Port Colborne Community Action Plan (PCCAP)

Report on the Terrestrial Natural Environment

(DRAFT)

September 4, 2024

Concise Summary

The Port Colborne Community Action Plan (PCCAP) was initiated by Vale Canada Limited (Vale) to address a number of important unresolved issues from the Community-Based Risk Assessment (CBRA).

Nearly 200 additional soil and vegetation samples were collected from the primary study area (PSA) from the CBRA. The study area for the PCCAP included Vale-owned lands between Reuter Road to the west and Lorraine Road to the east.

The PCCAP sampling program identified that the soil Ni concentrations in the Reuter Road woodlot were highly variable and twice as high than as characterized in the CBRA. A natural heritage inventory and woodlot health assessment conducted for the PCCAP has provided up-to-date information on the ecological status of the Vale lands east of Reuter Road. The inventory and assessment covered the areas that the Ministry of the Environment Conservation and Parks (MECP) was concerned had been under-assessed in the CBRA Natural Environment Ecological Risk Assessment (NE-ERA). Despite the elevated Ni concentrations on these lands, they support a diverse assemblage of flora and fauna, including one provincially rare, and four regionally rare plant species, as well as significant wildlife habitat and significant woodlands, the latter which were found to be in fair to excellent condition. Most (73%) of the plant species identified in the study area were native to Ontario, as compared to 63% in Ontario as a whole. Seemingly, the risk to the natural environment from the elevated metal levels in the soil on these lands is subtle, possibly below the threshold for where frank toxicity can be observed at the level of terrestrial ecological communities present in the CBRA primary study area. During soil sampling for the PCCAP, apparent chlorosis (yellowing of leaves – an indicator of Ni toxicity in plants) was observed in spice bush (*Lindera benzoin*) plants in the Reuter Road woodlot. Following from these observations, vegetation sampling and analysis of chlorophyll concentrations in spice bush, a characteristic Carolinian forest shrub species, identified the presence of apparent chlorophyll suppression in relation to elevated metal levels (10% reduction at approximately 15,000 ppm Ni in soil), an indicator of Ni toxicity and a potential measure of plant impact in the woodlots.

Ni concentrations in maple leaves in the Reuter Road woodlot were similar to those observed in the CBRA and were substantially reduced since pre-closure conditions around the Ni refinery (ca. 1984).

A small metal speciation study was undertaken in the PCCAP and corroborated earlier speciation studies, in that the man-made mineral bunsenite (nickel oxide) was the predominant chemical form of Ni in the soils collected in the PCCAP. The Kd (soil-water distribution coefficient) was studied in the PCCAP after a significant rainfall event that left standing water in fields in the study area. The large Kd values in the study area reflect that the Ni is present in these soils as nickel oxide, which has relatively low solubility and is therefore poorly released from the soils and less toxic than would be expected from more soluble Ni forms such as nickel sulphate, which is often used in animal toxicity studies.

The PCCAP assessed soil decomposition processes using a tool that was not available during the CBRA (the Soil Microbiometer). The soil microbiometer testing indicated that soil microbial populations seemed to be in the range of normal although fungal-to-bacterial ratios were somewhat lower than might be expected in similar forested ecosystems.

Plant toxicity tests were conducted on mineral and organic soils from the PCCAP study area using lettuce and radish to allow for comparison with earlier findings. In organic soil, no reduction in germination, growth, and chlorophyll content could be determined up to approximately 4,400 ppm Ni, while in mineral soil, an EC_{10} (10% reduction in the measured variables) was present at 1,365 ppm Ni. No indicator of greater toxicity (i.e., EC_{20}) could be determined from the data. As with maple leaves, the Ni content in lettuce and radish leaves in the PCCAP testing show reduced levels in comparison to pre-closure MOE data, suggesting reduced uptake under current conditions.

Risk to wildlife was also assessed using the Quotient Method. Elevated risks (as high as RQ=20) were calculated for wildlife species in the Reuter Road woodlot. The risk estimates were driven mostly by soil Ni, although Ni in vegetation would also result in RQ>1 for the worst-case vegetation Ni concentrations (123 ppm Ni on a dry weight basis in the Reuter Road woodlot). The earlier risk estimates in the PSA from the CBRA Natural Environment Ecological Risk Assessment under-represented the risk to wildlife in the study area. Unacceptable risk can be calculated to be present for wildlife species, particularly in the Reuter Road woodlot.

The historical Ni, Cu, Co, and As contamination in the forested lands between Reuter Road and Lorraine Road is of concern to certain wildlife species that have home ranges smaller than the areas of the woodlots, particularly the Reuter Road woodlot. Risk drops off in open fields adjacent to these woodlots with decreasing soil metal concentrations. It is difficult to weigh the relative value of the risk quotient estimates against the natural heritage values, but given that these lands are present as part of the Nickel Beach Wetland Complex, a provincially significant wetland (PSW), it is unlikely that remediation (contaminated soil removal) could or should occur on these lands, given their high ecological value in a region with increased development threat to Carolinian forest. Despite the fact that the CBRA Natural Environment Ecological risk assessment significantly under-estimated risk, the conclusions of the CBRA Integration Report remain valid. The PSA from the CBRA should not undergo remediation by soil removal, which would result in the destruction of these woodlands. Natural attenuation is a preferred option. As the woodlots undergo continuous regeneration, the soil contamination will be buried by soil that is produced from the decay of treefall. As new methods for remediating forest lands are developed in the future, other management options may become available.

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1.0 Introduction

The Port Colborne Community Based Risk Assessment (CBRA) was initiated by Inco Limited, Vale Canada's predecessor, at the recommendation of Ontario Ministry of the Environment. The CBRA was intended to address chemical risk arising from the historical soil contamination from previous nickel refinery operations between 1918 and 1984 (when the nickel refinery ceased operation – it still operates as a cobalt and precious metal refinery under modern environmental practices). The CBRA consisted of three component risk assessments, Human Health, Ecological (Agricultural Crops), and Ecological (Natural Environment). The CBRA was guided by the MOE's 1997 *Guideline for Use at Contaminated Sites in Ontario*, the MOE's *Guidance on Site-Specific Risk Assessment at Contaminated Sites in Ontario* (MOE, 1996), and the Canadian Council of Ministers of the Environment's (CCME) *A Framework for Ecological Risk Assessment: General Guidance* (CCME, 1996), but the CBRA was not bound to these in a regulatory sense, as the CBRA was voluntary.

The three component risk assessment reports were submitted jointly to the Ministry of the Environment (at the Ministry's request) for official review in 2010 after all three risk assessments had been completed. For the Natural Environment Ecological Risk Assessment (ERA), data collection generally occurred in 2000 and 2001, the Risk Assessment report was completed in 2004 (JWEL, 2004a), and an addendum report was completed in 2005 (JWEL, 2005).

The Ministry of the Environment (MOE) provided comments to Vale in May, 2011 (MOE, 2011)[1].

The Ministry concluded that potential risks to the natural environment were underestimated, particularly at locations close to the refinery, but that the Natural Environment ERA appeared to provide sufficient information to characterize most ecological risks and to support the majority of the report's conclusions (MOE, 2011). However, the MOE review identified a number of deficiencies. Vale commissioned an Update Report in 2014 (Stantec, 2014) that included only limited new data, which did not resolve Ministry concerns. Aspects of Regulation 153/04 (the so-called Brownfields Regulation), which replaced the *Guideline* (MOE, 1997), were used to guide the Update Report, but again, as a voluntary wide-area risk assessment, the regulation was not a strict legal requirement.

The Port Colborne Community Action Plan (PCCAP) was initiated with the intention to seek MECP concurrence as to the assessment of ecological risk in the vicinity of Vale's Port Colborne Refinery. The PCCAP has supplemented the assessment with additional data and analysis intended to address remaining gaps in the Natural Environment ERA.

Because there is now such a significant amount of information from the original CBRA and 2014 update reports, their associated Ministry-Vale comment-response dialogues, and new PCCAP

[1] The comments and Vale's responses can be found in Appendix 4D of Stantec (2014).

data and analysis, this report will cite the reports only as necessary and will focus on MECP comments that are related to significant issues.

The Ministry expressed concern that adverse impacts are occurring as a result of exposure to COCs in soil, that woodlots nearest to the refinery had not been adequately characterized, that earthworms (i.e., decomposers) were not properly assessed, and that the lack of toxicity and/or field data on herbaceous plants was a major limitation of the CBRA and 2014 Update Report.

Ecological toxicity reference values (TRVs) based on the Modified Ecological Protection (MEP) concept were used in the 2014 Update Report at the recommendation of the consultant. A number of MECP comments expressed concern over the use of MEP for Port Colborne situation, and although the MEP approach is not directly used in the PCCAP, a discussion of the MEP concept is warranted for several reasons. Firstly, as will be shown below, the natural heritage inventory and woodlot health assessment conducted as a component of the PCCAP determined that despite the elevated Ni, Cu, Co, and As concentrations on these lands, they support a diverse assemblage of flora and fauna, including regionally and provincially rare species and species at risk. Secondly, a provincially significant wetland (PSW – part of the Nickel Beach Wetland Complex) is present on the Vale-owned lands, which contain significant woodlands characteristic of Ontario’s Carolinian zone, and significant wildlife habitat (North-South Environmental, 2021). It is conceivable that environmental protection provisions of regional, provincial, and federal policies and legislation would be applicable on these lands by virtue of the natural features present there. The soil on these lands should not be removed (causing destruction of the Carolinian habitat present there) just to meet a regulatory scheme (the brownfields regulation) that applies poorly to this situation. The MEP concept could offer a perspective for managing these lands going forward.

This report summarizes the results of new data collection activities in the PCCAP and provides updated estimates ecological risk for certain valued ecosystem components (VECs). This report is not a risk assessment, but includes elements of a risk assessment and incorporates both quantitative and qualitative data that provides additional context for understanding ecological risk of the highly elevated historically deposited chemicals of concern on the Vale-owned lands to the east of Vale’s Port Colborne Refinery site. Specifically, this report addresses the major issues raised by MECP reviews: characterization of the contamination in the most-heavily contaminated areas nearest the refinery, a new assessment of the soil decomposer pathways, and ecological assessment of plant communities within these areas.

It is now more than two decades since Inco Limited initiated the Port Colborne Community-Based Risk Assessment. Vale offers this report on the Natural Environment to the community of Port Colborne to summarize the current assessment of impacts present in the natural environment of Port Colborne due to the historically deposited chemicals of concern – nickel, copper, cobalt, and arsenic – in Port Colborne soils, with a focus on Ni, the predominant contaminant on these lands.

2.0 Natural Heritage Inventory and Woodlot Health Assessment

North-South Environmental Inc. was retained by Vale in 2021 to conduct a natural heritage inventory and woodlot health assessment meant to address a number of Ministry comments. In particular, MECP was concerned that the CBRA had averaged data from a wide geographical area, resulting in exposure point concentrations that had been dramatically reduced by the inclusion of data from areas with lower CoC concentrations, effectively reducing the risk estimates and underestimating risk. The natural heritage inventory was focused on Vale-owned lands that were within the primary study area of the CBRA natural environment ecological risk assessment (NE-ERA), the area for which risks may have been underestimated. The main findings of the North-South Environmental studies are summarized here. The full report (North-South Environmental, 2021) is available on Vale Canada's CBRA website (https://vale.com/community-based-risk-assessment-cbra-).

North-South Environmental provided a three-season reconnaissance inventory of plants and wildlife and a preliminary assessment of woodlot health and significant ecological features on undeveloped Vale-owned lands in Port Colborne (North-South Environmental, 2021). The Vale-owned lands exist between Reuter Road to the west, Lorraine Road to the east, Lakeshore Road to the south, and the Friendship community trail to the north (Fig. 1).

The natural heritage inventory included a vegetation community assessment, a woodland health survey, amphibian breeding surveys[2], breeding bird surveys, and marsh bird monitoring surveys. The conservation status of plants and wildlife identified in the study area was determined using the most recent species checklists from Ontario's Natural Heritage Information Centre (NHIC), and the Checklist of the Vascular Plants of Ontario's Carolinian Zone. North-South Environmental identified that there is the potential that the site supports habitat for Species at Risk. Sixteen significant species were documented on the site, and habitat for most of these species is present on the site (North-South Environmental, 2021).

2.1 Vegetation Communities

Three broad vegetation community series were delineated across the approximately 94 ha (hectare) study site (i.e., the primary study area from the CBRA), with twelve vegetation sub-types (North-South Environmental, 2021) (Fig. 2). The study area contains provincially and nationally rare Pin Oak (*Quercus palustris*) swamp communities (SWD1-3[3]), which are types of wetlands restricted to a narrow region of Ontario's Carolinian Zone, including Niagara Region. The Pin Oak swamps in the study area contain healthy, mature, Pin Oaks and other oaks and also support at least one rare plant species (White Pincushion Moss) and three regionally rare species, River Bulrush, False Waterpepper, and Limestone Bittercress (North-South Environmental, 2021).

[2] The amphibian survey information has been considered in Vale's Aquatic Survey Report (Vale, 2023a) and will not be discussed in detail in this report.

[3] SWD 1-3 is the ecological land classification (ELC) code for 'pin oak mineral deciduous swamp'

Swamp communities on the site were generally of high vegetation quality, supporting a larger than expected proportion of native species. North-South Environmental identified 157 species of flora within the study area, with most of the plant species (73%) being native to Ontario, the majority of which are considered “Secure” (S5) or “Apparently Secure” (S4) in the province (i.e., they are common to uncommon and not of conservation concern). The proportion of native species in the study area is relatively high compared to other areas of high agricultural disturbance in the province, the flora of Ontario as a whole comprises approximately 63% native species and 37% non-native species (North-South Environmental, 2021).

Large areas of marsh are dominated by the invasive non-native species Common Reed (*Phragmites australis* ssp. *australis*), a species that is known to out-compete most native marsh species (North-South Environmental, 2021).

2.2 Woodlot Health Survey

North-South Environmental conducted a preliminary reconnaissance of tree health focusing on four mature treed communities within the study area: two on the western part of the site just east of Reuter Road, and two on the eastern part of the site, west of Lorraine Road (locations shown in Figure 1). The woodlots corresponded with mature woodlots that were included in the CBRA NE-ERA study. Unfortunately, there were two numbering systems used to denote woodlots in the CBRA. These two woodlot numbering systems are discussed in the supporting Information document associated with this report (Vale, 2024a). Here, we refer to the Reuter Road woodlot (ecological land classification SWD 1-3[4]) and the Lorraine Road woodlot (ecological land classification SWD 3-3[5]). Sparsely treed communities within the southwestern part of the study area were not surveyed as they were meadow marsh/thicket swamps succeeding to treed swamps, resulting in a community of young, immature trees (North-South Environmental, 2021).

Tree health was assessed by undertaking detailed assessments of trees in six 0.05 ha sampling plots (i.e., two plots 12m in radius in each of the two primary woodland features in the study area, and one plot in each of the two eastern woodlots) and extrapolating the results to the entire unit (Fig. 1). Within each plot, all trees larger than 10 cm in diameter were inventoried and an assessment of their overall condition was given using six classes, from excellent condition (Class 1) to dead or almost dead (Class 6). North-South Environmental referred to the Reuter Road Woodlot as the “western woodland” in its report (North-South Environmental, 2021). Two survey stations in that 8.1-hectare woodlot were sampled and the overall tree health there was in good to excellent condition, with a mean condition class of 1.48 and 1.97 in the northern and southern survey units, respectively. The third tree health survey unit was the roughly 2.8 ha portion of the Lorraine Road woodlot located east of Wignell Drain (Fig. 1), which had a mean condition class of 2.98 (fair to good condition). The fourth tree health survey unit was a 0.79 ha portion of the Lorraine Road woodlot located northeast of unit 3 (Fig. 1) which had a mean condition class of 2.42 (fair to good) (North-South Environmental, 2021).

[4] SWD 1-3 is the ELC code for ‘pin oak mineral deciduous swamp’.

[5] SWD 3-3 is the ELC code for ‘swamp maple mineral deciduous swamp’.

2.3 Wildlife

2.3.1 Amphibians

Eight amphibian species were noted on the site during amphibian surveys and remote Froglogger recordings. These included Spring Peeper (*Pseudacris crucifer*), American Toad (*Anaxyrus americanus*), Northern Leopard Frog (*Lithobates pipiens*), Wood Frog (*Lithobates sylvaticus*), Chorus Frog (*Pseudacris triseriata*), Green Frog (*Lithobates clamitans*), American Bullfrog (*Lithobates catesbeianus*), and the endangered Fowler's Toad (*Anaxyrus fowleri*) (southern portion of the site). A ninth species, Pickerel Frog (*Lithobates palustris*), was tentatively identified (North-South Environmental, 2021).

Figure 1. Study boundaries and sampling/survey stations. Woodlot tree health survey units are marked in black text and tree health sampling stations are marked with green 'Christmas trees'. Adapted from Figure 2 of North-South (2021).

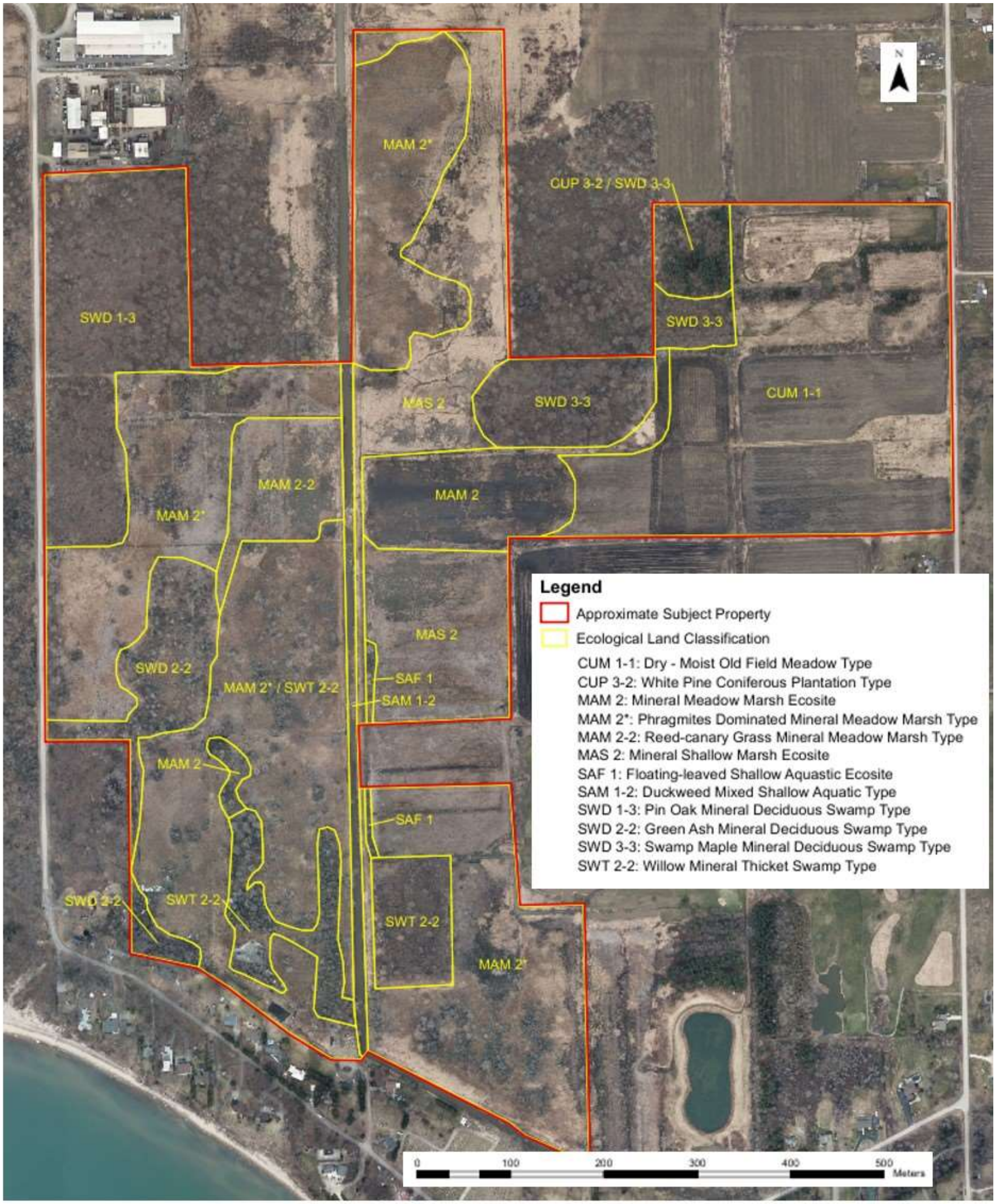

Figure 2. Ecological land classification of the Vale-owned lands. Adapted from North-South (2021).

2.3.2 Birds

A total of 55 bird species were seen in the study area during breeding bird surveys and other field investigations. The majority of these were determined to be possible or probable breeders in various habitats in the study area and three species were confirmed to be breeding in the study area. All of the bird species seen in the study area are native to Ontario and the majority (93%) are common and widespread species in Ontario (North-South Environmental, 2021).

Four bird species at risk and species of conservation concern were identified: Barn Swallow (*Hirundo rustica*), Bobolink (*Dolichonyx oryzivorus*), Eastern Wood-pewee (*Contopus virens*) and Wood Thrush (*Hylocichla mustelina*). All of the vegetation communities in the study area provide breeding habitat for a variety of bird species, but the majority of species were birds of patchy woodland, hedgerow and forest edge, which breed in the study area's deciduous swamp communities and other treed areas. A few marsh-breeding species were recorded, mostly those that also nest in other types of habitat, such as Common Yellowthroat (*Geothlypis trichas*) and Red-winged Blackbird (*Agelaius phoeniceus*). One marsh-obligate species was recorded that is restricted to larger marshes: Marsh Wren (*Cistothorus palustris*), but this species was only heard during the first visit in late May when abundant standing water was present on the site and was likely a late migrant (North-South Environmental, 2021).

2.4 Analysis of Significant Features

2.4.1 Habitat for Species at Risk

North-South Environmental provided discussion of habitat for Endangered and Threatened species that were either directly observed or for which there is a high probability of occurrence based on screening criteria. The report identified that Fowler's Toad was present on southern portions of the site. Barn Swallows were observed foraging over the study area, but are unlikely to breed on the site due to lack of appropriate nesting habitat. A Bobolink was observed on only one occasion during the study. There is suitable habitat for endangered bat species on the Vale-owned lands, but no acoustic surveys were conducted as part of the survey.

2.4.2 Provincially Significant Wetland

A Provincially Significant Wetland (PSW), part of the Nickel Beach Wetland Complex, is mapped on the site (North-South Environmental, 2021). Patches of wetland occur throughout the site, as well as on the active refinery site to the west of Reuters Road. There is potential that these wetland areas could be added to the Nickel Beach Wetland Complex by the Ministry of Northern Development, Mines, Natural Resources and Forestry (MNDMNRF), which is responsible for mapping and evaluating wetlands in Ontario: wetland complexes can be modified at any time as new information becomes available (North-South Environmental, 2021).

2.4.3 Significant Woodlands

North-South Environmental considered that all mature woodlands on the site should be classified as significant ecological features.

2.4.4 Significant Wildlife Habitat (SWH)

North-South Environmental identified that the Vale-owned lands can be considered as candidate or confirmed SWH for several different aspects (Table 1). Twenty years earlier, in 2001, a woodlot health assessment study was completed as part of the CBRA Natural Environment Risk Assessment (Trees Unlimited, 2002). That study was completed from a forestry perspective, whereas the 2021 Woodlot Health Assessment was undertaken from a broader ecological perspective. The 2001 woodlot health assessment identified an unacceptably high proportion of "unacceptable growing stock" (UGS), reflecting a silviculture perspective, which considered that UGS above 20% would "warrant a stand improvement harvest to prevent the introduction of disease and insects, maintain vigour and overall stand quality", and that the "unusually high percentage of UGS could lead to greater amounts of wildlife habitat but lower future timber production" (Trees Unlimited, 2002). The 2021 survey focused on habitat considerations and identified significant wildlife habitat (SWH) on the study lands (Table 1), all located in what had been the primary study area of the CBRA, which MECP review had expressed concern regarding underestimated risk. The trends predicted in the 2001 woodlot survey appear to have been realized in the successive twenty years.

2.5 Summary - Natural Heritage Inventory and Woodlot Health Assessment

The natural heritage inventory and woodlot health assessment has provided up-to-date information on the ecological status of the Vale lands east of Reuter Road. The inventory and assessment covered the areas that the Ministry of the Environment Conservation and Parks (MECP) was concerned had been under-assessed in the CBRA Natural Environment Ecological Risk Assessment (NE-ERA). Despite the contamination levels on these lands, they support a diverse assemblage of flora and fauna. Seemingly, the risk to the natural environment from the elevated metal levels in the soil and sediment on these lands is subtle, possibly below the threshold for where frank toxicity can be observed at the level of terrestrial ecological communities present on the Vale lands in the CBRA primary study area.

Table 1. Significant Wildlfie Habitat (SWH) present on the Vale-owned lands east of Reuter Road as reported by North-South Environmental (North-South, 2021)

Seasonal Concentration Areas of Animals	Raptor wintering area (candidate) Bat maternity colony (candidate) Turtle wintering area (candidate) Migratory butterfly stopover area (candidate) Landbird migratory stopover area (candidate)
Specialized Habitat for Wildlife	Turtle nesting area (candidate) Amphibian breeding habitat (woodland and wetland types) (confirmed)
Habitat for Species of Conservation Concern	Shrub/early successional bird breeding habitat (candidate) Habitat for provincially rare species (confirmed) Habitat for species of special concern: Monarch, Eastern Wood-peewee, and Wood Thrush (confirmed) Marsh breeding bird habitat (candidate)

3.0 CoC Concentrations in Soil on the Vale-owned lands

MECP comments on the original Natural Environment Risk Assessment and the 2014 Update Report, identified that the soils in the primary study area of the CBRA had been under-sampled and therefore likely underestimated exposure. Vale agrees with that assessment. The PCCAP therefore included additional soil sampling to identify the potential for remediation of the most heavily contaminated woodlot soils, particularly in the Reuter Road woodlot, nearest to the refinery fenceline.

Surface (grab) soil samples were collected in 2020, 2021, 2022, and 2023, as the PCCAP developed. Figure 3 provides the overall borders of the Vale lands that were sampled in the PCCAP, denoted by yellow borders and opaque yellow shading. The general locations of the sample collection stations are provided in Figures 4-8. The yellow borders and shading are overlain on these figures for overall comparison of sample locations in the study area. The Reuter Road woodlot samples collected in 2020 were collected at 44 sampling locations (stations) (Fig. 4). Samples collected at a given sampling station are denoted by the sampling year (i.e., 20-, 21-, or 22- for 2020, 2021, and 2022 sampling years) followed by sampling location number. Samples taken from the same location in all three years would be identified as 20-07, 21-07, and 22-07, for station 7, as an example. In 2020, only soil samples were collected. In 2021 and 2022, co-located vegetation and soil were taken from stations in a series of sample collection efforts: 21-100 series; 21-200 series; 22-300 series; 22-400 series; 22-500 series; and 22-600 series. In 2023, five soil and co-located maple leaf samples were collected (samples M23-01 to M23-05).

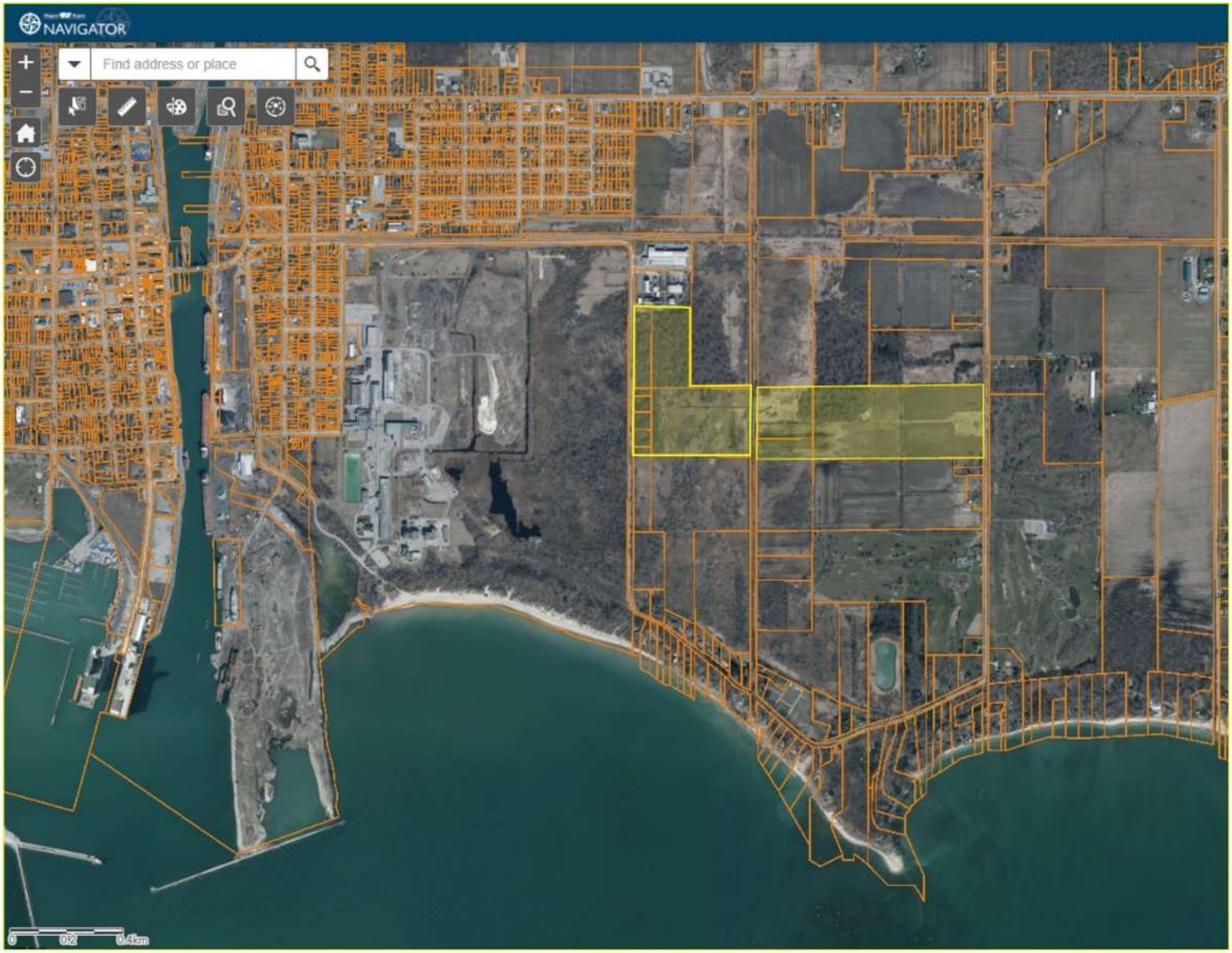

Figure 3. Approximate boundaries of Vale-owned lands where PCCAP soil and vegetation sampling was conducted. Imagery from Niagara Navigator (https://navigator.niagararegion.ca/portal/apps/webappviewer/).

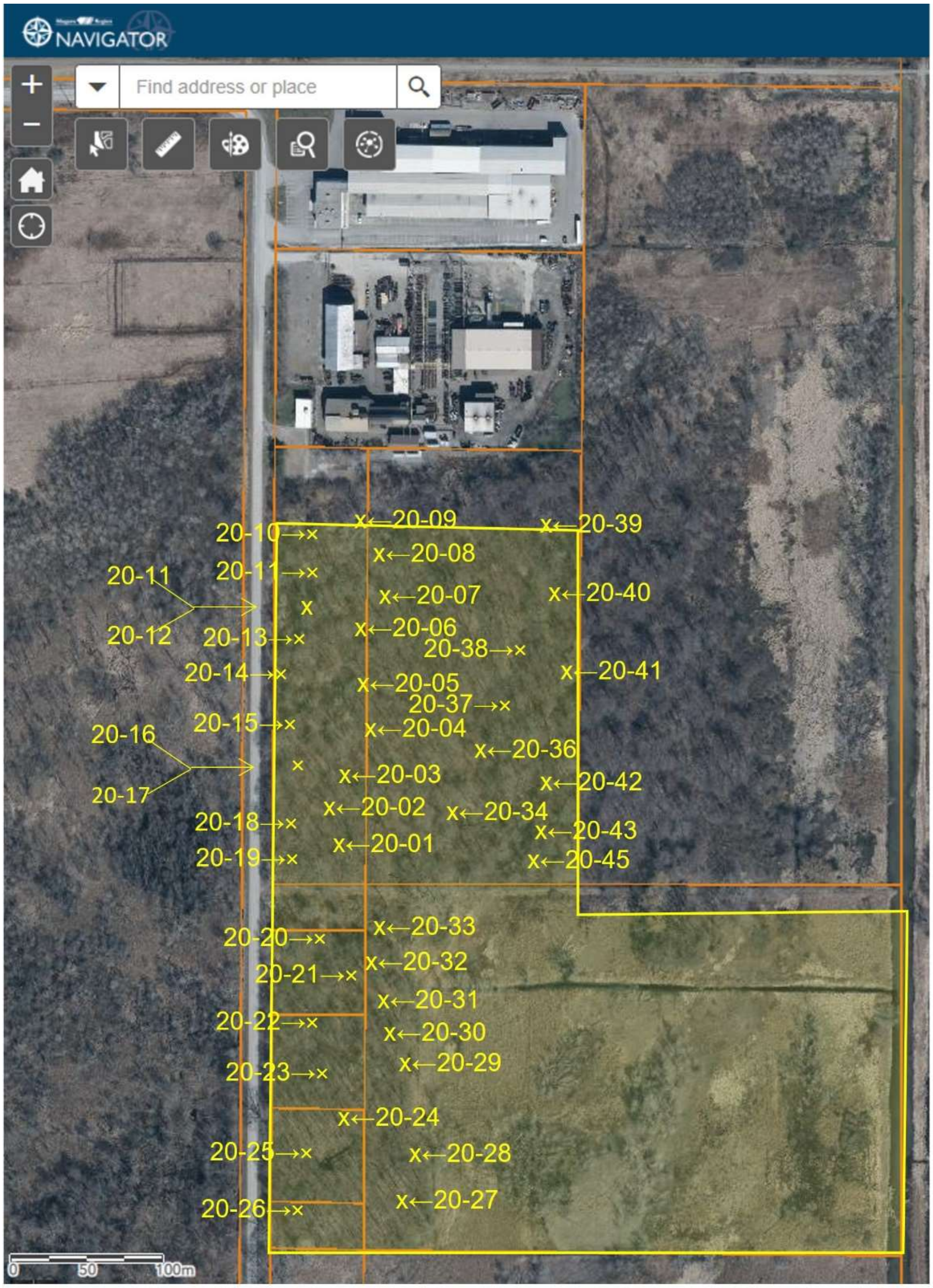

Figure 4. Approximate location of 2020 sample collection locations in Reuter Road woodlot. Samples 20-12 and 20-17 were peat-like samples taken from the forest floor surface above samples 20-11 and 20-16, respectively, which were consolidated soil samples. Imagery from Niagara Navigator (https://navigator.niagararegion.ca/portal/apps/webappviewer/).

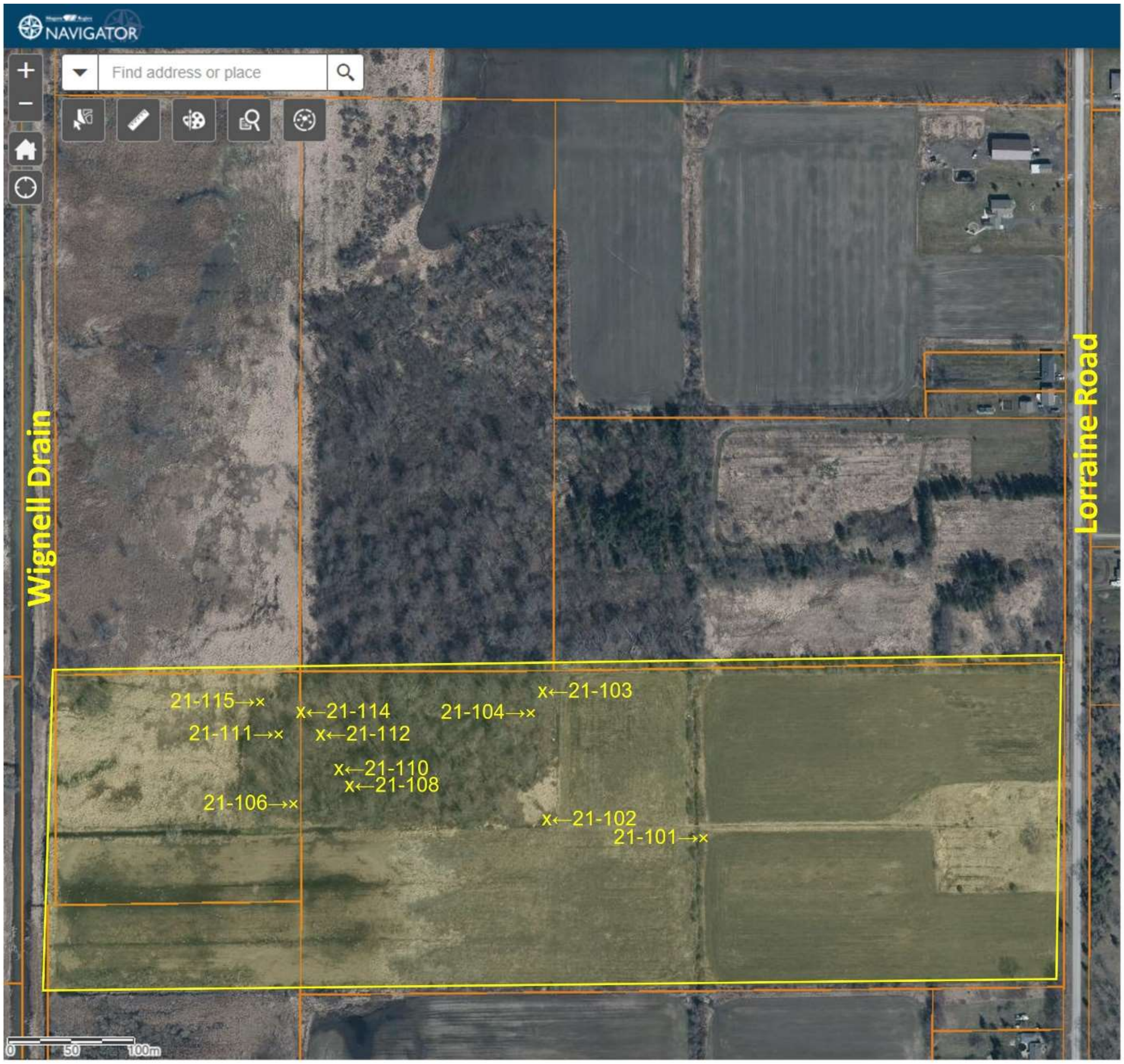

Figure 5. Location of 21-100 sample series stations on Vale-owned lands east of Wignell Drain from 2021 sampling. Imagery from Niagara Navigator (https://navigator.niagararegion.ca/portal/apps/webappviewer/).

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Figure 6. Approximate locations of 200 series sample collection sites. They are field/forest edge samples. Imagery from Niagara Navigator (https://navigator.niagararegion.ca/portal/apps/webappviewer/).

Figure 7. Location of 22-400 sample series stations on Vale-owned lands in 2022. These are woodlot and field samples. Imagery from Niagara Navigator (https://navigator.niagararegion.ca/portal/apps/webappviewer/).

Figure 8. Approximate location of 300 series and 500 series sample collection stations in Reuter Road woodlot in 2022. Imagery from Niagara Navigator (https://navigator.niagararegion.ca/portal/apps/webappviewer/).

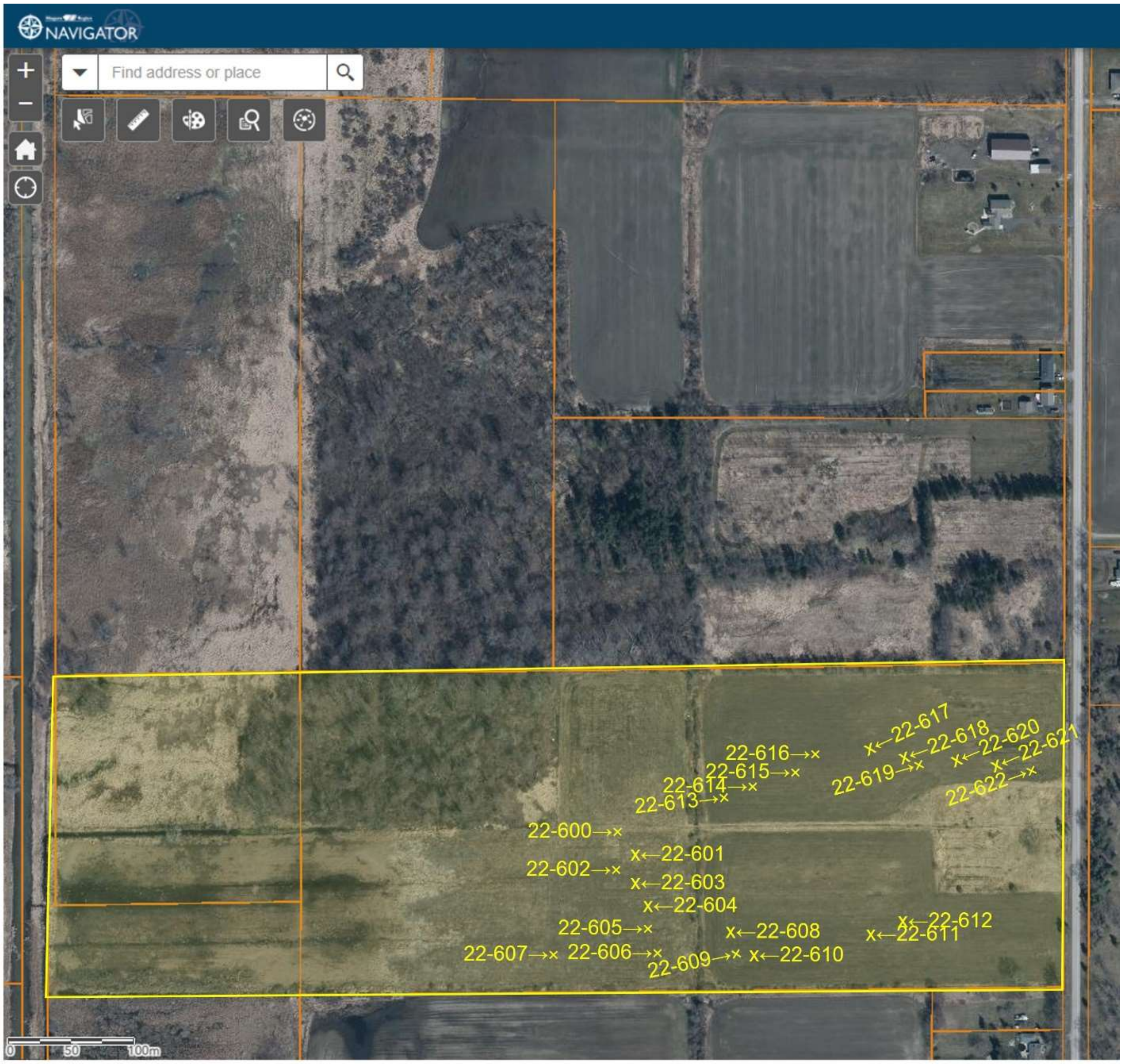


Figure 9. Location of the 600 series samples. Soil and co-located soybean samples were collected from the Vale-owned field that was illegally planted with soy in 2022. Imagery from Niagara Navigator (https://navigator.niagararegion.ca/portal/apps/webappviewer/).

In total, 188 soil samples were collected in the PCCAP natural environment survey work on the Vale-owned lands. Of these, 84 were collected in 2022 with co-located vegetation samples, and five were collected in 2023, also with co-located soil samples. Surface soil grab samples were collected by hand using a trowel. In the case of soil samples co-located with vegetation samples, the soils were collected from around the base of the plant stem or from around the roots, as appropriate. In some cases, a single soil sample was associated with more than one plant.

Analytical

Soils were dried at 70° C for 48 hours, disaggregated by hand using a mortar and pestle, sieved (344 µm) and packed by hand into sample cups (Chemplex 1330 SE, Chemplex Industries, Palm City, Florida) sealed with mylar film (Chemplex No. 257) and analyzed by handheld XRF (Olympus Delta). Certified Refence Materials (CRMs) (U.S. National Institute of Standards and Testing (NIST) CRMs 2710a and 2711a) and blanks (SiO_2) were typically analyzed with sets of samples analyzed by the handheld XRF. Information on the CRM results is provided in the Supporting Information (Vale, 2024a).

CoCs (Ni, Cu, Co, and As) in Soil

Among the Vale-owned lands off the refinery site proper, the Reuter Road woodlot received the highest emission loads from the historical Inco nickel refinery, being immediately adjacent to the refinery. The PCCAP has therefore intensively sampled the Reuter Road woodlot (Fig. 4) to improve estimates of ecological risk and to identify the potential for soil remediation. The Reuter Road woodlot is approximately 8 hectares in area and has an ecological land classification of “pin oak mineral deciduous swamp” (SWD 1-3) (Fig. 2) (North-South Environmental, 2021). A dataset of 109 soil samples from the woodlot have been aggregated to provide the exposure-point concentrations for risk estimation purposes (Table 2). These data represent the likely worst-case soil concentrations for soil exposure and soil-to biota transfer that is applicable to fauna with home ranges under 8 hectares in area. The 95% upper confidence limit on the mean (UCLM) value for Ni in Table 2 (30,452 ppm) is approximately one third larger than the value (22,861 ppm Ni) assessed in the 2014 Update Report and is essentially double the 15,200 ppm soil Ni value used as the exposure-point concentration in the original CBRA Natural Environment Risk Assessment.

Table 2. Ni, Cu, Co, and As concentrations (ppm, as reported by the XRF analyzer) in soil samples from the Reuter Road woodlot.

	Ni	Cu	Co	As
Arith. Mean	27,038	3,135	182	93
SD	15,681	1,627	123	40
n	109	109	93	109
95%CL	3,414	354	29	9
95UCLM	30,452	3,489	211	101
95LCLM	23,624	2,780	153	84

A second forested area in the Vale-owned lands in the CBRA primary study area is the 3.56 ha Lorraine Road woodlot, located east of the Wignell Drain off of Lorraine Road. The relevant statistical characteristics of that dataset are provided in Table 3.

Table 3. Ni, Cu, Co, and As concentrations (ppm, as reported by the XRF analyzer) in soil samples from the Lorraine Road woodlot.

	Ni	Cu	Co	As
Mean	3,894	511	64	29
SD	2,433	275	8	11
n	27	27	27	27
95%CL	1,114	126	3	5
95UCLM	5,007	637	67	34
95LCLM	2,780	385	60	24

Metal concentrations in soils from non-forested areas (fields and forest edges) adjacent to the Reuter Road and Lorraine Road woodlots are provided in Table 4. The UCLM value for these data represents the worst-case exposure concentration for estimating risk for fauna that occupy field niches (6,208 ppm Ni).

Table 4. Ni, Cu, Co, and As concentrations (ppm, as reported by the XRF analyzer) in soil samples from field and field-forest edge samples from the PCCAP. Co concentrations are all detection limit values.

Lorraine Road field & forest edge					Reuter Road field & forest edge				
	Ni	Cu	Co	As		Ni	Cu	Co	As
Mean	725	104	51	10	Mean	3335	456	53	29
SD	276	40	9	4	SD	2561	256	9	14
n	43	43	42	43	n	7	7	7	7
95%CL	98	14	3	1	95%CL	2873	287	10	15
95UCLM	823	118	54	11	95UCLM	6208	743	62	44
95LCLM	627	90	48	9	95LCLM	461	169	43	14

Soil CoC data from the entire PCCAP study area are presented in Table 5. These data would have all been considered to have been in the primary study area of the CBRA (depicted in Map 1 in Appendix D of Volume 1 of the CBRA Natural Environment Ecological Risk Assessment (JWEL, 2004a).

Table 5. Ni, Cu, Co, and As concentrations (ppm, as reported by the XRF analyzer) among woodlot and field soil samples collected in the PCCAP. Co concentrations are all detection limit values.

	Ni	Cu	Co	As
Mean	16,583	1,940	124	62
SD	17,189	1,880	111	48
n	188	188	172	188
95%CL	2,833	310	19	8
95UCLM	19,415	2,249	143	70
95LCLM	13,750	1,630	105	54

Table 6 provides an indication of the heterogeneity in soil Ni concentration in the Reuter Road woodlot over the course of the PCCAP. Between two and seven soil samples were collected at the general location of each sampling station, within 2-3 m of each other. The large coefficients of variation (CVs) provide an indication of the heterogeneity of Ni concentrations in the woodlot. This heterogeneity indicates that "hot spot" clean-up is unlikely to be a useful remedial option for these woodlots.

Table 6. Soil Ni concentrations from samples collected at the same sample stations in 2020, 2021, and 2022. Samples were collected within approximately 1-3 m of each other.

Sample Station	Soil [Ni] ppm (d.w.)	Mean	SD	CV (%)
7	21,100 5,641 54,400	27,047	20,345	75.2
15	61,500 38,400 16,900 53,700	42,625	17,019	39.9
18	54,400 2,937 3,461 69,100	32,475	29,734	91.6
22	16,000 39,400 46,400	33,933	12,999	38.3
24	12,300 15,500 55,300	27,700	19,560	70.6
36	27,100 17,500 19,100 29,700 17,900 5,631 3,383	17,188	9,128	53.1
41	33,500 27,600 13,500 25,300	24,975	7,269	29.1
301	14,100 70,300	42,200	28,100	66.6
302	23,000 20,400	21,700	1,300	6.0
303	10,500 32,200	21,350	10,850	50.8
408	2,659 6,208	4,434	1,775	40.0
409	2,282 3,318 3,755	3112	611	19.6
410	3,895 3,170 3,330	3465	311	9.0
411	8,214 1,667	4941	3274	66.3
418	18,700 12,300	15500	3200	20.6
423	2,257 16,100	9179	6922	75.4
428	2,528 1,662 2,341	2177	372	17.1
430	2,951 3,373 3,044	3123	181	5.8

4.0 CoCs in Vegetation

4.1 Analytical

Fresh weight values of vegetation samples were recorded and vegetation samples were dried at 70° C for 48 hours and dry weight values were then recorded. Dry weight values are used in this report. Dried vegetation samples were broken-up by hand, ground by mortar and pestle, placed into sample cups (Chemplex 1330 SE, Chemplex Industries, Palm City, Florida) sealed with mylar film (Chemplex No. 257) and analyzed by handheld XRF (Olympus Delta). In 2022, the chlorophyll content in selected vegetation samples was determined prior to drying. Chlorophyll was measured in fresh samples of plant leaves using a CCM-300 chlorophyll content meter (Opti-Sciences, Hudson, NH, USA). Chlorophyll results were averages of 10 readings from 10 separate leaves from each plant that was analyzed.

4.2 Tissue CoC Concentrations in Vegetation

One hundred and forty-seven samples of vegetation from the PCCAP are reported in Table 7, organized by vegetation type. One composite sample of insect larvae collected from acorns was also included in the table. Dry-weight average values for several vegetation types exceeded phytotoxicity thresholds of 40-80 ppm (d.w.) in vegetation which were previously discussed in the CBRA Crops risk assessment (JWEL, 2004b[6])

[6] Pages 3-3 to 3-7 (section 1.2.2 and 1.2.9 of Vol. I Part 3 (Greenhouse Trials) of JWEL, 2004b)

Table 7. Average Ni concentrations in co-located PCCAP soil and tissue (vegetation, insect larvae) samples. Rightmost column: soil-to-plant transfer factors (TF).

Vegetation Type	Ecological Community	Soil Type	Soil [Ni] (mg/kg) [95% C.L.] (n)	Tissue [Ni] (mg/kg d.w.) [95% C.L.] (n)	Ni TF (plant:soil) [95% C.L.] (n)
Acorns	Swamp forest	Organic	12,125 [1,543; 22,706] (7)	23.8 [1.7; 45.9] (7)	0.006 [-0.005,0.016] (5)
Fern	Swamp forest	Organic	5,642-27,600 (range for 2 values)	58-750 (range for 2 values)	0.0074 [0; 0.093] (2)
Grass	Swamp forest, meadow	Organic, clay	790-1072 (range for 2 values)	7-10 (range for 2 values)	0.009 [0.007; 0.011] (2)
Misc. leaves	Swamp forest	Organic	15,790 [4,480; 27,101] (11)	55.8 [20.1; 91.5] (11)	0.009 [0.002; 0.015] (11)
Phragmites	Marsh	Organic, clay	3,374 [0; 7,187] (5)	7.4 [6.4; 8.4] (5)	0.004 [0; 0.008] (5)
Apple fruit	Forest edge	Organic, clay	765 (1)	6 (1)	0.008
Fungi	Swamp forest	Organic	24,721 [0; 58,593] (3)	165 [0; 353] (3)	0.018 [0; 0.071] (3)
Goldenrod	Field, forest edge	Organic, clay	1,390 [847;1,933] (21)	15.4 [8;23] (21)	0.015 [0.008; 0.021] (21)
Insect larvae from inside acorns	Swamp forest	Organic	5,462 (1)	7 (1)	NA
Spice bush fruit	Swamp forest	Organic	17,137 [9,294; 24,979] (14)	87.8 [70.5; 105.1] (14)	0.010 [0.004; 0.015] (14)
Spice bush leaves	Swamp forest	Organic	17,233 [14,044; 20,421] (74)	111.5 [91; 132] (74)	0.009 [0.008; 0.011] (74)
Virginia creeper	Swamp forest	Organic	6,078 [725; 11,430] (6)	141.5 [29.3; 253.7] (6)	0.031 [0; 0.064] (6)
Soy beans[1]	Field	Organic, clay	641 [539; 744] (23)	28.5 [20.5; 36.5] (23)	0.044 [0.035; 0.053] (23)

1. Soy beans were illegally planted on Vale-owned land in 2022. Tissue Ni values are for seeds, not leaves or stems.

Soil-to-plant transfer factors (TFs), which have been included in Table 7, are a measure of the tendency for transfer of chemical substances from soil to plants due to biological uptake. TFs have gained prominence in nuclear science and radioecology (USNRC, 2014), but have been used here to aid in understanding the phytobioavailability and environmental mobility of the historically deposited chemicals of concern (discussed later in this report).

4.3 Chlorosis as an indicator of CoC toxicity (based on Chlorophyll-to- leaf Ni concentration relationships)

In relation to the high vegetation concentrations in Table 7, field observations had identified that some spicebush leaves in the Reuter Road woodlot appeared to be chlorotic (Fig. 10). This is not necessarily surprising, given that the average Ni concentration in spicebush leaves was 111.5 ppm, in excess of the apparent upper toxicity threshold level of approximately 80 ppm. Chlorosis is an indicator of Ni toxicity in plants (JWEL, 2004b; CCME, 2015), so the presence of chlorosis in shrubs from the woodlot could reflect an adverse effect of the elevated metals in the soil and vegetation.

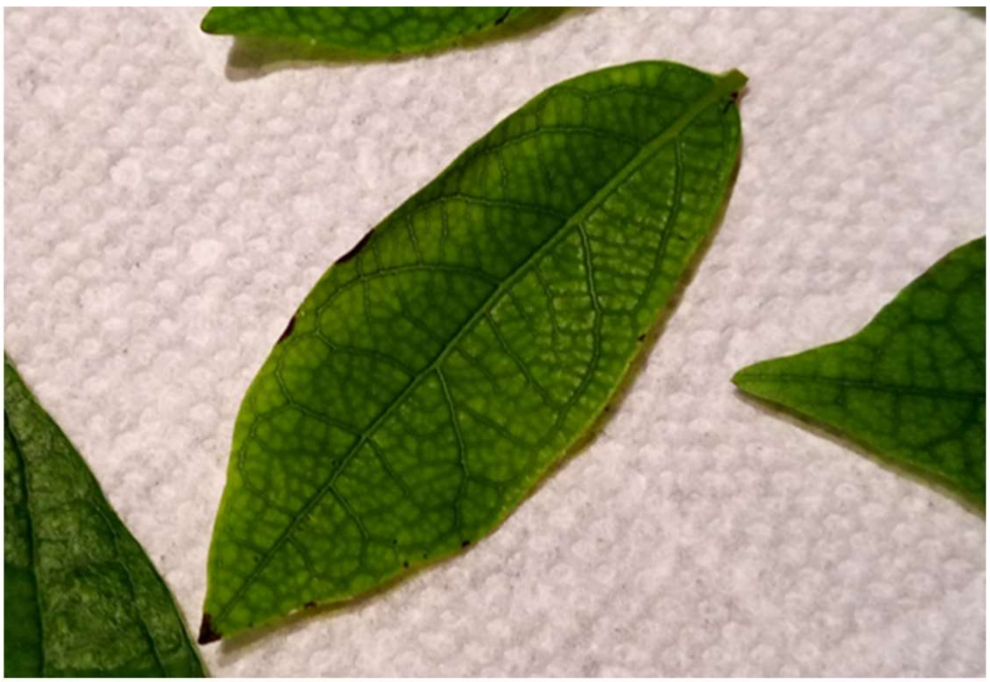


Figure 10. Apparent chlorosis in spicebush leaves.

The natural heritage inventory and woodlot health survey had identified that the Reuter Road woodlot appeared to be ecologically normal. However, chlorosis in woodlot vegetation might indicate the presence of incipient toxicity that could be measured and used to characterize risk to plants from the soil contamination. Therefore, in 2022, vegetation sampling included CoC and chlorophyll concentrations in leaves to address one of the shortcomings of the CBRA that had been identified by the MECP (inadequate assessment of plant communities). The apparent presence of chlorosis was first observed in spicebush (*Lindera benzoin*), an indicator shrub of the Carolinian Ecological Zone (MNR, 2000) and the prominent understory shrub species in the Reuter Road woodlot (North-South Environmental, 2021). Spicebush was selected as the primary candidate species for developing a relationship between chlorophyll content and soil and tissue Ni. Although chlorophyll was measured in several plant species, sampling of spicebush was more intensive. Prior to weighing and drying leaves for CoC analysis, average chlorophyll values were obtained from each plant by measurements from 10 leaves. In the field, small spicebush plants appeared to show chlorosis more frequently than larger plants, visually, and a small difference was suggested by chlorophyll measurements (Fig. 11). This could be indicative of impact of elevated CoCs on germination and growth of seedlings or small spicebush plants growing from stolons in surface soil containing elevated metals. It is possible that the deeper root systems of larger, established, plants reduce potential impacts of Ni and the other CoCs on chlorophyll metabolism relative to smaller plants.

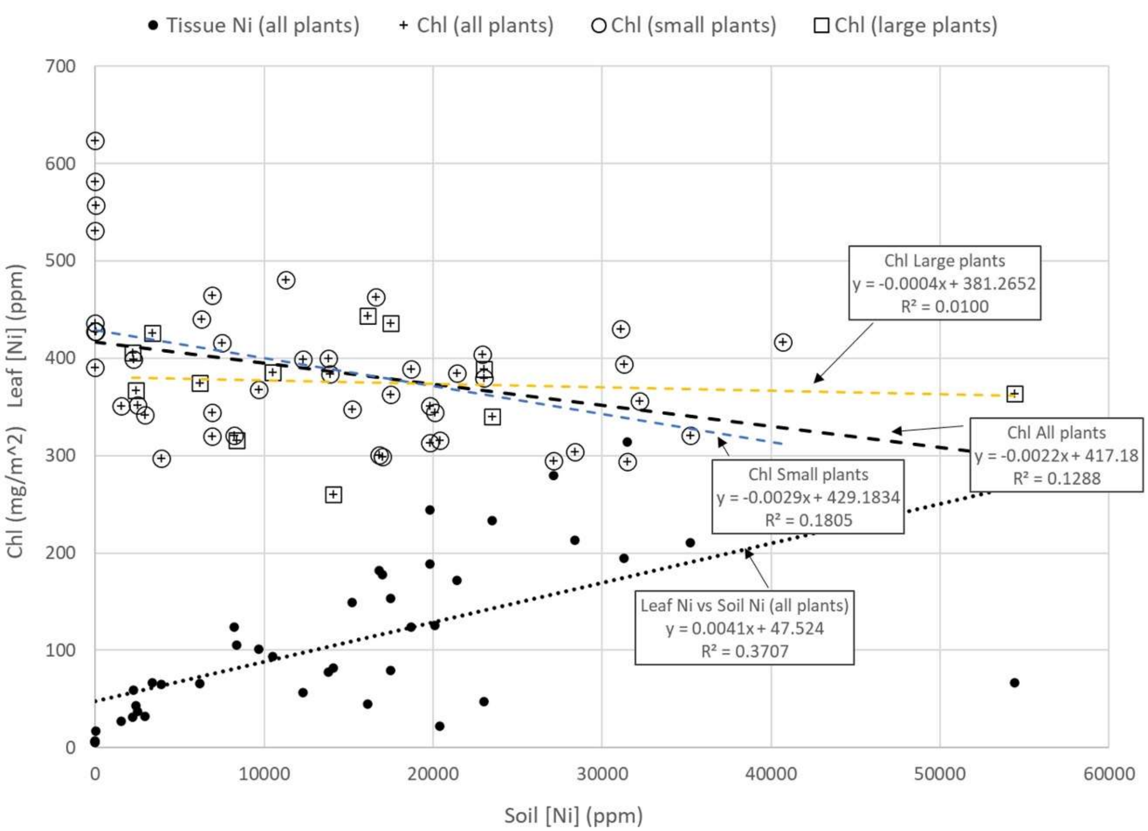


Figure 11. Chlorophyll and Ni in spicebush leaves in relation to soil Ni.

The inclusion of large plant data with small plant data in the linear regression increases the variability (i.e., decreases the fit/R^2) (Fig. 11). The best best-fit line for these data is for the regression that includes only small plants (R^2 = 0.1805), although the linear relationship would not be considered strong. Furthermore, the moderate negative slope of the concentration-response curve suggests an inhibitory concentration-response relationship.

An EC_{10} (the soil Ni concentration associated with a ten percent reduction in chlorophyll concentration) can be calculated based on both leaf Ni content (122 ppm Ni) and soil Ni (15,369 ppm) (Fig. 12).

This EC_{10} value is quite large in relation to toxicity reference values for vegetation in the scientific literature. The preliminary chl-based EC_{10} occurs at a Ni soil concentration that is roughly half that of the UCLM for woodlot soils (Table 2). An EC_{20} based on chlorophyll inhibition would occur at a soil Ni concentration of 40,799 ppm. These values bracket the Ni UCLM for woodlot soils (30,452 ppm). The large value of the EC_{10} for chlorophyll inhibition in spicebush comports with the observations of the natural heritage inventory and woodlot health assessment (North-South Environmental, 2021) and the earlier CBRA (JWEL, 2004a).

Plant Visual Injury (PVI) is used in the European Union to assess risk-relevant endpoints for non-target terrestrial plants (NTTP) in herbicide registration (Fellmann et al. 2023). PVI relies on qualitative visual assessment of several endpoints, including chlorosis, using a 50% effect level (EC_{50}). An EC_{50} would not be calculable from this data set, even using the quantitative chlorophyll analysis approach used here, which represents a considerable advancement over qualitative assessments used in the PVI approach.

The likely major reason for the large EC_{10} values is the chemical form of the CoCs as poorly environmentally mobile species. It is also possible that biological reasons could contribute to the large EC_{10} values: physiological acclimation may be occurring via the up-regulation of phytochelatin- or metallothionein-like protein pathways. It is also possible that the elevated metals in the soil over the past century represents a genetic selection pressure for more metal-tolerant spicebush plants in the Reuter Road woodlot. Evidence compatible with this possibility was presented in the maple key germination tests conducted in the CBRA, which identified that maple seeds collected from the primary study area displayed less toxic response to exposure at 3,000 ppm Ni in soil than did “control” seeds collected from outside the study area (JWEL, 2004a). Lastly, the CoCs in the most heavily contaminated soils in the Reuter Road woodlot can be heterogenous (see Table 6). It is possible, in addition to the aforementioned possible explanations, that spicebush seeds germinate in soil containing CoCs that are below thresholds of toxicity.

The apparent chlorosis which was observed in the spicebush plants in 2022 PCCAP sampling also appeared to be present in Virginia creeper and goldenrod. For 11 samples of goldenrod, the regression equation for chlorophyll content as a function of soil Ni concentration was $y = 0.002x + 326.76$ (R^2 = 0.0028) – essentially a horizontal line, indicating that no inhibition of chlorophyll was seen (up to a soil Ni concentration of 3,735 ppm). For 11 samples of Virginia creeper, the regression equation for chlorophyll content as a function of soil Ni concentration was y = -0.0003x + 326.11 (R^2 = 0.0181) – also essentially a horizontal line, indicating that no inhibition of chlorophyll was seen (up to a soil Ni concentration of 70,300 ppm).

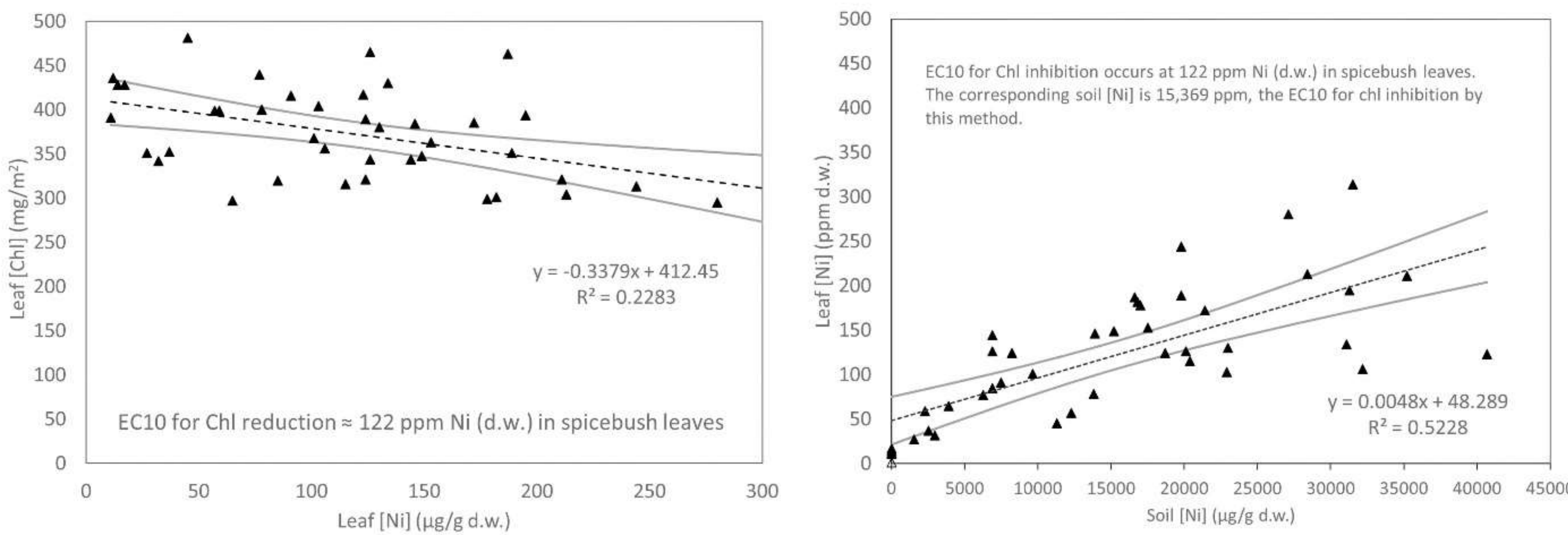


Figure 12. Total chlorophyll concentrations in spicebush leaves from small plants in relation to soil and leaf Ni concentrations. Left panel – leaf [Chl] vs. leaf Ni. Right panel – leaf [Ni] vs. soil [Ni].

4.4 Nickel in Unwashed Tree Leaves: A Comparison of Current and Historical Data

The MECP and Vale have disagreed as to whether the Port Colborne phytotoxicity literature from the period before the closure of the Ni refinery are applicable to the present conditions, forty years after the refinery's closure. Vale provides the following analysis to support its position regarding the use of those earlier findings.

Figure 13 provides additional context for the findings of the 2021 Natural Heritage Inventory and Woodlot Health Assessment and the chlorophyll survey. In Fig. 13, data from Ministry reports from before and after the closure of the Ni refinery (Air Pollution Control Branch 1959, MOE 1975, MOE 1976, MOE 1977, MOE 1979, MOE 1989, MOEE 1994), the CBRA (JWEL 2004a), and the PCCAP (reported here) are included to demonstrate the reductions in Ni concentrations in vegetation over time, following the implementation of pollution control equipment in 1960 and cessation of Ni refining in 1984. Maple leaves were typically sampled – often silver maple leaves in MOE surveys.

The characteristics of the linear regression lines from the leaf [Ni]-soil [Ni] relationships in Fig. 13 are tabulated in Table 8. The slopes of the regression lines describe the concentration-response relationship between soil Ni and Ni in leaves. In the years 1974, 1975, and 1976, the Ni refinery was still operational. In 1986, 1991, and 2023, the refinery had ceased operation for two, seven, and thirty-nine years, respectively. The slopes of the concentration-response relationship have decreased 83 times over the 49-year span of the observations. The y-axis intercepts have decreased from 134 ppm Ni in 1974 to 10 ppm in samples from the PCCAP collected in 2022 and 2023. This means that the Ni content in trees growing in soils with elevated Ni concentrations are now approaching those growing in soils with background Ni concentrations. (i.e., approaching zero – the background maple leaf Ni concentration in the CBRA being 1.1 ppm Ni (data from Table 41 of Vol. V of JWEL, 2004a).

Additional information important to understanding Ni levels in trees from the most impacted areas is given by the coefficient of determination (R^2) and the standard error of the regression (SER). Large values of R^2 indicate substantial concentration-response, while small values of the SER indicate good fit between the data and the regression line. The explanatory value of regression lines approaching zero slope is frequently overlooked due to the small magnitude of the concentration-response relationships (low R^2), but small SER values associated with such cases indicate good fit – i.e., zero-slope regression lines have explanatory value. For example, zero-slope lines can indicate saturability of response, which is a meaningful phenomenon.

Following the cessation of aerial metal deposition from the Ni refinery stack emissions onto trees, the metal content in unwashed leaves showed a reduction, which was evident two years after Ni refinery closure in 1984. The current levels of Ni in mature trees are similar to that observed in the CBRA based on year 2000 and 2001 data.

PCCAP sampling of maple leaves included only seven trees in the Reuter Road woodlot (highest soil concentrations), but the highest leaf [Ni] was 35 ppm, associated with a soil Ni concentration of 26,500 ppm.

Table 8. Trends among Ni concentrations in unwashed maple leaves as a function of soil Ni concentrations 1974-2023.

Year/Source	Slope	Intercept	R^2	Standard Error of the Regression	Predicted Leaf [Ni] at 5,000 ppm Ni in soil	Predicted Leaf [Ni] at 1,000 ppm Ni in soil
1974/MOE(1975)	0.0166	133.76	0.352	94.9	216.8	150.4
1975/MOE(1976)	0.008	72.106	0.399	63.8	112.1	80.1
1977/MOE(1979)	0.0069	96.567	0.329	66.7	131.1	103.5
1986/MOE(1989)	0.0028	15.586	0.403	23.6	29.6	18.4
1991/MOE(1994)	0.0007	12.612	0.032	9.7	16.1	13.3
PCCAP (2021-2023)	0.0002	10.211	0.052	11.5	11.2	10.4
CBRA Avg. "H" samples[1] 10.2 mg/kg						
CBRA Avg. "M" samples[2] 9.7 mg/kg						
CBRA Avg. "C" samples[3] 1.1 mg/kg						

[1] "H" samples from the CBRA primary study area from Table 41 of the CBRA Natural Environment ERA. These samples were thought to represent the highest exposures based on the most elevated soil Ni concentrations.

[2] "M" samples from the CBRA primary study area from Table 41 of the CBRA Natural Environment ERA. These samples were thought to represent moderate exposures based on moderately elevated soil Ni concentrations.

[3] "C" samples from the CBRA from Table 41 of the CBRA Natural Environment ERA. The "C" samples were "control" (reference) samples from areas with normal (background) soil Ni concentrations.

The toxicity of refinery emissions in time periods before the refinery closure in 1984 would have included an atmospheric deposition component. Based on sampling conducted in 1979 and 1980, Ministry of the Environment (MOE) scientists reported that, in soils with 5,000 ppm Ni, the uptake of Ni directly from contaminated soil accounted for 15% (30 ppm) of the Ni present in unwashed tree foliage within 2 km downwind of the refinery. Soil re-entrainment, natural background, and refinery emissions were believed to account for the remaining 10, 5, and 70% (20, 6, and 140 ppm), respectively (MOE, 1981). In 2023, in the absence of aerial deposition for almost 40 years, the predicted Ni concentration in foliage at 5,000 ppm Ni in soil is 11.2 ppm (Table 8), virtually all of which is attributable to uptake from soil. The MOE's 1981 report inferred the relative contributions listed above from the Ni:Al ratios in leaves and soil, under the assumption that the Al in foliage was primarily due to wind-blown dust rather than direct root uptake from soil. It is more likely that Al in foliage comes from root uptake (US EPA, 2003) rather than wind-blown dust, so the MOE's 1981 allocation of foliar Ni concentration to wind-blown Ni from soil was more likely also contributed from airborne emissions, including the likely stomatal uptake of insoluble aerosols and the soluble Ni component of emissions as seen by Kozlov et al. (2000).

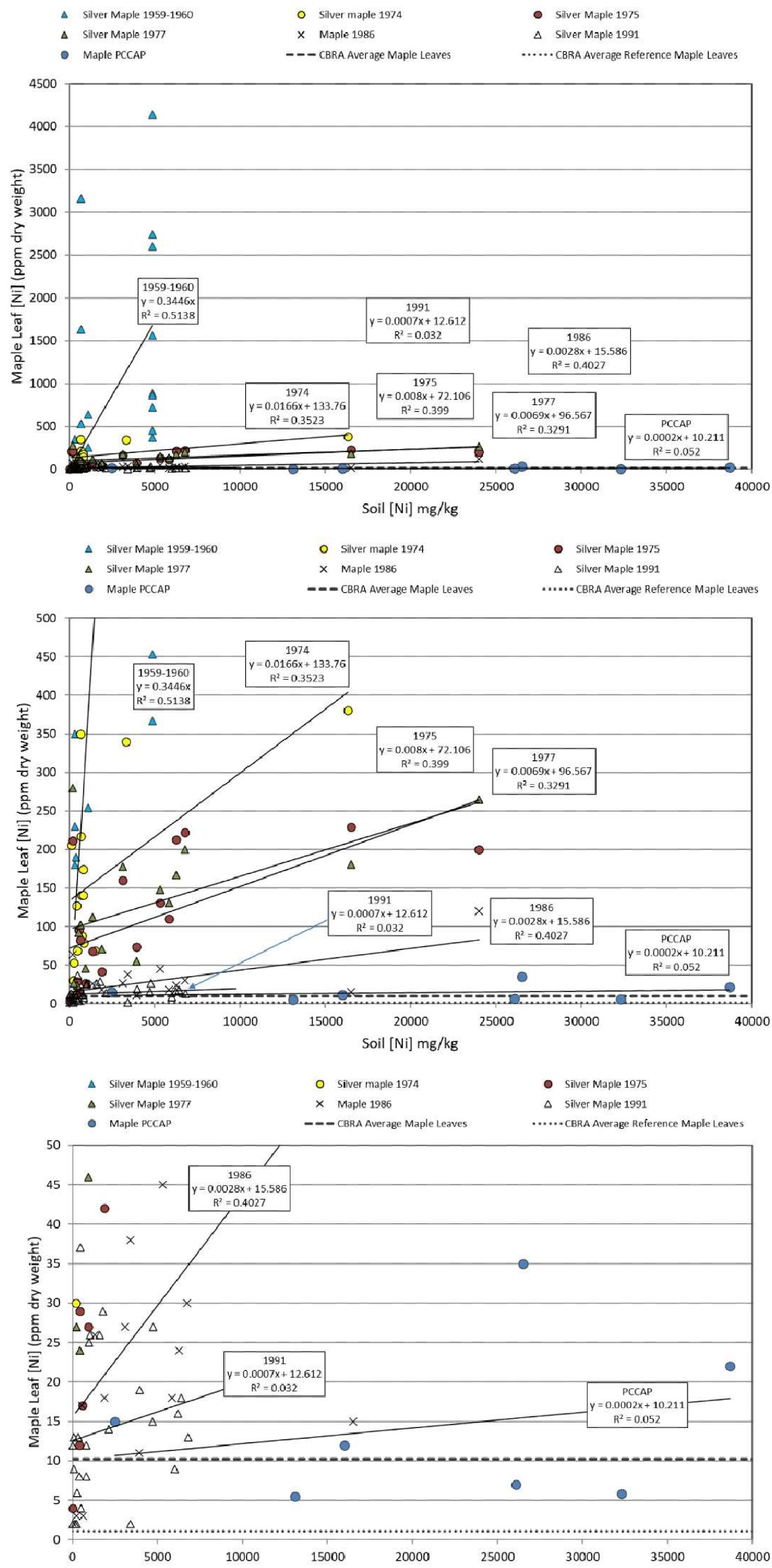


Fig. 13. Ni in maple leaves 1959-2023. Upper panel – view of all data. Middle and bottom panels – views of y-axis closer to the origin.

To further illustrate the trends in tree leaf Ni concentrations (unwashed leaves), pre-closure unwashed tree leaf data were aggregated as were post-closure tree leaf data (Fig. 14). The differences between these two data sets are striking and visually apparent in Fig. 14, with no overlap of the confidence bands for these sample populations. It is clear that the Ni content in maple leaves in 2023 are much reduced, reflecting a likely reduced risk to woodlot health, as indicated by the natural heritage inventory. Phytotoxicity observed before emissions were curtailed in 1984 would have included a foliar toxicity component as well as a root uptake component, so comparison of pre-closure phytotoxicity data with post-closure phytotoxicity data cannot ignore this consideration. Vale and MECP have previously discussed this issue in comment-response dialogues, particularly with respect to the agricultural crops risk assessment. Vale believes that this new assessment supports the view that pre-closure field phytotoxicity data from around the refinery should not be used to assess current phytotoxicological risk.

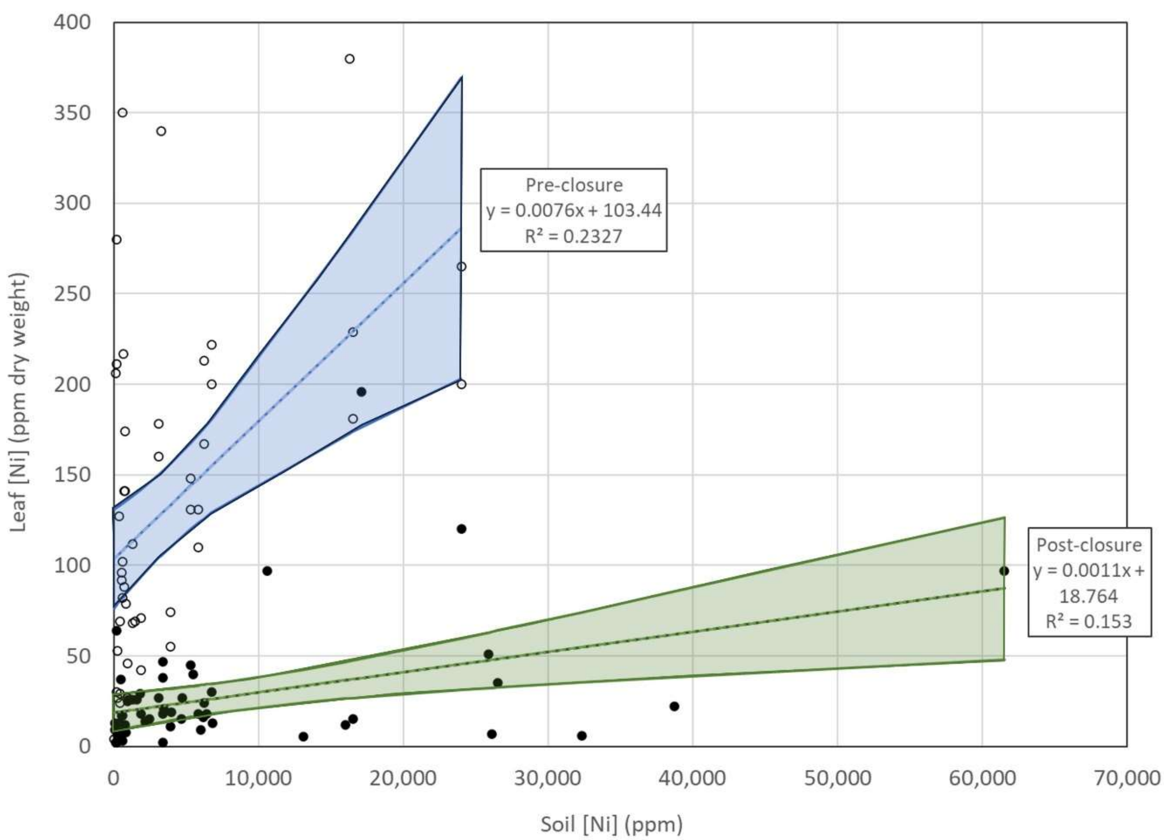


Fig. 14. Ni in unwashed maple leaves from MOE studies in 1974, 1975, and 1976 (pre-closure – open circles and blue shaded 95% confidence limits). Post-closure data from MOE studies in 1986 and 1991, CBRA data from 2000-2001, and from the PCCAP in 2023 are aggregated with solid circle symbols: green shading denotes the 95% confidence limits.

5.0 Speciation, Kd, and Environmental Fate

The natural heritage and woodlot health survey had identified that the Reuter Road woodlot appeared to be ecologically normal despite the very high concentrations of Ni, Cu, Co, and As in the soils. This likely reflects the chemical form (speciation) of the CoCs, which are present as poorly mobile and poorly bioavailable forms.

The speciation of the CoCs in samples collected in the PCCAP was assessed in three composited soil samples and one composited sediment sample. The samples were provided to SGS Canada Limited (Lakefield, Ontario) for speciation analysis (SGS, 2023). One of the samples was a composite of the "600" series of samples (named 22-600 in the SGS report), which were collected along a gradient of CoC concentration on the Vale-owned lands east of Wignell Drain and west of Lorraine Road (Fig. 9). Soil sample 74275 was a mineral soil and sample 74276 was an organic soil, both of which were assayed for plant toxicity in toxicity tests reported below in this report. The sediment composite sample was composited from sediment samples SED1-SED9, and has been discussed previously in the PCCAP aquatic survey draft report previously submitted to MECP for comment (Vale, 2023a).

The current speciation analysis identified that the nickel in the soil and sediment samples was present largely (>98%) as nickel oxide (bunsenite) in the samples assayed under the PCCAP (SGS, 2023). This speciation reflects the current speciation situation in the Port Colborne soils and sediments nearest to the existing operational refinery property line (i.e., in the primary study area from the CBRA) and is consistent with previous speciation studies conducted for the CBRA (JWEL, 2007) and the 2014 Update Report (Stantec, 2014). The Ni in the soils in the Reuter Road woodlot within the CBRA's primary study area is present predominantly as Ni oxide (bunsenite), a poorly soluble and poorly bioavailable form of Ni (water solubility 27.1 µg/L (ECHA, 2023)).

The soil-to-water distribution coefficient (Kd) is a quantitative indicator of the environmental mobility of an element, and is defined as the ratio of the concentration of the element in soil (mg/kg dry weight) divided by the equilibrium concentration (mg/L) in contacting water, with units of L/kg (Sheppard et al., 2009). Kd is inversely related to mobility, with increasing Kd values indicating lower mobility. The Kd can be useful to understand the potential for transport of metals from the soil to surface water (agricultural drains) or in standing water (vernal pools).

There are many variants among the methods used for determining Kd (Sheppard et al., 2009), some of which are likely not truly equilibrium values due to short extraction times of hours. Non-equilibrium Kd estimates are considered to be distribution ratios (Rd) – approximations of the Kd (ASTM, 1993)). Here, Kd and Rd will be used interchangeably.

In the PCCAP, Kd was estimated directly in the field by collecting co-located water and soil samples (VP4-VP10) at seven locations on Vale-owned lands on October 20, 2022 when standing water was present on the Vale-owned lands after a significant rain event between October 12-16 (25.2 mm on October 12, 35.8 mm in total). These field-collected samples represent the best possible data that could exist for estimating Kd – they were collected from standing water in actual field conditions with a soil-to-water contact time of 8 days. Classical Kd methods utilize a 7-day contact time and a 10:1 water-to-soil ratio (Sheppard et al., 2009). Dissolved metals were measured in the field-collected water samples by Bureau Veritas, Mississauga, and metals in the co-located soil samples were measured by hand-held XRF (Olympus Delta). Rd was also estimated in the laboratory from subsamples of these seven soils. Soil samples were provided to SGS Canada Inc. of Lakefield, Ontario and leached with deionized water (1:30 soil-water ratio) for 2 hours. The liquid phase was 0.45 micron filtered and analyzed for dissolved metals and metals in the associated soil samples were determined by ICP-MS. Rd values were also developed from aqueous leach data from the CBRA (JWEL, 2004b). The contact times for both of these latter sets of samples were short, so they were likely non-equilibrium leaches and therefore should be considered to be Rd, not Kd, and are probably higher values than the true Kd.

The field Kd and Rd values are presented in Fig. 15. The geometric mean value for Ni Kd in Canadian agricultural soil (1,600 L/kg) has been included in Fig. 15 for reference (Sheppard et al. 2007). The Ni Kd/Rd for Port Colborne soils (11,137 L/kg), reflects the presence of the Ni in the soil from historical refinery emissions, which is largely present as poorly soluble oxidic Ni forms. In contrast, the Ni Kd values for 106 Canadian agricultural soils without historical industrial Ni deposition was 1,600 L/kg (for soil Ni concentrations of 2.5-69 mg/kg). This smaller Kd reflects greater potential mobility of the Ni present in unimpacted natural soil, the Ni in these soils being derived from erosion of local geologic parent material. The Sheppard Kd is of a similar magnitude as the 1,259 L/kg Kd value for Ni cited for a range of American soils (US EPA, 2005). The Ni Kd for the Port Colborne soils is roughly ten times higher than the Kd for a range of background soil Ni conditions depicted by Sheppard et al. (2007) and US EPA (2005). It should be noted that the Rd values for control soils from the CBRA aqueous leach tests are very similar to the geometric mean Kd for Canadian agricultural soils (‘x’ symbols in Fig. 15). These control soils were all natural soils with no elevated industrial metal species and so it is not unexpected that Ni mobility in these soils would be similar to those of Sheppard et al. (2007), which were also natural, uncontaminated soils.

In the PCCAP Aquatic Survey report, it was shown that ambient Ni concentrations in surface water reflect the high Kd (low mobility and low bioavailability) associated with the historical refinery emissions, not the generic Kd (Vale, 2023a).

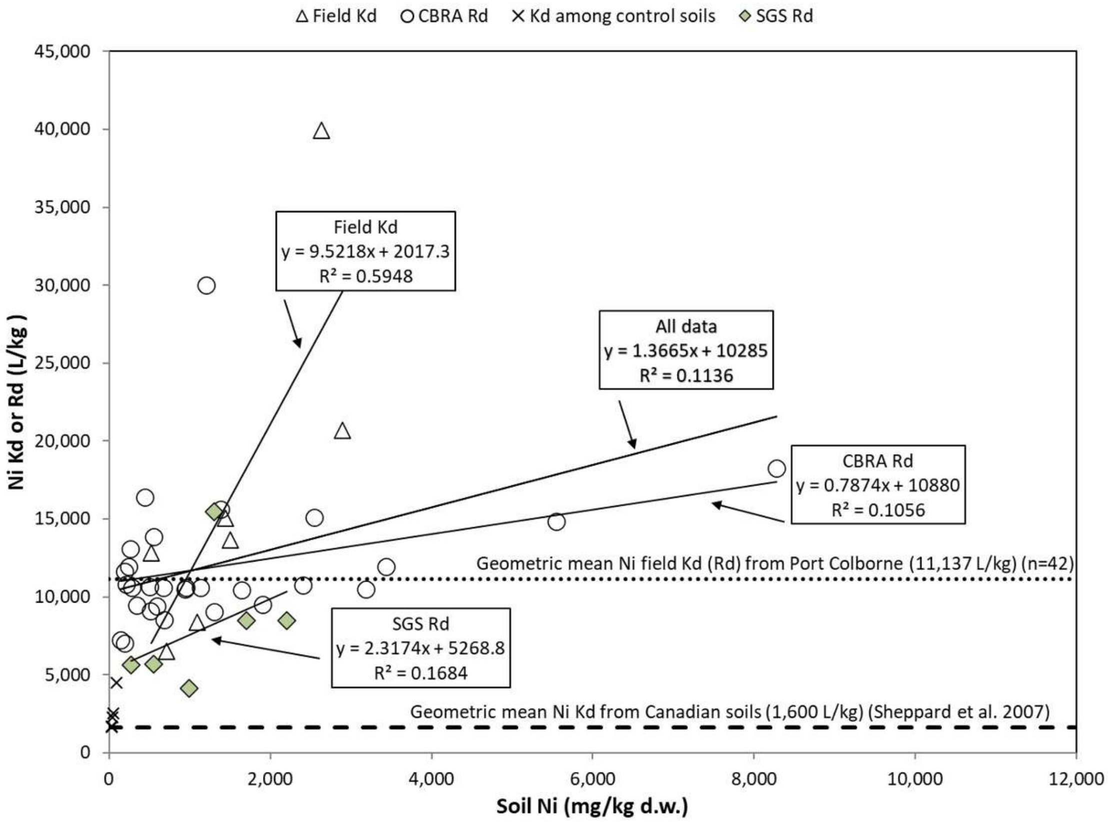


Fig. 15. Soil-water distribution coefficients (Kd) or distribution ratios (Rd) associated with the excess soil Ni from the legacy deposition from the Port Colborne Ni refinery.

6.0 Assessment of Decomposition of Vegetation in Forest Floor Litter

The Ministry of Environment, Conservation, and Parks (MECP) provided a number of comments regarding decomposition processes, generally, in the CBRA (see "Summary of Review Comments" (and Vale responses-to) comments 35, 66, 189, 223, 224, 226, 228, 229, 230, 231, 232, and 233 of MECP comments on the CBRA Natural Environment Risk Assessment (MOE, 2011)). The CBRA Natural Environment Ecological Risk Assessment evaluated decomposition using a standing litter assessment approach (Kilty Springs Environmental, 2001), of which the MECP was critical. In particular, MECP was critical that rates of litter decomposition had not been determined and that the decomposition pathway had not been adequately assessed.

MECP also provided a number of comments on earthworms, which represent a decomposer organism that was also used as an indicator organism for toxicity to soil invertebrates. (See "Summary of Review Comments" (and Vale responses-to) comments 1, 10, 35, 121, 122, 123, 144, 161, 176, 177, 178, 185, 189, 190, 191, 192, 195, 202, 220, and 235 of MECP comments on the CBRA Natural Environment Risk Assessment (MOE, 2011)) and in comment 30 of

MECP comments on the 2014 Update Report (MOECC, 2016a) and comment 29 of MOECC (2016b).

Earthworms were studied in the CBRA Natural Environment Risk Assessment with a perspective that earthworms are an important component of a healthy soil ecosystem. In the twenty years since the CBRA was initially undertaken, a different scientific and societal perspective has developed regarding earthworms. The Ministry of the Environment, Conservation, and Parks now considers earthworms to be invasives (Ontario Parks, 2022). Earthworms are believed to have been eliminated from the lands of what is now Canada due to Wisconsonian glaciation, but were subsequently reintroduced by human activity in the early 1800s (Choi et al., 2017). Choi et al. (2017) note that soils, vegetation, and ecosystem processes in Canadian temperate forests have developed in the absence of earthworms following glacial recession. Earthworm invasions can cause major shifts in ecosystem functioning and services, and can impact forest floor soil structure, nutrient dynamics, soil biogeochemistry, and plant community composition (Choi et al. 2017, Suárez et al. 2003). Furthermore, earthworms can also shift the soil decomposer community from one dominated by decomposing fungi to one dominated by bacteria (Choi et al. 2017). Deep burrowing earthworm species cause the conversion of mor soils (which are characterized by a thick organic layer at the soil surface) into "mull" soils (in which the organic matter is thoroughly mixed with mineral soil) in as little as three years following arrival of the earthworms (Evers et al. 2012).

In earthworm-free deciduous forests, the organic forest floor continually cycles nutrients and provides a seedbed for understory plants species (Evers et al. 2012). The introduction of earthworms to the deciduous forest floor disrupts this equilibrium, reducing or eliminating the forest floor "duff" (litter) layer, ultimately resulting in changes in plant species from those requiring a duff seedbed to species that do not (Choi et al., 2017; Evers et al., 2012).

Exotic earthworm invasion is expected to be a significant factor influencing the structure and function of temperate forest ecosystems for decades to come, and at sites with inherently thick forest floors, the most dramatic effect of earthworm invasion was the loss of forest floor litter (Bohlen et al. 2004). Going forward, the management of temperate deciduous forests will need to consider important drivers of nutrient cycling and loss, including not just climate and pollution, but also earthworm invasion (Bohlen et al. 2004).

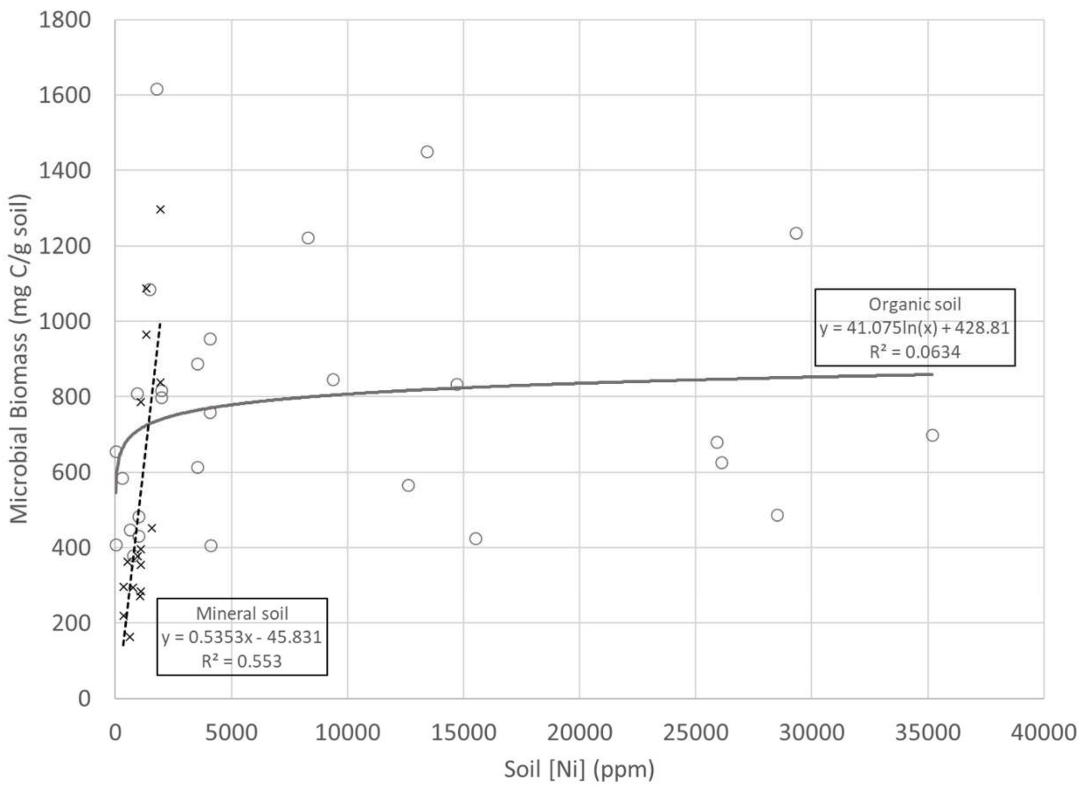
Earthworm study in the CBRA was interpreted at the time to indicate the impairment of decomposition in the most heavily contaminated woodlot soils. The low numbers of earthworms in the most contaminated woodlots closest to the refinery fenceline does indeed suggest a negative effect of the CoCs on these invasive soil organisms, as the woodlot soils are otherwise a rich organic muck soil that should be an ideal habitat for earthworms, and earthworms are present in the organic field soil just down-gradient from the leeward edges of these woodlots. It would certainly appear that earthworms are being impaired from proliferating in these woodlots.

Earthworm toxicity tests in the laboratory were used in the CBRA to identify thresholds for developing risk-based soil concentrations. That approach is useful to the extent that toxicity thresholds for soil invertebrates, generally, could be identified from such study. The evidence from the natural heritage inventory and woodlot health assessment is that the woodlots along Reuter Road are normal at the macro level despite the significantly elevated CoC concentrations in the woodlot soil (North-South Environmental, 2021).

In the CBRA, the forest floor litter study and earthworm population and toxicity studies were intended to be used to identify community-level impairment and infer risk to the ecological decomposition pathway on a gradient of CoC concentrations. However, due to our previously incomplete understanding, these two lines of evidence were interpreted in such a way that cast doubt on the conclusions of the CBRA with respect to ecological decomposition pathways, as noted in MECP comments. In retrospect, the inverse relationship between standing leafy litter and soil CoC concentrations simply reflects that earthworm populations have not established in the woodlots with the highest CoC concentrations, thereby preserving the natural state of the forest floor in temperate, deciduous (Carolinian) forests, with their characteristic thick litter layer and mor soils. It does not necessarily mean that decomposition has been impaired, just that invasive earthworms have not begun to convert the mor soils of the organic soil woodlots into mull soils, with the attendant loss of the litter bed from the forest floor.

It is now recognized that earthworms are invasive, and should earthworm populations become established in the Reuter Road woodlot, for example, the Carolinian character of the woodlot could be threatened. The PCCAP has not studied earthworms further and has not conducted a litter study. Rather, microbial and fungal biomass in soil has been measured using a new rapid test that has become available since the CBRA and 2014 Update Report – the soil microbiometer (www.prolificearthsciences.com), which has been validated by Prolific Earth Sciences (Fitzpatrick et al., 2021, Prolific Earth Sciences, 2023).

Trends in microbial biomass and fungal/bacterial ratios in mineral (field) and organic (woodlot) soils are presented in Fig. 16.



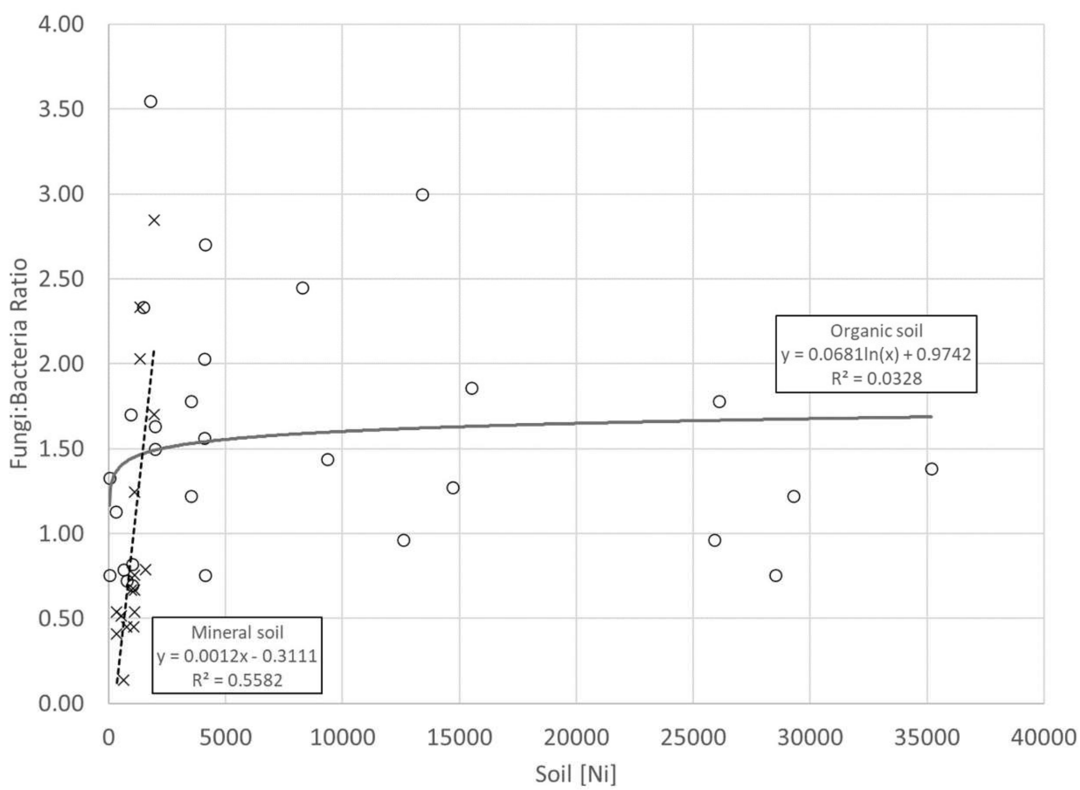


Figure 16. Soil microbial biomass (top panel). Fungi:Bacteria biomass ratio (bottom panel). Mineral soils – x symbols. Organic soils – circle symbols.

The average microbial biomass in organic (woodlot) soils was 764 mg C/kg soil (95% C.I. [626,902]), while in mineral soils it was 528 mg C/kg soil (95% C.I. [318,738]). These values are similar to those generalized for temperate forest and grassland biomes (He et al., 2020) (Table 9). It appears that microbial biomass is not abnormal in the tested soils. The F:B ratios in the Port Colborne soils tested (Fig. 13) appear to be lower than in the generalized grassland and temperate forest biomes (Table 9). Higher F:B ratios are thought to indicate more active microbial decomposition, but *Acidobacteria* and *Actinobacteria* are both important bacterial decomposer taxa, as observed in fungicide-treated soils (Malik et al., 2016), so in the absence of additional more specific breakdown of microbial species composition in these soils, the salient point is that the soil bacterial biomass is similar to what might be expected for these biomes.

Table 9. Soil microbial biomass in various biomes around the globe. Adapted from He et al. (2020).

Biome	Microbial Biomass (F+B)[1] mg C/kg	Fungi:Bacteria ratio
Unvegetated ground	217.3	7.8
Desert	23.8	2.5
Grassland	277.9	3.4
Pasture	902.8	2.3
Cropland	278.5	3.2
Shrub	263.6	4.8
Savanna	147.7	2.3
Tropical/subtropical forest	661.4	2.1
Temperate Forest	311.4	4.9
Boreal forest	1460.5	5.5
Tundra	4112.0	8.6
Natural wetlands	422.4	3.6

[1]F+B refers to Fungi plus Bacteria

To summarize, the information collected regarding the decomposer pathway in the CBRA Natural Environment Risk Assessment and this PCCAP do not suggest an impaired decomposer pathway. The forest litter study conducted in the CBRA (Kilty Springs Environmental, 2002) showed an inverse relationship between soil CoC concentrations and litter biomass. However, it is now known that the higher standing litter biomass present in the most-contaminated woodlots is not abnormal and reflects the inherent nature of temperate deciduous forests (Carolinian deciduous forest in this case) in the absence of invasive earthworms, which tend to reduce the standing litter biomass, converting mor soils to mull soils. The observed inverse relationship between the soil CoCs and standing litter biomass likely does reflect that earthworm populations have been unable to establish reproducing populations in the Reuter Road woodlot due to CoC toxicity. However, the decomposition processes that are caused by invasive earthworms are not normal in these Carolinian deciduous forests, so the absence of earthworms and higher standing litter biomass observed in the primary study area of the CBRA should not be considered to be an unequivocal gauge of soil decomposition processes. MECP comments in that regard should be considered with caution. In the PCCAP, a relatively recent tool for measuring soil microbial biomass carbon has been used to show that soil microbial biomass appears to be in a normal range. It should also be noted that the CBRA litter study identified that forest floor litter in the Reuter Road woodlot was not accumulating, but was simply higher than in other local woodlots. Together, the PCCAP soil microbiometer data, the CBRA litter study, and the natural heritage inventory and woodlot health assessment seem to suggest that, despite the very high soil CoC concentrations, the forest systems in the Reuter Road woodlot and the primary study area seem to be functioning normally. It is possible that the elevated metals in soil have served as a selection pressure for the soil microbial community and that the organisms have developed tolerance to the metals over the past hundred years.

7.0 Organic and Mineral Soil Toxicity Tests

Ministry comments (see 'global' comment #2 of MOE (2011) recommended that soil quality criteria derived from the CBRA for Port Colborne should "*include the results all crop studies in the scientific literature that were conducted in the Port Colborne area where soil nickel concentrations are reported*". Vale has contended that studies conducted before closure of the former Ni refinery are not comparable with current conditions and the associated risk to plants there. The plant toxicity tests included in the PCCAP were conducted to enable comparison with earlier testing in the CBRA in 2000 and 2001 as well as testing conducted by the Ministry before Ni refinery closure and as recent as 1992. As discussed previously (see Fig. 14), a comparison of pre-closure and post-closure metal levels in tree leaves supports the observation that conditions before and after Ni refinery closure are different. Vale's view is that the additional burden of aerial deposition on plant leaves while the refinery was operational were different from the current conditions and that conclusions on toxicity and risk due to soil contamination in the absence of foliar exposure are not comparable and should be avoided.

Organic and mineral soils were collected from hand-dug test pits in the former Grotlaar farm adjacent to the Reuter Road woodlot (organic soil) and the former Davison farm on Lorraine Road. The soils were blended to obtain the test concentrations (Table 10).

The soils were separated into two batches (A and B), the A batches used for radish toxicity tests and the B batches for lettuce toxicity tests. The soils were delivered to Aquatox Testing and Consulting (Aberfoyle, ON) for the tests, which were conducted using Environment Canada's test method EPS 1/RM/45 (Environment Canada, 2005). (*Latuca sativa*, "salad bowl") and radish (*Raphanus sativus*, "French breakfast"), were used. The French Breakfast strain was previously used in the CBRA crops studies. Lettuce had been examined in MOE studies from the time prior to the closure of the Ni refinery in 1984.

Table 10. Organic and Mineral Soil Concentrations in Soils Used for Radish and Lettuce Toxicity Tests.

Container	Soil Type	Sample	Ni	Cu	Co	As
1A	Organic	Field control	38	9.5	39	2.2
2A	Organic	low Ni	1168	193	51	19.2
3A	Organic	med low Ni	2428	279	56	27.6
4A	Organic	med Ni	4159	540	49	28.2
5A	Organic	med hi Ni	3713	496	47	28.4
6A	Organic	hi Ni	4360	572	52	28.6
1B	Organic	Field control	17	11.6	34	2
2B	Organic	low Ni	1000	162	55	1
3B	Organic	med low Ni	1972	289	52	1
4B	Organic	med Ni	4072	560	50	27.9
5B	Organic	med hi Ni	3527	508	47	32.2
6B	Organic	hi Ni	4107	569	49	27.7
7A	Mineral	Field control	27	24.3	58	5.9
8A	Mineral	low Ni	416	51	53	7.5
9A	Mineral	med low Ni	903	122	50	11.8
10A	Mineral	med Ni	901	122	54	11.2
11A	Mineral	med hi Ni	1229	172	53	16.5
12A	Mineral	hi Ni	1979	240	54	19.6
7B	Mineral	Field control	37	21.4	59	5
8B	Mineral	low Ni	351	54	55	6.8
9B	Mineral	med low Ni	1090	126	53	12.8
10B	Mineral	med Ni	1093	149	55	12.7
11B	Mineral	med hi Ni	1333	167	53	18
12B	Mineral	hi Ni	1941	247	57	19.6

Measurements of emergence, shoot length, root length, shoot dry weight, root dry weight, and leaf chlorophyll content were taken from each of four replicate pots from each soil concentration. The values were converted to a percentage-of-control basis and averaged for the four replicate pots for each soil-concentration combination. Linear regression was used to visualize the percentage-of-control-adjusted data.

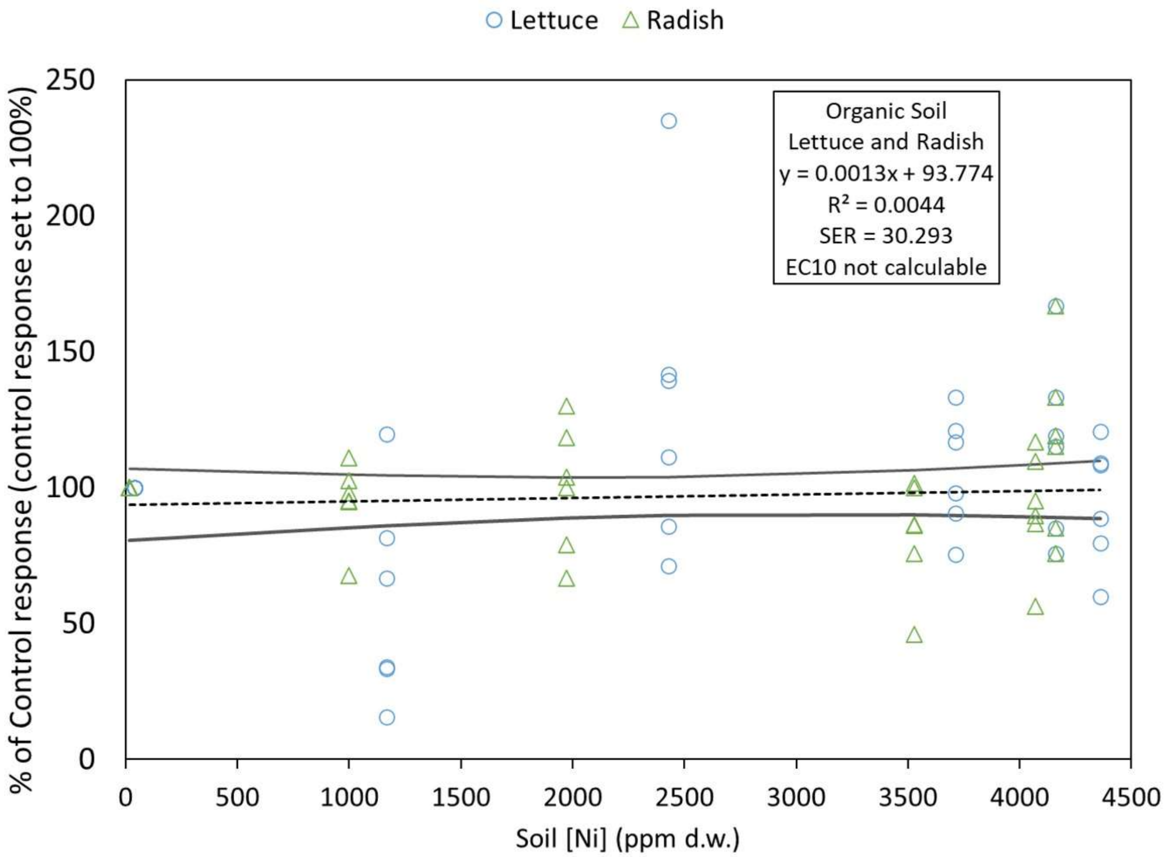


Fig. 17. Soil toxicity test characterization for organic soils. Lettuce and radish data presented jointly.

For the organic soil, an EC10 was not calculable for the concentration range up to approximately 4,200 ppm Ni (Fig. 17). For the mineral soil, an EC_{10} of approximately 1,365 ppm Ni was estimated from the aggregated data (Fig. 18).

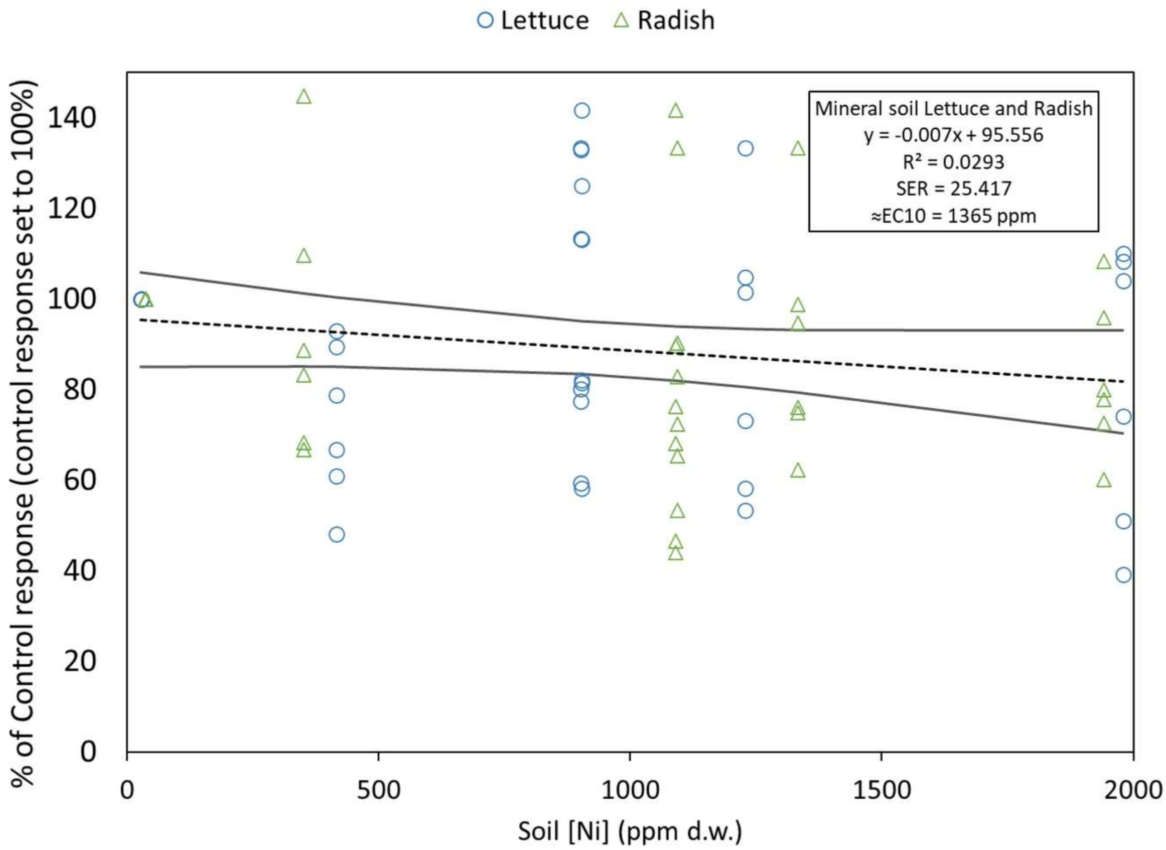


Fig. 18. Soil toxicity test characterization for mineral soils. Lettuce and radish data presented jointly.

In Fig. 19, dry weight Ni concentrations in lettuce leaves from pre-and post-closure studies have been grouped by whether the leaves were washed or unwashed. It can be clearly visualized that these groupings represent different relationships between leaf Ni and soil Ni, with the Ni concentrations in washed leaves having a shallower slope than unwashed leaves. Fig. 19 includes pre-closure data from 1980 (Bisessar, 1981). Bisessar's data showed elevated Ni in unwashed leaves relative to washed leaves, and the Ni content in the washed leaves was similar to the Ni content in lettuce leaves from the present day PCCAP toxicity tests. Together, these indicate that in 1980, while the Ni refinery was operational, surface-deposited Ni was present on lettuce leaves on the Overholt farm adjacent to the Ni refinery. It is evident that pre-closure studies are not directly comparable to present day studies due to the presence of atmospherically deposited Ni on the lettuce in 1980 which would have contributed to toxicity (reduced crop yields) at that time.

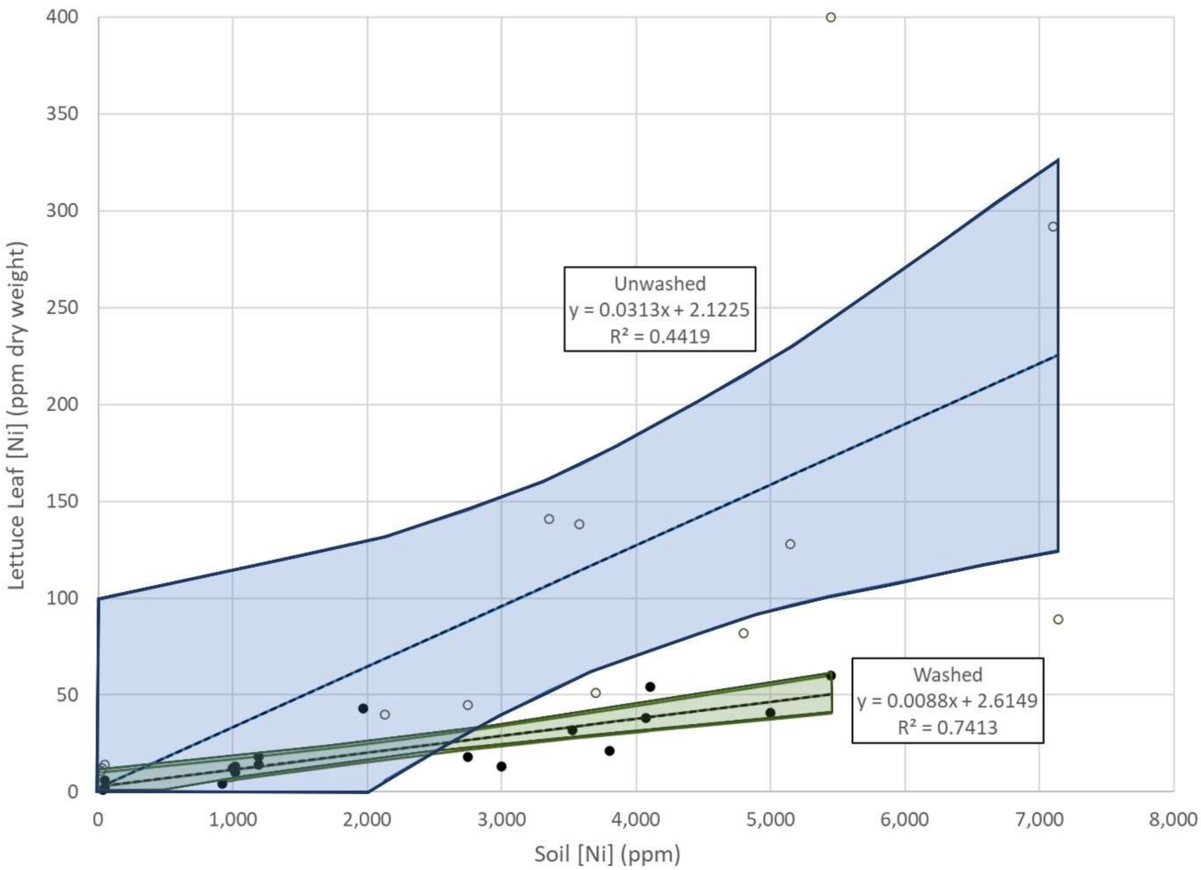


Fig. 19. Ni in unwashed and washed lettuce leaves. Pre-closure data (open circles with blue shading of 95% confidence limits) on "unwashed" leaves from Linzon (1978), Bisessar (1981). Data for "washed" leaves (filled symbols and green shading of 95% confidence limits) from Bisessar (1981), Bisessar and Palmer (1986), and PCCAP. "Washed-leaf" data are similar from pre-closure and post-closure data sources.

In Fig. 20, dry weight Ni concentrations in radish leaves have been grouped by whether they were from pre-or post-closure conditions. The majority of the leaves were washed. The Bisessar (1981) radish data were from washed leaves, whereas it is unclear whether the Frank et al. (1982) were washed or unwashed. Therefore, the data in Fig. 20 have been grouped as pre-or post-closure. The confidence bands for the pre-and post-closure data for radish leaf Ni concentrations overlap entirely, although the span of the post-closure confidence band reflects a smaller range of leaf [Ni] across the range of soil concentrations. The small data set for the pre-closure conditions results in a wide confidence band. Therefore, Fig. 20 is not conclusive but adds to the weight of evidence. It is reasonable to conclude that conditions from times before the closure of the Inco Port Colborne Ni refinery in 1984 are different from post-closure conditions – presumably due to the cessation of airborne deposition of Ni from refinery operations post-1984. Vale has used data generated by the MOE to the degree possible in this analysis.

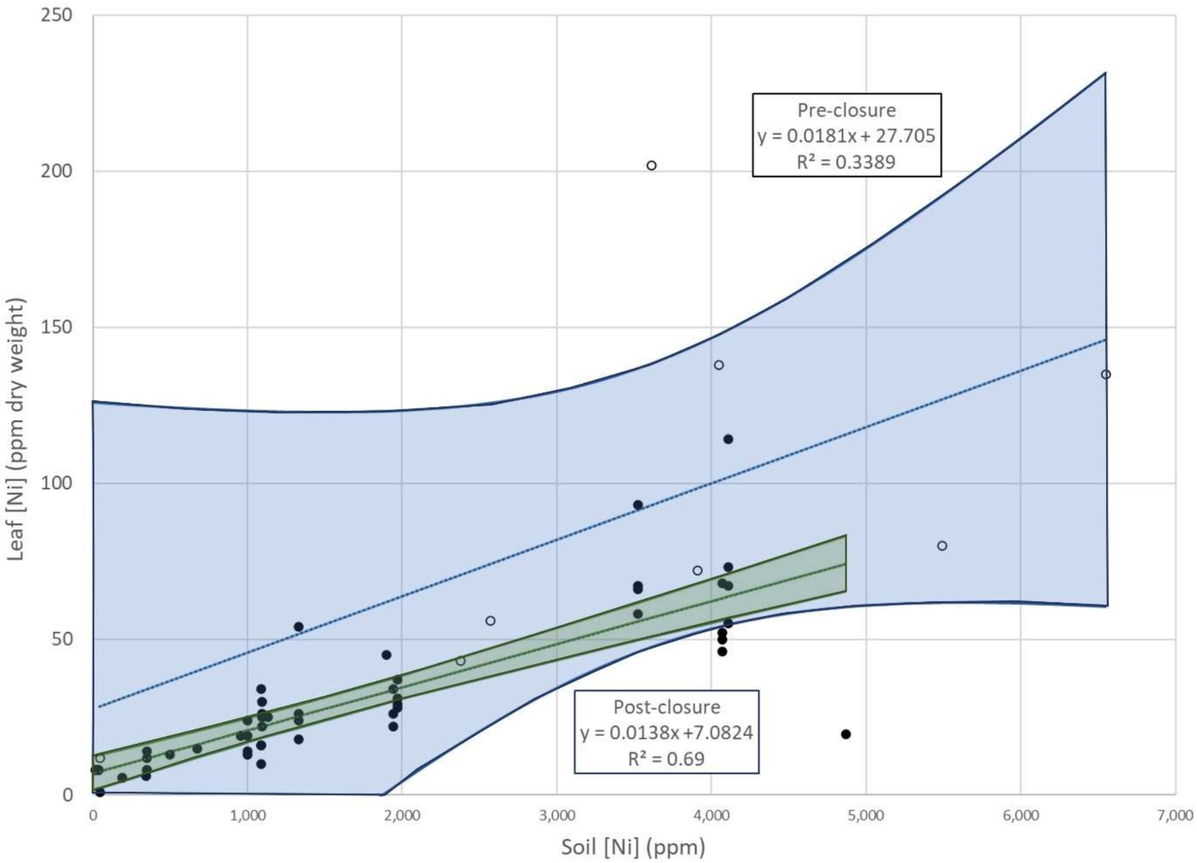


Fig. 20. Ni in radish leaves. Pre-closure data (open circles with blue shading denoting 95% confidence limits) on radish leaves from 1980 (Bisessar (1981) and Frank et al. (1982)). Post-closure data (filled symbols and green shading denoting 95% confidence limits) from the CBRA crops risk assessment (JWEL, 2004a) and the PCCAP radish toxicity test.

8.0 Risk Estimation by the Quotient Method

Vale (the successor to Inco, the original proponent of the CBRA) and the Ministry of the Environment Conservation and Parks (MECP, the successor to MOECC and MOE) have had numerous discussions regarding the component risk assessments of the CBRA since the CBRA was initiated in 2000. At this point, the document trail of reports and comment/response dialogues on the Natural Environment Ecological Risk Assessment is extensive and Vale has created this report to provide closure to the CBRA's assessment of risk in the natural environment (terrestrial). Vale accepts that the formalized use of the quotient method to assess risk typically requires detailed assessment of the standard risk assessment components (problem formulation, hazard assessment, toxicity assessment, exposure assessment, and risk characterization). These components have been presented twice, in two separate reports, amounting to thousands of pages of documentation. Therefore, Vale is presenting a truncated assessment of risk to wildlife in what had been the primary study area from the CBRA, an area in which risk had been underestimated previously.

As with other aspects of this report, this section is focused on Ni.

For background regarding previous problem formulations, the reader is directed to JWEL (2004a) and Stantec (2014). The chemicals of concern are Ni, Cu, Co, and As, which were previously selected in the CBRA based on specific criteria (JWEL, 2004a). In the PCCAP, risk to the aquatic environment has been assessed in a separate report (currently issued as a draft (Vale, 2023a)), and will not be addressed here. Mammalian wildlife receptors that have been observed at the site during the PCCAP or for which evidence of presence on site exists (e.g., scats and tracks) include the short-tailed shrew, cottontail rabbit, raccoon, coyote, red fox, and whitetail deer. Avian receptors observed at the site include the American woodcock and American robin. This assessment selected the short-tailed shrew, the cottontail rabbit, raccoon, and whitetail deer as mammalian receptors and woodcock and robin as avian receptors. These receptors were thought to encompass a range of exposure that is towards the higher end of potential exposure, focusing on forest dwelling species that could be present in the woodlots having the highest soil CoC concentrations.

Exposure to these receptors occurs primarily via soil and diet. Previously, in the CBRA natural environment ecological risk assessment, the Ni content in various ecological organisms that could serve as dietary sources of Ni in the forest ecosystems are presented in Table 11.

Table11. Average [Ni] in various biota that could be food items for ecological receptors. Source: CBRA Natural Environment Ecological Risk Assessment (JWEL, 2004a).

Data Source in Chapter 6 of the CBRA Natural Environment ERA (JWEL, 2004a)	Organism	Avg. value for [Ni] (mg/kg)
Table 6-3	Tadpole	85.1
Table 6-4	Frog	3
Table 6-5	Maple Leaves	10
Table 6-5	Maple Sap	0.048
Table 6-5	Maple cotyledons	10.1
Table 6-6	Wild grapes	0.9
Table 6-7	Un-purged earthworms (entire study area)	304.9
Table 6-8	Un-purged earthworms (organic soil-woodlots)	402.7
Table 6-9	Un-purged earthworms (field)	438
Table 6-10	Un-purged earthworms (organic soil)	303
Table 6-10	Purged earthworms (organic soil)	213
Table 6-11	Insects (woodlots)	14.73
Table 6-11	Spiders (woodlots)	15.36
Table 6-12	Arthropods	9.3
Table 6-13	Meadow voles	26.3 (max. value)
	Arithmetic Average	122.4
	Arithmetic average excluding earthworms	17.5

In the PCCAP, additional soil sampling was conducted in what was considered to be the CBRA's primary study area (PSA) to better characterize the risks there (a shortcoming of the CBRA Natural Environment Risk Assessment). As a result of this sampling, it can be seen that two distinct woodlots are present in the primary study area by virtue of the different levels of contamination in them. For wildlife with home ranges smaller than the woodlots, risk specific to these individual woodlots can be estimated. Additional field sampling adjacent to these woodlots was also conducted. Sampling of vegetation co-located with these new soil samples occurred at 186 sampling locations. Statistical characteristics of the sample populations of soil were presented earlier in this report (Tables 2-5). Statistics for Ni concentrations in vegetation used for calculating risk quotients are provided in Table 12. The overall concentrations in biota in the PCCAP and the original CBRA are similar. In the CBRA, the average biota Ni concentrations were significantly influenced by earthworm data. Without considering earthworms, the biota Ni concentrations were much lower. In contrast, in the PCCAP, the average vegetation Ni concentration was 123 ppm, including spicebush leaves and fruit.

Dietary Ni exposure due to ingestion of animal matter other than earthworms would be lower than as depicted in Table 12. However, the high soil Ni concentrations account for the majority of the estimated risk to wildlife receptors, so these values were used in estimating risk to such receptors regardless of that fact.

Table 12. Ni concentrations in vegetation samples collected from the study area during the PCCAP.

	Soil			
	Reuter Road Woodlot	Lorraine Road woodlot	Field & forest edge samples Reuter Road	Field & forest edge samples Lorraine Road
Mean	123.0	57.6	6.6	19.9
SD	118.2	54.7	1.0	15.4
n	96	41	6	43
95%CL	27.5	19.9	1.3	5.5
95UCLM	150.4	77.5	7.9	25.3
95LCLM	95.5	37.6	5.2	14.4

The estimation of risk by the Quotient method requires a toxicity reference value (TRV) as a comparator with the estimated site exposure. The risk quotient (RQ) is the ratio of the site exposure for a given receptor (i.e., the wildlife organism for which toxic risk is being estimated). Regarding TRVs, the CBRA Natural Environment Risk Assessment assessed nickel risk to mammals using a TRV of 30 mg/kg/d based on a LOAEL (lowest adverse effect level) derived from the Springborn one generation reproductive toxicity study (SLI, 2000a). The TRV value was actually for nickel sulfate hexahydrate and should have been adjusted to a Ni basis. As a result, the Ni risk was underestimated by a factor of roughly 4.5 for those receptors in the CBRA. As outlined in Vale (2020b), the LOAEL-derived Ni TRV derived from SLI (2000a) is 16.5 mg Ni/kg/d (i.e., adjusted to a Ni basis), which is the TRV that should be used for non-ungulate mammalian receptors. For ungulates, a TRV of 13.5 mg Ni/kg/d is justified based on the exposure of cattle to oral Ni carbonate by O'Dell et al. (1971). For comparison, the TRV used by the MECP to derive Ontario's current soil quality standards (including ungulates) is 80 mg/kg/d. This is a very brief discussion of TRVs, but there have been extensive discussions between Vale and MECP regarding ecological and human health. Vale understands that the TRVs selected for ecological and human risk are appropriate for the purpose.

The values of other variables used for risk quotient estimation are explained in the footnotes to Tables 13 and 14 below and are mostly self-explanatory. For clarity, the oral bioavailability adjustment for soil intake is the ratio between the oral bioavailability of soil from the study area and the oral bioavailability of nickel sulfate hexahydrate, the highly soluble form of Ni that the TRV was derived from. It is an adjustment factor that accounts for the lower bioavailability of the Ni in the study area (as previously shown in the Kd discussion earlier in this report).

Risk quotients estimated for the selected ecological receptors are presented in Table 13 (herbivores) and Table 14 (omnivores).

Substantial risks are calculated to be present in the Reuter Road woodlot, for the short-tailed shrew (RQ=20.6), American woodcock (RQ=5.9, and the cottontail rabbit (RQ=5.0). Moderate unacceptable risk was calculated to be present for racoon (RQ=1.9) and American robin (RQ=2.5). Whitetail deer was found to not have unacceptable risk (RQ=0.7) in the Reuter Road woodlot. The cause of unacceptable risk was primarily the soil Ni content, so receptors with the highest soil intake rates per body weight (such as the short-tailed shrew) have the highest calculated risk, while those with lower body-weight-specific soil intake (such as the whitetail deer) have the lowest risk. However, the dietary Ni concentration is also important for estimating unacceptable risk. For the short-tail shrew in the Reuter Road woodlot, a risk quotient of 1.0 (i.e., no unacceptable risk) would occur at a soil Ni concentration of 1,640 ppm, but only with a dietary Ni concentration of around 3 ppm, which is essentially a background Ni concentration. Therefore, the primary study area from the CBRA represents a high-risk scenario to wildlife with small home ranges, such as the short-tailed shrew, both due to soil ingestion and food intake.

Table 13. Ni Risk: Risk estimates for herbivorous mammals in the PCCAP. Bolded values for the risk quotients indicate exceedence of the TRV.

Exposure Scenario		Body Weight (BW) (kg)[1]	TRV (LOAEL)[2]	Food Intake(kg/d)[1]	Water Intake (L/d)[1]	Soil Intake (kg/day)[3]	Dietary [Ni] ppm[4]	Soil [Ni] ppm[5]	Soil Ni BAv[6]	Water [Ni] (mg/L)[7]	ADD (mg/kg/d)[8]	Risk Quotient[9]
Reuter Road Woodlot	Cottontail rabbit	1.2	16.5	0.237	0.116	0.0149	123	30,452	0.155	0.24	83.0	**5.0**
Lorraine Road Woodlot	Cottontail rabbit	1.2	16.5	0.237	0.116	0.0149	57.6	5,007	0.155	0.24	21.1	**1.3**
Lorraine Road field and forest edge	Cottontail rabbit	1.2	16.5	0.237	0.116	0.0149	25.3	824	0.155	0.24	6.6	0.4
Reuter Road field and forest edge	Cottontail rabbit	1.2	16.5	0.237	0.116	0.0149	7.9	6,208	0.155	0.24	13.6	0.8
Overall PCCAP	Cottontail rabbit	1.2	16.5	0.237	0.116	0.0149	106.9	19,415	0.155	0.24	58.6	**3.6**
Reuter Road Woodlot	Whitetail Deer	56.5	13.9	1.74	3.7	0.0783	123	30,452	0.155	0.24	10.3	0.7
Lorraine Road Woodlot	Whitetail Deer	56.5	13.9	1.74	3.7	0.0783	57.6	5,007	0.155	0.24	2.9	0.2
Lorraine Road field and forest edge	Whitetail Deer	56.5	13.9	1.74	3.7	0.0783	25.3	824	0.155	0.24	1.0	0.1
Reuter Road field and forest edge	Whitetail Deer	56.5	13.9	1.74	3.7	0.0783	7.9	6,208	0.155	0.24	1.6	0.1
Overall PCCAP	Whitetail Deer	56.5	13.9	1.74	3.7	0.0783	11.8	19,415	0.155	0.24	4.5	0.3

1. Body weight, food consumption rate, and water consumption rate were taken from Table B.1 of Sample et al. (1997).

2. The TRV for the cottontail rabbit is the LOAEL of 16.5 mg Ni/kg/day from Vale (2020a). The TRV used to assess whiteail deer risk was derived from Table 1 of O'Dell et al. (1971), which studied the toxicity of oral Ni carbonate on male bovine calves. For the 1,000 ppm supplementation treatment in that study: 1,557 mg Ni daily intake ÷ 112 kg = 13.9 mg Ni/kg/day.

3. Soil intake for the eastern cottontail was from Table 4-5 of US EPA (1993). Soil intake rate for whitetail deer (4.5% of diet) was average of 2% of diet for mule deer (Sample et al. 1997) and bison (7% of diet) from Beyer et al. 1994.

4. Ni concentrations in the diet are 95UCLM values for vegetation samples (ppm d.w.) collected from the sampling areas for the respective exposure scenarios.

5. Soil Ni concentrations for the exposure scenarios are from Tables 2-5 of this report, respectively.

6. Soil Ni oral bioavailability adjustment (BAv) was calculated as follows: Ni bioavailability (0.3%) among organic soils (Dutton et al., 2019) ÷ $NiSO_4 \cdot 6H_2O$ bioavailability (1.94% - Dutton et al., 2020).

7. Water [Ni] was the maximum value for water in vernal pools (0.24 mg/L) as reported in the Aquatic Survey Report (Vale, 2023a).

8. ADD (average daily dose) = (Food intake × Dietary [Ni]) + (water intake × water [Ni]) + (soil intake × soil BAc × soil [Ni]). No adjustment was made for Ni bioavailability in food, as it was found that background bioavailability of Ni in food was similar to oral bioavailability of $NiSO_4 \cdot 6H_2O$ (Dutton et al., 2019).

9. Risk Quotient = ADD ÷ TRV

Table 14. Omnivore Ni risk. Risk estimates for omnivorous receptors in the PCCAP. Bolded values for the risk quotients indicate exceedence of the TRV.

Exposure Scenario		Body Weight (BW) (kg)[1]	TRV (LOAEL)[2]	Food Intake(kg/d)[1]	Water Intake (L/d)[1]	Soil Intake (kg/day)[3]	Dietary [Ni] ppm[4]	Soil [Ni] ppm[5]	Soil Ni BAv[6]	Water [Ni] (mg/L)[7]	ADD (mg/kg/d)[8]	Risk Quotient[9]
Reuter Road Woodlot	Short-tailed Shrew	0.015	16.5	0.009	0.0033	0.0008	123	30,452	0.155	0.24	340.1	**20.6**
Lorraine Road Woodlot	Short-tailed Shrew	0.015	16.5	0.009	0.0033	0.0008	57.6	5,007	0.155	0.24	78.4	**4.8**
Lorraine Road field and forest edge	Short-tailed Shrew	0.015	16.5	0.009	0.0033	0.0008	25.3	824	0.155	0.24	22.4	**1.4**
Reuter Road field and forest edge	Short-tailed Shrew	0.015	16.5	0.009	0.0033	0.0008	7.9	6,208	0.155	0.24	59.1	**3.6**
Overall PCCAP	Short-tailed Shrew	0.015	16.5	0.009	0.0033	0.0008	106.9	19,415	0.155	0.24	233.9	**14.2**
Reuter Road Woodlot	Raccoon	4	16.5	0.216	0.328	0.0203	123	30,452	0.155	0.24	30.6	**1.9**
Lorraine Road Woodlot	Raccoon	4	16.5	0.216	0.328	0.0203	57.6	5,007	0.155	0.24	7.1	0.4
Lorraine Road field and forest edge	Raccoon	4	16.5	0.216	0.328	0.0203	25.3	824	0.155	0.24	2.0	0.1
Reuter Road field and forest edge	Raccoon	4	16.5	0.216	0.328	0.0203	7.9	6,208	0.155	0.24	5.3	0.3
Overall PCCAP	Raccoon	4	16.5	0.216	0.328	0.0203	106.9	19,415	0.155	0.24	21.1	**1.3**
Reuter Road Woodlot	American Woodcock	0.197	107.0	0.216	0.328	0.0203	123	30,452	0.155	0.24	621.7	**5.8**
Lorraine Road Woodlot	American Woodcock	0.197	107.0	0.216	0.328	0.0203	57.6	5,007	0.155	0.24	143.5	**1.3**
Lorraine Road field and forest edge	American Woodcock	0.197	107.0	0.216	0.328	0.0203	25.3	824	0.155	0.24	41.3	0.4
Reuter Road field and forest edge	American Woodcock	0.197	107.0	0.216	0.328	0.0203	7.9	6,208	0.155	0.24	108.2	1.0
Overall PCCAP	American Woodcock	0.197	107.0	0.216	0.328	0.0203	106.9	19,415	0.155	0.24	427.8	**4.0**
Reuter Road Woodlot	American Robin	0.077	107.0	0.093	0.0106	0.0019	123	30,452	0.155	0.24	262.6	**2.5**
Lorraine Road Woodlot	American Robin	0.077	107.0	0.093	0.0106	0.0019	57.6	5,007	0.155	0.24	88.3	0.8
Lorraine Road field and forest edge	American Robin	0.077	107.0	0.093	0.0106	0.0019	25.3	824	0.155	0.24	33.7	0.3
Reuter Road field and forest edge	American Robin	0.077	107.0	0.093	0.0106	0.0019	7.9	6,208	0.155	0.24	32.8	0.3
Overall PCCAP	American Robin	0.077	107.0	0.093	0.0106	0.0019	106.9	19,415	0.155	0.24	201.8	**1.9**

1. Body weight, food consumption rate, and water consumption rate were taken from Table B.1 of Sample et al. (1997).
2. The TRV for mammals is the LOAEL of 16.5 mg Ni/kg/day derived in Vale (2020a). The TRV used to assess avian Ni risk was based on Cain and Pafford (1981) - derived in Sample et al. (1996).
3. Soil intake rates are from (US EPA, 1993).
4. Ni concentrations in the diet are 95UCLM values for vegetation samples (ppm d.w.) collected from the sampling areas for the respective exposure scenarios.
5. Soil Ni concentrations for the exposure scenarios are from Tables 2-5 of this report, respectively.
6. Soil oral Ni bioavailability adjustment (BAv) was calculated as follows: Ni bioavailability (0.3%) among organic soils (Dutton et al., 2019) ÷ $NiSO_4 \cdot 6H_2O$ bioavailability (1.94% - Dutton et al., 2020).
7. Water [Ni] was the maximum value for water in vernal pools (0.24 mg/L) as reported in the Aquatic Survey Report (Vale, 2023a).
8. ADD (average daily dose) = (Food intake × Dietary [Ni]) + (water intake × water [Ni]) + (soil intake × soil BAc × soil [Ni]). No adjustment was made for Ni bioavailability in food, as it was found that background bioavailability of Ni in food was similar to oral bioavailability of $NiSO_4 \cdot 6H_2O$ (Dutton et al., 2019).
9. Risk Quotient = ADD ÷ TRV

9.0 Discussion

The Port Colborne Community-Based Risk Assessment (CBRA) was initiated by the International Nickel Company (Inco) in year 2000 at the recommendation of the Ontario Ministry of the Environment (MOE). A natural environment ecological risk assessment was undertaken as one component of the CBRA. The three component risk assessments (a human health risk assessment was also conducted) were submitted to the MOE in 2010 and the Ministry provided comments in 2011. Numerous discussions between the Ministry and Vale (the new corporate owner of Inco Limited) occurred to attempt to bridge disagreements between Vale and the MOE culminated with the production of an Update Report in 2014. The update report was intended to resolve the technical disagreements, but included very little new data, and ultimately failed to satisfy Ministry concerns. The Port Colborne Community Action Plan (PCCAP) was initiated by Vale in 2020 to address outstanding issues. Under the PCCAP, the natural environment considerations have been divided into an Aquatic Survey and the terrestrial ecological aspects.

In Vale's PCCAP execution document (Vale, 2020), Vale proposed several activities. A woodlot forestry survey was proposed, but it was decided to conduct and ecological survey rather than a forestry-based survey. One notable difference between a forestry-based survey and an ecological-based survey is that impaired woodlot health from a forestry (wood harvesting) perspective can represent beneficial forest health from an ecological perspective, with snags, cavities, and downed trees providing habitat rather than harvestable lumber. This was noted in the CBRA by Trees Unlimited (2002). Therefore, it was decided to change the focus from forestry to ecology (natural heritage) in the PCCAP.

Soil sampling and ecological survey work was restricted to Vale-owned lands, and given the generally positive findings of the natural heritage inventory on those lands, Vale believes that the most obvious decision for woodlot risk management is to leave the woodlots as ecological habitat. It is likely that, over time, the soil concentrations will become buried through the decay of fallen trees and accumulated leaf litter, which have low Ni concentrations relative to the soil. Recently, four large canopy trees have been uprooted and fallen in the Reuter Road woodlot and are in the process of decaying, so this process is occurring at present. This will occur on a long-term time frame of decades to a century or more.

The PCCAP execution document indicated that soil mapping would be conducted to determine the potential for remediation activities to occur in the woodlots on the Vale-owned lands. However, soil Ni concentrations were highly variable on a spatial scale of 1-3 m and given that level of heterogeneity, soil Ni concentration maps would be highly speculative and potentially quite inaccurate. Coupled with the findings of the natural heritage inventory, Vale did not complete the soil mapping efforts, as remediation by soil removal is now seen to not be a realistic risk management approach.

The PCCAP woodlot studies have evaluated a new approach to study soil microbial populations, the soil microbiometer from Prolific Earth Sciences, which has shown that microbial biomass in the surface soils of the Reuter Road woodlot is in a normal range, although the fungal:bacterial ratios are somewhat low and could indicate some level of impairment of soil decomposition, as fungi are generally more important decomposers than bacteria. Additionally, as noted in this report, the relatively large amounts of forest floor litter observed in the CBRA litter study is not necessarily an indicator of impaired soil decomposition, and the relative absence of earthworms from the Reuter Road woodlot soil should not be construed to indicate impaired decomposition either. The soil microbiometer results mesh with the findings of the natural heritage inventory. Despite the high levels of metal in the woodlot soils, the woodlots have good ecological values.

During soil sampling in the Reuter Road woodlot in 2020, apparent chlorosis (a sign of Ni toxicity) was observed in spicebush leaves. This had not been anticipated when the PCCAP was being planned, but Vale recognized chlorophyll measurements in leaves as a potential indicator of impairment (i.e., risk to flora) which was likely more meaningful than *ex situ* toxicity tests since it represented actual field-measured impairment. An EC_{10} (the soil Ni concentration associated with a ten percent reduction in chlorophyll concentration) was estimated to occur at 15,369 ppm (soil Ni). This value is considerably higher than toxicity endpoints determined in the CBRA and the MECP's proposed risk-based soil concentration. 1,200-2,400 ppm soil Ni (MECP, 2018), but may be reasonable given the findings of the natural heritage inventory.

The Ni content in maple leaves was measured in the Reuter Road woodlot in 2023 and found to be similar to the concentrations determined in the CBRA in 2001 and 2002 and very much reduced since MOE studies on maple leaves were conducted in the 1970s.Vale's analysis of the pre-closure and post-closure (including MOE data from 1986 and 1991) maple leaf Ni concentrations showed that historical MOE data from periods prior to the closure of the Inco Ni refinery in 1984 are not comparable to those of present-day. Vale and MECP have previously discussed this issue in comment-response dialogues, particularly with respect to the agricultural crops risk assessment. Vale believes that this new approach supports the view that pre-closure field phytotoxicity data from around the refinery should not be used to assess current phytotoxicological risk.

Toxicity tests using radish and lettuce were undertaken on organic and mineral soils collected from the Vale-owned lands surrounding the Wignell Drain. These lands had been previously used for agricultural cropping. Measurements of germination, growth, and chlorophyll content in the seedlings were aggregated, and for the organic soil, an EC_{10} was not calculable for the concentration range up to approximately 4,200 ppm Ni, while for the mineral soil, an EC_{10} of approximately 1,365 ppm Ni was estimated from the aggregated data. Lettuce and radish were selected for the toxicity testing to allow comparison with earlier data, including from the CBRA and MOE studies (pre-and post-closure). For lettuce, it was possible to find historical MOE data from before and after the Ni refinery closure and it can be seen that washed lettuce leaves (i.e., that were washed prior to Ni analysis) had similar Ni content in both pre-closure and post-closure situations but that unwashed leaves had a higher Ni content, which would be expected to contribute to toxicity via foliar uptake. For radish leaves, a trend of reduced Ni content in post-closure samples relative to pre-closure samples was evident. Pre-closure vegetation data are not representative of current conditions and should not be used to represent current risk.

Using the quotient method, unacceptable risk could be calculated for wildlife in the primary study area from the CBRA, and in particular, in the Reuter Road woodlot. These findings correct the earlier risk assessment findings of the CBRA natural environment risk assessment, which had indicated no unacceptable risk for any wildlife receptor. A soil concentration exceeding 1,400 ppm Ni would result in unacceptable risk for short-tailed shrews in the Reuter Road woodlot, even if the dietary component of exposure was 7 ppm Ni – the Ni concentration measured in insect larvae found in acorns in the Reuter Road woodlot.

It is difficult to provide a single value that could represent a safe soil concentration for the primary study area from the CBRA – the area between Reuter Road and Lorraine Road. Based on the PCCAP studies, a range of soil Ni concentrations between 1,365 ppm and 15,369 ppm could be put forward for vegetation. The lower end of this scale is similar to the range proposed by MECP to denote a safe Ni level for plants in the natural environment, while the upper end of this range, or higher might be reasonable at a plant community level. For wildlife a soil concentration of 1,400 ppm could be calculated as representing a safe level using the quotient method (for short-tailed shrew).

It appears that despite the contamination levels, the primary study area of the CBRA, which contains remnants of Carolinian forest that are increasingly under threat from human development pressures, has high ecological value. The complete picture is complicated. Vale believes that remediation of these lands, which is part of a provincially significant wetland, is not feasible and that natural attenuation of the contaminated lands is the only viable management alternative.

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