Manaaki Whenua
Landcare Research

Baseline analysis of Bay of Plenty wetland data

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Baseline analysis of Bay of Plenty wetland data

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Summary

Project and client

- Wetland vegetation monitoring plots were established in Bay of Plenty wetlands by Manaaki Whenua – Landcare Research (MWLR) between 2014 and 2021.
- This report compares exotic plant cover and soil nutrient data from these initial plot measurements with national data, and investigates correlations between these plot data and assessments of wetland condition and land-cover change in the surrounding area.
- This work was undertaken for Bay of Plenty Regional Council.

Objectives

- To summarise initial measurement data from Bay of Plenty wetlands.
- To test for significant correlations between plot measurement data and surrounding landscape cover.

Methods

- Measurements of soil nutrient status (total nitrogen, total phosphorus, and nitrogen:phosphorus ratio) in Bay of Plenty wetlands was summarised and visually compared with national data held by MWLR.
- Linear mixed models and generalised linear mixed models were used to test for correlations between exotic species cover & richness and:
  - an assessment of wetland condition (Wetland Condition Index)
  - soil nutrients
  - land cover in the surrounding landscape in aggregated categories.
- Linear mixed models were used to test for correlations between soil nutrients and:
  - the Wetland Condition Index
  - land cover in the surrounding landscape in aggregated categories.
- All comparisons were made across all measured plots, and included wetland class (e.g. swamp or fen) and vegetation type (predominantly woody or herbaceous) as response variables to test their effect.

Results

- Soil nitrogen and phosphorus concentrations in Bay of Plenty wetlands are similar to those in wetlands in the rest of New Zealand.
- Landscape disturbance variables in 200, 500, and 1,000 m buffers were highly correlated.
- Soil nitrogen and phosphorus were not found to be significant predictors of exotic plants in wetlands.

- The aggregated Group 1 Land Cover Database category that includes exotic forest with natural land cover was more often associated with differences in exotic weeds than when exotic forestry was included with agriculture and horticulture (Group 2).
- Wetland class (swamp or fen), the proportion of agriculture/horticulture within 500 m of a plot, and hydrological integrity were the variables most frequently associated with exotic plant invasion of wetland plots (by presence, cover where present, or species richness).

Conclusions

- Buffers of 500 m around monitoring plots are appropriate for assessing the influence of landscape disturbance variables on wetland condition.
- There is some evidence that the amount of agriculture/horticulture surrounding wetlands and hydrological integrity are associated with the abundance of exotic plants in Bay of Plenty wetlands.

Recommendations

- Continue monitoring wetland vegetation in the existing plots, and expand this network to more modified wetlands if possible.
- Use a 500 m buffer distance for disturbance variables in future analyses.
- Include exotic forest with natural land cover in Land Cover Database aggregate categories when assessing the effects of land cover on wetland exotic plants.
- Include more plots (including from more weedy wetlands, under-represented wetland types, and wetlands from other regions) in future analyses.
- Following remeasurement of the monitoring plots, analysis of change in exotic plants over time should be undertaken, and this could include the disturbance variables identified here.

1 Introduction

Wetland vegetation monitoring plots were established in Bay of Plenty (BOP) wetlands by Manaaki Whenua – Landcare Research (MWLR) from 2014 to 2021 following the methodology of Clarkson et al. (2014). These plots form part of the Natural Environment Regional Monitoring Network (NERMN) programme undertaken by Bay of Plenty Regional Council as part of its statutory responsibilities under the Resource Management Act 1991.

2 Background

Bay of Plenty Regional Council contracted MWLR to develop and implement a system for monitoring the ecological state and trend of a representative set of BOP wetlands. The monitoring is for various reporting requirements (including NERMN), which can be used to assess the efficiency and effectiveness of regional policies and plans.

There are four main parts to the project.

A Develop a framework to assess the priorities for wetland monitoring based on historical vs extant wetland type and geographical spread (e.g. Ecological District), and ecological values/ecological integrity: this will yield a representative set of priority wetlands for monitoring, and timelines on a 5-year rotation with annual progress reports.

B Develop and trial a sampling approach and monitoring system in a range of wetland classes and vegetation types: this involves provision of detailed guidelines for establishing vegetation plots; plus replication, plot size, and overall condition assessment incorporating standard procedures and any subsequent refinements.

C Implement the wetland monitoring system over a 5-year period.

D Carry out data analysis to establish baselines for monitoring wetland extent and condition.

Parts A, B, and C of this project have now been completed (Fitzgerald et al. 2013; Clarkson et al. 2014). This report covers Part D.

3 Objectives

The objectives of the work are to:

- summarise initial measurement data from BOP wetlands to provide a visual comparison with wetland data from the rest of New Zealand
- investigate whether these baseline data are correlated with surrounding land cover in fixed-distance buffers and sub-catchments that may function as proxies for disturbance pressures on the wetlands.

4 Methods

4.1 Data sources

Wetland vegetation monitoring plots were established in BOP wetlands by MWLR from 2014 to 2021 following the methodology of Fitzgerald et al. (2013) and Clarkson et al. (2014). These data are stored in a database held by MWLR, along with data from other wetlands throughout New Zealand, measured since 1994 and contributed by many agencies and individuals. All data manipulation and analyses were performed using R (v4.1.2; R Core Team 2021).

Wetland Condition Index (WCI) component scores for BOP wetlands, and soil total nitrogen (N), soil total phosphorus (P), species cover, wetland class, and vegetation structural class were extracted from the national wetland database on 29 June 2022 for use in this report. The WCI components used in analyses were 'Change in hydrological integrity', 'Change in physico-chemical parameters', 'Change in ecosystem intactness', and 'Change in browsing, predation, & harvesting regimes'. The WCI component 'Change in dominance of native plants' was not included in analyses where exotic plant cover or richness were the response variables, because these are essentially the inverse of native plant dominance. The scale for WCI component scores ranges from 5 (no, or very low, change from expected original state) to 0 (extreme change from original state). Details of the WCI components are described in Clarkson et al. (2004) and Clarkson et al. (2014).

Where plots have been measured more than once, all remeasurements were discarded. Wetland class and structural class (Johnson & Gerbeaux 2004) were assessed at the wetland level and plot level, respectively. Vegetation structural class was aggregated into broad vegetation types (woody, herbaceous, and non-vegetated; see Appendix 1). Soil samples were not collected and analysed for all plots in the wetland database, and only the subset of plots where these data are available were used in statistical analyses.

Land-cover data were extracted from the Land Cover Database version 5.0 (LCDB; Landcare Research New Zealand Ltd 2020) and clipped to 200, 500, and 1,000 m buffers around each BOP wetland plot using the sf package (Pebesma 2018). LCDB categories were aggregated into three broad categories (natural, developed, and agriculture/horticulture), with exotic forestry treated as either natural (Group 1) or combined with agriculture/horticulture (agriculture/horticulture/silviculture) (Group 2; see Appendix 2). For each aggregated group, correlation between buffer sizes was assessed using Pearson correlation coefficients with the Hmisc package (Harrell 2021).

A spatial data set of sub-catchments developed for the Department of Conservation was used to select LCDB cover in drainage catchments around the BOP wetlands. This data set was constructed from a 15 m digital elevation model. More complete details of this can be found in Ausseil et al. (2008).

The number of address points within 200, 500, and 1,000 m of each plot was supplied by BOP Regional Council as a proxy for population density, which, along with land cover, were assumed to give broad indices of disturbance in the landscape surrounding wetland plots

4.2 Comparison of Bay of Plenty and national wetland soil nutrients

Soil total N, total P, and the N:P ratio were plotted for BOP and other New Zealand wetlands to provide a visual comparison. Wetland classes not recorded in BOP (bog, pākihi and gumland) were excluded from all comparisons, as wetlands of these types typically have extremely low nutrient values. Vegetation structural classes within the wetland classes recorded in BOP were also compared with national data and within aggregated vegetation types.

4.3 Plot exotic plant cover

Linear mixed models (LMMs) and generalised linear mixed models (GLMMs) were used to identify whether the abundance of exotic plants in BOP monitoring plots was correlated with nutrient variables in the plot, wetland condition variables at the wetland level, and disturbance variables in the surrounding landscape. Plots measured before 17 November 2013 were not used in these analyses, as these are not part of the NERMN monitoring scheme and used different methods for plant cover and wetland condition assessments.

Exotic plant cover data are semi-continuous, with zero or a positive number of species present in each plot, and each exotic species (where present) having cover up to 100%. Total exotic species cover was calculated by adding the cover of each exotic species in a plot, so that the total could be greater than 100% and resulting in data distribution skewed to the right but with many zeros. To accommodate this skewed distribution, a two-part model process was used, with presence/absence of exotic species modelled using GLMMs with binomial error distribution, and total cover (square root transformed) of exotic species in plots where they were present modelled with LMMs.

Exotic plant richness (the number of exotic species in a plot) was modelled using GLMMs with Poisson error distribution, which is appropriate for count data such as these.

The presence of exotic species, total cover where exotic species were present, and exotic species richness were modelled separately against (a) components of the WCI, (b) soil nutrients, and (c) surrounding landscape disturbance variables (address points and LCDB categories). In all models, wetland was included as a random effect to account for the fact that plots within a wetland are likely to be more similar than plots from different wetlands.

4.4 Plot soil nutrients

Correlation between soil N and P concentration and wetland condition on the one hand, and landscape disturbance variables on the other, was tested by fitting LMMs to the data, with wetland as a random effect to account for lack of independence between plots within a wetland.

The glmmTMB package (Brooks et al. 2017) was used to fit all models. Models were tested using a simulation-based approach with 1,000 iterations using the DHARMa package (Hartig 2021). Models were rejected that displayed significant residual deviation from expected distributions, which indicates potential misspecification, such as using an inappropriate error distribution.

The exploratory nature of these analyses led to many statistical tests being performed. Undertaking multiple simultaneous statistical tests increases the probability of some results appearing significant when they are simply the result of random chance. However, adjusting for these inflated 'type 1' errors in exploratory studies such as this is difficult (Bender & Lange 2001). Following Bender and Lange (2001), no multiplicity adjustment was made here, and statistical significance was assessed at the $\alpha = 0.05$ level. 'Significant' results should thus be treated with caution, and further work is needed to properly test the corresponding hypotheses.

5 Results

5.1 Bay of Plenty and national wetland soil nutrients

Soil N and P data for 220 BOP plots from 57 wetlands, and 447 plots from 132 wetlands elsewhere in New Zealand, were available from the wetland database. The BOP plots occurred across seven wetland classes. Two of these classes (seepage and shallow water) were not represented in the data from other regions (Figure 1). These plots were also classified into 14 vegetation structural classes (Figure 2), which were aggregated into the three general vegetation types shown in Figure 3. Plots classified as 'litterland' (and thus non-vegetated; see Appendix 1) represented three plots of dense willow that had recently been sprayed with herbicide, causing complete defoliation.

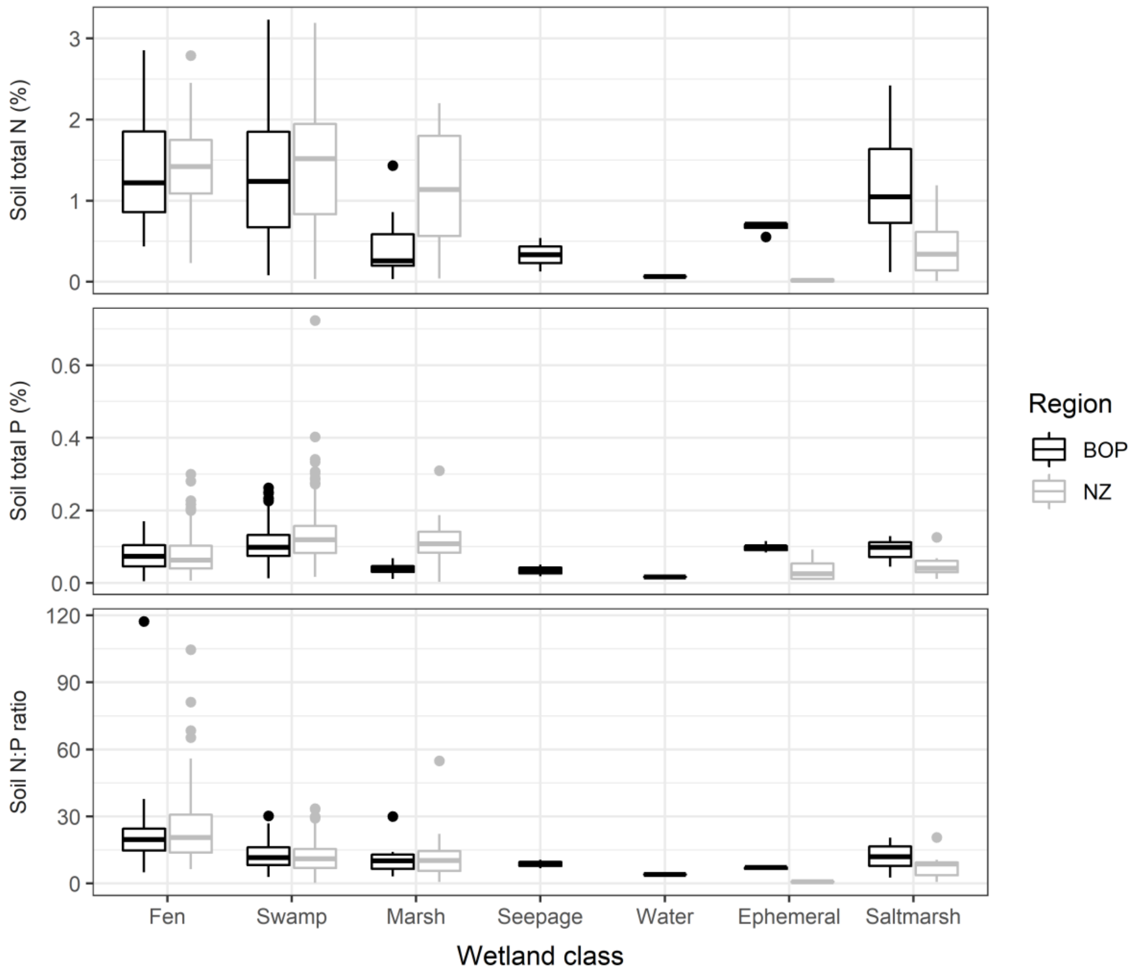

Figure 1. Box plots showing median and upper and lower quartiles for soil nitrogen (N) and phosphorus (P) in Bay of Plenty wetland monitoring plots and the rest of New Zealand for wetland classes occurring in the Bay of Plenty.

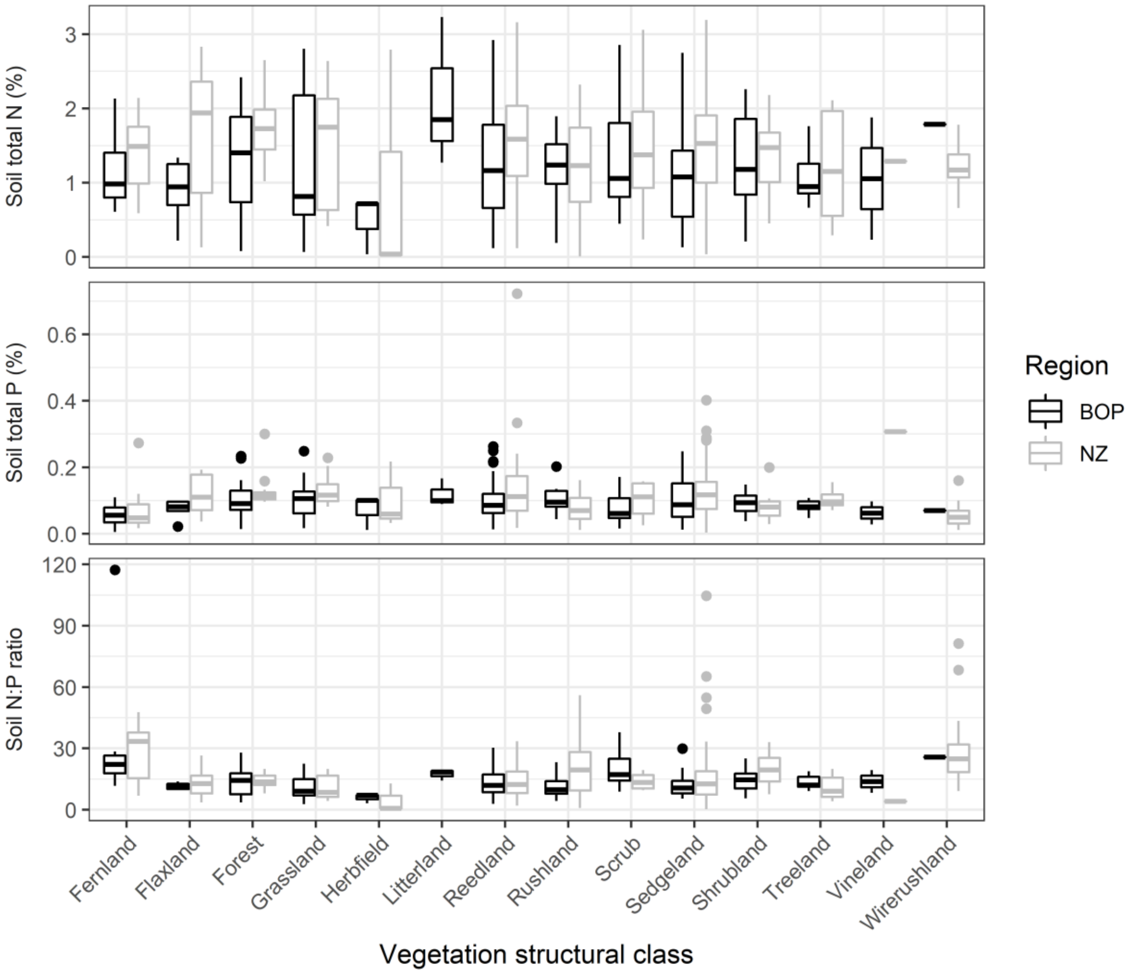

Figure 2. Box plots showing median and upper and lower quartiles for soil nitrogen (N) and phosphorus (P) in Bay of Plenty wetland monitoring plots and the rest of New Zealand for vegetation structural classes occurring in the Bay of Plenty.

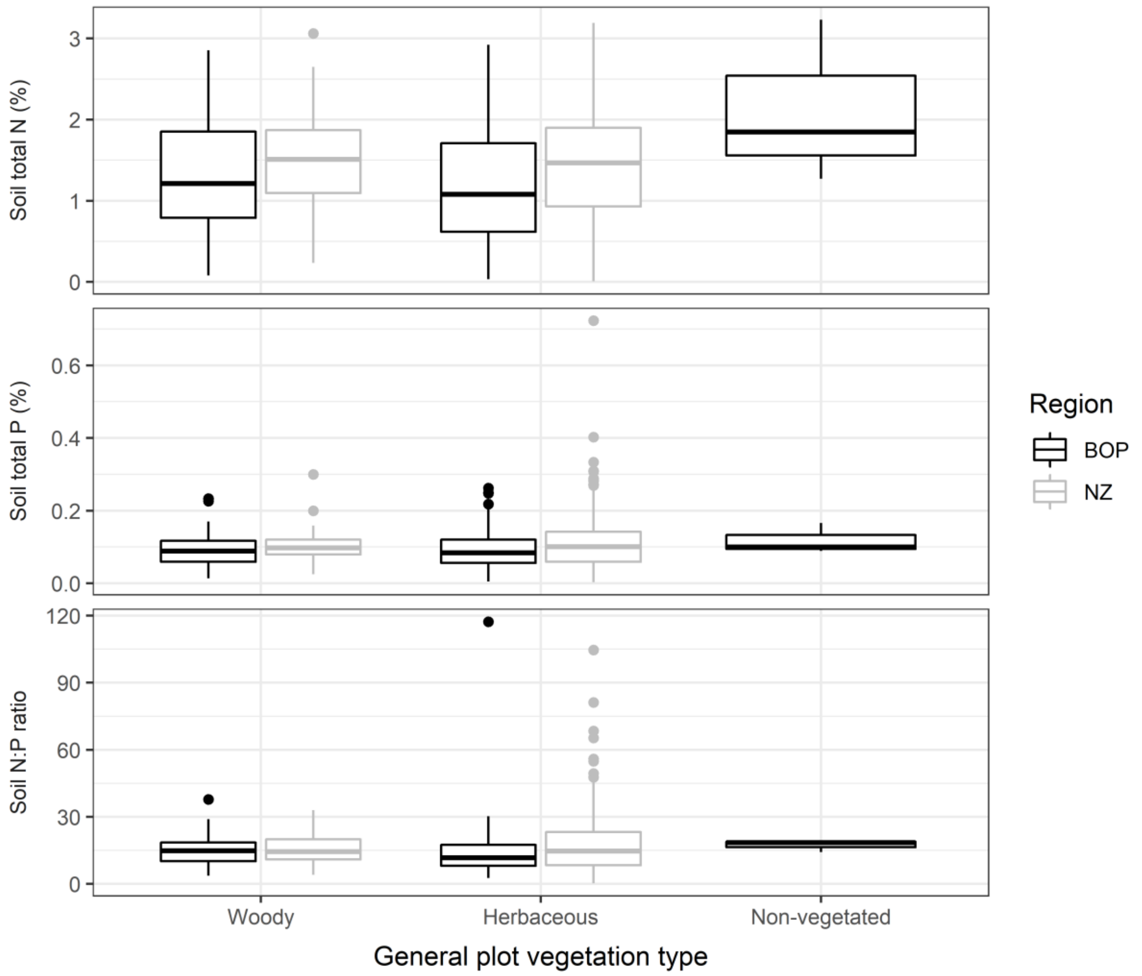

Figure 3. Box plots showing median and upper and lower quartiles for soil nitrogen (N) and phosphorus (P) in Bay of Plenty wetland monitoring plots and the rest of New Zealand for vegetation structural classes occurring in the Bay of Plenty aggregated into broad vegetation types.

5.2 Landscape disturbance variable correlation

There was high (r > 0.5) and significant ($P < 0.05$) correlation between landscape disturbance variables derived from LCDB5 at all three buffer distances tested for Group 1 (Table 1) and Group 2 (Table 2) aggregations of categories. Correlation between the 500 m buffer distance and the other buffer distances was higher than between the 200 m and 1,000 m buffers, so only data from 500 m buffers were used in subsequent analyses.

Table 1. Pearson correlation coefficients (r) and significance level (*P*) for pairwise comparison of three buffer distances around wetland monitoring plots for Group 1 aggregated land-cover categories (% Natural, % Agriculture/Horticulture, and % Developed)

Buffer distance (m)	% Natural	% Agriculture/Horticulture	% Developed
200 vs. 500	0.911 ($P < 0.001$)	0.874 ($P < 0.001$)	0.852 ($P < 0.001$)
500 vs. 1,000	0.917 ($P < 0.001$)	0.884 ($P < 0.001$)	0.873 ($P < 0.001$)
200 vs. 1,000	0.740 ($P < 0.001$)	0.632 ($P < 0.001$)	0.556 ($P < 0.001$)

Table 2. Pearson correlation coefficients (r) and significance level (*P*) for pairwise comparison of three buffer distances around wetland monitoring plots for Group 2 aggregated land-cover categories (% Natural, % Agriculture/Horticulture/Silviculture, and % Developed)

Buffer distance (m)	% Natural	% Agriculture/ Horticulture/Silviculture	% Developed
200 vs. 500	0.881 ($P < 0.001$)	0.85 ($P < 0.001$)	0.852 ($P < 0.001$)
500 vs. 1,000	0.879 ($P < 0.001$)	0.875 ($P < 0.001$)	0.873 ($P < 0.001$)
200 vs. 1,000	0.65 ($P < 0.001$)	0.588 ($P < 0.001$)	0.556 ($P < 0.001$)

In the 500 m Group 1 disturbance variables, % Natural was significantly correlated with % Agriculture/Horticulture (r = -0.743, $P < 0.001$). In the 500 m Group 2 disturbance variables, % Natural was significantly correlated with % Agriculture/ Horticulture/ Silviculture (r = -0.726, $P < 0.001$). The aggregated category % Developed is the same in both groups and was significantly correlated with the number of address points (r = 0.901, $P < 0.001$). Including strongly colinear variables like these can cause problems with model fitting, so % Natural and % Developed were dropped from analyses.

5.3 Exotic plant cover and richness

Data for 283 plots across 63 BOP wetlands were extracted from the wetland database. Most of these plots were classified as swamp (173) or fen (62). Other wetland classes had too few plots (20 or fewer each) for reliable modelling and were excluded from analyses where wetland class was included as a variable. Plots classified as herbaceous (186) and woody (91) were included in models where vegetation type was included as a variable, but non-vegetated plots (6) were excluded. Each model was therefore fitted to (a) the full set of data, (b) swamp and fen data, and (c) plots dominated by woody or herbaceous vegetation.

5.3.1 Exotic plants and Wetland Condition Index

Exotic plant presence

Across all the data (ignoring the effects of wetland class or vegetation type) there were no significant effects of WCI on the presence of exotic plants. When allowing for interaction between WCI and wetland class (i.e. different effects for wetlands classed as swamp or fen), there were significantly more exotic plants in swamps compared to fens ($P = 0.003$), a negative effect of hydrological integrity ($P = 0.010$) and physico-chemical parameters ($P = 0.013$), a positive effect of browsing, predation & harvesting regimes ($P = 0.048$), and significant interactions between wetland class (swamp or fen) and hydrological integrity ($P = 0.011$), ecosystem intactness ($P = 0.005$), and browsing, predation, & harvesting regimes ($P = 0.011$) on the presence of exotic plants.

When allowing for interaction between WCI and vegetation type (i.e. different effects for wetland dominated by woody or herbaceous vegetation), there was a significant interaction between vegetation type and ecosystem intactness on the presence of exotic plants ($P = 0.024$).

Exotic plant cover where present

Across all data (ignoring the effects of wetland class or vegetation type), in plots where exotic plants were present there was a significant negative effect of hydrological integrity on exotic plant cover ($P < 0.001$).

When allowing for interaction between WCI and wetland class, no effects were significantly correlated with exotic plant cover.

When allowing for interaction between WCI and vegetation type, there were significantly fewer exotic plants in herbaceous compared to woody plots ($P < 0.001$), and there was a negative effect of hydrological integrity ($P = 0.040$), and browsing, predation, & harvesting regimes ($P = 0.032$), but no significant interactions.

Exotic plant richness

Correlation between exotic plant richness and WCI could not be modelled using all data, or when allowing for interaction between WCI and wetland class

When allowing for interaction between WCI and vegetation type, there was a significant negative effect of the physico-chemical component of the WCI in relation to exotic species richness ($P = 0.013$).

5.3.2 Exotic plants and soil nutrients

Exotic plant presence

Correlation between the presence of exotic plants and soil nutrients (N and P) could not be modelled adequately without allowing for interaction between wetland class or vegetation type. With these interactions included in the models, there were no significant effects.

Exotic plant cover where present

The effects of soil N and P on exotic plant cover were not significant when not allowing for differences by wetland class or vegetation type.

When interaction between soil nutrients and wetland class was included, there was significantly more exotic plant cover in swamps compared to fens ($P = 0.021$). Allowing for interaction between soil nutrients and vegetation type could not be modelled acceptably.

Exotic plant richness

The effects of soil N and P on exotic plant richness were not significant when not allowing for differences by wetland class or vegetation type.

When interaction between soil nutrients and wetland class (swamp and fen only) was included, there was significantly more exotic plant richness in swamps compared to fens ($P < 0.001$). Including interaction between soil nutrients and vegetation type could not be modelled acceptably.

5.3.3 Exotic plants and Group 1 landscape disturbance within 500 m

Exotic plant presence

Across all data (ignoring the effects of wetland class or vegetation type), there was a significant positive effect of the proportion of agriculture/horticulture ($P = 0.031$) within 500 m of a plot (but not the number of address points) on the presence of exotic species.

When allowing for differences between wetland class (swamp or fen) or vegetation type (woody or herbaceous), there were no significant effects related to the presence of exotic species.

Exotic plant cover where present

Across all data (ignoring the effects of wetland class or vegetation type), there was a significant positive effect of the proportion of agriculture/horticulture ($P = 0.001$) within 500 m of a plot (but not the number of address points) on the cover of exotic species where present.

When including interaction between wetland class (swamp or fen) and the disturbance variables, there was a significant interaction between agriculture/horticulture and wetland class on the total cover of exotic species ($P = 0.032$).

When including interaction between vegetation type (woody or herbaceous) and the disturbance variables, there was a significant positive effect of agriculture/horticulture

($P < 0.001$), and a significant interaction between agriculture/horticulture and vegetation type ($P = 0.050$).

Exotic plant richness

Across all data (ignoring the effects of wetland class or vegetation type), there was a significant positive effect of the proportion of agriculture/horticulture ($P = 0.001$) within 500 m of a plot (but not the number of address points) on exotic species richness.

When including interaction between wetland class (swamp or fen) and the disturbance variables, there was a significantly higher exotic plant richness in swamps compared to fens ($P = 0.043$), and a positive effect of the number of address points within 500 m of a plot ($P = 0.024$), but no significant interaction terms.

When including interaction between vegetation type (woody or herbaceous) and the disturbance variables, there was a significant interaction between the address points and vegetation type ($P = 0.026$).

5.3.4 Exotic plants and Group 2 landscape disturbance within 500 m

Exotic plant presence

There were no significant effects of Group 2 disturbance variables on the presence of exotic species, across all data, or allowing for interactions with wetland class or vegetation type.

Exotic plant cover where present

Across all data (ignoring the effects of wetland class or vegetation type), there was a significant positive effect of the amount of agriculture/horticulture/silviculture within 500 m of a plot on the amount of exotic plant cover where present ($P = 0.009$).

When an interaction was included in the model so that the effect of the disturbance variables (% agriculture/horticulture/silviculture and number of address points) could differ for each wetland class (swamp or fen), no effects were significant.

When an interaction was included in the model so that the effect of the disturbance variables could differ for each vegetation type (woody or herbaceous), there was a significant positive effect of agriculture/horticulture/silviculture on the amount of exotic plant cover where present ($P = 0.042$).

Exotic plant richness

Across all data (ignoring the effects of wetland class or vegetation type), there was a significant positive effect of the proportion of agriculture/horticulture/silviculture within 500 m of a plot on exotic plant species richness ($P = 0.014$).

When an interaction was included in the model so that the effect of the disturbance variables (% agriculture/horticulture/silviculture and number of address points) could differ for each wetland class (swamp or fen), there was a significant positive effect of the number of address points within 500 m of a plot on exotic plant species richness (P = 0.013).

When an interaction was included in the model so that the effect of the disturbance variables could differ for each vegetation type (woody or herbaceous), no effects were significant.

5.3.5 Exotic plants and Group 1 landscape disturbance within sub-catchment

The sub-catchment layer used to select landscape disturbance variables has incomplete coverage, and 27 of the 283 wetland plots (from 6 of 63 wetlands) were thus excluded from analyses of catchment disturbance variables.

Exotic plant presence

There were no significant effects of Group 1 disturbance variables in the sub-catchment on the presence of exotic species, across all data, or allowing for interactions with wetland class or vegetation type.

Exotic plant cover where present

There were no significant effects of sub-catchment disturbance variables on exotic plant cover across all data (ignoring the effects of wetland class or vegetation type), or when allowing for interaction between the disturbance variables and wetland class (swamp or fen).

When an interaction was included in the model so that the effect of the disturbance variables could differ for each vegetation type, there was significantly less exotic plant cover in herbaceous plots than in woody plots (P = 0.007).

Exotic plant richness

Across all data (ignoring the effects of wetland class or vegetation type), there was a significant positive effect of the proportion of agriculture/horticulture within the sub-catchment of a plot on exotic plant species richness (P = 0.018).

When an interaction was included in the model so that the effect of the disturbance variables could differ for each wetland class (swamp or fen), no effects were significant. However, there was evidence for a negative effect of woody compared to herbaceous vegetation types when this was included as an interaction in the model (P = 0.025).

5.3.6 Exotic plants and Group 2 landscape disturbance within sub-catchment

Exotic plant presence

There were no significant effects of Group 2 disturbance variables on the presence of exotic species, across all data, or allowing for interactions with wetland class or vegetation type.

Exotic plant cover where present

There were no significant effects of sub-catchment disturbance variables on exotic plant cover across all data (ignoring the effects of wetland class or vegetation type), or when allowing for interaction between the disturbance variables and wetland class (swamp or fen) or vegetation type (woody or herbaceous).

Exotic plant richness

There were no significant effects of sub-catchment disturbance variables on exotic plant richness across all data (ignoring the effects of wetland class or vegetation type), or when allowing for interaction between the disturbance variables and vegetation type (woody or herbaceous).

Interactions between the disturbance variables and wetland class (swamp or fen) could not be modelled.

5.4 Soil nutrient correlation

Soil nitrogen

Soil N could not be modelled acceptably as a function of WCI, Group 1 disturbance variables (agriculture/horticulture and address points) within 500 m, with or without allowing for variation by wetland class or vegetation type; or Group 2 disturbance variables (agriculture/horticulture/silviculture and address points) within 500 m, without allowing for variation by wetland class or vegetation type.

A model with soil N as a function of Group 2 disturbance variables differing by wetland class was fitted acceptably, but no effects were significant. A model with soil N as a function of Group 2 disturbance variables differing by vegetation suggested a significant positive effect of agriculture/horticulture/silviculture on soil N ($P = 0.041$).

It was not possible to fit models of Soil N in relation to sub-catchment disturbance variables for Group 1 and Group 2 LCDB categories, when allowing for interaction between the disturbance variables and wetland class (swamp or fen), or vegetation type (woody or herbaceous).

Models using all the data and ignoring interaction effects of wetland class or vegetation type were fitted acceptably, but no sub-catchment disturbance variables were found to be significant.

Soil phosphorus

There were no significant effects of WCI components on soil P across all data where variation by wetland class and vegetation types was not included, and when allowing for variation by wetland class. Where variation by vegetation type was included, there was a significant negative effect of the WCI score for change in ecosystem intactness ($P = 0.024$).

There were no significant effects of Group 1 disturbance variables (agriculture/horticulture and address points) on soil P when variation by wetland class was included. The effect of WCI on soil N across all data regardless of wetland class or vegetation type, and when allowing for variation in vegetation type, could not be modelled acceptably.

There were no significant effects of Group 2 disturbance variables (agriculture/horticulture/silviculture and address points) on soil P, across all data or when allowing for variation by wetland class or vegetation type.

It was not possible to fit models of soil P in relation to sub-catchment disturbance variables, for Group 1 and Group 2 LCDB categories, when allowing for interaction between the disturbance variables and wetland class (swamp or fen) or vegetation type (woody or herbaceous).

Models using all the data and ignoring interaction effects of wetland class or vegetation type were fitted acceptably and suggest significant negative effects of the number of address points in the sub-catchment on soil P, irrespective of whether land cover was aggregated as Group 1 ($P = 0.008$) or Group 2 ($P = 0.009$).

6 Discussion and conclusions

Box plot graphical summaries of BOP wetland soil data indicate that for most wetland classes and vegetation structural types, BOP wetlands are within the soil N and P range of wetlands nationally. Soil N and P were both lower in BOP marshes, and higher in saltmarshes, than nationally. However, few (20) saltmarsh plots are included in the wetland database, because it is primarily intended for freshwater wetland monitoring and generally only includes saltmarshes near the edge of freshwater types. Marshes represent a range of wetland subtypes with different nutrient contents (Clarkson et al. 2015), so this is not surprising.

Although wirerushland plots in BOP appear to have high soil N levels compared to the rest of New Zealand, this vegetation type is rare in BOP and is represented by a single plot, which may not be typical. The soil N and P data collected from BOP wetlands provide a sound baseline against which future measurements can be compared, and with which to compare BOP wetlands to national trends.

The indices of landscape disturbance surrounding wetlands were not significantly different at any of the buffer distances tested (200, 500, or 1,000 m). Herlihy et al. (2019) found a similar high correlation between 200, 500, and 1,000 m land-cover buffers around US wetland plots, reinforcing that the size of buffers within this range is not important. Because 500 m buffers were slightly more closely correlated with 200 and 1,000 m buffers than between these buffers, 500 m was considered appropriate to investigate the possible effects of landscape disturbance on wetland exotic plants and soil nutrients.

Investigating the possible relationships between exotic plants and soil nutrients, and between exotic plants and aspects of wetland condition, wetland class, vegetation type, and features of the surrounding landscape, required fitting 84 different models. Making many comparisons in exploratory analyses like this increases the probability of results appearing to be statistically significant when they are simply due to random chance. Correcting for this is difficult and, even if possible, prone to introducing the opposite problem, whereby real effects are missed (Bender & Lange 2001). For this reason, and the complicated interpretation of interacting effects, the sizes of potentially significant effects are not discussed, and the results presented here should be treated with caution and used to develop specific questions and work to test these.

Wetland class – either swamp or fen – was the variable most frequently statistically significantly associated with exotic plant invasion of wetland plots (by presence, cover where present, or species richness). This was followed by the proportion of agriculture/horticulture within 500 m of a plot, and then by the hydrological integrity component of the WCIU. The aggregated Group 1 LCDB category, which includes exotic forest with natural land cover, was more often associated with differences in exotic weeds than when exotic forestry was included with agriculture and horticulture (Group 2).

There was some evidence of lower soil P with more address points within the surrounding sub-catchment. However, soil N and P were generally difficult to model as response variables. Neither soil N nor soil P were found to be significant explanatory predictors of exotic plants in wetland plots. This suggests there is not a strong relationship between wetland nutrients and surrounding land cover, that soil nutrients are not limiting, and that other factors are stronger drivers of weeds in BOP wetlands.

However, this does not mean that soil nutrients are not important drivers of other aspects of wetland ecology that were not investigated here, such as native vegetation structure. If the plots that have been remeasured after 5 years show little change, and in the absence of obvious changes that are likely to affect soil nutrients (such as flooding, fire, vegetation clearance or other large disturbances), soil sampling frequency could be reduced to 10-yearly.

These results suggest that future work should focus on the effect of the proportion of agriculture and horticulture within 500 m of monitoring plots, and the hydrological integrity component of the WCI, as potential drivers of exotic weediness in wetlands. For example, these variables could be included in an analysis of changes in exotic plants over time following remeasurement of the monitoring plots.

The data are biased towards lower exotic plant cover and richness (Figure 4), so the addition of more weedy plots may help to improve model performance.

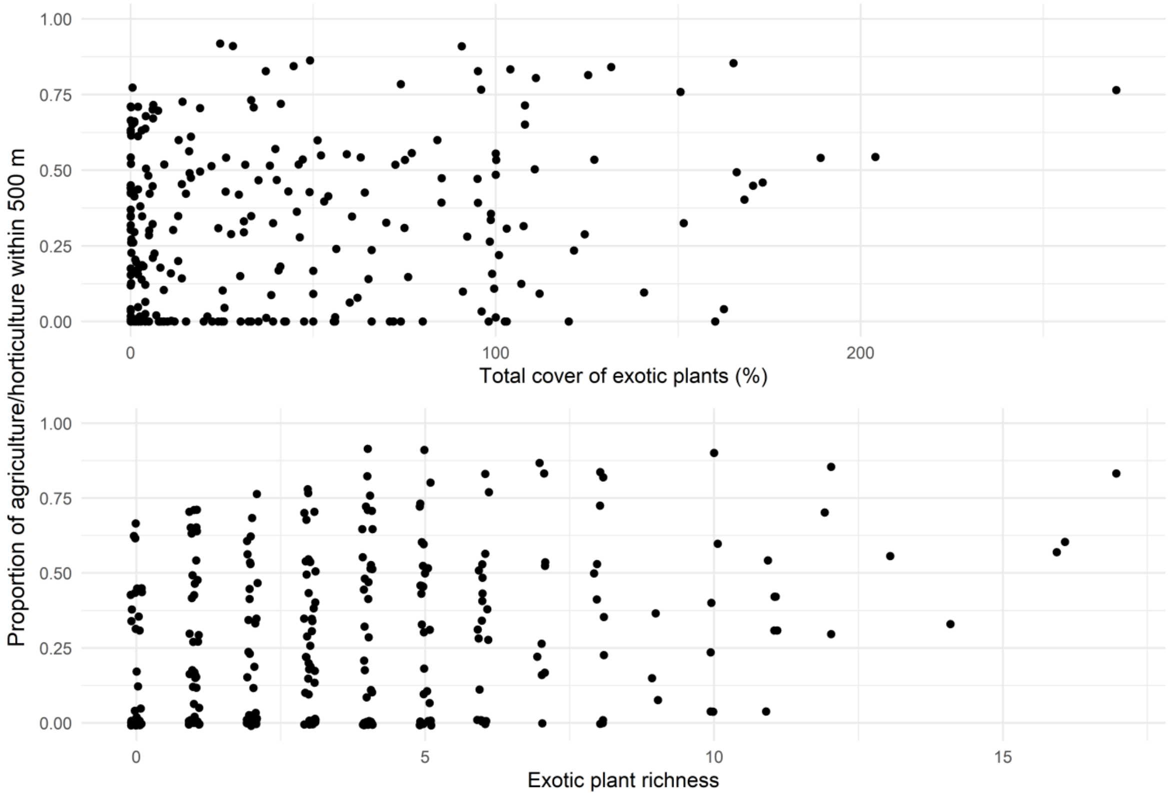

Figure 4. Total cover (% summed across species) and richness (number of species) of exotic plants in Bay of Plenty wetlands in relation to the proportion of land cover within 500 m that is classed as agriculture or horticulture. Exotic richness points have been 'jittered' a small amount to reduce over-plotting.

7 Recommendations

The established BOP wetland vegetation plots should continue to be monitored using the current methods, although soil sampling could be reduced to 10-yearly if the first remeasurement shows little change, and where there has not been obvious disturbance, such as fire, flooding, or vegetation removal that may change the soil nutrients.

The possible relationship between exotic weediness (richness, presence and cover) in wetlands and wetland hydrological integrity and agriculture/horticulture (LCDB Group 1 aggregate categories) should be further investigated. Disturbance variables should be assessed within 500 m buffers around monitoring plots. Because of the large amount of variation within and between wetlands, a larger sample of wetlands, including more weedy wetlands and under-represented wetland classes, should be included in future analyses of remeasurement data, and this could include wetlands from other regions in similar bioregional settings.

Following remeasurement of the monitoring plots, analyses of changes in exotic plants over time should be undertaken, and the variables identified here included in these analyses to account for their possible effects.

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Appendix 1 – Vegetation structure recorded for Bay of Plenty wetlands and their aggregated vegetation type

Vegetation structure	Vegetation type
Forest	Woody
Scrub	Woody
Shrubland	Woody
Treeland	Woody
Fernland	Herbaceous
Flaxland	Herbaceous
Grassland	Herbaceous
Herbfield	Herbaceous
Reedland	Herbaceous
Rushland	Herbaceous
Sedgeland	Herbaceous
Vineland	Herbaceous
Wirerushland	Herbaceous
Litterland	Non-vegetated
Mudfield	Non-vegetated
Shallow water	Non-vegetated

Appendix 2 – Land Cover Database classes within 1,000 m of Bay of Plenty wetland monitoring plots and their aggregated cover type groups

LCDB5 2018 class name	Aggregate Group 1	Aggregate Group 2
Alpine Grass/Herbfield	Natural	Natural
Broadleaved Indigenous Hardwoods	Natural	Natural
Built-up Area (settlement)	Developed	Developed
Deciduous Hardwoods	Natural	Natural
Depleted Grassland	Natural	Natural
Estuarine Open Water	Natural	Natural
Exotic Forest	Natural	Agriculture/horticulture/silviculture
Fernland	Natural	Natural
Flaxland	Natural	Natural
Forest - Harvested	Natural	Agriculture/horticulture/silviculture
Gorse and/or Broom	Natural	Natural
Gravel or Rock	Natural	Natural
Herbaceous Freshwater Vegetation	Natural	Natural
Herbaceous Saline Vegetation	Natural	Natural
High Producing Exotic Grassland	Agriculture/horticulture	Agriculture/horticulture/silviculture
Indigenous Forest	Natural	Natural
Lake or Pond	Natural	Natural
Landslide	Natural	Natural
Low Producing Grassland	Agriculture/horticulture	Agriculture/horticulture/silviculture
Mangrove	Natural	Natural
Manuka and/or Kanuka	Natural	Natural
Matagouri or Grey Scrub	Natural	Natural
Mixed Exotic Shrubland	Natural	Natural
Orchard, Vineyard or Other Perennial Crop	Agriculture/horticulture	Agriculture/horticulture/silviculture
Permanent Snow and Ice	Natural	Natural
River	Natural	Natural
Sand or Gravel	Natural	Natural
Short-rotation Cropland	Agriculture/horticulture	Agriculture/horticulture/silviculture
Sub Alpine Shrubland	Natural	Natural
Surface Mine or Dump	Developed	Developed
Tall Tussock Grassland	Natural	Natural
Transport Infrastructure	Developed	Developed
Urban Parkland/Open Space	Developed	Developed