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Nickel in forests – a short review on its distribution and fluxes

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Abstract

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The distribution and cycling of nickel (Ni) in forests is greatly affected by their proximity to emission sources of the metal. The throughfall deposition is always richer in Ni than the bulk deposition. It can be inferred that some dry deposition enriches the throughfall. In remote forested areas, the hydrological fluxes of Ni do not differ a lot from those in litterfall. In addition, the current year needles in conifers have higher concentrations than the older needles, a sign of absorption and mobility of the metal. In contrast, near an industrial Ni source the older needles accumulate much more of the metal. The Ni content in bark tissue can be used to map the deposition distribution of the metal around an area (rural or urban). The concentrations of Ni in forest soils is also dependent on their distances from the Ni emission sources and the nature of the soil parent material. The Ni concentrations increase with soil depth due to the geogenic origin of the metal. Low pH greatly enhances the mobility of the metal in soils, much more than the leachability of organic matter.

Keywords

forests, hydrology, litterfall, nickel, soil, vegetation

Introduction

Nickel was established as an essential micronutrient for the growth of temperate cereal crops in 1975 being a component of the enzymes urease and hydrogenase (Dixon et al., 1975). Nickel works as a cofactor to enable urease to catalyze the conversion of urea into the ammonium ion, which plants can use as a source of nitrogen. The activity of hydrogenase provides the ATP necessary for nitrogen reduction into ammonia (Dalton, 1985). Based on these criteria, Brown et al. (1987) argued, in the late 1980s, that nickel is a nutrient essential for plant life. Ruter (2005) found out that the disorder (stunted plants) observed in nurseries of river birch (*Betula nigra* L.) was due to low supplies of Ni. Wood et al. (2006) reported that the little-leaf disorder of pecan [*Carya illinoinensis* (Wangenh.) K. Koch] was caused by Ni deficiency. The authors applied foliar application of Ni and the symptoms disappeared proving in this way the first known example of Ni deficiency in orchard crops. Despite these findings, there has been more concern about the toxicity of Ni than about deficiency (Nieminen et al., 2007). The toxicity of Ni to organisms has been known for a long time and most research on Ni has concentrated largely on its possible effects on plants growing near industrial activities emitting Ni or on plants growing on serpentine soils derived from ultrabasic igneous rocks (Uren, 1992). In high concentrations, Ni reduces seed germination, root and shoot growth, biomass accumulation, and final production. In addition, Ni toxicity can cause chlorosis, necrosis and inhibition of various physiological processes (photosynthesis, transpiration) (Hassan et al., 2019). The interest on the effects of Ni on forest plants was initially derived from the fact that forest species were often close to industrial sources of

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Ni. Moreover, there was a broad interest on metal deposition on forest ecosystems. In this context, Nikonov et al. (2001) examined the cycle of Ni in a pine forest. Çakir and Akburak (2017) examined the concentration and fluxes of Ni in pure and mixed stands of oak and beech in Turkey. Offenthaler et al. (2009) measured the concentration of Ni in bulk and throughfall deposition in a forest in the Alps in Austria. Hagemeyer et al. (1994) measured the Ni concentration in beech wood. Sawidis et al. (2012) determined the Ni concentration in evergreen species in the area of Attiki, Greece. So far, there has not been information on the thresholds for deficiency or toxicity in forest species. There are excellent reviews on Ni availability in soils (Uren, 1992) and general biogeochemistry of Ni (Nieminen et al., 2007). The aim of this review was a little more specific, i.e. to collect, quote and draw conclusions on Ni distribution and cycling in forests on remote areas or in the vicinity of industrial plants. Ecological regions having ultramafic rocks as soil parent material giving rise to serpentine soils with a very high content of Ni will not be examined. The text will be broken down to the hydrological paths of the metal and its distribution in vegetation and soil.

Hydrological cycle

The concentrations of Ni in the bulk deposition is generally low in remote areas. Usually it is below one μg L^{-1}. Close to pollution centers, it can be much higher. In the urban environment of the Izmir city, Turkey, the wet only deposition had an average Ni concentration of 7.4 μg L^{-1} (Muezzinoglu and Cizmecioglu, 2006). In the proximity of a metal smelting industry located at Sudbury, Ontario, the Ni concentration rose high and reached 174 μg L^{-1} in bulk deposition (Jeffries and Snyder, 1981). The Ni concentration in throughfall even in forests away from industrial activities varies a lot depending on the soil type and its chemical composition. In six forest types in France (*Picea abies* Karst., *Fagus sylvatica* L., *Abies alba* Mill.), Gandois et al. (2010a) found a range of 0.25 to 0.66 μg L^{-1} in bulk deposition and 0.41 to 0.79 μg L^{-1} in throughfall. In all types, the concentrations of Ni in throughfall were higher than that in the bulk deposition. In agreement with the previous authors, Michopoulos et al. (2018) found a range of 0.12–1.34 μg L^{-1} in bulk deposition and 0.23 to 4.58 μg L^{-1} in throughfall in a Bulgarian fir (*Abies borisii-regis* Mattf.) stand in central Greece. Huang et al. (2011) found a median Ni concentration of 0.48 μg L^{-1} in the bulk deposition and 1.02 μg L^{-1} in throughfall in a Norway spruce forest in Germany. Ukonmaanaho et al. (1998) measured a range of 0.25–2.70 μg L^{-1} in bulk deposition and 0.93–12.3 μg L^{-1} in throughfall in 4 catchments in Finland with mixed forests of Scots pine (*Pinus sylvestris* L.), Norway spruce (*Picea abies* Karst.), and deciduous species (mainly *Betula* spp.). The reason for the throughfall enrichment is probably the dry deposition and not the leaching. Ni is considered medium among metals with regard to its ability to enrich aerosols, which later on can deposit on forests. Other metals (for example As and Cd) have much greater ability (Steiness and Friedland, 2005). After assessing monthly bulk deposition chemistry for two years at Lake Redon, in Central Pyrenees, Spain, Bacardit and Camarero (2009) inferred that nickel had intermediate properties suggesting a balance of both natural and polluting sources.

The concentrations of Ni in soil solution are usually higher than those in bulk and throughfall deposition. Bergvist et al. (1989) reviewed the leachability of metals in temperate forest ecosystems. They found that Ni, Zn and Cd were very susceptible to changes in soil acidity. As a result, a gradual release of metals from the mineral soil and an increase in soil solution concentration of metals through the B horizon are characteristic features of acid soils. For this reason when referring to Ni concentrations in soil solution the status of acidity in soils should be given. Equally important are the way of soil solution collection (tension or zero tension lysimeters) and the characterization of soils in terms of texture analysis. In France, in acid sandy soils, Gandois et al. (2010b) using suction cups in a silver fir stand found a Ni concentration of 6.75 μg L^{-1} at a depth of 20 cm and 2.99 μg L^{-1} at the depth of 75 cm. In a Norway spruce forest stand in Germany in an acid sandy loam soil the Ni concentration in soil solution (zero tension lysimeters) had a median of 1.22 at 20 cm depth and 1.37 μg L^{-1} at 90 cm depth (Huang et al., 2011). Higher concentrations (6.82–19.4 μg L^{-1}) of Ni in soil solution extracted with zero tension lysimeters at a depth of 35 cm in acidic podzol soils were found by Ukonmaanaho et al. (1998) in mixed forests in Finland mentioned above. It is not only pH that enhances the leaching of Ni from soils. In Sweden, Bergvist (1987) found that in a brown earth forest (spruce and beech) soil at a depth of 35 cm the Ni concentrations in the leachates (zero tension lysimeters) reached a value of 4 μg L^{-1}, whereas in a podzol soil the Ni concentration was 2 μg L^{-1}. The podzol soil had higher amounts of organic matter and the author attributed this fact that Ni is not a metal related to the leaching of humus (like Cu, Pb and Cr). Table 1 summarizes information about Ni concentrations in the hydrological cycle.

Hydrological and litterfall fluxes

The hydrological and litterfall fluxes of Ni refer to the amounts of Ni per unit of area per time that enter or leave a forest ecosystem. Usually they are expressed in g ha^{-1} yr^{-1} but other units are possible. In general in forested areas away from metal smelting industries the Ni fluxes in bulk, throughfall deposition and litterfall do not differ a lot. In the mountain area of Lake Redon in Central Pyrenees mentioned above, the fluxes of Ni in the bulk deposition ranged from 5.2 to 6.5 g ha^{-1} yr^{-1} (Bacardit and Camarero, 2009). In two holm oak (*Quercus ilex* L.) forests in Spain, the throughfall fluxes ranged from 7 to 7.3 g ha^{-1} yr^{-1}, whereas the bulk deposition Ni content was below the detection limit (Avila and Rodrigo, 2004). In Germany, in a remote forest of Norway spruce, the Ni fluxes were 5.0, 8.7 and 5.3 g ha^{-1} yr^{-1} for bulk, throughfall deposition and litterfall, respectively. It is worth mentioning

that the Ni fluxes in throughfall in this forest were higher than those in litterfall. For the soil solution, the fluxes were 11.5 and 8.3 g ha^{-1} yr^{-1} at the depths of 20 and 90 cm, respectively (Huang et al., 2011). In two forested sites in Finland Ukonmaanaho et al. (2001) found 2.4 g ha^{-1} yr^{-1} in the litterfall of a Scots pine (*Pinus sylvestris* L.) stand and 6.2 g ha^{-1} yr^{-1} in the litterfall of a mixed stand of Norway spruce, birch and aspen. In the Northeastern France in the Vosges Mountains, Gandois et al. (2010b) found rather high fluxes of Ni in the soil solution, i.e. 43 and 24 g ha^{-1} yr^{-1} at the depths of 20 and 70 cm, respectively. When there is an industrial Ni source, things change. In the area of a smelting center of Ontario in Canada, the bulk deposition fluxes ranged from 74 to 1,560 g ha^{-1} yr^{-1} (Jeffries and Snyder, 1981). Derome and Nieminen (1998) examined elemental fluxes at the distances of 0.5, 4 and 8 km from a Cu-Ni smelter in Finland in a Scots pine ecosystem. They found that at the 0.5 km, the bulk deposition fluxes were 600 g ha^{-1} yr^{-1}, in the throughfall 1,400 g ha^{-1} yr^{-1} and the solution flux at 40 cm depth was 500 g ha^{-1} yr^{-1}.

Input of Ni to forests through weathering fluxes

There are not many works on the Ni inputs to forests through weathering. Gandois et al. (2010b) applied the Profile model (Sverdup and Warfinge, 1993) to find the weathering of base cations and the ratio of metals to base cations in parent material to find the release of trace metals (Pacès, 1998). He found a weathering flux of 0.47 g ha^{-1} yr^{-1} in the soil of a silver fir stand. This is a low value, which was attributed to the sandy nature of soils. Starr et al. (2003) used the Zirconium method. Zr mainly occurs in the mineral form $ZrSiO_4$, which is extremely resistant to weathering (Tole, 1985), and for this reason it can be used as an internal standard to calculate the weathering losses of other elements. They applied the method to podzol soils under Scots pine in eastern Finland. They found higher weathering fluxes for Ni than the previous authors. More specifically, they found a range of 2.93 to 4.46 g ha^{-1} yr^{-1}, which were even higher than the litterfall fluxes in those Scots pine stands. It would be interesting to see future works with this subject in more clayey soils.

Vegetation

The concentrations of Ni in plant tissues reflect the distance from a local source of Ni emissions together with properties of soils. In a remote fir forest Michopoulos et al. (2018) found an average of 3.81 mg kg^{-1} in current year needles and 2.53 mg kg^{-1} in second year needles of Bulgarian fir. Higher concentrations of Ni in current needles (2.3 mg kg^{-1}) than in second year ones (1.7 mg kg^{-1}) were also found by Nikonov et al. (2001) in Scotch pines in Russia in unpolluted areas. Gandois and Probst (2012) also found a decreasing trend from young needles to older needles (4.7–3.5 mg kg^{-1}) in silver fir in the south of France, in the Pyrenees Mountains. In general, when certain nutrients are deficient in the plant tissue, older leaves are able to translocate them to younger leaves (Mauseth, 1998). Nutrients with this ability are mobile nutrients, and include N, P, K, S and Mg. It seems that plants apply this mechanism in an environment deficient in Ni. When the distance to a pollution source become smaller, the concentrations increase in all needle ages. The difference here is that the Ni concentrations in older needles increases. Nikonov et al. (2001) found 273 and 396 mg kg^{-1} in current and second year of Scots pine needles, respectively at

Table 1. Concentrations (μg L^{-1}) of Ni in the hydrological cycle of some forests. In the soil solution the concentrations are inside the parentheses

Location	Vegetation	Bulk	Throughfall	Reference
France	*Picea abies*	0.38	0.49	Gandois et al. (2010a)
France	*Fagus sylvatica*	0.25	0.45	Gandois et al. (2010a)
France	*Abies alba*	0.46	0.74	Gandois et al. (2010a)
Central Greece	*Abies borisii regis*	0.12–1.34	0.23–4.58	Michopoulos et al. (2018)
Finland (South to North)	*Pinus sylvestris, Picea abies, Betula* sp.	0.25–2.70	0.93–12.3	Ukonmaanaho et al. (1998)
Germany (Bavaria)	*Picea abies*	0.11–4.16	0.27–11.7	Huang et al. (2011)
		Soil solution and depth		
South Sweden	*Picea abies*	15 cm (1.5)	35 cm (4.0)	Bergvist (1987)
South Sweden	*Fagus sylvatica*	15 cm (4.0)	35 cm (3.8)	Bergvist (1987)
Germany(Bavaria)	*Picea abies*	90 cm (0.97–3.20)		Huang et al. (2011)
Eastern Finland	*Pinus sylvestris*	40 cm (2.93–4.40)		Starr et al. (2003)

a distance of 8 km away from a Cu-Ni smelter in Russia. In any case, the magnitude of Ni concentration in unpolluted areas is low and it is high in proximity to pollution sources. In the Sudbury Region (Ontario, Canada), Nkongolo et al. (2008) found a range of Ni concentration in the needles of black spruce (*Picea mariana* Mill.) 17.0 to 21.1 mg kg^{-1}, whereas in the control site the respective concentration was 3.48 mg kg^{-1}. In Finland, Derome and Niemenen (1998) measured the Ni content in one-year needles of Scots pine at various distances from a Cu-Ni smelter. At 8 km, the concentration was 5.08, at 4 km 7.8 and at 0.5 km 43.5 mg kg^{-1}. Rautio and Huttunen (2003) collected and analyzed needles of Scots pine from plots located along a 350 km-long transect extending from the vicinity of the Monchegorsk smelter complex on the Kola Peninsula, NW Russia, through Finnish Lapland to the Finnish-Swedish border. They found a Ni concentration of 50 mg kg^{-1} in current year needles and over 100 mg kg^{-1} in the second year needles of Scots pine close to pollution sources. Parzych et al. (2017) determined the Ni concentration in six pine species within the area of the forest at the University botanic garden in the city of Kosice (Slovakia). The concentrations were rather high having a range of 3.5 to 17 mg kg^{-1}. The authors did not mention any source of metal smelting around the area. As the second year needles had higher concentration from the current year ones, some Ni deposition could have taken place. For example, Scots pine had a concentration of 7.3 mg kg^{-1} in current year needles and 17.1 mg kg^{-1} in current+ 1-year's needles. In addition, the Ni concentrations in the bark was very high (91 mg kg^{-1}). McGee et al. (2007) measured low concentrations (0.65–2.47 mg kg^{-1}) of Ni in broadleaves in Maine, USA (Table 2). However, high concentrations of Ni can also appear in broadleaves. In the Ukrainian Carpathians, Shparyk and Parpan (2004) found 8.5 mg kg^{-1} in beech leaves and 45 mg kg^{-1} in oak (*Quercus robur* L.) leaves located close to a more polluted site.

A question about needle/leaves analysis that arises is to wash or not wash (before analysis). Rautio and Huttunen (2003) found that the Ni concentration in the needle wax of Scots pine in the work mentioned above, in the area with the highest deposition (close to smelter) was 20- to over 30-fold higher than the internal concentrations. When the Ni deposition was low, there was no significant difference between internal and total concentrations in needles. Therefore, a high Ni concentration close to pollution source does not necessarily mean that Ni has entered plant cells. On the other hand washing removes a potential risk to forest plants because the Ni entrance into plant cells can also take place from the needle surfaces. Nieminen et al. (2004) found that pine seedlings grown in unpolluted soil could absorb Ni through deposition from a nearby Cu-Ni smelter. In the author's opinion, both analyses are useful to draw conclusions with regard to Ni toxicity.

Apart from the leaf/needle tissues, the trunk wood and the trunk bark present special interest. Schelle et al. (2008) used the bark tissue of 642 tree species to map the deposition of Ni, Cd and As in the area of Sheffield, UK. They found that the concentrations of Ni and Cd were greatest close to a large steel works, their probable source, and declined markedly within 500 m of it and from there more gradually over several kilometers. In contrast, trunk wood accumulates elements mainly from the soil and its metal concentration does not reflect the atmospheric pollution (Rossini Oliva and Mingorance, 2006). In the trunk wood of a sugar maple (*Acer saccharum* Marsh.) stand in Ontario, USA, Morrison and Hogan (1986) found higher concentrations of Ni (0.5 mg kg^{-1}) with regard to Cd (0.19 mg kg^{-1}) and Pb (0.3 mg kg^{-1}). Michopoulos et al. (2018) found 0.501 mg kg^{-1} in the trunk bark and 0.277 mg kg^{-1} in the trunk wood of a Bulgarian fir. Lower concentrations (0.05 mg kg^{-1}) in the trunk wood were found by Gandois et al. (2010b) but similar ones in the bark (0.58 mg kg^{-1}) of a mature silver fir (*Abies alba* Mill.) stand. The ratio of the metal concentrations in tree bark over the respective one in wood was used as an indication of atmospheric pollution (Rossini Oliva and Mingorance, 2006). Gandois et al. (2010b), however, argued that this ratio should be used with caution as in remote and unpolluted forests the increased metal concentrations in tree barks might be due to metal leaching from canopy and not directly from the atmosphere.

Table 2 is a concise source of information with regard the Ni concentrations in needles/leaves as well as wood and bark of some forest species.

Soils

When dealing with heavy metals in soils, the method of determination is important. The reason is that the fractions from which the metals come from and consequently their concentrations differ. The real total metal concentration is attained by digestion with HF acid, fusion with Na bicarbonate or Li metaborate and the use of X-Ray Fluorescence. The so called "pseudo total" concentrations is carried out by extraction with concentrated HNO_3, HCl, $HClO_4$ acids or aqua regia (1:3 HNO_3:HCl). There are also the chelating agents (EDTA, DTPA and organic acids of low molecular weight) which extract metals (supposedly the bioavailable ones) from the soil organic fraction or the clay one. The metal concentrations of the latter method is lower than the others. Nygård et al (2012) carried out a large survey with regard to distribution of 32 elements (extracted with HNO_3) in organic surface soils in Norway. They classified Ni as an element markedly affected by local pollution sources rather than by transboundary pollution. In a region in northern Norway close to two Russian smelters they found 6.65 mg kg^{-1}, whereas in the other areas (11 in total) the Ni concentrations ranged 2.55 to 5.43 mg kg^{-1}. In a variety of 23 forested sites in Switzerland, Blaser et al. (2002) found higher concentrations of Ni (determined with X-Ray Fluorescence). The highest concentrations were found in soils derived from limestones and sedimentary rocks (44–60 mg kg^{-1} in the organic horizons and 64–159 mg kg^{-1} in the deeper mineral horizons). In a remote forest soil over flysch, Michopoulos et al. (2018) found similar concentrations, using aqua regia and HF acid as digests, in the FH layer (44 mg kg^{-1}). In the mineral horizons the Ni went increasing with depth and

Table 2. Concentrations (mg kg^{-1}) of Ni in the needles/leaves as well as trunk bark and trunk wood of some forest species

Location	Vegetation	Needles/leaves	Trunk bark	Trunk wood	Close to Ni emission source	Reference
Kola Peninsula, NW Russia	*Pinus sylvestris*	2.3 in current year 1.7 in current+1			NO	NIKONOV et al. (2001)
Kola Peninsula, NW Russia	*Pinus sylvestris*	273 in current year 396 in current+1			YES	NIKONOV et al. (2001)
Kola Peninsula, NW Russia	*Pinus sylvestris*	50 in current year 120 in current+1			YES	RAUTIO and HUTTUNEN (2003)
Slovakia	*Pinus sylvestris*	7.3 in current year 17.1 in current+1	91		Possible	PARZYCH et al. (2017)
Slovakia	*Pinus nigra*	3.7 in current year 5.5 in current+1	80		Possible	PARZYCH et al. (2017)
Attiki, Greece	*Pinus brutia*	Mixed needles 9.37-24.3			Urban environment	SAWIDIS et al. (2012)
Kola Peninsula, NW Russia	*Betula pubescens*	58.2			YES	KOZLOV et al. (2000)
Ukrainian Carpathians	*Abies alba*	4.66			NO	SHPARYK and PARPAN (2004)
North-eastern France	*Abies alba*	2.75	0.58	0.05	NO	GANDOIS et al. (2010b)

Table 2. Continued

Location	Vegetation	Needles/leaves	Trunk bark	Trunk wood	Close to Ni emission source	Reference
Central Greece	*Abies borissi regis*	3.81 in current year 2.53 in current+1	0.50	0.28	NO	MICHOPOULOS et al. (2018)
Algoma District, Ontario, Canada	*Acer saccharum*	6.60	6.50	0.50	NO	MORRISON and HOGAN (1986)
Sudbury region Ontario, Canada	*Picea mariana*	Mixed needles 3.48			NO	NKONGOLO et al. (2008)
Sudbury region Ontario, Canada	*Picea mariana*	Mixed needles 17.0-21.0			YES	NKONGOLO et al. (2008)
Ukrainian Carpathians	*Quercus robur*	45.0			YES	SHPARYK and PARPAN (2004)
Maine, USA	*Populus grandidentata*	2.47			NO	MCGEE et al. (2007)
Maine, USA	*Betula papyrifera*	1.66			NO	MCGEE et al. (2007)
Maine, USA	*Acer rubrum*	0.65			NO	MCGEE et al. (2007)
Maine, USA	*Abies balsamea*	3.63 in current year			NO	MCGEE et al. (2007)
Slovakia	*Picea abies*	2.60 in current+1			NO	MANKOVSKA (1998)

Table 2. Continued

Location	Vegetation	Needles/leaves	Trunk bark	Trunk wood	Close to Ni emission source	Reference
Slovakia	*Fagus sylvatica*	3.87 3.87			NO	MANKOVSKA (1988)
Ukrainian Carpathians	*Fagus sylvatica*	8.5			NO	SHPARYK and PARPAN (2004)
NE Spain	*Arbutus unedo*	0.75-1.09			NO	SARDANS and PEÑUELAS (2007)
NE Spain	*Quercus ilex*	1.96–2.13			NO	SARDANS and PEÑUELAS (2007)
NE Spain	*Phylirea latifolia*	0.92–1.15			NO	SARDANS and PEÑUELAS (2007)

reached 73 mg kg^{-1} in the 40–80 cm. Mutsch et al. (1996) also found increasing concentrations of Ni (extracted with NH_4^+-acetate-EDTA) with soil depth in an area in the Austrian Alps having limestone as a soil parent material. The concentrations ranged from 6.0 to 30 mg kg^{-1} in forest floors and 26 to 82 mg kg^{-1} in the mineral horizons. Hernandez et al. (2003) used a mixture of HNO_3/HF/$HClO_4$ as digesting agents and found similar concentrations in forest soils derived by marl in France (53–73 mg kg^{-1}). In soils over sandstones, Ni concentrations are low. Gandois et al. (2010b) extracted heavy metals with a mixture of HF/$HClO_4$ and found a Ni range of 2.38–6.38 mg kg^{-1} in forest sandy soils the northeastern part of France. The pattern of increasing concentrations of Ni with depth is due to the geogenic origin of this metal. Together with Cr, the Ni content in soils has great dependence on the nature of parent material. In forest soils in Germany, the proportions of the variance in the Ni and Cr (extracted with aqua regia) concentrations explained by the parent rock type were 43 and 47%, respectively, whereas for Pb it was 25% (Utermann et al., 2019). The concentrations in the soils in Norway found by Nygård et al. (2012) mentioned above were so low probably because the humus horizon in that cold climate had not any clay particles containing Ni. In soils having acidic parent material, the Ni concentrations were lower. In unpolluted forest soils (podzols) in Poland, Andersen et al. (1994) using aqua regia found 6.1 and 2.1 mg kg^{-1} of Ni in the surface (O horizon) and mineral layers, respectively. A little higher value in the forest floor (average 9.2 mg kg^{-1}) was found in unpolluted forest soils in 97 sites in Latvia by Brumelis et al. (2002), who used HNO_3 for digestion. In Poland, Chrzan et al. (2013) found similar concentrations of Ni (8.0–9.5 mg kg^{-1}) extracted with HNO_3 in the surface soils of three forested stands in different distances from Krakow. When forest soils are near a metal smelter, the Ni concentrations rise abruptly. In central England, Watmough et al. (1995) found a range of HNO_3 extractable Ni of 13–112 mg kg^{-1} in the 0–10 cm soil layer. In an urban forest park near Naples in Italy in the surface mineral soils with a volcanic parent material the median Ni (extracted with a mixture of HNO_3/HF acids) concentration was 76 mg kg^{-1} and deeper (15–20 cm) 88 mg kg^{-1} (De Nicola et al., 2003). In a soil survey in the forests of the Czech Republic, Suchara and Sucharová (2002) used a mixture of HNO_3/H_2O_2 and found a range of 6.3 to 53 mg kg^{-1} of Ni in the humus layer. They argued that the highest Ni concentrations were found in the sites where the element had been most accumulated in central Bohemia near steel works. Reimann et al. (2001) found that Ni (extracted with aqua regia) had a high spread in both forest floor and C horizon in forest soils of the Arctic region in Europe. In the first case, the spread was attributed to the existence of local smelters and the in second to the different parent material.

Conclusions

The existence of Ni smelters can dramatically enhance the concentrations and fluxes of Ni in forests. In conifer needles, a large quantity of the metal can be trapped by the wax and end up on the forest floor through litterfall. When Ni is in short supply in forest species, the mechanism of translocation is applied to provide new tissues with the metal. In forest soils, Ni can be accumulated in the surface horizon. Unlike other metals (Cu and Pb), the soil pH plays a more important role than the organic matter in the metal mobilization and migration further down the soil profile.

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