6.4 Wetland condition index

Author, affiliation: Olivia Rata Burge (MWLR)

Citation for this chapter: Burge, O.R. (2024). Wetland condition index. *In:* Lohrer, D., et al. *Information Stocktakes of Fifty-Five Environmental Attributes across Air, Soil, Terrestrial, Freshwater, Estuaries and Coastal Waters Domains*. Prepared by NIWA, Manaaki Whenua Landare Research, Cawthron Institute, and Environet Limited for the Ministry for the Environment. NIWA report no. 2024216HN (project MFE24203, June 2024). [https://environment.govt.nz/publications/information-stocktakes-of-fifty-five-environmental-attributes]

State of knowledge of the "Wetland condition index" attribute: Good / established but incomplete – general agreement, but limited data/studies

There is no 'one' wetland condition index: a condition index could be any combination of biological or biogeophysical chemical indicators that are considered relevant and are practical to measure and monitor.[1] However, there is a wetland condition index (WCI) used by some (not all) councils in New Zealand. The WCI is described primarily in the 'Handbook for monitoring wetland condition' [1] and updated by more recent single council-specific reports [2], [3] and discussed further in a report aimed at Tier 2 (regional) monitoring [4]. There are no known comparisons between the New Zealand WCI and other ground-based indices; however, there will be evidence and studies linking the relevant indicator components (Figure 1) to ecological integrity. The overall structure of the WCI is shown below in Figure 1.

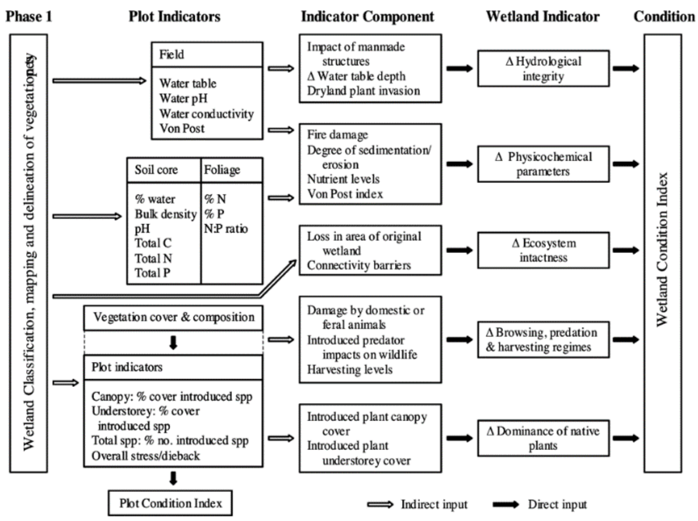

Figure 1: Links between wetland and plot indicators and Phase 1 of the Co-ordinated Monitoring of New Zealand Wetlands project

Figure 1. Structure of the WCI reproduced from the Handbook for Monitoring Wetland Condition [1].

[1] And in fact, assessing questions such as, how well an indicator such as 'ecosystem intactness' is related to 'ecological integrity' may end up being rather circular.

The New Zealand WCI is an example of 'multi-metric indices', where multiple attributes are combined to assess ecological or biological systems [5]. Ruaro et al. [5] note, "*differentiating natural variability from anthropogenic impacts is the major challenge in creating and applying [multi-metric indices]".*

A review (restricted to USA) of a 'rapid' condition assessment (2 people spending half a day in the field, plus a total of half a day office work thereafter) noted critical factors to consider with respect to wetland condition indices were [6]:

- Sampling boundary
- Inclusion of wetland type[1], and reference values for different wetland types due to their different ecological and hydrological settings
- Ideally the index returns one 'integrated' score
- Separate components for ecology and 'value-added components' – e.g., adding 'green space' in a very urban setting should be assessed separate to condition of the wetland itself
- Verification of the index with comprehensive ecological data.

The New Zealand WCI does not delineate separate reference values for different wetland types where there is natural variability, such as the Von Post index [3], which is expected to be scored lower in swamps than bogs, as the peat is naturally more degraded in swamps. This is an opportunity for the future. There was an interim attempt to identify quantitative limits for certain variables for wetlands, by wetland type, however, this was never followed up, and lacked data for certain wetland types [8].

Councils have raised concerns with the 'subjective' nature of the qualitative scoring component of the WCI. There is a lack of knowledge on how much variability in condition scores are due to operator differences, particularly across regional councils or other institutions. Differences in judgement affect even quantitative metrics, such as plant cover, and are ideally (a) minimised and (b) the residual accounted for, in assessing differences in wetland condition [9].

There is also a GIS-based analysis of wetland condition, the EII, described in Ausseil et al [10]. It provides a value where ecological integrity could be rated from 1, pristine, to 0, where 0 means complete loss of biodiversity and associated ecological function, that over 60% of wetlands were measured at less than 0.5 on the ecosystem integrity index. This indicated high levels of human-induced disturbance pressure and sustained biodiversity loss. A recent study [11] has found a reasonable correlation (r^2 = 0.66) between the WCI (Clarkson et al 2004) and the EII [10].

Internationally, other countries have also developed wetland condition indices, such as Australia [12], South Africa [13], the USA [14]. Remote-sensed metrics are beginning to be developed [15]. Here we primarily consider the established WCI as a potential attribute of Ecological Integrity.

[1] Wetland type such as bog, fen, swamp. Refer to [7] for wetland types of New Zealand

Part A—Attribute and method

A1. How does the attribute relate to ecological integrity or human health?

The New Zealand WCI is a tool used to assess the ecological health and integrity of wetland ecosystems [1]. Although the WCI is an ecological measure, there are several indirect links between wetland condition and human health:

- Hydrological function of the wetland (a component of the WCI – refer Figure 1) will affect ecosystem services provided to humans (e.g., flood risk mitigation). An assessment of wetland values [16] notes their critical role in the water cycle, thus providing water security for humans.
- Soil nutrients and other variables will indicate the extent to which a wetland is able to provide water filtration ecosystem services – clean water is a key element of human health. Ecosystem services reports set out the value of ecosystem services provided by wetlands in New Zealand [17, 18].
- Climate regulating services are linked to human health via avoidance of heat-related illnesses and spread of infectious diseases. Peatlands (e.g., bogs and peat swamps) are a critical stock of stored carbon, and ecologically intact peatlands continue to sequester carbon [19], [20].
- The WCI is designed to assess ecological integrity, with indicators such as exotic species abundance, soil nutrients, and impacts of introduced herbivores and predators [1]. A recent study [11] has found a reasonable correlation (r2 = 0.66) between the WCI [1] and the wetland ecological integrity index (EII; [10]).

A2. What is the evidence of impact on (a) ecological integrity or (b) human health? What is the spatial extent and magnitude of degradation?

There is little field-based assessment of the New Zealand wetland condition index against ecological integrity (which would be circular if we accept that the WCI is meant to represent components of ecological integrity) or human health.

As noted above, the WCI is positively correlated with the EII, and evidence for impact on ecological impact has been documented for New Zealand in Ausseil et al. [10], who found that across New Zealand, where ecological integrity could be rated from 1, pristine, to 0, where 0 means complete loss of biodiversity and associated ecological function, that over 60% of wetlands were measured at less than 0.5 on the ecosystem integrity index. This indicated high levels of human-induced disturbance pressure and sustained biodiversity loss. This survey was GIS-based, no field work involved.

A3. What has been the pace and trajectory of change in this attribute, and what do we expect in the future 10 - 30 years under the status quo? Are impacts reversible or irreversible (within a generation)?

There is a limited published literature on the 'attribute' (wetland condition index) and rates of change within it, with 'Grey' reports that set out states and trends in WCI for specific parties/sites [36] and the Clarkson et al report [8] which linked environmental indicators to differences in wetland condition indices across space being the only known available information.

Overall, there has probably been a focus on wetland extent (which is also of critical importance – see wetland extent attribute) and perhaps insufficient attention paid to wetland condition.

Key drivers of degradation in New Zealand inland wetlands are drainage, fire, nutrient addition and invasive species [11], [21], [22], [23], [24], [25], [26], [27]. All these drivers may also affect wetland extent through direct mechanisms (drainage, mainly) and indirect mechanisms (other drivers).

Restoration or rehabilitation of inland wetlands varies widely among different wetland types, but in most cases, requires multiple interventions such as restoring the hydrological regime (i.e., usually reversing the effects of past drainage manipulations), reducing environmental stresses such as nutrients (nitrogen and phosphorus), and management of both biological invaders (especially weeds like willows) and reintroduction or planting of native species [37]. Restoration effort and success vary from relatively 'easy' for open water wetlands by restoring hydrological regimes, to extremely difficult for more complex systems that have undergone a tipping point in condition such as domed peat bogs. In general, most wetland restoration requires major long-term management interventions over the long-term, and the success of these efforts for improving ecological integrity is likely, but not yet known.

A4-(i) What monitoring is currently done and how is it reported? (e.g., is there a standard, and how consistently is it used, who is monitoring for what purpose)? Is there a consensus on the most appropriate measurement method?

Our understanding is some councils use the wetland condition index, others, such as Auckland Region, use other methods. Other councils are yet to undertake any comprehensive monitoring. Where MWLR conducts monitoring on behalf of councils, the data may be stored in the NZ Wetland Database (which is in need of modernising). The question of replication is a live one – particularly with respect to the number of plots required for the purpose – regionally representative monitoring will require less than a detailed investigation of one wetland, for example. The Bellingham et al [4] Tier 2 monitoring report recommended the WCI, with some modifications/extensions, as the nationally-consistent reporting method for condition.

A4-(ii) Are there any implementation issues such as accessing privately owned land to collect repeat samples for regulatory informing purposes?

Access to field sites, some of which may be on private land, is required for assessments. This can create implementation issues (e.g., affect assessment frequency).

A4-(iii) What are the costs associated with monitoring the attribute? This includes up-front costs to set up for monitoring (e.g., purchase of equipment) and on-going operational costs (e.g., analysis of samples).

Labour is the biggest cost: where wetland plots are randomised, the majority of the time may be spent navigating through vegetation to get to a plot. Typically, two people undertake monitoring per plot: one undertakes vegetation measures; the other, soil, foliage, and other environmental variables. The time spent at a plot will depend on factors such as species richness (more species takes longer), plot size (larger plots will take longer), skills of the botanist (less skilled botanists will need to spend more time identifying plants), and ability to dig in the soil (affecting soil sampling and water samples). Some investment in information management, and health and safety gear (normal outdoor gear, plus water gear such as waders), and travel costs.

A5. Are there examples of this being monitored by Iwi/Māori? If so, by who and how?

Taura et al [28] set out iwi involvement in wetland monitoring, but not specifically wetland condition index monitoring.

A6. Are there known correlations or relationships between this attribute and other attribute(s), and what are the nature of these relationships?

There will be clear linkages between other attributes that affect hydrological function and nutrient cycling within wetlands. There will be links between wetland extent and wetland condition, and the wetland condition index for NZ takes into account the historical loss of extent of wetlands in the catchment [1].

Part B—Current state and allocation options

B1. What is the current state of the attribute?

The current state of the attribute is poorly understood due to a lack of widespread, systematic field monitoring. Some councils currently undertake monitoring across a representative set of wetlands in their region, and this number is likely to increase with the uptake of monitoring required under the NPS Freshwater Management. The interim report on potential quantitative limits [8] and the GIS-based EII paper [10] are the only two published syntheses known.

B2. Are there known natural reference states described for New Zealand that could inform management or allocation options?

No, but this information could be collected. MWLR recently collected information on ~20 'intact' and degraded wetlands included WCI, for a vegetation classification. Areas of lower human impacts [38] could be assessed to derive reference condition scores, and then recent work in quantifying natural variability could be applied to calculate a natural baseline including variability in composition, for a more quantitative baseline [29], in addition to 'natural' variability in WCI scores. Palaeoecology can also provide critical insights into historical wetland and vegetation types, although it cannot infer a historical WCI score [21].

B3. Are there any existing numeric or narrative bands described for this attribute? Are there any levels used in other jurisdictions that could inform bands? (e.g., US EPA, Biodiversity Convention, ANZECC, Regional Council set limit)

Clarkson et al [8], p7 set out the following, but we highlight this was from an interim report that needs further field verification:

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).

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: <10 (<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.

B4. Are there any known thresholds or tipping points that relate to specific effects on ecological integrity or human health?

Tipping points are likely from both hydrological changes and nutrient enrichment/eutrophication, but these have not been quantified or documented to the best of our knowledge.

B5. Are there lag times and legacy effects? What are the nature of these and how do they impact state and trend assessment? Furthermore, are there any naturally occurring processes, including long-term cycles, that may influence the state and trend assessments?

Yes. Drainage is the major form of reduction in wetland extent in New Zealand [21]. Drainage near wetlands takes multiple years to reach ‘equilibrium’ [30] and even then, peat shrinkage rates continue on drained peatland in the Waikato particularly [31]. Furthermore, carbon sequestration may apparently continue in drain-affected wetlands, however this is due to woody plant invasion, which has a time-limited effect on carbon, unlike peat-forming species that sequester carbon into the soil [32]. The effect of drain may also take time to become apparent on the plant community, and as such, there are many wetlands around New Zealand that may be ‘under the influence’ of cryptic drain effects [24]. Fertilisation may have cryptic effects (causing lagged invasions) where long-lived plants persist but will not reproduce in eutrophied – or drained, or both – settings [23], [32].

B6. What tikanga Māori and mātauranga Māori could inform bands or allocation options? How? For example, by contributing to defining minimally disturbed conditions, or unacceptable degradation.

There is some work in this area, but it tends to be for complementary streams of monitoring that iwi have autonomy over. A search of New Zealand published materials by authors Garth Harmsworth and Yvonne Taura (MWLR) would be a good entry point for publicly accessible materials.

Part C—Management levers and context

C1. What is the relationship between the state of the environment and stresses on that state? Can this relationship be quantified?

Key pressures on wetlands include drainage, eutrophication, invasive species, and fire, which are described sequentially below.

The Ashburton Lakes/O tu Wharekai is an example of where the relationship between a stressor (nutrients) and the receiving wetland has not been quantified well enough to guide management [39]. In other areas, the nutrient limits have been calculated, but are yet to be met.

The relationship between drains and effects on wetlands is a multivariate problem that is affected by soil type, drainage depth, distance from wetland, wetland hydrology, and time since drainage [24]. As such, there is no simple bivariate relationship between drainage and impacts, except perhaps, the more extensive the drainage, the more likely to be negative impacts.

Fire has caused substantial changes, particularly historically, on wetland vegetation and type: see review by McGlone [21].

Invasive species have negative effects on wetlands [22], [33], [34], however, there are few known relationships (for wetlands, and more generally) for impacts as a function of invader biomass.

C2. Are there interventions/mechanisms being used to affect this attribute? What evidence is there to show that they are/are not being implemented and being effective?

C2-(i). Local government driven

C2-(ii). Central government driven

C2-(iii). Iwi/hapū driven

C2-(iv). NGO, community driven

C2-(v). Internationally driven (e.g., obligations to Convention on Biological Diversity, Kunming-Montreal Global Biodiversity Framework)

There has not been enough monitoring of interventions at the "Tier 2" scale (assessment of management interventions) to have strong evidence on the matter. However, because the WCI assesses clear drivers of decline [1], we expect that actions that are effective in addressing drivers of decline will affect the wetland condition index. Condition index can be broken down into constituent parts to focus on management actions. See wetland restoration handbook [36] and a local council example [40].

Part D—Impact analysis

D1. What would be the environmental/human health impacts of not managing this attribute?

This question is almost too broad to answer, given the number of ecological and hydrological attributes that make up the wetland condition index. Given the number of current pressures on wetlands (refer above – drainage, eutrophication, invasive species, fire – refer answer to QA3), without management, the various ecological and hydrological attributes that make up the wetland condition index will decline. As such, the ecological and human health values that are associated with wetlands (see answer to QA1) would be diminished, however, the specific impacts will depend on the sub-component of the index that is reduced.

D2. Where and on who would the economic impacts likely be felt? (e.g., Horticulture in Hawke's Bay, Electricity generation, Housing availability and supply in Auckland)

It is difficult to describe with certainty the economic impacts, because a decline in wetland condition index might be driven by a decline in just one of the indicator components. For example, a decline in a component of ecological integrity might cause a similar drop in WCI score compared to one caused by a decline in hydrological function. Yet the economic implications of this decline are likely to differ. For examples of where decline in extent causes economic issues, see the answer to the extent attribute on this question.

D3. How will this attribute be affected by climate change? What will that require in terms of management response to mitigate this?

We consider impacts of wetland by type. Mangroves may shift in distribution, may migrate south in New Zealand with warming water; they may also shift in response to sea level rise (reductions in seaward extent, increases in landward extent). Remaining wetlands that receive overland flow (swamps, marshes, fens) may suffer increased sediment and nutrient deposition if the increase in extreme events comes to pass; this may lead to wetland loss, if not reductions in ecological integrity. Increased wildfire may allow establishment of weeds. Salinity and inundation due to sea-level rise may cause declines in condition, and ultimately, loss of extent, for coastal, or near-coastal, wetlands.

The bogs in the Waikato are already a climatic oddity [21], [35] and their resilience to a warming climate is unknown. It is possible the peat-forming species will be unable to persist in a warming climate, and therefore the vast bulk of carbon sequestration will cease (depending on the replacement vegetation community). Bogs in the Waikato are also under threat of climate change due to salinization, as peat subsidence (due to drainage).

Across all wetland types, shifts in rainfall patterns may affect wetland condition, particularly in areas that are already suffering from drainage [24].

Management responses will need to be tailored to impact type. For some impacts, such as sea level rise, management may be limited to allowing inward migration of coastal wetlands (if economically and socially feasible). Reducing drainage stressors may increase wetland resilience to extreme events, or reductions in rainfall. Acceptance of plant community change may be required where current species cannot persist in their current geographical niche - management should turn to how to manage successions to the next-most valued plant (and animal) communities. For example: if salinisation affects *Empodisma* in Hauraki Plains wetlands, and the service of carbon sequestration is desired, consider transitioning to *Apodasmia* communities, which can tolerate some degree of salinity, but are also peat formers (to a lesser extent than *Empodisma*).

References:

[1] B. R. Clarkson, B. K. Sorrell, P. N. Reeves, P. D. Champion, T. R. Partridge, and B. D. Clarkson, Handbook for monitoring wetland condition. Coordinated monitoring of New Zealand wetlands. A Ministry for the Environment SMF funded project. Wellington, New Zealand: Ministry for the Environment, 2004. [Online]. Available: http:// www.landcareresearch.co.nz/research/biocons/restoration/docs/handbook2004.pdf

[2] B. R. Clarkson, N. B. Fitzgerald, and J. M. Overton, "A methodology for monitoring Bay of Plenty Wetlands," Manaaki Whenua - Landcare Research Contract Report LC1779, Hamilton, New Zealand, LC1779, 2014. Accessed: Aug. 31, 2020. [Online]. Available: https://www.landcareresearch.co.nz/__data/assets/pdf_file/0007/181348/Clarkson-Fitzgerald-Overton-BOP-wetland-monitoring-LC1779.pdf

[3] B. R. Clarkson and S. Bartlam, "Tukituki Catchment. State of the Environment monitoring of Hawke's Bay wetlands," Manaaki Whenua - Landcare Research, Hamilton, New Zealand, HBRC Report No. RM 17-06. HBRC Publication No. 4928, 2017. Accessed: Aug. 31, 2020. [Online]. Available: https://www.landcareresearch.co.nz/__data/assets/pdf_file/0008/181349/Clarkson_Bartlam_2017-LC2713_HBRC-wetland-monitoringHBRCcover.pdf

[4] P. J. Bellingham et al., "Standardised methods to report changes in the ecological integrity of sites managed by regional councils. Manaaki Whenua – Landcare Research Contract Report LC3903.," Manaaki Whenua - Landcare Research, Lincoln, New Zealand, LC3903, 2021.

[5] R. Ruaro, É. A. Gubiani, R. M. Hughes, and R. P. Mormul, "Global trends and challenges in multimetric indices of biological condition," Ecological Indicators, vol. 110, p. 105862, Mar. 2020, doi: 10.1016/j.ecolind.2019.105862.

[6] M. S. Fennessy, A. D. Jacobs, and M. E. Kentula, "An evaluation of rapid methods for assessing the ecological condition of wetlands," Wetlands, vol. 27, no. 3, pp. 543–560, Sep. 2007, doi: 10.1672/0277-5212(2007)27[543:AEORMF]2.0.CO;2.

[7] P. Johnson and P. Gerbeaux, Wetland types in New Zealand. Wellington, New Zealand: Astra Print for the Department of Conservation, 2004.

[8] B. Clarkson, J. Overton, A. Ausseil, and H. Robertson, "Towards quantitative limits to maintain the ecological integrity of freshwater wetlands: Interim report," Landcare Research, Hamilton, New Zealand, LC1933, 2015.

[9] N. W. H. Mason, R. J. Holdaway, and S. J. Richardson, "Incorporating measurement error in testing for changes in biodiversity," Methods in Ecology and Evolution, vol. 9, no. 5, pp. 1296–1307, 2018, doi: 10.1111/2041-210X.12976.

[10] A.-G. E. Ausseil, W. L. Chadderton, P. Gerbeaux, R. T. T. Stephens, and J. R. Leathwick, “Applying systematic conservation planning principles to palustrine and inland saline wetlands of New Zealand,” Freshwater Biology, vol. 56, no. 1, pp. 142–161, Jan. 2011, doi: 10.1111/j.1365-2427.2010.02412.x.

[11] M. M. McKeown, O. R. Burge, S. J. Richardson, J. R. Wood, E. A. D. Mitchell, and J. M. Wilmshurst, “Biomonitoring tool for New Zealand peatlands: Testate amoebae and vascular plants as promising bioindicators,” Journal of Environmental Management, vol. 354, p. 120243, Mar. 2024, doi: 10.1016/j.jenvman.2024.120243.

[12] C. Spencer, A. I. Robertson, and A. Curtis, “Development and testing of a rapid appraisal wetland condition index in south-eastern Australia,” Journal of Environmental Management, vol. 54, no. 2, pp. 143–159, Oct. 1998, doi: 10.1006/jema.1998.0212.

[13] D. C. Kotze, D. M. Macfarlane, and D. J. Ollis, “Chapter 5.7 - WET-Health, a Method for Rapidly Assessing the Ecological Condition of Wetlands in Southern Africa,” in Wetland and Stream Rapid Assessments, J. Dorney, R. Savage, R. W. Tiner, and P. Adamus, Eds., Academic Press, 2018, pp. 545–550. doi: 10.1016/B978-0-12-805091-0.00056-6.

[14] M. E. Kentula and S. G. Paulsen, “The 2011 National Wetland Condition Assessment: overview and an invitation,” Environ Monit Assess, vol. 191, no. 1, p. 325, Jun. 2019, doi: 10.1007/s10661-019-7316-4.

[15] G. M. Suir and D. A. Wilcox, “Evaluating the use of hyperspectral imagery to calculate raster-based wetland vegetation condition indicator,” Aquatic Ecosystem Health & Management, vol. 24, no. 4, pp. 103–114, Oct. 2021, doi: 10.14321/aehm.024.04.13.

[16] D. Russi et al., “The Economics of Ecosystems and Biodiversity for Water and Wetlands. IEEP, London and Brussels.,” Ramsar Secretariat, Gland, 2013. Accessed: Mar. 21, 2024. [Online]. Available: https://www.teebweb.org/wp-content/uploads/2013/04/TEEB_WaterWetlands_Report_2013.pdf#page=11.64

[17] B. R. Clarkson, A.-G. E. Ausseil, and P. Gerbeaux, “Wetland ecosystem services,” in Ecosystem services in New Zealand, J. R. Dymond, Ed., Lincoln, New Zealand: Manaaki Whenua Press, 2013, pp. 192–202.

[18] M. G. Patterson and A. O. Cole, “‘Total economic value’ of New Zealand’s land-based ecosystems and their services,” in Ecosystem services in New Zealand – conditions and trends, J. R. Dymond, Ed., Lincoln, New Zealand: Manaaki Whenua Press, 2013, pp. 496–510.

[19] A.-G. E. Ausseil, H. Jamali, B. R. Clarkson, and N. E. Golubiewski, “Soil carbon stocks in wetlands of New Zealand and impact of land conversion since European settlement,” Wetlands Ecol Manage, vol. 23, no. 5, pp. 947–961, Oct. 2015, doi: 10.1007/s11273-015-9432-4.

[20] J. P. Goodrich, D. I. Campbell, and L. A. Schipper, “Southern Hemisphere bog persists as a strong carbon sink during droughts,” Biogeosciences, vol. 14, no. 20, pp. 4563–4576, Oct. 2017, doi: 10.5194/bg-14-4563-2017.

[21] M. S. McGlone, “Postglacial history of New Zealand wetlands and implications for their conservation,” New Zealand Journal of Ecology, vol. 33, no. 1, pp. 1–23, 2009.

[22] O. R. Burge, K. A. Bodmin, B. R. Clarkson, S. Bartlam, C. H. Watts, and C. C. Tanner, “Glyphosate redirects wetland vegetation trajectory following willow invasion,” Appl Veg Sci, vol. 20, no. 4, pp. 620–630, Oct. 2017, doi: 10.1111/avsc.12320.

[23] O. R. Burge et al., “Plant responses to nutrient addition and predictive ability of vegetation N:P ratio in an austral fen,” Freshwater Biology, vol. 65, no. 4, pp. 646–656, 2020.

[24] O. R. Burge, R. Price, J. M. Wilmshurst, J. M. Blyth, and H. A. Robertson, “LiDAR reveals drains risks to wetlands have been under-estimated,” New Zealand Journal of Ecology, vol. 47, no. 1, 2023.

[25] H. A. Robertson, A.-G. Ausseil, B. Rance, H. Betts, and E. Pomeroy, “Loss of wetlands since 1990 in Southland, New Zealand,” New Zealand Journal of Ecology, vol. 43, no. 1, pp. 1–9, 2019.

[26] K. Denyer and M. Peters, “The root causes of wetland loss in New Zealand: an analysis of public policies & processes,” National Wetland Trust, Hamilton, New Zealand, 2020. Accessed: Dec. 01, 2023. [Online]. Available: https://www.wetlandtrust.org.nz/wp-content/uploads/2021/02/ROOT-CAUSES-OF-WETLAND-LOSS-IN-NZ_Jan-2021.pdf

[27] J. P. S. Sukias et al., “Jump-starting podocarp forest establishment in a wetland dominated by invasive willow,” Restoration Ecology, vol. n/a, no. n/a, p. e14031, 2023, doi: 10.1111/rec.14031.

[28] Y. Taura, C. van Schravendijk-Goodman, and B. R. Clarkson, Eds., Te Reo o Te Repo - The Voice of The Wetland. Connections, understandings and learnings for the restoration of our wetlands. Hamilton, New Zealand: Manaaki Whenua - Landcare Research and Waikato Raupatu River Trust, 2017. Accessed: Jun. 05, 2023. [Online]. Available: https://www.landcareresearch.co.nz/assets/Publications/Te-reo-o-te-repo/Te_Reo_o_Te_Repo_Voice_of_the_Wetland_complete_book.pdf

[29] O. R. Burge, S. J. Richardson, J. R. Wood, and J. M. Wilmshurst, “A guide to assess distance from ecological baselines and change over time in palaeoecological records,” The Holocene, vol. 33, no. 8, pp. 905–917, Apr. 2023, doi: https://doi.org/10.1177/09596836231169.

[30] N. B. Fitzgerald, S. Basheer, and M. McLeod, “Peat subsidence near drains in the Waikato Region,” Environment Waikato, Hamilton, New Zealand, Environment Waikato Technical Report 2005/40, 2005. Accessed: Oct. 08, 2021. [Online]. Available: https://waikatoregion.govt.nz/assets/WRC/WRC-2019/tr05-40.pdf

[31] J. Pronger, L. A. Schipper, R. B. Hill, D. I. Campbell, and M. McLeod, “Subsidence Rates of Drained Agricultural Peatlands in New Zealand and the Relationship with Time since Drainage,” Journal of Environmental Quality, vol. 43, no. 4, pp. 1442–1449, 2014, doi: 10.2134/jeq2013.12.0505.

[32] B. R. Clarkson, V. M. Cave, C. H. Watts, D. Thornburrow, and N. B. Fitzgerald, “Effects of lowered water table and agricultural practices on a remnant restiad bog over four decades,” Mires Peat, vol. 26, no. 19, pp. 1–13, Jul. 2020, doi: 10.19189/MaP.2019.OMB.StA.1876.

[33] J. W. Griffiths, C. J. Howell, and D. Burlace, “Mapping Grey Willow (Salix cinerea) stand architecture using airborne laser scanning: implications for large-scale tree weed control,” Ecological Management & Restoration, vol. 18, no. 1, pp. 66–70, 2017, doi: 10.1111/emr.12241.

[34] B. R. Clarkson, V. M. Cave, S. Bartlam, C. H. Watts, D. Thornburrow, and Q. Paynter, “Status of forest remnants invaded by tradescantia (Tradescantia fluminensis Vell.) following introduction of biocontrol beetles and manual clearance after three years,” New Zealand Journal of Botany, vol. 0, no. 0, pp. 1–25, 2023, doi: 10.1080/0028825X.2023.2279297.

[35] D. I. Campbell and J. L. Williamson, “Evaporation from a raised peat bog,” Journal of Hydrology, vol. 193, no. 1, pp. 142–160, Jun. 1997, doi: 10.1016/S0022-1694(96)03149-6.

[36] https://www.landcareresearch.co.nz/assets/Publications/Wetland-restoration-handbook/Chp_13_Monitoring_2012.pdf

[37] https://www.landcareresearch.co.nz/publications/wetland-restoration/)

[38] Burge OR, Law R, Wakefield S. 2024. A spatial layer of human terrestrial pressures for New Zealand (under review). New Zealand Journal of Ecology.

[39] https://environment.govt.nz/publications/otuwharekaiashburton-lakes-lessons-learnt-report/

[40] https://www.gw.govt.nz/assets/Documents/2023/11/2016-23-wetland-health.pdf.