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Towards quantitative limits to maintain the ecological integrity of freshwater wetlands: Interim report

Towards quantitative limits to maintain the ecological integrity of freshwater wetlands: Interim report

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August 2015

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Landcare Research Contract Report:	LC1933

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Contents

Summary

Project and Client

- The Department of Conservation (DOC) contracted Landcare Research to identify potential variables that could be used to describe limits for maintaining the ecological integrity of wetlands.
- Ecological integrity includes both the ecological condition of current wetlands and the degree of representation of their full environmental range across biogeographical regions.
- For purposes of this project the analysis focused on describing limits to maintain ecological condition by analysing trends between indicators of condition (e.g. wetland condition index, native plant abundance) and physico-chemical variables that are considered important drivers of wetland ecosystem function (e.g. soil nitrogen and phosphorus levels).
- The development of limits is considered critical to improving the management of wetlands both in public conservation land administered by DOC and in other areas.
- The variables identified in the project may also inform the development of attributes under future versions of the National Objectives Framework (NOF) under the National Policy Statement for Freshwater Management.

Objectives

- Collate data from a range of sources on wetland condition, proportion of the original wetland area remaining, and physico-chemical status into a standalone database.
- Develop and implement an analytical approach to identify the physico-chemical variables (attributes) that best explain the variation in wetland condition across New Zealand.
- Refine the set of draft attributes, and associated states previously presented to DOC and MfE for soil nutrients and wetland area remaining, building on initial analyses of soil nutrient limits.
- Recommend priorities for filling key gaps in the database, further statistical analysis, and the application of wetland limits in regional and national settings.

Methods

- Data from plot-based vegetation surveys, soil chemistry analyses, wetland mapping, and GIS models (FENZ) of 169 wetlands were integrated and used to quantify limits to maintain the ecological health of wetlands.
- Geospatial data on the proportion of the original wetland area remaining according to wetland type were calculated for all wetland sites.
- A three-stage analytical approach was applied, which was considered a robust methodology for quantifying wetland limits. This involved: simple box-plots and tabular summaries of physico-chemical variables; scatterplots to assess relationships

between ecosystem health variables (response variables) against physico-chemical variables and other variables likely to influence wetland condition (predictor variables); and statistical modelling, using Generalized Regression Analysis and Spatial Prediction (GRASP), to find the predictor variables that explained the variation in condition for each wetland type.

Results

- Data were most comprehensive for bog, fen, and swamp wetland types, although information on gumlands and marshes was also available.
- It was difficult to find clear patterns between wetland condition and individual variables due to the complex and variable nature of wetlands in New Zealand. However, a number of the multivariate GRASP models performed well (cross validation $r^2 > 0.6$) in explaining the variation in wetland condition.
- Variables regularly identified as explaining the variation in ecosystem health for bogs, fens and swamps included: proportion of wetland area remaining, nitrate integrity (GIS layer), soil total nitrogen, soil total phosphorus, and soil N to P ratio.

Conclusions

- Wetland systems are distinctly different from river and lake ecosystems in that in most places wetland systems have been drastically reduced in extent. Thus the fundamental cause of wetland system degradation is further loss and drainage.
- For those portions of wetland systems remaining, a subset of variables may be suitable for setting limits to maintain the condition of wetland ecosystems in New Zealand, in particular the proportion of wetland area remaining, nitrate integrity, and soil nitrogen and phosphorus levels.
- Attributes have been presented that could be considered for further development under national and regional policy. However, it is important to recognise these attributes were effective in a multivariate setting, which reflects the unique multi-stressor effects on different wetland types.
- Further refinement of attributes should be a 2-scale process to reflect the importance of wetland intactness on ecological condition, and the magnitude of wetland loss nationally, that is:
    - Development of an attribute focused on the proportion of wetland area remaining, with limits developed in relation to drainage and clearing of wetland habitat.
    - Modelling of physico-chemical attributes (e.g. soil phosphorus levels) following the suggested analytical approach in this study.

Recommendations

- Present the preliminary results from this study to regional councils, MfE and other agencies involved in setting limits for wetland management and seek feedback on how to progress the work.

- Improve the coverage of the database to help address some significant information gaps, particularly the poorer condition wetlands.
- Investigate the ability to improve the prediction of nutrient loading to wetlands using land cover and land use information or modelling.
- Partner with a regional council to develop wetland limits for different wetland types.

1 Introduction

Freshwater wetland ecosystems are distributed across a wide range of geographic regions from lowlands to alpine areas. Given over 30% of the New Zealand land mass is managed as public conservation land, large areas of wetland are relatively intact with minimal disruption to ecological processes. A significant number of wetlands are also situated on conservation land or private land where there has been extensive land-use conversion. Wetlands in modified catchments are subject to changes in hydrological regime, physico-chemical status (e.g. increased nutrient inputs), weed invasion, and decline in their overall extent.

In a review of wetland management in New Zealand, Myers et al. (2013) noted that different regional authorities have applied different policy measures to protect the natural character of wetlands. They also noted that improved wetland management depends on improved monitoring of policy effectiveness. Implicit in applying more strategic policy measures and monitoring is a good level of scientific understanding of the pressures that can lead to degradation of the ecological health of wetlands. Once the main pressures are identified, specific rules or limits can be applied to ensure the condition of wetland ecosystems is maintained or enhanced. For example, excess loading of nutrients (particularly nitrogen and phosphorus) has been recognised internationally as altering the ecological function and composition of wetlands (Mitsch & Gosselink 2007; Verhoeven et al. 2006). In New Zealand, excess nutrient loading is also recognised as a key driver of wetland degradation (Clarkson et al. 2004; Sorrell et al. 2007) but at present there is limited guidance on the maximum recommended concentrations of nitrogen or phosphorus for different types of wetlands.

Approaches to quantify limits that maintain the ecological health of wetlands have been developed in other countries. For example, the United States Environment Protection Agency published a manual to help state agencies describe nutrient criteria to protect wetlands from over-enrichment (EPA 2008). This manual recommends the application of wetland classification systems, statistical models, and biological indicators to assess the relationships among nutrients, vegetation or algae, soil, and other variables.

Another key issue with regard to wetland management in New Zealand is the drainage and clearance of wetlands (Myers et al. 2013). The impact of wetland loss on the condition of remnant wetlands has not been quantified. If this information were available it would likely facilitate improvements in regional planning and policies.

The background we describe above provides the context for this investigation of limits to maintain the ecological integrity of freshwater wetlands. The Department of Conservation administers over 60% of the remaining wetlands in New Zealand (by area) and therefore seeks guidance on limits to maintain and improve the values of wetlands within public conservation land.

The study is also directly aligned to the New Zealand government's freshwater reforms. A Discussion Document published by the Ministry for the Environment (MfE) outlined proposed amendments to the National Policy Statement – Freshwater Management (NPS-FM) and a process for setting freshwater limits and bottom lines to protect the health of freshwater ecosystems (Ministry for the Environment 2013). The subsequent NPS-FM 2014 established a National Objectives Framework (NOF) for lakes and rivers, which consists of freshwater attributes (variables) to be managed within compulsory national values (for

Ecosystem Health and Human Health for Recreation), and a process for setting freshwater objectives. The NOF will support and guide regional councils in the setting of freshwater objectives in regional plans. The previous Discussion Document also referred to the intended development of specific attributes for wetland ecosystems within the NOF, e.g. total nitrogen, total phosphorus, sediment, in order to 'protect the significant values of wetlands'.

Under the NOF, freshwater objectives and bottom lines (that provide the minimum level of acceptable standards) are required to maintain 'Ecological Health', given the NPS-FM requires that overall water quality within a region is maintained or improved. Within the Ecosystem Health national value, work is well underway for developing attributes for several water body types, particularly lakes and rivers (Ministry for the Environment 2013). However, development for wetland limits is less advanced and this report provides an important step in determining and progressing attributes for wetlands.

An initial set of potential soil nutrient attributes related to wetland ecological functioning was presented to the NOF Science Review Panel in June 2013, which recommended further refinement and development.

The Department of Conservation subsequently contracted Landcare Research to progress the development of wetland attributes by undertaking a technical analysis to identify significant trends or thresholds between indicators of ecosystem health in wetlands (e.g. wetland condition index, native plant abundance) and key drivers of wetland ecosystem function (e.g. nitrogen, phosphorus). The goal is to illustrate the degree to which ecosystem health indicators, the biological or 'response variables' are predicted by differences in physico-chemical variables.

The potential attributes presented to the Scientific Advisory Board in 2013 were derived from the Landcare Research (LCR) wetland database as at February 2013 (MBIE-funded Restoring Wetlands Programme). The present project integrates data from a wider range of sources: LCR Wetland Database updated to May 2014, Freshwater Environments of New Zealand GIS database (FENZ; Ausseil et al. 2008), and Department of Conservation wetland surveys (Northland, Canterbury).

It is important to recognise that wetland systems are distinctly different from riverine and lacustrine systems in the patterns of degradation. Lakes and river systems have generally maintained their original extent, with various modifications such as alterations of course, damming, nutirnet enrichment, sedimentation, etc. However, for wetland systems the most significant impact by far is reduction in areal extent by clearance and drainage. Those portions of the wetland remaining are then impacted by various factors such as nutrient inputs and sedimentation.

This investigation supports and informs wetland management at local, regional and national scales while contributing to the discussion to develop limits for wetlands in national and regional policies and plans.

2 Objectives

The aim of the project was to identify the environmental variables that are most related to the ecosystem health of freshwater wetlands. This information is needed to guide the setting of objectives for wetland restoration, and the setting of limits to protect ecosystem values. The project is also likely to help inform work by councils and central government to implement and extend the NPS on freshwater management.

The specific objectives for this phase of the project were to:

- collate data from a range of sources, at the wetland site scale, on wetland condition and physico-chemical status into a standalone database
- undertake geospatial analysis to calculate the proportion of wetland area remaining for all wetland sites included in the database
- develop and implement an analytical approach to identify the physico-chemical variables (attributes) that best explain the variation in wetland condition across New Zealand
- refine the draft attributes, and associated states for soil nutrients and wetland area remaining, building on the initial analysis for soil nutrient limits (J Overton, B Clarkson, H Robertson, unpubl. information 2013)
- recommend priorities for filling key gaps in the database, further statistical analysis, and the application of wetland limits in national and regional settings.

3 Methods

3.1 General approach

We investigated the relationships between several measures of wetland condition (response variables) and a range of quantitative soil and other environmental characteristics (predictor variables or attributes). Our analyses aimed to find what attributes could reliably predict various aspects of wetland condition for different wetland types. We used a staged approach to our analyses. The first stage was simple and fairly descriptive, while later stages were more complex, involving multivariate statistical models, but provided the ability to distinguish the attributes that best predict various aspects of wetland condition.

3.2 Wetland types selected

Analyses were undertaken according to five major wetland types in New Zealand as their distinctive physico-chemical characteristics influence ecological function and natural variation of physical and chemical variables, such as soil pH levels (Johnson & Gerbeaux 2004). The five types investigated in the study were:

- Bog
- Fen

- Swamp
- Marsh
- Gumland

For the purposes of this interim report our detailed assesment focused on bogs, fens, and swamps, as these are the main wetland types in New Zealand and because more data were available for statistical analysis.

Other wetland types – shallow water, seepage, and ephemeral wetland – were not used either because of a lack of data (e.g. shallow water) or because they were subsumed within other types (e.g. ephemeral wetland within marsh).

3.3 Variables

The variables applied in this investigation were classified into two groups, "predictor variables", which are mainly physico-chemical parameters considered drivers of wetland health, and "response variables", which are the measures of wetland condition. Tables 1 and 2 list the variables that were explored within the major wetland types.

Table 1 Summary of predictor variables investigated for explaining the variation in wetland condition

Predictor Variables	Description	Code	Units
Physico-chemical	Soil pH	SoilpH	pH Unit
	Soil Bulk Density	SoilBD	g/cm^3
	Soil total nitrogen: gravimetric	SoilTotalN	%
	Soil total nitrogen: volumetric	SoilTotalN.Vol	mg/cm^3
	Soil total phosphorus: gravimetric	SoilTotalP	mg/kg
	Soil total phosphorus: volumetric	SoilTotalP.Vol	mg/cm^3
	Soil N:P ratio	SoilNtoP	ratio
	Soil total C: gravimetric	SoilTotalC	%
	Soil total C: volumetric	SoilTotalC.Vol	mg/cm^3
GIS-based	Proportion of wetland area remaining for the wetland type at an an individual wetland scale	PropAreaWetland TypeRemaining	0–1
	Nitrate integrity, a surrogate measure of impact of land use intensity (nitrate leaching risk), in FENZ* (from Ausseil et al. 2008, Leathwick et al. 2010)	FENZ.EI.Nitrate	0–1
	Wetland ecological integrity index, in FENZ* (Ausseil et al. 2008, Leathwick et al. 2010)	FENZ.EI	0–1

* FENZ = Freshwater Ecosystems of New Zealand, a national geospatial database that maps the extent, condition and threats of wetland, lake and river ecosystems.

Table 2 Summary of response variables investigated for explaining the variation in wetland condition

Response Variables	Description	Code	Units
Wetland ecological condition[1]	Wetland condition index (WCI of Clarkson et al. 2004)	TotalCondition	0–25
	Nutrient condition index (‘P3: Nutrient levels’ component of the WCI physico-chemical indicator)	NutrientCondition	0–5
	Wetland ecological integrity index of FENZ (Ausseil et al. 2008)	FENZ.EI	0–1
Biotic condition measures	Plant species richness: total native and exotic species	TotalRichness	*n*
	Proportion (%) of plant species richness that is native	PropSppNative	0–1
	Proportion (%) of plant species cover that is native	PropCovNative	0–1

[1] Ecological condition and ecological integrity are treated here as being synonymous and defined as an assessment of the structure, composition, and function of an ecosystem as compared to reference ecosystems with minimum human impact and operating within the bounds of natural or historic disturbance regimes (Lindenmayer & Franklin 2002; Young & Sanzone 2002; Langendoen et al. 2006). Although recent New Zealand definitions of ecological integrity include an assessment of the degree of occupancy of an ecosystem’s full environment range (‘ecosystem representation’ of Lee & Allen 2011), we limit our project to individual wetlands.

Note that the FENZ wetland ecological integrity measure was used as both a response variable and a predictor variable, but was not modelled against itself.

3.4 Data

Data for the analyses were extracted from the Landcare Research wetland database (140 wetlands, 610 plots), supplemented by DOC wetland data (29 wetlands, 52 plots), and FENZ GIS data (national wetland coverage; Ausseil et al. 2008). All data were plot-based, apart from the FENZ and WCI variables, which were at the wetland level.

Soil nutrients, vegetation cover, plant species composition, WCI, and nutrient condition were determined following methods in the wetland monitoring handbook (Clarkson et al. 2004). Soil nutrient status (e.g. soil total phosphorus concentration) was determined from cores removed at a known location and analysed by an accredited laboratory. Vegetation cover and plant species composition were determined from a vegetation survey plot, at the same location as the associated soil core. The WCI is a metric developed for state of the environment monitoring in which five ecological indicators are compared and scored against an assumed natural state (as at c. 1840): hydrological integrity; physico-chemical parameters; ecosystem intactness; browsing, predation and harvesting regimes (animal impacts); and dominance of native plants. Each indicator has a number of indicator components that are scored on a 0–5 scale, with 0 representing the most degraded condition and 5 the unmodified condition. Indicator scores, which represent the mean of its components, are summed to give a total WCI out of 25. The nutrient condition index is one component of the WCI (physico-chemical parameter) and has a maximum score of 5. Nutrient condition is determined from field observation, for example, excessive plant growth, change to high-nutrient species, or algal blooms indicating eutrophication.

3.5 Calculation of proportion of area of wetland type remaining

Geospatial information on current wetland extent and proportion of current versus historic extent per biogeographic unit is defined in Ausseil et al. (2008). We refined the FENZ spatial data on the proportion of current versus historic extent to get a better idea of the level of wetland loss at the site level. For this, we defined the historic patch of wetland as a contiguous historic area of the same wetland type as the current site, belonging to a same catchment. In GIS terms, we dissolved the historic extent based on wetland class (type), and intersected that layer with a catchment layer from the River Environment Classification (Leathwick et al. 2010). Each wetland site was then examined and the proportion of current versus historic area in the wetland patch recorded. FENZ information was available for 80% of the wetlands in the database. For the remaining unmapped sites, a visual assessment was made using Google Earth and topographic maps to estimate proportion of current versus historic.

3.6 Calculation of nitrate integrity

Nitrate integrity for each wetland site was based on the nitrate leaching risk from CLUES (Woods et al. 2006). The nitrate leaching risk within a catchment (for marsh, swamp) or within a 30-m buffer zone (for bog, fen, gumland) around each wetland site is applied in a transfer function to evaluate the impact of nitrate leaching on ecological integrity. Nitrate integrity varies from 0 (low ecological integrity, degraded wetland) to 1 (high ecological integrity of the wetland). It is one of the components that define the wetland ecological integrity from FENZ.

3.7 Attribute states for ecological condition

A key feature of the NOF is the description of specific states of Ecosystem Health for each attribute, ranging from A (excellent condition) to D (poor condition), as outlined in the NPS for Freshwater Management (Ministry for the Environment 2014).

The US EPA have developed wetland condition indices by combining biotic metrics into an Index of Biological Integrity (IBI), and biotic metrics and abiotic metrics into an index of ecological integrity (EI) for wetlands (EPA 1998; Faber-Langendoen et al. 2006). According to EPA (1998), although individual metrics may respond differently, the index scores should form a relatively straight line when plotted against a gradient of human disturbance (Fig. 1).

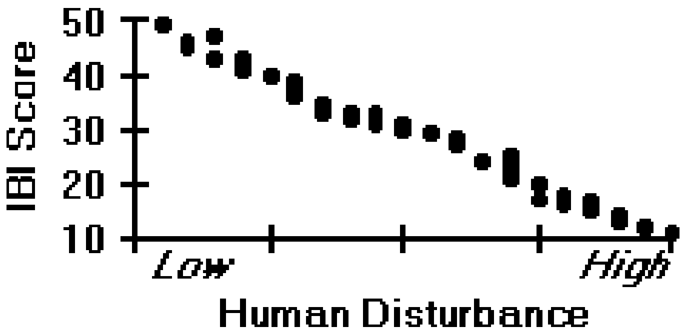

Figure 1 Index of Biological Integrity Scores of 40 wetlands. Source: EPA 1998.

Following this approach, we selected working breakpoints for the states of wetland health around New Zealand. As the Wetland Condition Index (WCI) ranges from 0 to 25, our preliminary working states were evenly distributed scores of:

- A: >20–25 (>80%); excellent
- B: >15–20 (>60–80%); good
- C: >10–15 (>40–60%); moderate
- D: <u><</u>10 (<u><</u>40%); poor; degraded

The national bottom line is set at the boundary between States C and D (Ministry for the Environment 2014). However, as data from lower condition wetlands were limited (scores mostly above 15), we combined the B and C categories and used three states of condition:

- Excellent (A)
- Good–Moderate (B–C)
- Degraded (or poor) (D)

The ranges may need to be re-assessed following inclusion of data from more degraded wetlands. For example, the national bottom line threshold may be better set at WCI = 12.5 (50% of the WCI maximum) or even at WCI = 15.

3.8 Analysis

Data were analysed according to three approaches of increasing complexity. Specifically:

i. Box-plot and tabular summaries of variable ranges. The simplest analysis was to create box plots and tables that summarised soil and other variables for different wetland types and states of WCI. The box plots guided selection of potentially distinctive soil variables at the wetland type level, and the tables provided a summary of the mean, and 10th and 90th percentiles of soil and other variables for states of condition within each wetland type.

ii. Scatterplots of variables relative to condition. To get a better idea of how soil variables changed with WCI, we produced scatterplots of each variable against condition for each wetland type.

iii. Generalised additive (multivariate) models. To assess which variables were useful predictors of wetland condition, and their explanatory power, we used generalised additive models to model WCI as a function of a range of predictor variables. These methods are detailed below.

3.8.1 Box plot and tabular summaries of variable ranges

As different wetland types have distinctive physico-chemical characteristics (Johnson & Gerbeaux 2004) we constructed box plots of soil data (pH, total N gravimetric, total N volumetric, total P gravimetric, total P volumetric, N:P ratio, total C gravimetric, total C volumetric, von Post, and bulk density) for bog, fen, swamp, marsh, and gumland to guide selection of those soil variables that best distinguished between the types.

Tabular summaries of the soil variables listed above and other predictor and response variables, i.e. nutrient condition index, wetland ecological integrity, nitrate integrity, native species richness, and area remaining in relation to wetland condition index, were then collated. We defined WCI states of ‘excellent’, ‘good’, ‘moderate’, and ‘poor’ ecosystem health (A, B, C, and D respectively) with reference to specific numeric ranges following the approach used by the United States Environmental Protection Agency (EPA 1998). We present the mean, 10th percentile and 90th percentile for the excellent and good/moderate states (A, B/C) within the bog, fen, and swamp types. The states B and C have been grouped due to the limited number of wetlands with lower WCI scores. There were insufficient data within the poor condition category (D), and within the marsh and gumland types for meaningful analyses, and these are not considered further.

The variables that showed notable contrasts between both wetland types and states were selected as candidates for model development.

3.8.2 Scatterplots of variables relative to condition

Scatterplots showing the relationship between the WCI and the predictor and response variables by wetland type were produced for the wetland condition states of excellent and good/moderate. The process was repeated using the nutrient condition component of the WCI (WCI.nutrient) in place of the WCI.

Five soil variables and two other physical variables were selected as predictor variables for the GRASP models on the basis of their apparent ability to discriminate between their measured values and wetland type and/or wetland condition. These were Soil total phosphorus:gravimetric, Soil total phosphorus:volumetric, Soil total nitrogen:gravimetric, Soil total nitrogen:volumetric, Soil N:P ratio, Proportion of wetland area remaining, and Nitrate integrity.

3.8.3 Generalised additive models to determine factors that explain condition

Wetland ecological health measures (response variables) were modelled using generalized additive models (GAMs) in the package GRASP (Generalized Regression Analysis and Spatial Prediction; Lehmann et al. 2002). GRASP is a collection of scripts in statistical software (Splus or R) that facilitate the analysis and interpretation of GAM models.

GAM analyses were performed separately within each wetland type. The six response variables (wetland ecological integrity, nutrient condition index, native species cover, native species richness, wetland condition index, total richness) were modelled against three different sets of predictor variables. The first set consisted of only the soil variables, i.e. Soil total nitrogen: gravimetric, Soil total phosphorus: volumetrix, Soil total phosphorus: volumetric, soil N:P ratio. The second set comprised the GIS variables, Proportion of wetland area remaining and Nitrate integrity, and the third set contained the soil and the GIS variables. The Bayesian Information Criteria (BIC) was used to select models.

Analyses produced by GRASP include:

- Scatterplots of each predictor variable in relation to each response variable.
- The GRASP regression models. Each model shows the curves of one response variable (y-axis) against the chosen predictor variables (x-axes). Inspection of these curves allows one to see whether the response variable is increasing or decreasing in any given range of the predictor variable, and whether it is a linear or non-linear relationship. Because the model is a multiple regression, the y-axis of each graph is the additive contribution of that variable to the model. Each curve also shows pointwise standard errors (dashed lines) that indicated the uncertainty about the relationship. The distribution of the observed points along the x-axis can be seen in the small hash marks along the x-axis.
- Model validation and cross-validation statistics. These analyses test the ability of the model to explain and predict the variable of interest. A value of >0.6 for the cross-validation statistic indicates the model is performing relatively well at explaining the variation in wetland ecological health.
- GRASP contribution graphs. These are bar graphs that show the relative importance (strength) of the predictor variables for predicting the response variables. For each predictor variable, the 'drop' and 'alone' contributions are graphed. The 'drop' contribution shows the amount of deviance lost when the variable is dropped from the final chosen model. The 'alone' contribution shows the amount of variance that is explained when the response variable is modelled against each predictor variable alone, without any of the other variables. Drop contributions are generally lower than alone contributions, because variables overlap in the variance that they predict. Note that the drop and alone contribution graphs have different scales on their x-axes.

The outputs of the GRASP analysis provide a powerful test of which predictor variables are useful to predict the different components of condition, and their relative importance. These models can be used to predict the wetland condition, given the values of the predictor variables, or to estimate the change in condition from a given shift in the predictor variable. This multivariate analytical approach was considered suitable for identifying which physico-chemical pressure, or set of pressures, are having the greatest impact on the condition of wetlands in New Zealand.

4 Results

4.1 Box plot summary of soil characteristics of different wetland types

The soil physico-chemical parameters that best separated the wetland types were pH, total carbon gravimetric, total phosphorus gravimetric, total nitrogen gravimetric, and N:P ratio (Figs 2–6). Along a gradient of bog, fen, swamp, and marsh (inverse of wetland development gradient; Clarkson et al. 2004), wetland soils generally increase in pH and phosphorus, and decrease in carbon and N:P ratios. Patterns for nitrogen were less clear, in particular for marshes, which had a wide range of nitrogen levels. Although most marshes are at the higher end of the nutrient and pH gradients, there are also oligotrophic marshes that are nutrient-poor, such as in sand dune ecosystems, and therefore a wide nutrient range for marshes can be expected. Gumland is a distinctive oligotrophic wetland type that has low soil pH, nitrogen, and carbon, exceptionally low phosphorus, and high N:P ratios.

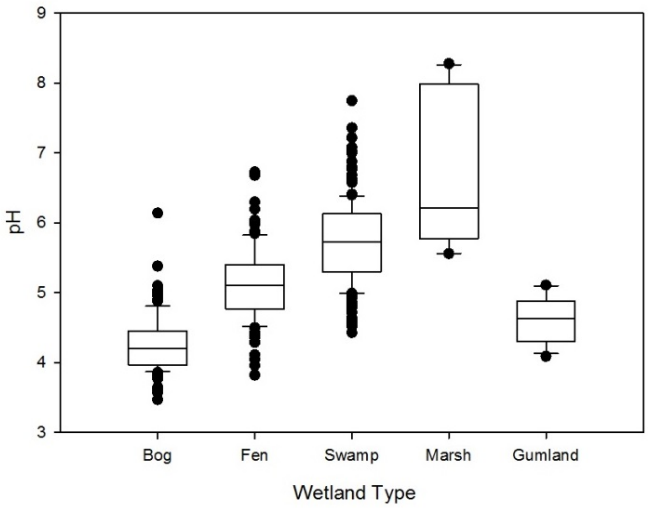

Figure 2 Box plots showing medians, and upper and lower quartiles for soil pH in wetland types. Bog *n* = 109; fen *n* = 105; swamp *n* = 146; marsh *n* = 12; gumland *n* = 13.

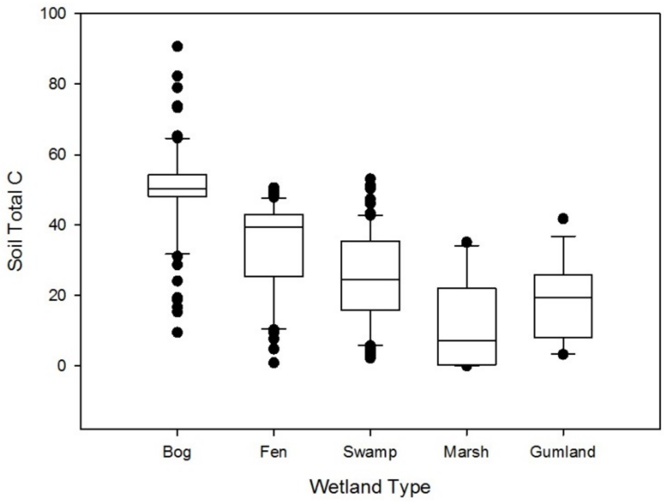

Figure 3 Box plots showing medians, and upper and lower quartiles for soil total C (gravimetric) in wetland types. Bog *n* = 81; fen *n* = 74; swamp *n* = 120; marsh *n* = 12; gumland *n* = 13.

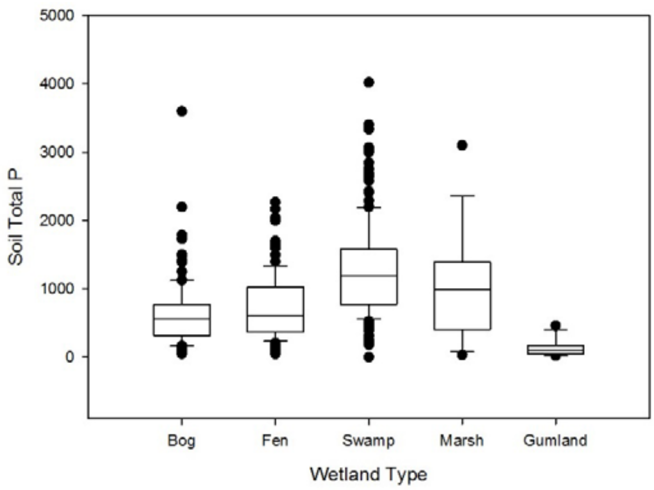

Figure 4 Box plots showing medians, and upper and lower quartiles for soil total P (gravimetric) in wetland types. Bog *n* = 110; fen *n* = 105; swamp *n* = 186; marsh *n* = 15; gumland *n* = 13.

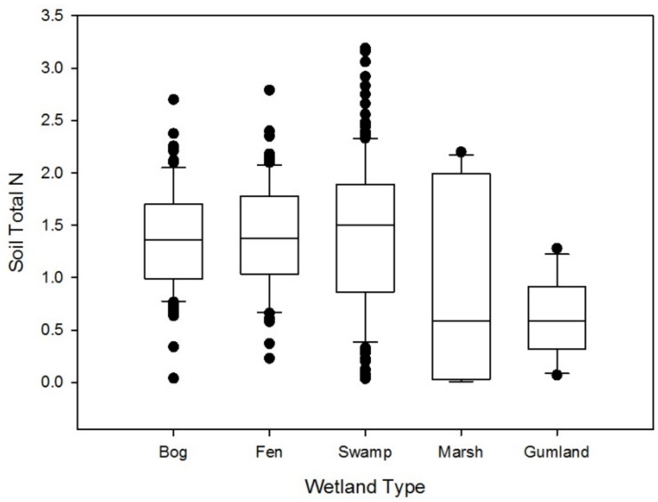

Figure 5 Box plots showing medians, and upper and lower quartiles for soil total N (gravimetric) in wetland types. Bog *n* = 112; fen *n* = 104; swamp *n* = 187; marsh *n* = 15; gumland *n* = 13.

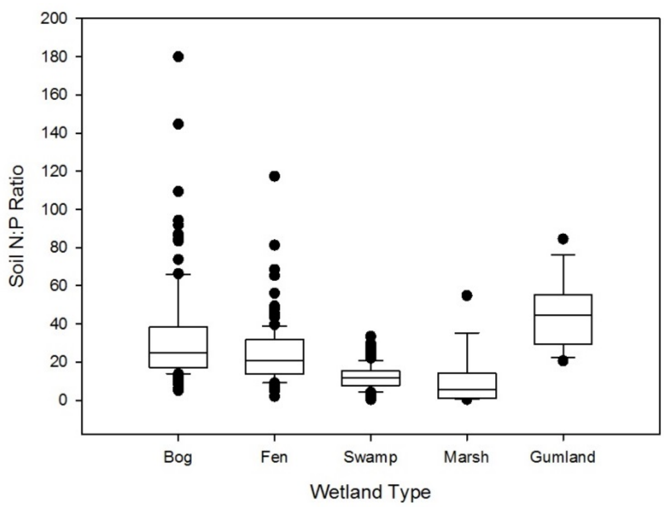

Figure 6 Box plots showing medians, and upper and lower quartiles for soil N:P ratios in wetland types. Bog *n* = 110; fen *n* = 104; swamp *n* = 186; marsh *n* = 15; gumland *n* = 12.

While the box plot summaries do not identify which variables are having an effect on wetland condition, they accurately characterise different wetland types. For example, bogs in New Zealand have pH <5.5 (except for one outlier). Therefore, if a bog is degraded to the point where pH is >5.5 this may signify an unacceptable change in ecological health.

Further investigation of the potential for the box-plot summaries to quantify D (Degraded) State/Band thresholds is proposed.

4.2 Tabular summaries for variables by wetland state and type

Means, 10th percentiles, and 90th percentiles for all the predictor variables analysed were summarised for excellent and good/moderate wetland condition states (WCI >20–25; >15–20) by wetland type (swamp, fen, and bog: Appendix 1). Of all the variables, the nutrient-based combinations of N and/or P, and proportion of wetland type remaining were best in reflecting differences between both wetland types and changes between different condition states. For example, mean values for soil total phosphorus (vol.) increased substantially for fens and swamps between the excellent and good/moderate states, while there were no differences evident for soil pH between the condition states (Appendix 1).

4.3 Scatterplots

The scatterplots of the Wetland condition index (WCI, or Total Condition) and/or Nutrient condition index and the physico-chemical variables showed some promising correlations; however, these were not always consistent between wetland types. Relationships for soil total nitrogen (gravimetric), soil total phosphorus (gravimetric) and Area remaining (PropAreaWetlandTypeRemain) are provided below (Figs 7–15).[1]

4.3.1 Soil total nitrogen (gravimetric)

A negative relationship between Soil total nitrogen (gravimetric) and Wetland condition index was observed for all three wetland types analysed (Figs 7–9). Although the correlations were typically weak, this identifies the potential for soil total nitrogen (gravimetric) to influence wetland condition in association with other physico-chemical variables.

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[1] All scatterplots are supplied as a zip file, and are available from the authors.

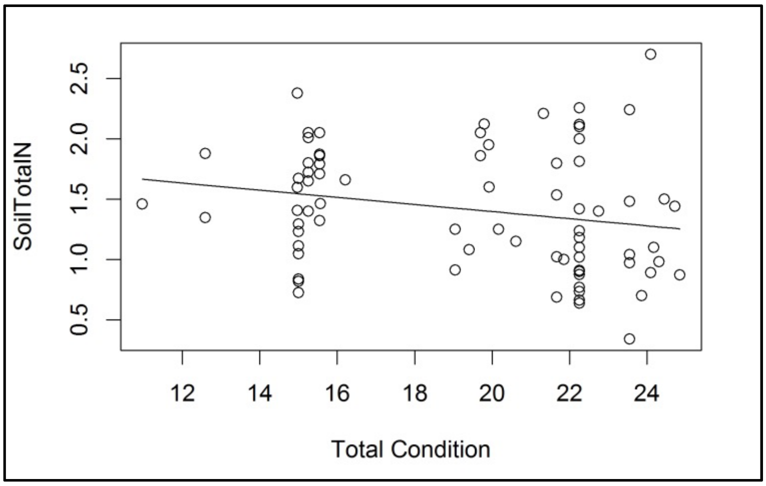

Figure 7 Scatterplot of Soil total nitrogen (gravimetric) in relation to Wetland condition index (Total Condition) for bogs; wetland *n* = 27; plot *n* = 75.

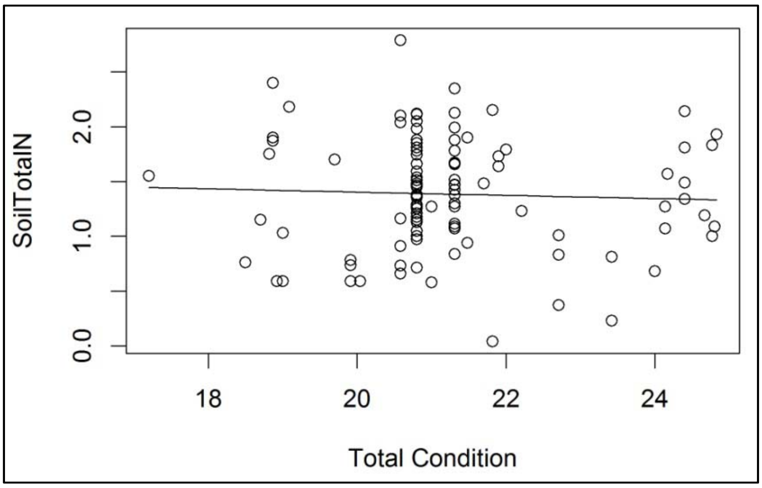

Figure 8 Scatterplot of Soil total nitrogen (gravimetric) in relation to Wetland condition index (Total Condition) for fens; wetland *n* = 31; plot *n* = 103.

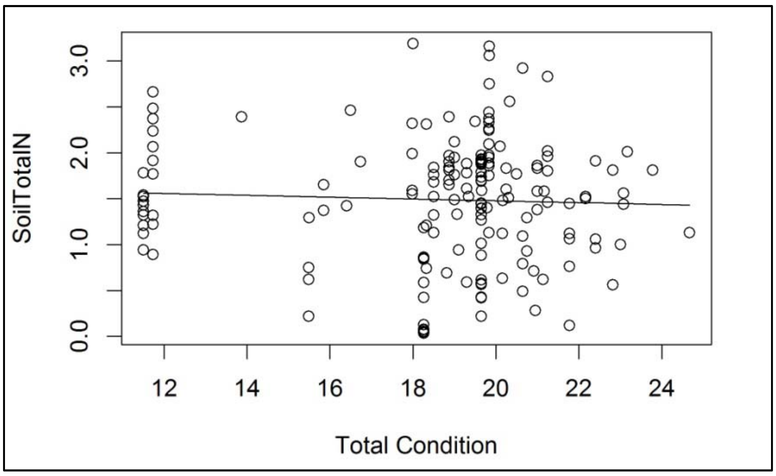

Figure 9 Scatterplot of Soil total nitrogen (gravimetric) in relation to Wetland condition index (Total Condition) for swamps; wetland *n* = 54; plot *n* = 167.

4.3.2 Soil total phosphorus (gravimetric)

A negative relationship between Soil total phosphorus (gravimetric) and wetland condition was observed for fens and swamps (Figs 11–12). The slight positive correlation for bogs (Fig. 10) may be due to the lack of data from bogs subjected to elevated P loads and the influence of outlier data points. Although the correlations were sometimes weak, this identifies the potential for Soil total phosphorus (gravimetric) to influence wetland condition in association with other physico-chemical variables.

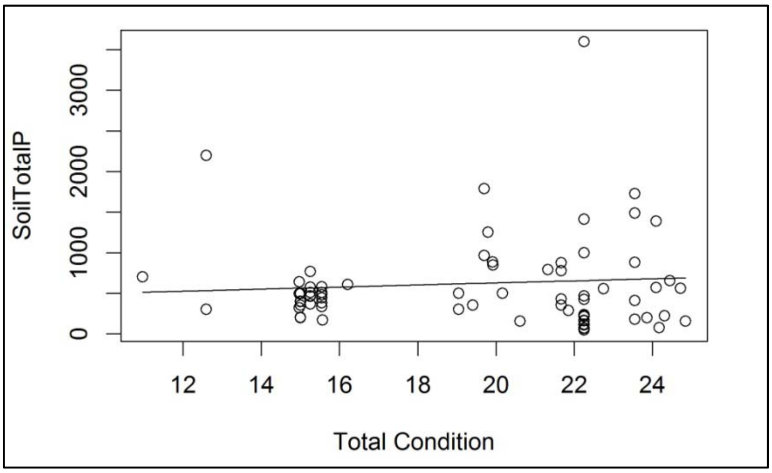

Figure 10 Bogs: scatterplot of soil total phosphorus (gravimetric) in relation to Wetland condition index (Total Condition); wetland *n* = 27; plot *n* = 74.

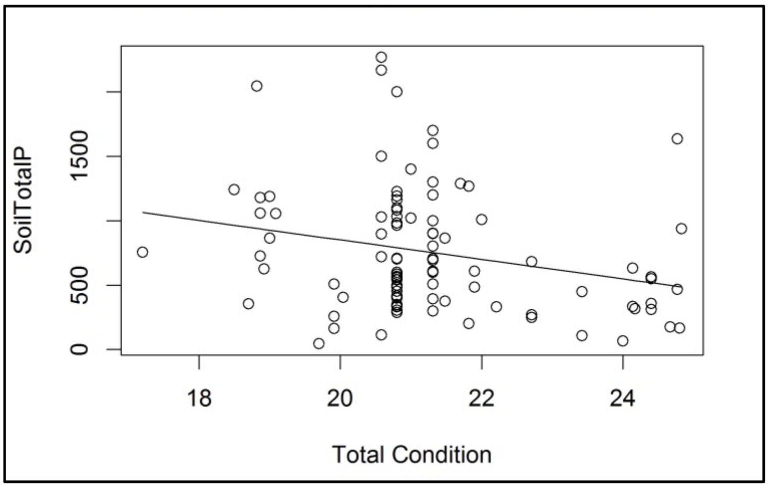

Figure 11 Fens: scatterplot of soil total phosphorus (gravimetric) in relation to Wetland condition index (Total Condition); wetland *n* = 31; plot *n* = 103.

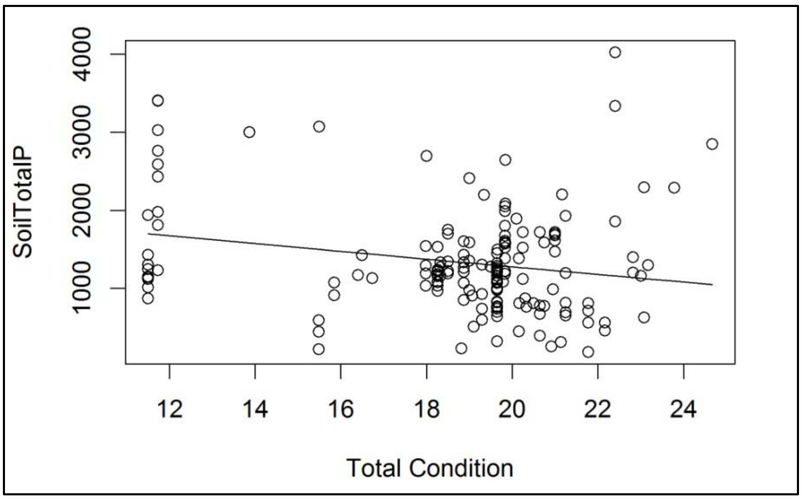

Figure 12 Swamps: scatterplot of soil total phosphorus (gravimetric) in relation to Wetland condition index (Total Condition); wetland *n* = 54; plot *n* = 166.

4.3.3 Area remaining

For bog, fen and swamp, the Wetland condition index and Area remaining (PropAreaWetland TypeRemain) showed a positive relationship, indicating that condition decreases with wetland loss (Figs 13–15).

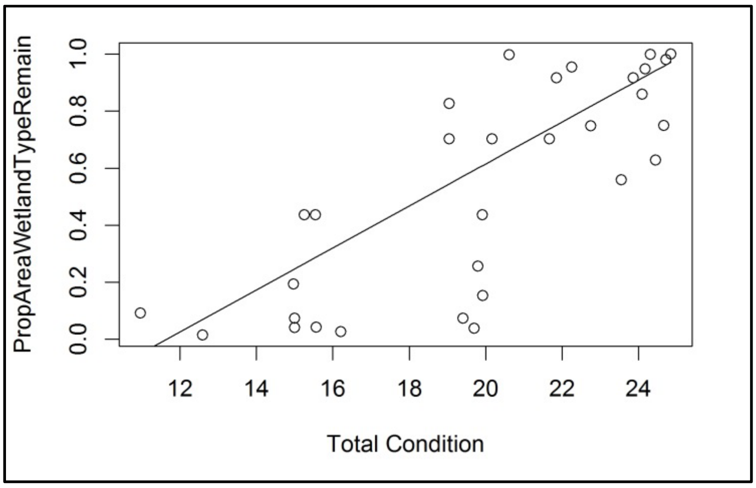

Figure 13 Bogs: scatterplot of Area remaining in relation to Wetland condition index (Total Condition); wetland *n* = 28; plot *n* = 129.

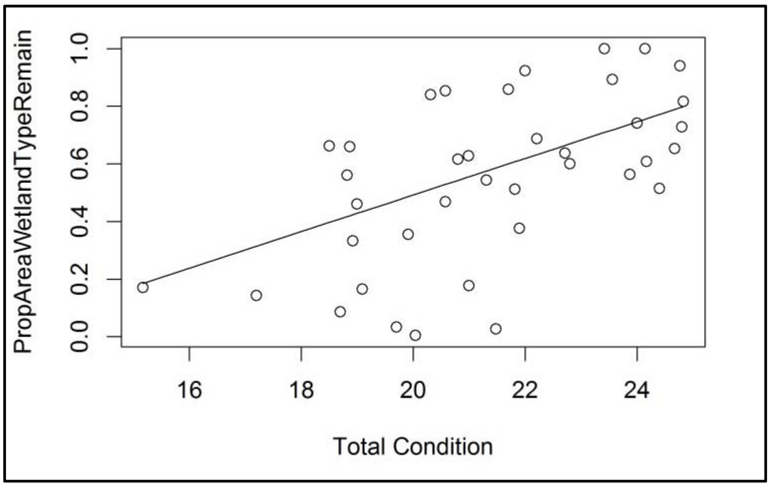

Figure 14 Fens: scatterplot of Area remaining in relation to Wetland condition index (Total Condition); wetland *n* = 37; plot *n* = 218.

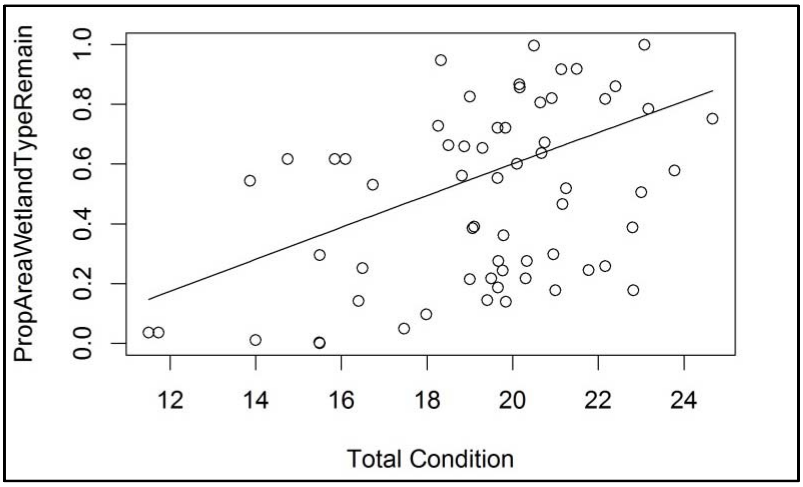

Figure 15 Swamps: scatterplot of Area remaining in relation to Wetland condition index (Total Condition); wetland *n* =58; plot *n* =194.

4.4 GRASP analysis

The significance and explanatory power of the individual relationships (section 4.3) were not assessed. Instead, multiple regressions were used in the generalised additive models to assess a range of variables together, and find which are significant predictors of condition, and their joint explanatory power to explain condition for each wetland type.

The GRASP analysis outputs for the three sets of predictor variables (soils only, GIS only, and soils and GIS) are summarised in Tables 3–5. The predictor variables that were most useful in predicting the different components of wetland condition (response variables) were Soil total phosphorus:gravimetric (and/or Soil total phosphorus:volumetric); Area remaining, Nitrate integrity, Soil total nitrogen:volumetric (and/or Soil total nitrogen:gravimetric); and Soil N:P ratio. Within the models, the higher the cross-validation values, the more robust the model, and in general, cross-validation values should not fall below 0.5. Wetland condition index (WCI or Total condition) consistently yielded high to very high cross-validation values for all wetland types and for the predictor variables, particularly the GIS only (Table 4) and soils/GIS (Table 5) variable sets. Overall, the 'soil and GIS' predictor variable set had a greater suite of predictor variables, a greater number of cross-validations, and higher cross-validations, indicating more robust models. Within this set, the Wetland condition index yielded the highest cross-validation values of all the response variables within each of the wetland types: bog (0.89), fen (0.662), and swamp (0.85) (Table 5). Therefore, the remainder of this report focuses on development of Wetland condition index as the response variable with high potential for describing ecosystem health for use in national and regional policy, such as future iterations of the NPS-FM (Ministry for the Environment 2014). We also investigate the application of the NOF template for defining limits, or states, for individual attributes.

It should also be noted that the Wetland ecological integrity index (FENZ.EI) was shown to be a good predictor of the Wetland condition index (WCI) for bogs, fens and swamps (Table 4), indicating the GIS-derived wetland ecological integrity index scores (from the FENZ national database) can probably be used in cases where the field-based WCI scores for individual wetlands are not available.

Table 3 Summary of GRASP models based on soil predictor variables. Predictor variables in each row are ranked according to contribution to model. Trend: pos = positive, neg = negative, mix = mixed/not clear

Wetland Type	Reponse Variable	Model Cross-Validation	Model Validation	Predictor Variables										
				n	Soil NtoP	Trend	Soil TotalP.Vol	Trend	Soil TotalP	Trend	Soil TotalN.Vol	Trend	Soil TotalN	Trend
Bog	FENZ.EI	val. Failed	val. failed	1			1	gen. neg						
	NutrientCondition	0.566	0.662	3					3	pos	1	neg	2	pos
	PropCovNative	0.854	0.881	1					1	neg				
	PropSppNative	0.442	0.589	1					1	neg				
	TotalCondition	0.599	0.721	2			2	mix			1	neg		
	TotalRichness	0.232	0.534	2					1	mix			2	gen. pos
Fen	FENZ.EI	no model	no model											
	NutrientCondition	no model	no model											
	PropCovNative	val. failed	val. failed	1	1	pos								
	PropSppNative	val. failed	val. failed	1			1	neg						
	TotalCondition	0.369	0.425	2	1=	pos					1=	neg		
	TotalRichness	0.628	0.676	3			1	mix	3	pos	2	pos		
Swamp	FENZ.EI	no model	no model											
	NutrientCondition	0.216	0.243	1					1	neg				
	PropCovNative	no model	no model											
	PropSppNative	val. failed	val. failed	1	1	pos								
	TotalCondition	0.185	0.219	1					1	neg				
	TotalRichness	0.39	0.518	3					1	mix	3	pos	2	mix

Table 4 Summary of GRASP models based on GIS predictor variables. Predictor variables in each row are ranked according to contribution to model. Trend: pos = positive, neg = negative, gen = generally, mix = mixed/not clear

Wetland Type	Reponse Variable	Model Cross-Validation	Model Validation	Predictor Variables						
				n	FENZ.EI	Trend	FENZ.EI.-Nitrate	Trend	PropAreaWetland-TypeRemain	Trend
Bog	NutrientCondition	0.814	0.848	3	2=	pos	2=	pos	1	pos
	PropCovNative	no model	no model							
	PropSppNative	no model	no model							
	TotalCondition	0.91	0.931	3	2	gen pos	3	pos	1	gen pos
	TotalRichness	0.193	0.544	3	3	pos	1	gen neg	2	mix
Fen	NutrientCondition	0.768	0.803	2	1	pos			2	mix
	PropCovNative	no model	no model							
	PropSppNative	no model	no model							
	TotalCondition	0.701	0.881	2	1	gen pos	2	mix		
	TotalRichness	0.345	0.524	2	2	mix			1	mix
Swamp	NutrientCondition	0.768	0.826	3	1	mix	3	mix	2	mix
	PropCoverNative	no model	no model							
	PropSppNative	no model	no model							
	TotalCondition	0.887	0.893	2	1	mix			2	mix
	TotalRichness	0.464	0.537	2	1	mix			2	mix

Table 5 Summary of GRASP models based on soil and GIS predictor variables. Predictor variables in each row are ranked according to contribution to model. Trend: pos = positive, neg = negative, mix = mixed/not clear. Low cross-validation values for Bog total richness indicate a model that validates well but is unstable under cross-validation

Wetland Type	Reponse Variable	Model Cross-Validation	Model Validation	Predictor Variables														
				n	Soil-NtoP	Trend	Soil-TotalP.Vol	Trend	Soil-TotalP	Trend	Soil-TotalN.Vol	Trend	Soil-TotalN	Trend	FENZ.EI.-Nitrate	Trend	PropAreaWet-landTypeRemain	Trend
Bog	FENZ.EI	0.041	0.221	1			1	gen neg										
	NutrientCondition	0.826	0.874	3			2=	mix			2=	neg					1	pos
	PropCovNative	0.88	0.907	1					1	neg								
	PropSppNative	0.48	0.647	1					1	neg								
	TotalCondition	0.89	0.92	4			4	mix			3	neg			2	mix	1	pos
	TotalRichness	0.1	0.701	4			2	mix			3	gen neg			1	gen neg	4	pos
Fen	FENZ.EI	0.39	0.395	2	2	gen pos											1	mix
	NutrientCondition	0.352	0.665	2	1	gen pos									2	mix		
	PropCovNative	val. failed	val. failed	2	1	pos									2	gen neg		
	PropSppNative	val. failed	val. failed	1							1	neg						
	TotalCondition	0.662	0.689	3	2	pos									3	mix	1	pos
	TotalRichness	0.661	0.748	3			2	mix			3	pos					1	mix
Swamp	FENZ.EI	0.521	0.528	1													1	pos
	NutrientCondition	0.743	0.806	3					3	neg					2	mix	1	mix
	PropCovNative	0.299	0.351	2			1	neg	2	neg								
	PropSppNative	0.468	0.688	1	1	pos												
	TotalCondition	0.85	0.875	3					2	gen neg					3	pos	1	mix
	TotalRichness	0.507	0.613	4					1	mix	3	pos	2	mix	4	pos		

4.4.1 Bog: wetland condition index

The model for Wetland condition index within the bog wetland type is presented in Figure 16 (cross validation = 0.89). Four variables contribute to the model in the order of Area remaining > Nitrate integrity > Soil total nitrogen:volumetric > Soil total phosphorus: volumetric (Fig. 16). In general, wetland total condition increases with proportion of wetland area remaining and decreases with increasing Soil total nitrogen:volumetric. The trends for Nitrate integrity and Soil total phosphorus:volumetric are more complex. Within the model, Area remaining contributes approximately twice as much as Nitrate integrity and three times as much as Soil total nitrogen: volumetric and Soil total phosphorus: volumetric to the model (see left hand bar charts in Fig. 17).

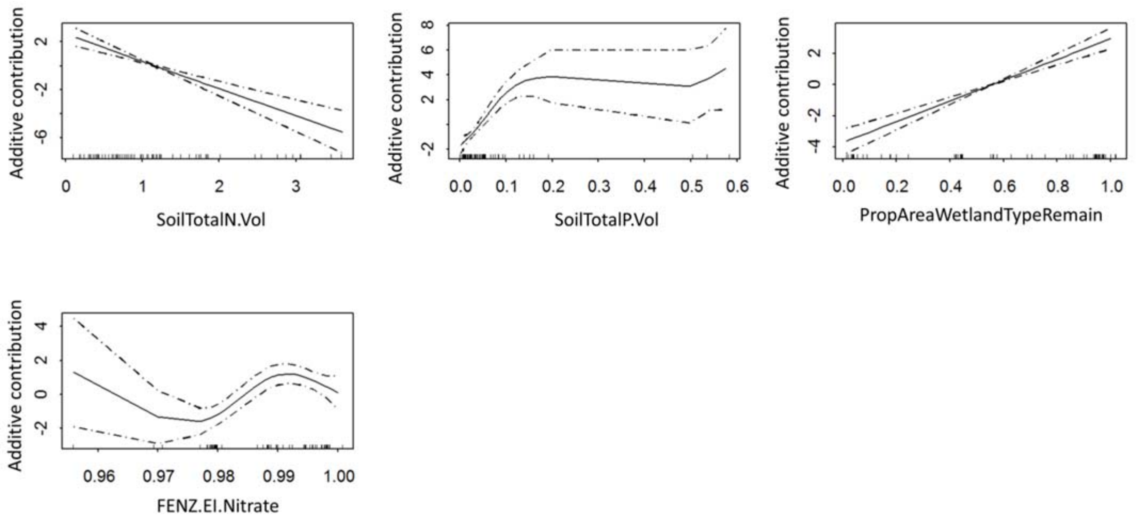

Figure 16 Bogs: GRASP model of Wetland condition index against the four chosen predictor variables. Soils and GIS predictor data set. See section 3.8.3 for explanation of graphs.

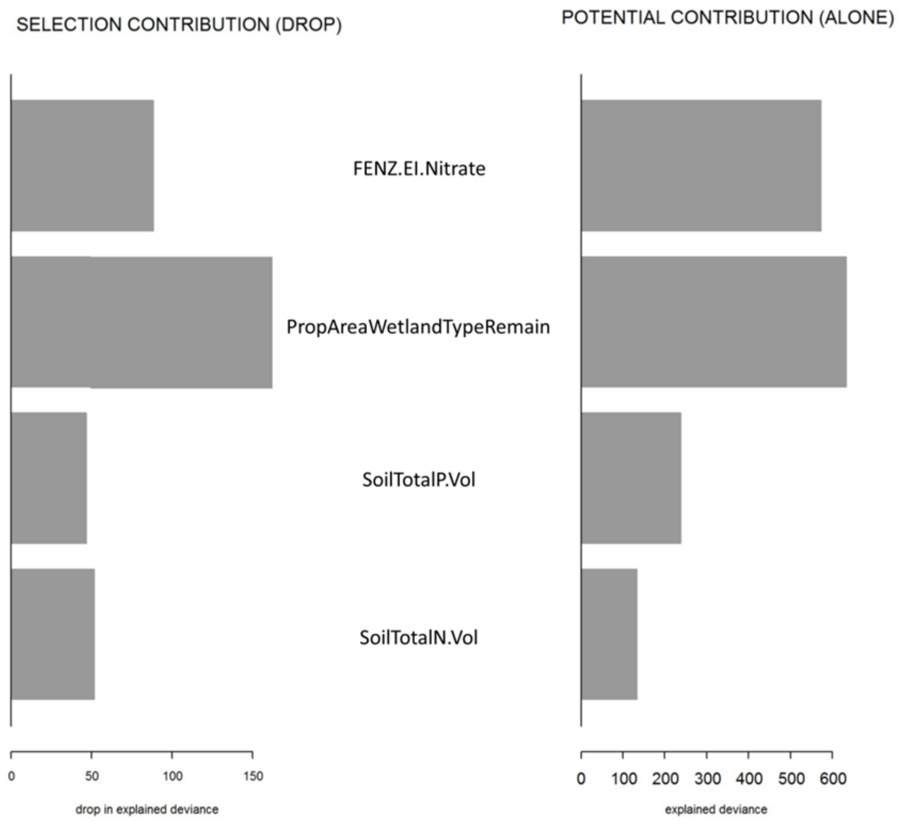

Figure 17 Bogs: GRASP contribution graphs showing contribution of predictor variables to the Wetland condition index model (Selection Contribution). Soils and GIS predictor data set. See section 3.8.3 for explanation of graphs.

4.4.2 Fen: wetland condition index

The model for Wetland condition index within the fen wetland type is presented in Figure 18 (cross-validation = 0.66). Three variables contribute to the model in the order of Area remaining > Soil N:P ratio> Nitrate integrity (Fig. 19). The dominant contribution is from Area remaining. Wetland condition increases with Area remaining (although not linearly), Nitrate integrity and Soil N:P ratio. Increases in Soil N:P ratio may be indicative of lower soil P levels in good condition wetlands.

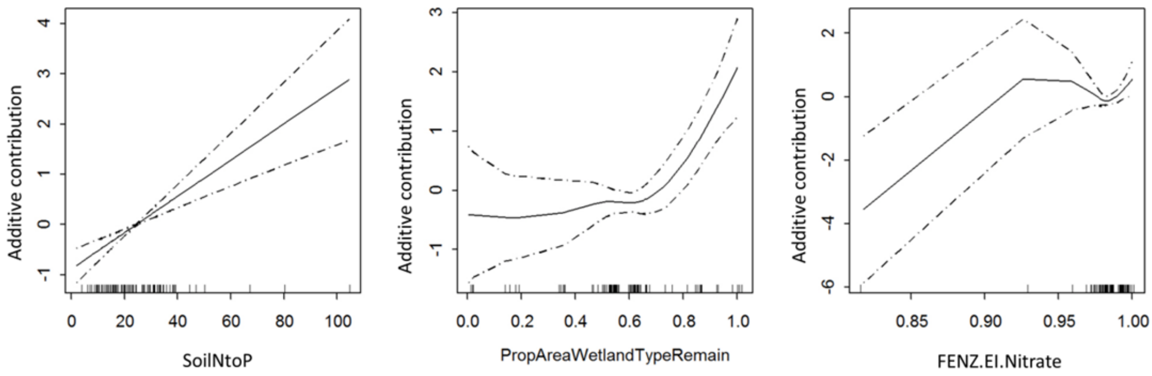

Figure 18 Fens: GRASP model of Wetland condition index against the three chosen predictor variables. Soils and GIS predictor data set. See section 3.8.3 for explanation of graphs.

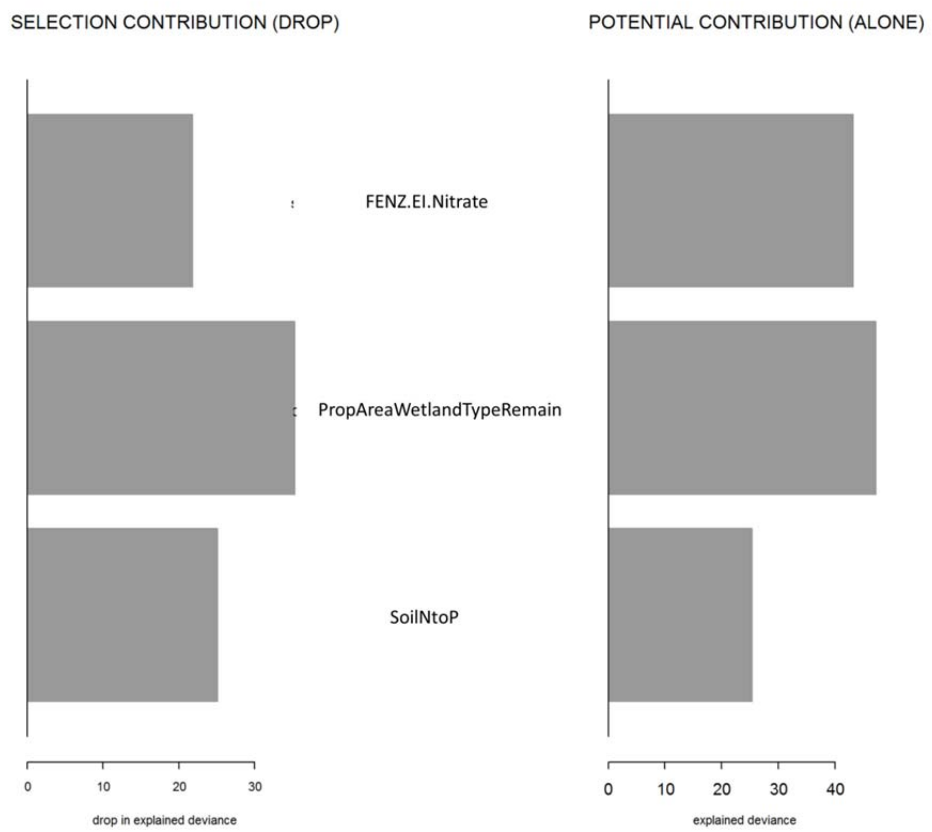

Figure 19 Fens: GRASP bar charts showing contribution of predictor variables to the Wetland condition index model (Selection Contribution). Soils and GIS predictor data set. See section 3.8.3 for explanation of graphs.

4.4.3 Swamp: wetland condition index

The model for Wetland condition index within the swamp wetland type is presented in Figure 20 (cross-validation = 0.85). Three variables contribute to the model in the order of Area remaining > Soil total phosphorus (gravimetric) > Nitrate integrity (Fig. 21); however, the overwhelmingly dominant contribution is from Area remaining. In general Wetland condition index increases with Area remaining (although not linearly) and Nitrate integrity, and decreases with Soil total phosphorus (gravimetric) (again not linearly).

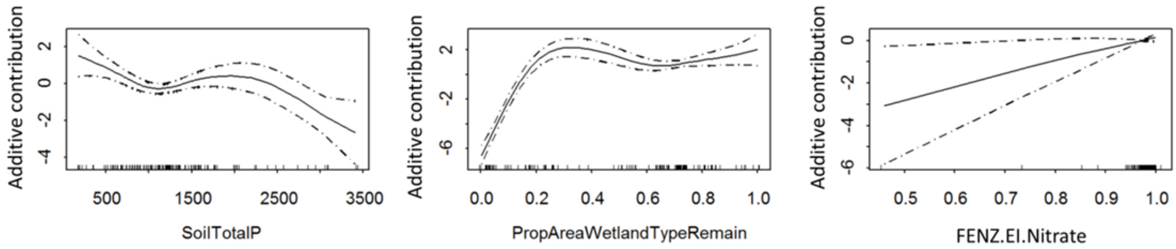

Figure 20 Swamps: GRASP model of Wetland condition index against the three chosen predictor variables. Soils and GIS predictor data set. See section 3.8.3 for explanation of graphs.

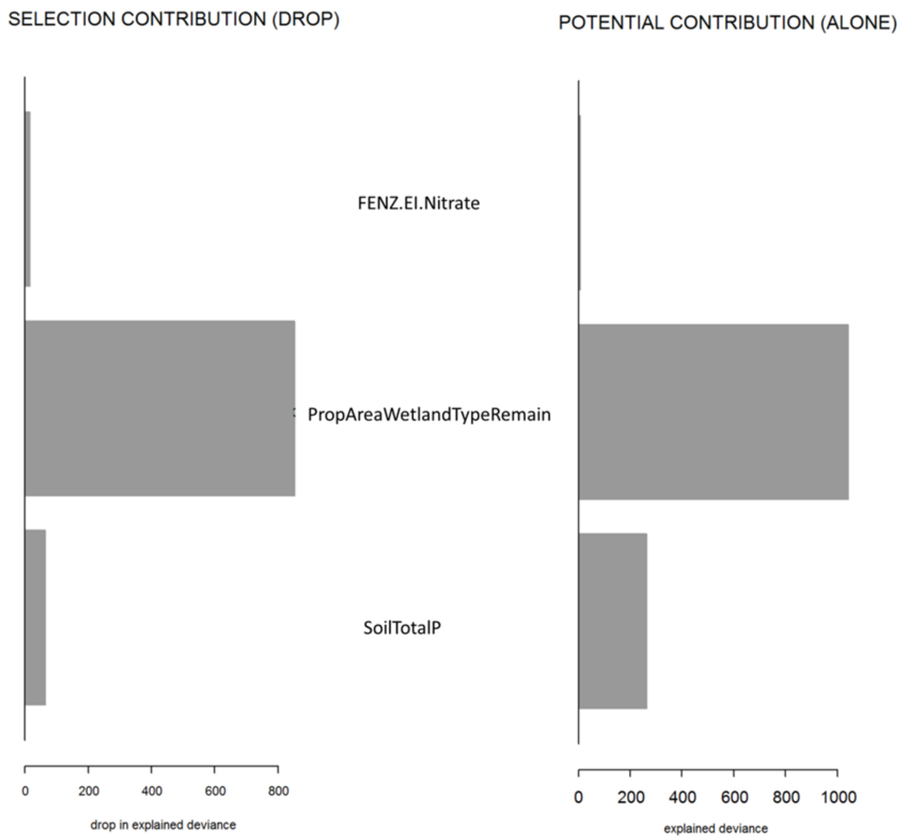

Figure 21 Swamps: GRASP bar charts showing contribution of predictor variables to the Wetland condition index model (Selection Contribution). Soils and GIS predictor data set. See section 3.8.3 for explanation of graphs.

4.5 Potential attributes in scoping limits for freshwater wetlands

This interim report aims to present a robust analytical approach for quantifying limits for maintaining the ecological health of freshwater wetlands. Based on the descriptive and analytical results described above, a subset of potential attributes is defined. The attributes are limited to the bog and swamp wetland types; however, the approach can be applied to fens and other wetland types in the future. The potential attributes may also be refined as additional data becomes available from impacted wetlands or under-represented geographical regions.

The following sections (4.5–4.7) provide an indication of the how model outputs can be utilised for the development of attributes for wetland limit setting. The NOF attributes for lakes and rivers (Ministry of the Environment 2014) comprise single physico-chemical variables such as N or P levels. However, using a single, independent attribute does not apply easily to wetlands because loss of original extent is an overriding driver of wetland degradation, and due to the unique combination of cumulative pressures at each wetland site that impacts on condition.

The interim wetland attributes we have identified operate in a multivariate context, which reflects their combined effect on the condition of portions of wetlands that remain. For such attributes to be applied in national and regional policy it may be required to develop multi-variate look-up tables based on the GRASP analysis, in which measured values for the relevant attributes at a wetland are entered, and multi-variate algorithms from GRASP (e.g. Fig. 20) used to calculate an overall attribute state.

4.5.1 Potential attributes and limits for ecosystem health: bog

Ecosystem health in bogs, as measured by Wetland condition index, is represented by a multivariable table, with four attributes listed in order of predictive reliability: Area remaining, Nitrate integrity, Soil total nitrogen:volumetric, and Soil total phosphorus: volumetric (Table 6).

The ranges for Attribute States of Excellent and Moderate-Good are the 10th and 90th percentiles in Appendix 1, apart from the maximum values of 1 (i.e. 100% condition) for the Excellent States for Area remaining and Nitrate integrity. The preliminary Attribute States identify that loss of wetland area, elevated nitrogen, and altered phosphorus are associated with negative changes in the ecological health of bogs. These pressures often act in combination, therefore individual attribute component limits should not be used in isolation from the model. Further work to clarify the values for total phosphorus is required.

Table 6 Preliminary limits for maintaining the ecological health of bogs based on multiple variables (Area remaining, Nitrate integrity, Soil total nitrogen: volumetric and Soil total phosphorus: volumetric) derived from GRASP model outputs

Value	Ecosystem Health				
Freshwater Body Type	Wetlands (Bog)				
Attribute	**PropAreaWetland TypeRemaining**	**FENZ.EI. Nitrate**	**SoilTotalN. Vol**	**SoilTotalP. Vol**	
Attribute Unit	0–1 (1=100%)	0–1 (1=100%)	mg/cm^3	mg/cm^3	
Attribute State AS	**Numeric AS**	**Numeric AS**	**Numeric AS**	**Numeric AS**	**Narrative Attribute State**
Excellent	0.58–1.0	0.99–1.0	0.27–1.95	?	Wetland maintains ecological function
Moderate-Good	0.15–0.58	0.98–0.99	0.87–2.03	?	Ecological function slightly-moderately impacted
National Bottom Line					
Degraded	?	<0.98	>2.03	?	Ecological function approaching acute impact level

4.5.2 Potential attributes and limits for ecosystem health: swamp

Ecosystem health in swamps, as measured by Wetland condition index, was able to be represented by a single-attribute (Table 6). As Area remaining was the overwhelmingly dominant contributor to the model (Fig. 21) and cross-validation was high (0.85), we have not included the other two predictor variables (Soil total phosphorus (gravimetric), Nitrate integrity) for simplification purposes. However, this may be refined once more data from poorer condition swamps are incorporated into the model and the table is completed. Again, the Attribute State ranges are the 90th percentiles in Appendix 1, apart from the Attribute State Excellent having a maximum value of 1 (i.e. no wetland loss). In this instance, the Moderate–Good state has a maximum proportion remaining of 0.73 (Table 6). However, these ranges are likely to change with more data.

Table 6 Preliminary limits for maintaining the ecological health of swamps – based on the Area remaining variable (PropAreaWetlandTypeRemain) derived from GRASP model outputs

Value	Ecosystem Health	
Freshwater Body Type	Wetlands (Swamp)	
Attribute	**Area Remaining (PropAreaWetlandTypeRemain)**	
Attribute Unit	0–1 (1 = 100%)	
Attribute State	**Numeric Attribute State**	**Narrative Attribute State**
Excellent	>0.73	Wetland maintains ecological function
Moderate-Good	?	Ecological function slightly–moderately impacted
National Bottom Line		
Degraded	?	Ecological function approaching acute impact level

4.5.3 Limitations to Area remaining attribute

Although the Area remaining attribute has shown great potential in reliably predicting wetland condition, there are some limitations to its assessment and application. In general, wetland condition, i.e. wetland structure, composition and function, decreases with wetland loss. However, the numeric ranges for the states are currently very wide, e.g. the 10th percentile for the Swamp State of Excellent is a very low 0.18 (18% of historic area). This could be interpreted that further losses within a swamp could be acceptable, provided the swamp still remains in the Excellent State. Although this can be refined by narrowing the ranges for the States, as well as including more data from more degraded wetlands, there would still be potential for wetland loss within a State. This would occur unless *no net loss of wetlands* (as regulated in USA) is also an objective in itself, given the magnitude of their historical conversion to other land uses.

4.6 Future development of attributes

Further refinementof attributes should be a 2-scale process, that is:

- Development of an attribute focused on the proportion of wetland area remaining, with limits developed in relation to drainage and clearing of wetland habitat.
- Modelling of physico-chemical attributes (e.g. soil phosphorus levels) following the suggested analytical approach in this study.

The first step reflects the overriding importance of proportion of wetland type remaining in predicting the condition at an individual wetland scale, combined with the magnitude of the loss of historic wetland extent at a national scale (90% loss since European settlement; Ausseil et al. 2008). Management actions to prevent further loss in extent and condition of wetlands may include rules or guidance on drainage and clearance, both within and adjacent to wetlands, in policy and plans. Wetland area should be at least maintained, or increased by restoration of former wetland areas.

The second step reflects the influence of physico-chemical (and other) variables, e.g. soil nutrient inputs, likely to degrade wetland condition. Increased nutrients are usually a result of land-use activities, such as agricultural practices, and can also be managed through implementation of policy and plans.

Attribute examples have been provided in this interim report for bogs and swamps. There is the potential to characterise other variables (e.g. Soil total phosphorus (gravimetric), Soil total nitrogen (gravimetric), as well as expanding on the Wetland condition index variable for other states (Moderate and Degraded) and for other wetland types (particularly fens).

A key gap in the current data used for these analyses is the paucity of data on lower condition wetlands. The current wetland information comes largely from wetlands of relatively high/moderate condition, usually over a total condition of 15. This means our results are poorly informed by quantitative information from poor condition wetlands.

Other key gaps include the checking of outlier data points within the dataset, revisiting the ranges for the NOF States of A, B, C and D (ie Excellent, Good, Moderate, Degraded), rerunning the GRASP analyses for key variables, and constructing the Excel look-up tables for multi-variable attributes. This will then require testing and verification in a catchment or area which has, or will provide, comprehensive data for the full range of wetlands, e.g. develop a scoping project in partnership with a regional council.

5 Conclusions

- There is a significant resource of data from plot-based vegetation surveys, soil chemistry analyses, wetland mapping, and GIS models (FENZ) from which to quantify limits to maintain the ecological health of wetlands.
- Data are most comprehensive for bog, fen, and swamp wetland types, although information on gumlands and marshes is also available.
- Application of a three-stage analytical approach – from simple box-plots and tabular summaries of physico-chemical variables, to scatterplots of ecosystem health variables (response variables) against predictor variables, to statistical modelling – is considered a robust methodology for quantifying wetland limits.
- Analysis has revealed a subset of variables that may be suitable for setting limits to maintain the condition of wetland ecosystems in New Zealand, in particular the proportion of area of wetland type remaining, nitrate integrity, and soil nitrogen and phosphorus levels.
- Additional work is needed to develop the variables so they are suitable for broad-scale application, for example, in a revised NOF that includes wetlands. This includes obtaining a more comprehensive and robust dataset, refining the GRASP analysis, and working with regional councils and central government agencies involved in the freshwater reforms programme.
- Further development of attributes for wetland limit setting for national and regional policy should involve analysis at two different scales: first, limits that relate to the proportion of the wetlands remaining; and second, limits that relate to the key physico-chemical pressures on remaining wetlands.

6 Recommendations

We recommend further refinement and development according to the following steps and areas of work:

- Present the preliminary results at a meeting between the authors and a small group of freshwater policy experts, e.g. MfE, DOC, for feedback and guidance on how to progress the work. This will include discussions on the development of:
  - a two-scale approach: 1) original wetland: area remaining, and 2) current wetland: physico-chemical variables
  - attributes comprising multimetric variables
  - single biotic response measures, e.g. Native species cover or Total richness (which yielded some robust validations) instead of an overall wetland condition index
  - breakpoint refinement for the states to inform determination of the A, B, C, and D states (based on the Excellent, Moderate–Good, Degraded States in this report).
- Incorporate wetland monitoring data from other councils, e.g. Auckland Council, Environment Bay of Plenty, into the Landcare Research database, and target additional wetland survey, especially in poorer condition wetlands, to help address some significant information gaps in the analysis.
- Database clean-up and refinement:
  - investigate and correct, if appropriate, any outlier data in the database
  - refine the Nitrate integrity variable and/or incorporate the recently updated nitrate leaching component of CLUES (from NIWA)
  - develop and integrate other CLUES outputs (e.g. sediment load and phosphorus load) as predictor variables
- Rerun the analyses and produce look-up tables in Excel spreadsheets for multi-variables, based on the GRASP equations and metrics. Wetland condition and state are assessed for each wetland by entering the relevant wetland physico-chemical data into the Excel tables.
- Partner with a regional council to test the approach within the full range of wetlands in a sub-region.
- If appropriate, expand the analysis to hydrological modification by scoping case studies in wetlands subject to changes in water level, to help inform the future implementation of an attribute for water level.
- Refine attribute tables and approach, and present the results to MfE and the appropriate Science Review Panel.

7 Acknowledgements

We gratefully acknowledge the assistance of Robbie Price and Neil Fitzgerald for extracting data from the database and merging the different data sets. We also thank Rosemary Miller and Paula Warren for reviewing and improving the report, and Anne Austin for editing. The project was funded by Department of Conservation (contract INV4594) and supplemented by Ministry of Business Innovation and Employment (contract C09X1002).

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Appendix 1 – Variable means for Wetland condition index (TotalCondition) states by wetland type

TotalCondition	Type	Number	TotalCondition	NutrientCondition	SoilpH				SoilvonPost				SoilTotalN				SoilTotalN.Vol			
State		*n*	mean	mean	perc10	perc90	mean	*n*	perc10	perc90	mean	*n*	perc10	perc90	mean	*n*	perc10	perc90	mean	*n*
>20-25	Bog	16	22.711	4.671	3.948	5.008	4.494	39	1.5	4.8	2.9	23	0.697	2.136	1.282	39	0.266	1.949	0.921	35
>20-25	Fen	27	21.481	4.058	4.567	5.609	5.068	88	3.0	9.0	5.0	70	0.725	2.043	1.398	88	0.394	2.169	1.328	88
>20-25	Swamp	28	21.429	4.352	4.846	6.394	5.658	49	0.0	10.0	3.6	8	0.627	2.013	1.416	48	0.652	3.169	1.791	45
>15-20	Bog	9	16.070	3.892	3.645	4.527	4.128	22	3.0	7.0	4.2	51	1.257	2.050	1.690	22	0.866	2.026	1.390	22
>15-20	Fen	11	16.183	3.667	4.428	6.488	5.457	15	0.0	8.0	4.1	8	0.590	2.068	1.305	15	0.850	3.120	2.950	11
>15-20	Swamp	31	18.686	3.792	4.984	6.130	5.589	49	0.0	7.3	2.8	18	0.427	2.324	1.487	98	0.719	3.267	1.859	96

TotalCond	Type	SoilBD				SoilTotalP				SoilTotalP.Vol				SoilNtoP				SoilTotalC			
State		perc10	perc90	mean	*n*	perc10	perc90	mean	*n*	perc10	perc90	mean	*n*	perc10	perc90	mean	*n*	perc10	perc90	mean	*n*
>20-25	Bog	0.036	0.092	0.063	35	102.40	1427.60	648.64	39	0.005	0.114	0.062	35	11.213	92.309	45.256	39	46.28	53.68	49.42	23
>20-25	Fen	0.049	0.153	0.105	88	295.10	1330.00	747.16	88	0.016	0.176	0.083	88	11.024	37.637	24.776	88	12.70	47.72	34.57	60
>20-25	Swamp	0.060	0.250	0.164	46	452.60	2235.20	1277.62	47	0.047	0.376	0.189	45	5.415	24.872	14.024	47	8.90	42.70	26.19	44
>15-20	Bog	0.060	0.120	0.082	22	338.60	957.20	616.64	22	0.023	0.088	0.053	22	19.105	42.275	33.210	22	45.79	51.20	49.45	22
>15-20	Fen	0.080	0.510	0.231	11	200.40	1219.60	804.40	15	0.031	0.319	0.130	11	7.102	40.180	42.378	15	10.44	40.60	28.34	12
>15-20	Swamp	0.061	0.629	0.212	96	724.90	1715.00	1240.67	98	0.055	0.751	0.247	96	4.431	19.940	12.839	98	11.10	43.15	29.09	49

TotalCond	Type	SoilTotalC.Vol				FENZ.EI				FENZ.EI.Nitrate				PropSppNative				PropAreaWetlandTypeRemain			
State		perc10	perc90	mean	*n*	perc10	perc90	mean	*n*	perc10	perc90	mean	*n*	perc10	perc90	mean	*n*	perc10	perc90	mean	*n*
>20-25	Bog	17.92	47.76	29.54	19	0.234	0.828	0.429	44	0.988	0.999	0.973	44	0.86	1.00	0.95	45	0.58	0.95	0.86	44
>20-25	Fen	19.44	42.21	29.59	60	0.226	0.795	0.343	161	0.978	0.995	0.981	161	0.79	1.00	0.93	159	0.54	0.84	0.59	161
>20-25	Swamp	15.07	52.02	29.81	42	0.225	0.928	0.515	51	0.935	0.993	0.902	51	0.43	1.00	0.81	50	0.18	0.92	0.57	51
>15-20	Bog	30.14	61.27	40.80	22	0.346	0.346	0.352	51	0.979	0.989	0.980	51	0.80	1.00	0.94	51	0.15	0.44	0.40	51
>15-20	Fen	33.57	108.89	66.81	8	0.304	0.889	0.749	57	0.902	0.980	0.903	57	0.20	1.00	0.49	56	0.17	0.46	0.23	57
>15-20	Swamp	13.72	45.40	29.73	49	0.257	0.795	0.458	113	0.946	0.986	0.967	113	0.33	1.00	0.63	109	0.10	0.73	0.59	113