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RESEARCH

Revised extent of wetlands in New Zealand

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Abstract: Wetlands are highly valued and significant ecosystems with a large range of services and functions. To help manage and protect them, it is important to map and monitor their spatial extent and condition. However, wetlands have not yet been comprehensively and reliably mapped at the national level, although elements for mapping national coverage exist in two of our national databases: Waters of National Importance (WONI), and the New Zealand Land Cover Database (LCDB). The extent of freshwater wetlands in WONI was derived by identifying all types of freshwater wetlands, excluding inland saline. The extent of freshwater wetlands in the LCDB was derived by identifying areas with either a wet context, herbaceous freshwater vegetation, or flax. We then combined identified freshwater wetlands from the two databases recognising the superior boundary delineation of LCDB and the superior wetland detection of WONI. The current spatial extent of freshwater wetlands in New Zealand is now calculated at 249 214 ha, or 10.08% of the historical extent, rather than the 7.4% reported by LCDB5 alone. This is at least 5954 ha less than that in 1996. The revised extent of freshwater wetlands is an improvement over either WONI or LCDB because it now includes a more comprehensive set of wetlands over 0.5 ha in area with well-defined boundaries. However, the revised extent does not include small wetlands less than 0.5 ha in area. While adding little to the total area of wetlands in New Zealand, small wetlands have significant ecological value. The National Policy Statement for Freshwater Management mandates the national mapping of the small wetlands down to 0.05 ha, but we suggest their ecological value be considered in land use change decisions only, thereby avoiding the excessive cost of mapping many millions of small wetlands.

Keywords: ecosystem services, freshwater wetlands, saline wetlands, spatial extent, wetland loss

Introduction

Wetlands are terrestrial ecosystems that are permanently or intermittently wet. Accordingly, they support a range of plants and animals adapted to wet conditions (Stephenson et al 1983; Cromarty & Scott 1996; Johnson & Brooke 1998; Campbell & Jackson 2004; Johnson & Gerbeaux 2004; Peters & Clarkson 2010). They are formed either by poor soil drainage or by accumulation of water, and usually have emergent aquatic plants (Sorrell & Gerbeaux 2004; McGlone 2009). Freshwater wetlands include bogs, fens, swamps, and marshes; these lie on gradients of water flow (low to high), nutrient availability (low to high), pH (low to high), and peat content (high to low) (Sorrel & Gerbeaux 2004).

Wetlands provide many ecosystem services, including maintaining water quality and supply, regulating atmospheric gases, sequestering carbon, sustaining unique biota, and providing cultural, recreational, and educational resources (Zedler & Kercher 2005; Dise 2009; Clarkson et al. 2013). New Zealand wetland vegetation is well described (Wardle 1991; Johnson & Brooke 1998;)—as are wetland fish and birds (Best 1979; Ogle & Cheyne 1981; McDowall 1990; Heather & Robertson 1996)—but wetland algae and invertebrates are not (Sorrell & Gerbeaux 2004). Compared with other natural ecosystems, wetlands support a disproportionately high number of threatened plants and animals (Clarkson et al. 2013), including 67% of fresh-water and estuarine fish species (Allibone et al. 2010) and 13% of nationally threatened plant species (de Lange et al. 2009).

In New Zealand, wetlands have special significance for Māori for a large range of cultural and spiritual values and uses including mahinga kai (cultural harvest sites), cultural identity, and decision-making through Te Mana o Te Wai (Minister for the Environment 2020). For Māori they include important traditional gathering sites for food, rongoā (medicines), and many taonga species (such as fish, birds, and plants for weaving), There is currently renewed interest in knowing where these wetlands are, and what condition they are in, for sustaining, managing, and restoring Māori values and broader societal and ecological values (Taura et al. 2017).

To help manage these high-value ecosystems, it is necessary to map their spatial extent (Gumbley et al. 2005).

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It is critical that New Zealand produces a national overview of wetland distribution across landscapes and land use to inform planning and policy, and for state of the environment monitoring and reporting (Minister for the Environment 2020). National mapping can also highlight and prioritise issues, such as loss of wetlands, degradation, and loss of biodiversity, arising through land use changes (Robertson 2016). Mapping wetlands over large areal extents requires remote sensing of some form (Mahdavi et al. 2017). Many types of sensors have been used for automatic mapping of wetlands, but successful applications are usually limited to local scales (Guo et al. 2017), and national applications typically have low accuracies ~ 80% (Mahdianpari et al. 2020).

Despite their high importance, wetlands have not yet been reliably mapped at the national level in New Zealand, although elements exist in two national databases, WONI (Wetlands of National Importance) and LCDB (Land Cover Database), and in fragments of sub-national datasets maintained by some regional councils (Allan 2016). Wetlands of National Importance are derived from region-growing on satellite imagery (i.e. automated identification of similar colour around seed point) from seeds of field-identified wetland centres (Ausseil et al. 2011). The Land Cover Database wetlands are derived from visual interpretation of satellite imagery and manual delineation by an expert operator (Thompson et al. 2004). In this paper we derive a revised extent of freshwater wetlands in New Zealand by combining WONI and LCDB in a way that recognises the superior boundary delineation of LCDB and the superior wetland detection of WONI.

Methods

Databases used in study

Wetlands of National Importance is now a component of the wider FENZ (Freshwater Environments of New Zealand) database (Leathwick et al. 2010), a set of spatial data layers that describes and interprets environmental and biological patterns in New Zealand's lakes, rivers, and wetlands (Ausseil et al. 2011), providing the Department of Conservation with a systematic conservation, planning, and reporting tool. Wetlands of National Importance describes the environmental attributes, biodiversity values, pressures, and rankings of palustrine (inland, non-flowing, freshwater) wetlands, comprising three interrelated layers of historical typology, current sites, and current typology. Current sites were seeded from observational data of various origins, including authoritative wetland polygons from regional councils and authoritative point localities from regional councils (which then underwent a raster-based region-growing process on satellite imagery); and typology was based on evidential data from soil, substrate, vegetation, slope, and hydrology (Allan 2016; Newsome 2017). The ecological scope of WONI was intended to be simply palustrine and inland saline hydrosystems as defined by Johnson and Gerbeaux (2004). However, as visual inspection of the current typology reveals the inclusion of some riverine, estuarine, and lacustrine hydrosystems, mapping appears to have exceeded the intended scope. The minimum mapping unit is 0.5 ha.

The Land Cover Database is a multi-temporal classification of New Zealand's land cover. Manaaki Whenua – Landcare Research is the current compiler and custodian of the database and has been responsible for publishing the last three major revisions. Land cover is delineated by polygon boundaries and described by a land cover code and name (Thompson et al. 2004; Dymond et al. 2016) at five points in time: summer 1996/97, summer 2001/02, summer 2008/09, summer 2012/13, and summer 2018/19. As the name implies, the LCDB covers all New Zealand (including the Chatham Islands, but not the Kermadec or the subantarctic islands) and all terrestrial (and some intertidal) ecosystems. The LCDB conforms to elements of Topo50, New Zealand's 1:50 000 topographic database; for instance, the coastline, lakes and rivers are common. The minimum map unit of 1 ha is similar to that of Topo50.

When first created, LCDB was new mapping, either classified directly from SPOT and LandSat satellite imagery, or interpreted visually and digitised manually by image analysts (Newsome 2017). Visual interpretation was supported by selected field-based observations. Since then, the mapping of each new version of LCDB has embodied processes to improve polygon delineation mapping resolution and classification accuracy, not only for the new mapping date but also for all earlier dates. As such, it is an appropriate tool to track changes in wetland extent.

The Land Cover Database, at versions 2 and 3, was judged inappropriate for reporting on wetlands at national scale due to underestimations noted in the Wellington region (Davis et al. 2013). Since then, however, significant improvements have been made at versions 3.1, 4, and 5. The Land Cover Database currently maps 33 land cover classes on mainland New Zealand (two further classes cater for particular vegetation communities on the Chatham Islands). In respect of wetlands, four classes apply: Herbaceous freshwater vegetation, Herbaceous saline vegetation, Flaxland, and Mangrove. In addition, LCDB has a 'WETContext' flag that identifies all sites that are edaphically wetlands despite having a land cover that does not explicitly identify with wetlands. In this way, environments such as swamp-forests and wet heathlands can be recognised as wetlands while retaining their formal land cover class. In addition to a general improvement in mapping quality from version to version, LCDB has incorporated higher-quality wetland information from regional councils (Waikato, Bay of Plenty, Taranaki, Manawatū-Whanganui, Wellington, and Otago) and one district (Far North).

In short, because of the different mapping methodologies of WONI and LCDB, both are insufficient on their own to characterise the full extent of freshwater wetlands in New Zealand. Wetlands of National Importance maps a larger spatial extent of wetlands, but is still missing many wetlands mapped by LCDB. The Land Cover Database delineates wetland polygons more precisely than WONI, but also is missing many wetlands mapped by WONI. To create a more comprehensive and reliable national map of freshwater wetlands, WONI and LCDB need to be combined, the gaps filled, and the disagreements resolved.

Combining WONI and the LCDB

Our revised extent of freshwater wetlands derives from an explicit combination of WONI and LCDB5 at the national scale. Wetlands of National Importance freshwater wetlands were prepared by dissolving intervening boundaries between all the freshwater types, that is, all types excluding inland saline. These were aggregated and smoothed using a PAEK algorithm (Bodansky et al. 2002), and small slivers (< 0.05 ha) were eliminated to derive a uniform and conjunct WONI freshwater map. This was combined with the LCDB5 freshwater wetlands (herbaceous freshwater vegetation, or flax, or other non-saline communities with wet context), and proximity tools were used to investigate areas in common and areas of disagreement.

Areas of disagreement in contact with areas in common were considered delineation differences (i.e., having a core area of agreement but with differently drawn borders). Areas of disagreement detached from areas in common were considered detection differences – these identified wetlands detected by one database but not the other (Fig. 1). Delineation differences greater than 10 ha and having a tenuous connection to their area of agreement were visually checked to determine whether they were better classified as delineation or detection differences. Table 1 shows the areas of delineation and detection differences. Note that WONI wetlands have a significantly larger area than LCDB wetlands, by 66 326 ha, and also that WONI wetlands with detection difference have a significantly larger area than LCDB wetlands, by 49 536 ha.

Considering that LCDB5 was mapped from up-to-date and high-resolution satellite images of Sentinel-2 (European Space Agency 2021) and wetland information from regional and district councils, we consider both detection and delineation differences in LCDB5 to be probable wetlands. Wetlands of National Importance was based on evidential data of various origins, so we consider detection differences in WONI to be probable wetlands. However, because WONI boundaries were defined using raster-based region-growing on low resolution satellite imagery (LANDSAT TM: 30m pixels), we do not consider delineation differences in WONI to be probable wetlands (Figure 1).

Results

Combining areas in common, LCDB5 delineation and detection differences, and WONI detection differences, with tidy-ups as detailed in the Appendix, gave the revised extent of freshwater wetlands. Similarly, WONI saline wetlands (inland saline and reassessed polygons) were combined with LCDB5 saline wetlands to complete our revised extent of freshwater and saline wetlands in New Zealand. The area of the revised freshwater wetlands has increased from 182 864 ha, as reported by LCDB5, to 249 214 ha (Table 2), and the number of wetlands has increased from 14 360, as reported by LCDB5, to 19 355.

The similar area of the revised extent and WONI is merely coincidence, brought about by extra fragmentation and the tendency to overestimate the extent of wetland systems by WONI. This extra fragmentation, where wetlands in a group are identified as individuals rather than one wetland system, is demonstrated by WONI having over twice the number of wetlands as in the revised extent. The revised extent is 10.08% of the pre-European historical extent, mapped by Ausseil et al. (2011) from wet soil types, which compares with 7.4% reported by LCDB5. Table 2 also shows that the area of saline wetlands in the revised extent is 47 018 ha, only 266 ha greater than that of LCDB5, and almost entirely attributable to herbaceous saline vegetation and mangrove in LCDB5.

An analysis of wetland areas shows that large wetlands contribute disproportionately to the total area of wetlands in

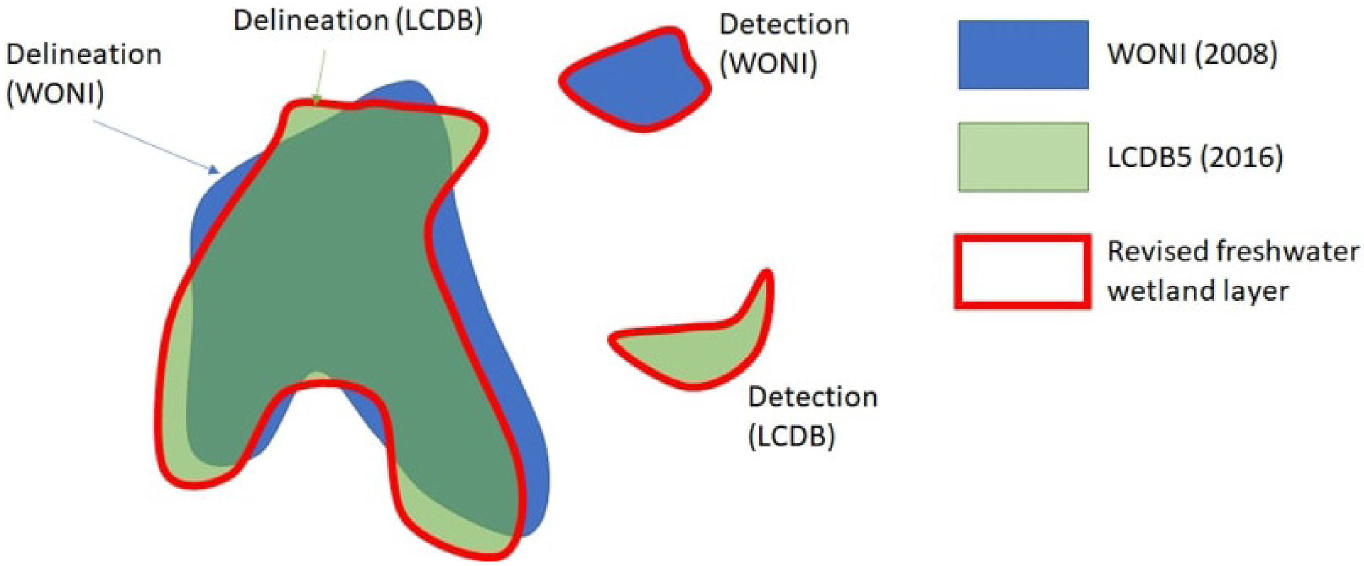

Figure 1. Schematic of detection and delineation differences. Blue shows WONI wetlands and green shows LCDB wetlands. The green wetland on its own is an LCDB detection difference. The blue wetland on its own is a WONI detection difference. Green touching blue is an LCDB delineation difference. Blue touching a green LCDB wetland is a WONI delineation difference.

Table 1. Area of freshwater wetlands for WONI and LCDB5, and areas of delineation and detection difference.

	Freshwater wetlands (ha)	Delineation (ha)	Detection (ha)
LCDB5	182 864	32 992	22 844
WONI	249 190	49 781	72 380

Table 2. Area of revised freshwater and saline wetlands in New Zealand by combining WONI and LCDB5.

	Freshwater wetlands (ha)	Number of freshwater wetlands	Saline wetlands (ha)	Number of saline wetlands
Historical	2 471 080			
WONI	249 190	45 732	291	75
LCDB5	182 864	14 360	46 752	6063
Revised extent	249 214	19 355	47 018	6080

New Zealand (Fig. 2 shows the distribution of wetland areas in 1 ha increments). Many wetlands are small, with 5750 of them less than 1 ha. The number of wetlands in area classes reduces exponentially as the area increases. For example, there are only 287 wetlands with an area between 9 and 10 ha. However, small wetlands do not contribute much to the cumulative area, because the larger wetlands, although less frequent, contribute disproportionately to the cumulative area (Fig. 3). For example, all the wetlands with an area of less than 10 ha (i.e. 83.7% in number) sum to 39 080 ha, which is only 15.6% of the cumulative area of all freshwater wetlands.

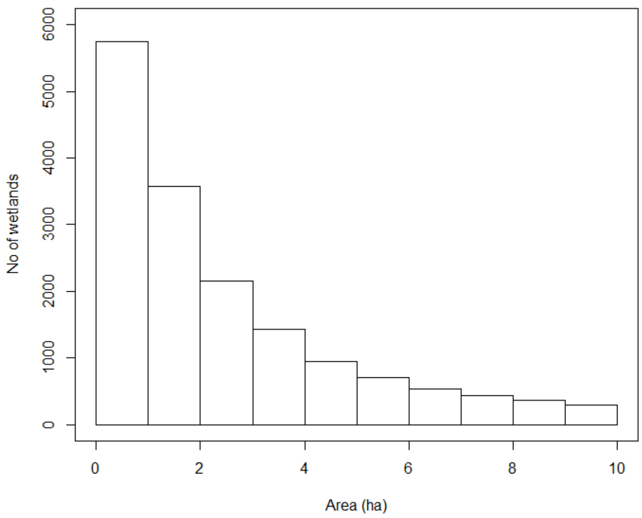

Figure 2. Number of wetlands within area classes.

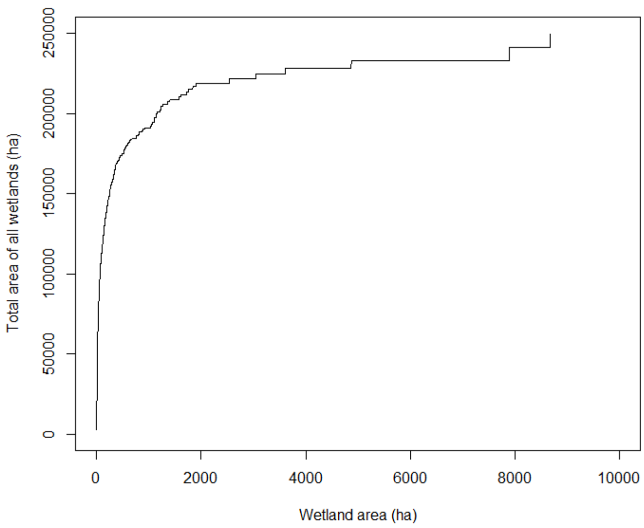

Figure 3. Total area of all wetlands with size (ha) less than that given on x axis.

Discussion

Revised extent and historical loss of wetlands

We have combined elements of the WONI wetlands database and the LCDB5 wetlands to form a revised extent of freshwater wetlands in New Zealand with total area 249 214 ha. This is 10.08% of the pre-European historical extent, rather than the 7.4% reported by LCDB5 and the 10.1% reported by Ausseil et al. (2011). (Note that the area of the historical extent is 9% of the total area of New Zealand.) The area of the revised extent may be further revised upwards as more detailed regional wetland databases are added to the LCDB – currently Waikato, Bay of Plenty, Taranaki, Manawatū-Whanganui, Wellington, and Otago regions have been included, as well as the Far North district.

The loss of 89.92% of historical wetlands is large in comparison with global reductions. Mitsch & Gosselink (2000) reported that about 50% of wetlands worldwide had been lost, ranging from relatively minor losses in boreal countries to more than 90% in some European countries. In some parts of New Zealand, the loss of wetlands has been extreme, such as in the Manawatū-Whanganui region on the plains between the Whangaehu and Manawatū Rivers (Fig. 4). Although most of the plains were originally wetlands, they have now been drained for agriculture. One of the three remaining wetlands, the Manawatū estuary (and associated saline wetlands), is internationally recognised through the RAMSAR convention (Gerbeaux 2003) for outstanding wildlife values. While few of the historical wetlands are likely to be restored in the future, because the land is now privately owned and devoted to agriculture which contributes significantly to the regional economy (Jones et al. 1995), the remaining wetlands and their associated ecosystem services could be protected, or enhanced, by maintaining their condition and connectivity with water courses (Sorrell et al. 2004; Ausseil et al. 2011; Myers et al. 2013).

Ministry for the Environment have reported a loss of 1247 ha of wetlands in New Zealand between 2001 and 2016 (Ministry for the Environment 2019). These were WONI wetlands discovered to have been completely lost by visual examination of satellite imagery (Belliss et al. 2017). Partial loss of wetlands was also noted but not quantified. The recently released LCDB5 quantifies the loss (full and partial) of freshwater wetlands between 1996 and 2018 as 5954 ha (Table 3). Given this continuing loss of freshwater wetlands, we suggest that the revised extent of wetlands be incorporated into the LCDB and that future losses from that extent be monitored.

Improvement of revised extent

The revised extent of wetlands is more comprehensive than LCDB because it includes wetlands from WONI that have local evidence of existence (i.e. the WONI detection differences).

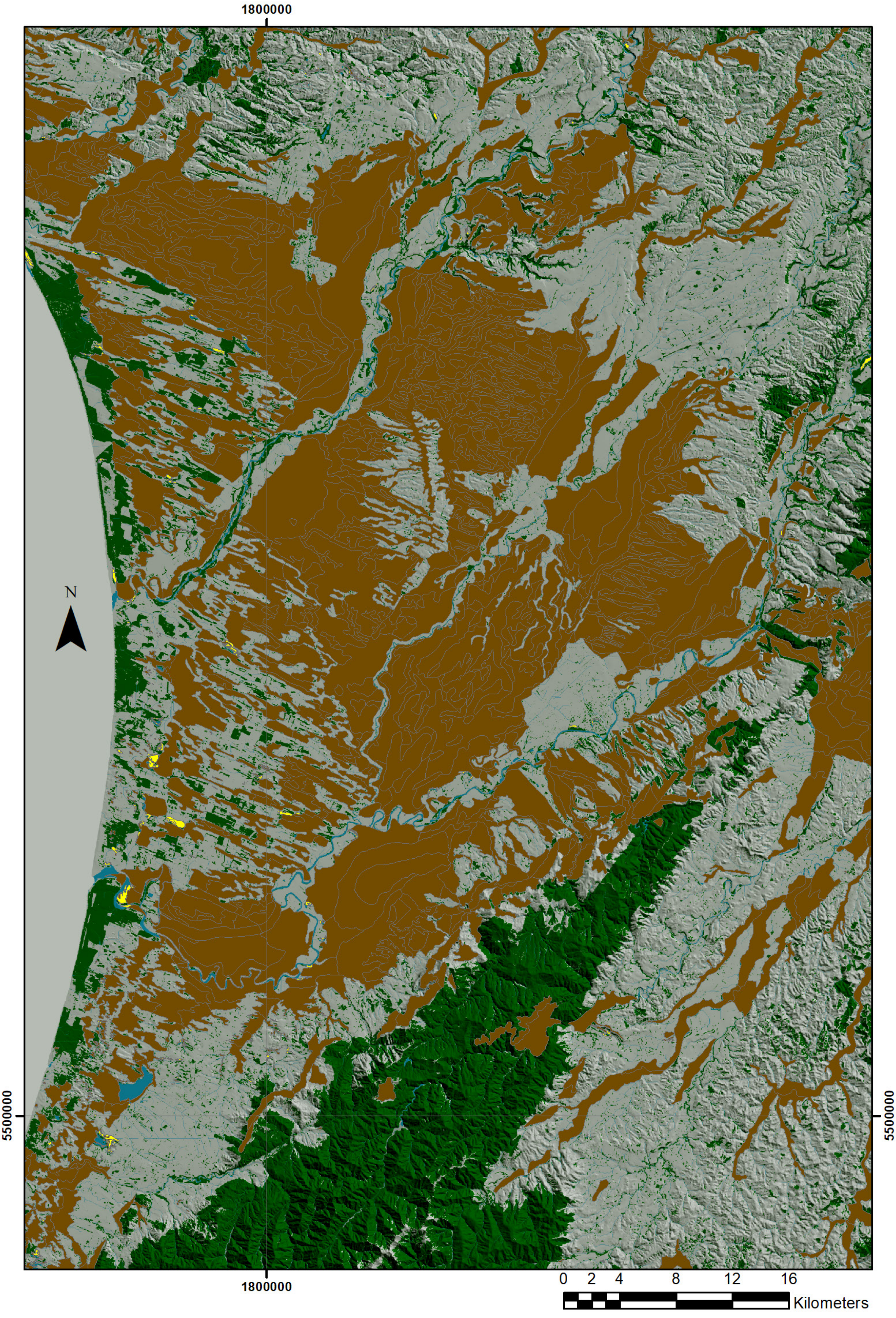

Figure 4. Map of current wetlands (yellow) and historical wetlands (brown) in the lower Manawatū-Whanganui region.

Table 3. The area of wetlands at five dates for LCDB5.

Years	Total area (ha)	Fresh water wetlands (ha)	Saline water wetlands (ha)
1996	235 750	188 818	46 931
2001	234 544	187 677	46 867
2008	232 849	186 002	46 846
2012	231 245	184 424	46 821
2018	229 617	182 864	46 752

The producers' accuracy of LCDB wetlands was assessed at 93.7% (NZ Land Cover Database 2012; Dunningham et al. 2000), so we would also expect the mapping accuracy of the revised extent to be of similar order, as it primarily comprises LCDB wetland polygons. The accuracy of the WONI detection differences is unknown (never reported), and therefore might reduce the producers' accuracy of the revised extent below 90%. However, it needs to be kept in mind that the accuracy of any wetland map is highly uncertain: as ground data are difficult to obtain, wetlands are highly dynamic and their energy signatures are constantly changing, and steep environmental gradients produce narrow ecotones below the resolving capacity of remote sensors (Gallant 2015). It is therefore difficult to ascertain a quantitative expression of accuracy. However, we can say that the process of mapping is nationally consistent, and more comprehensive and reliable than previous methods. All wetlands over 0.5 ha in area are included and their boundaries are well defined.

Ecological function

The areal extent of wetlands is an important first indicator of ecological function and associated conservation value. Ausseil et al. (2011) used a power law (following Rosenzweig 1995) relating conservation value to wetland area in their prioritisation of wetlands for conservation. This power law suggests that conservation value increases as area increases, but because the power exponent is less than one, it also suggests that the conservation value per unit area is greater for smaller wetlands. So small wetlands, while not contributing hugely to national areal extent (Fig. 3), may still contribute significantly to ecological function. Semlitsch and Bodie (1998) confirmed this when they found that small isolated wetlands contributed significantly to species biodiversity; as did Gibbs (1993) who found that small wetlands play a greater role in the metapopulation dynamics of wetland animals than their modest area implies.

The addition of the WONI database, with many more smaller wetlands than the LCDB, some down to 0.5 ha, will have significantly increased the biodiversity represented in the national areal extent (we noted no spatial pattern regarding the location of WONI wetlands that were added to the revised extent). In the absence of national consistent biodiversity data of wetlands, Ausseil et al (2011) used a typology of wetlands including bog, fen, swamp, marsh, pakihi/gumland, seepage, and inland saline. They used the typology together with measures of condition and complementarity to represent the proportion of remaining biodiversity. While the typology was useful, it was assessed using automated methods resulting in a low classification accuracy. We therefore recommend that the typology also be applied to the wetlands in the revised extent but using field assessment methods.

Māori values

An early study on Māori values identified areal extent and condition of wetlands as important environmental indicators (Harmsworth 2002). Loss of wetlands, as measured by areal extent, is keenly felt by Māori because of their whakapapa connection, spiritual attachment, and use of the resource for mahinga kai, all of which affects their sense of wellbeing (Awatere et al. 2017). Harmsworth (2002) also recognised that wetlands are considered part of an interconnected system linked to human values and uses, whereby all wetlands are linked from the mountains to the sea (Te Uta ki Tai) – palustrine wetlands (repo) are connected to rivers (awa, manga), lakes (roto), estuaries (wahapū), and the sea (te moana). To represent the physical inter-connection of wetlands across hydro-systems, classes and types, and landscapes, we propose tagging both freshwater and saline wetlands in the LCDB with identifiers that link them to the stream or river to which they drain. Simple GIS (geographic information system) queries on all wetlands in the system above a point of a water body, such as a river or estuary, could then be readily executed.

Avoiding loss or degradation of the remaining wetlands in New Zealand is a focus of the recently approved National Policy Statement for Freshwater Management (Minister for the Environment 2020). Clause 3.23 states that "Every regional council must identify and map every natural inland wetland in its region that is 0.05 hectares or greater in extent …". Although our revised freshwater wetland extent is an improvement on previous databases, the minimum mapping unit is 1 ha and so it will not achieve the 0.05 ha limit of the national policy statement. However, it would achieve a baseline for national reporting purposes, which would include most of the areal extent of wetlands, as small wetlands would not add significantly to the total area (Fig. 3).

The 0.05 ha limit of the national policy statement is overly optimistic for a national mapping exercise that would require excessive resources to map the several million small wetlands (estimated from the relationship between wetland number and area in Fig. 2) in New Zealand. Indeed, the difficulty of automating an objective nation-wide method for mapping wetlands suggests that obligatory mapping of wetlands down to 0.05 ha is problematic and should be replaced by another instrument that encourages the protection of wetland values without obligatory mapping. It would be more pragmatic for the obligation to be consideration of wetland values before a change in land use or management affecting those values; Robertson et al. (2019) reported land use change as major cause of wetland loss in Southland. This should require consideration of values coming from areas as small as 0.05 ha, or even smaller for ephemeral wetlands containing threatened species. This would require the mapping of several thousand small wetlands per year involved in land-use change, which could be achieved with moderate resources (available to most regional councils), rather than several million in total, which could only be achieved with excessive resources.

The revised extent of freshwater wetlands is an improvement because it now includes a more comprehensive set of wetlands over 0.5 ha in area with well-defined boundaries. This should help the management of wetlands at national and regional scales. In the economics of ecosystems and biodiversity (TEEB), the quantification of resources is thought to be an important part of management (ten Brink 2009), summed up with the maxim, “you can’t manage what you don’t measure”. With improved quantification of wetlands, benefits associated with wetlands are more likely to be maintained and enhanced. These benefits include not only maintenance and enhancement of multiple ecosystem services but also cost savings in climate change mitigation and adaption, and protection of biodiversity (Russi et al. 2013). We suggest that, in future, the revised extent of freshwater wetlands be incorporated into the LCDB in a supervised process to ensure quality is maintained. This will enable the full extent of freshwater wetlands in New Zealand to be monitored for change.

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Author contributions

JD, PN, and MS conceived the project idea. MS undertook the analysis. JD, GH, and AA provided interpretation. JD, MS, and GH wrote the paper.

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Supplementary material

Additional supporting information may be found in the supplementary material file for this article:

Appendix S1. Tidy-ups for the revised extent of freshwater wetlands.

The New Zealand Journal of Ecology provides supporting information supplied by the authors where this may assist readers. Such materials are peer-reviewed and copy-edited but any issues relating to this information (other than missing files) should be addressed to the authors.