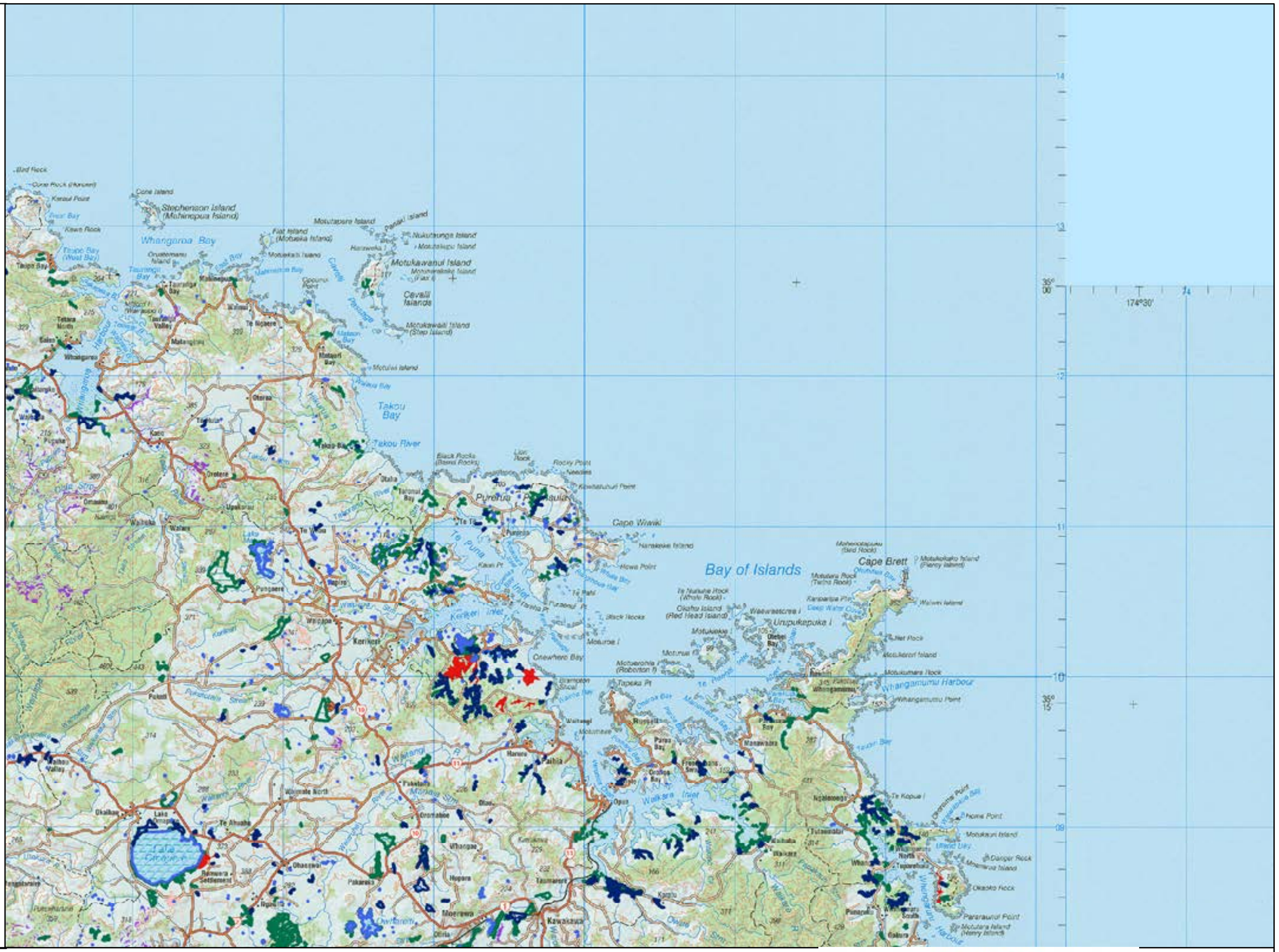
Legend

NIWA
Taihoro Nukurangi



Rangaunu Harbour
Doubtless Bay
Tauroa Point
(Reef Point)
Tauroa Peninsula
Kaitaia
Ahipara
MAUNGATANIWHA
RANGE
Tokerau Beach
East Beach

Legend



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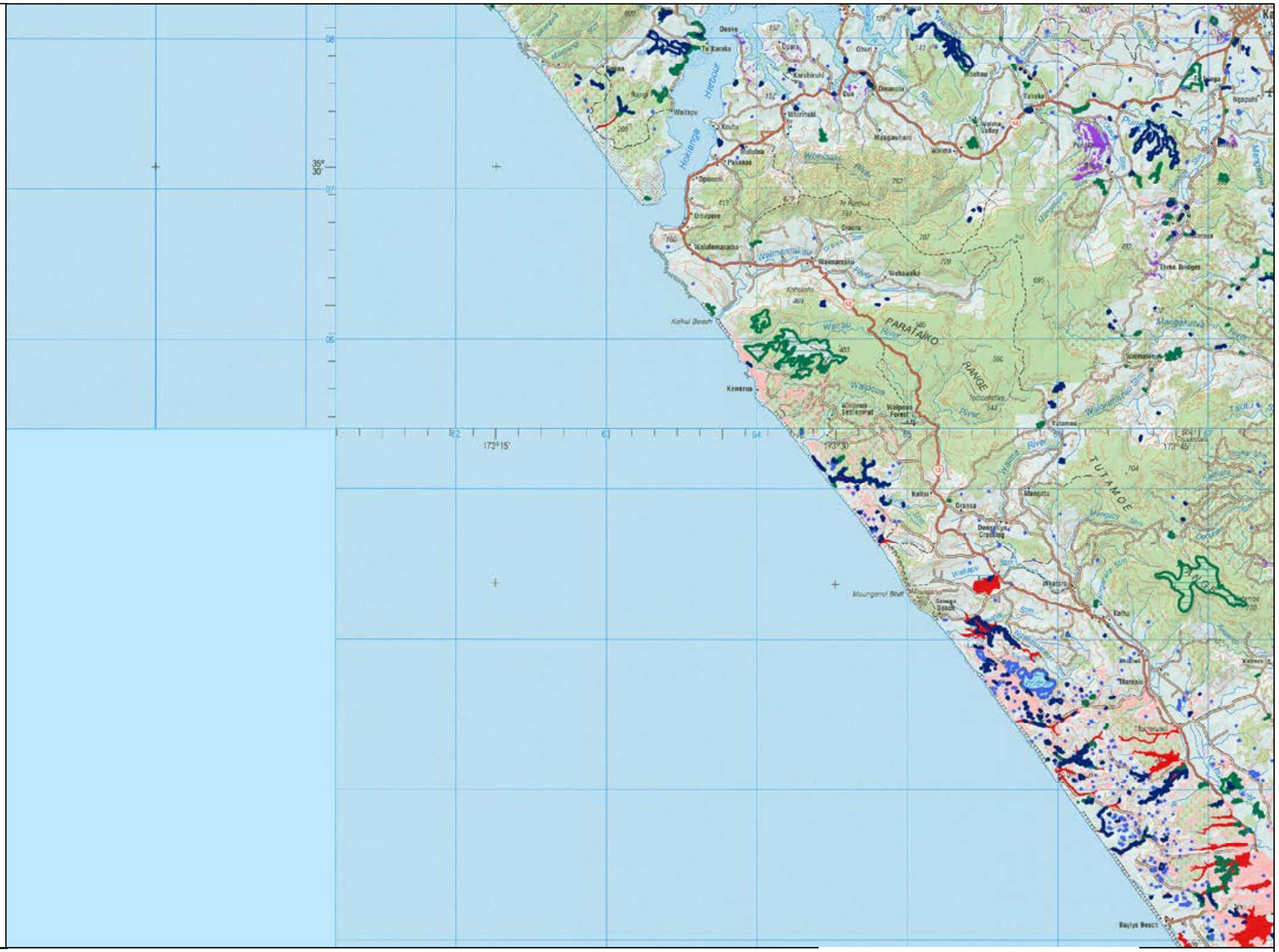

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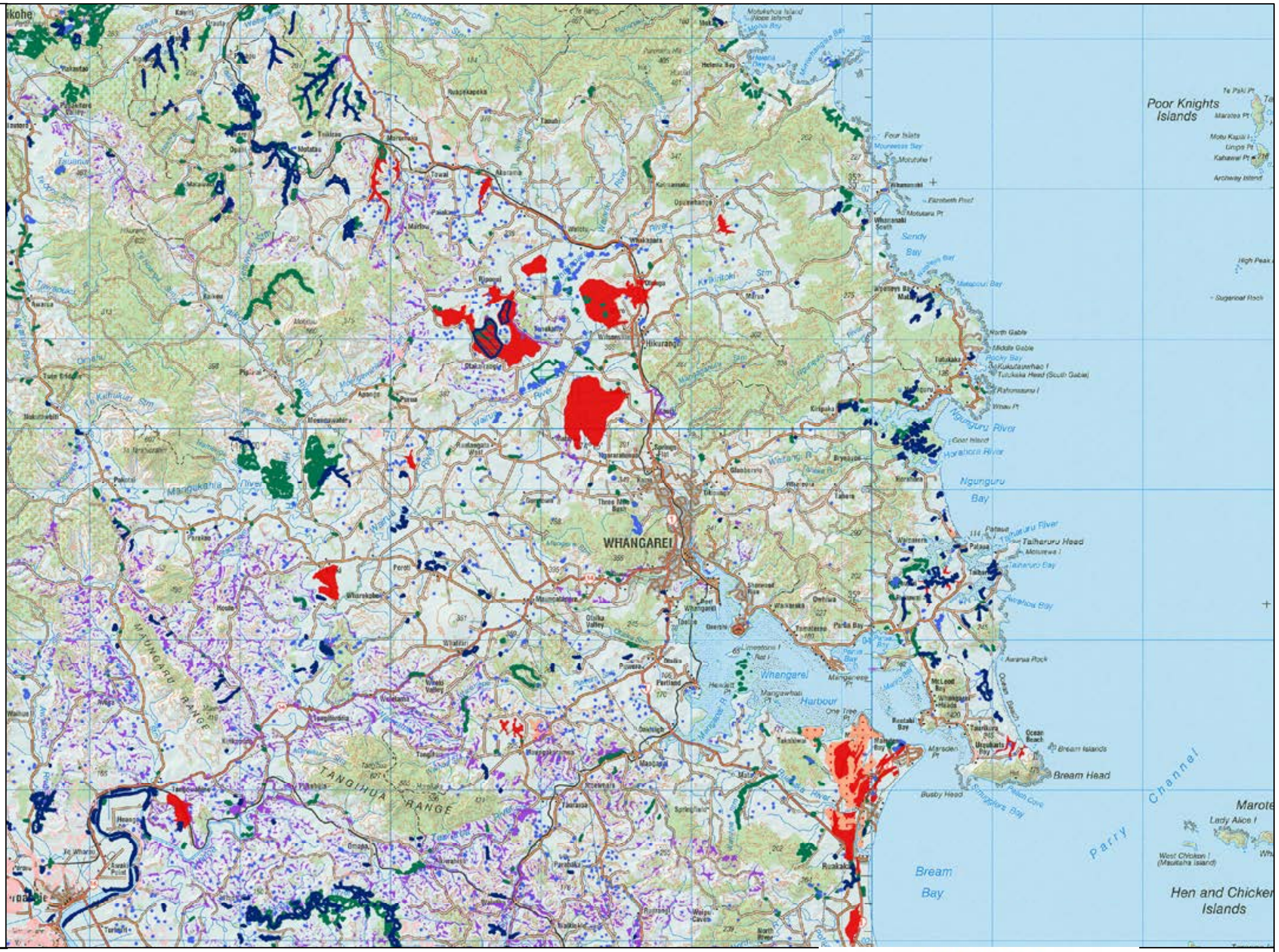

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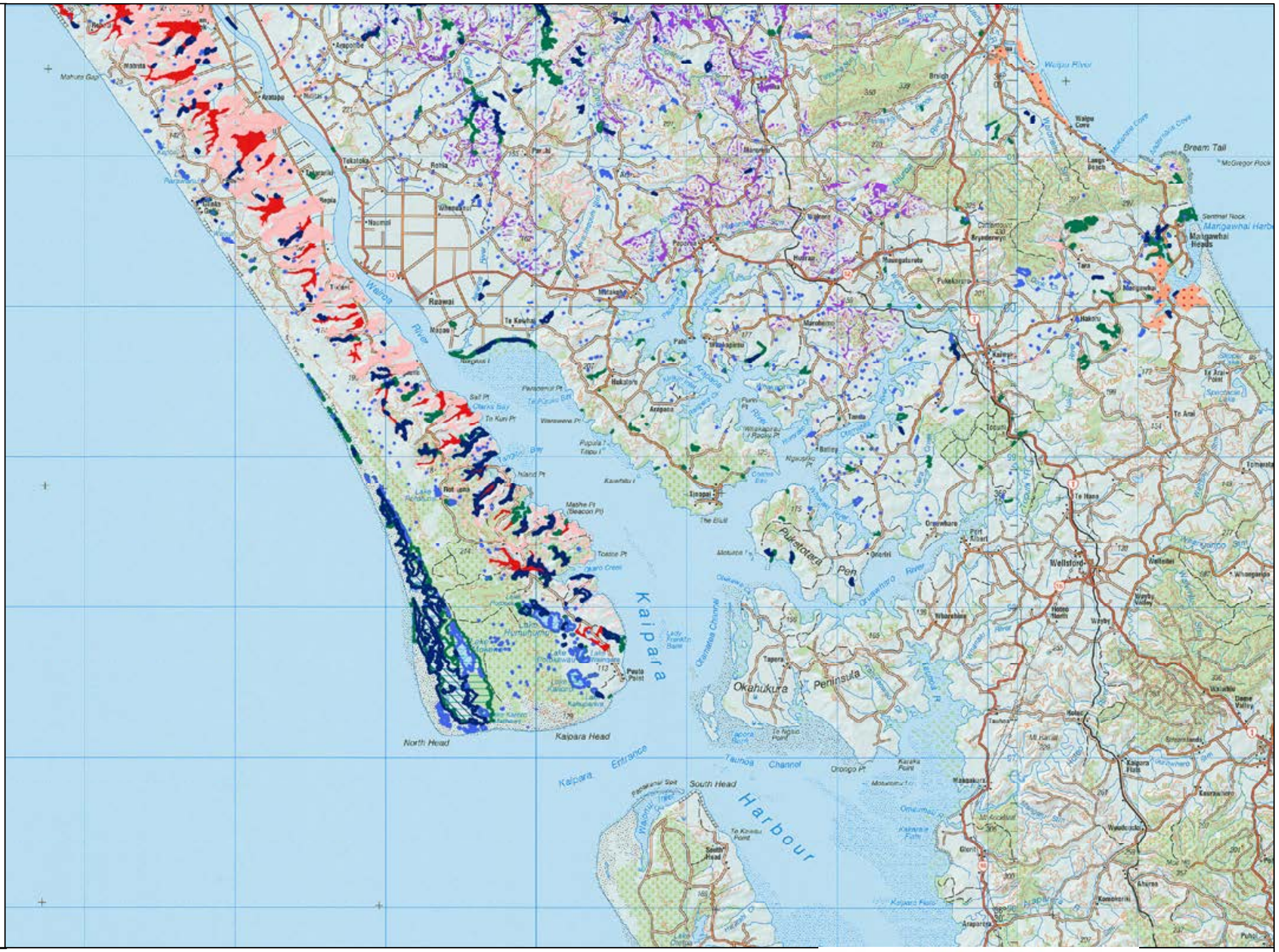
NIWA
Taihoro Nukurangi



Legend

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