TÜBİTAK

Research Article

Turk J Bot
33 (2009) 33-40
© TÜBİTAK
doi:10.3906/bot-0801-2

Nickel Hyperaccumulation in *Bornmuellera kiyakii* Aytaç & Aksoy and Associated Plants of the Brassicaceae from Kızıldağ (Derebucak, Konya-Turkey)

Roger D. REEVES[1], Nezaket ADIGÜZEL[2,*], Alan J. M. BAKER[1]

[1]School of Botany, University of Melbourne - AUSTRALIA

[2]Faculty of Arts and Science, Gazi University, Ankara - TURKEY

Received: 07.01.2008
Accepted: 09.01.2009

Abstract: Recent exploration of an area of ultramafic geology in south-western Turkey led to the discovery and description of a new species, *Bornmuellera kiyakii* Aytaç & Aksoy (Brassicaceae). This was of particular interest to us because of the earlier discovery of nickel hyperaccumulation (Ni concentrations exceeding 0.1% of plant dry weight) in 6 other taxa in this small genus from Albania, Greece, and Turkey. We report herein that *B. kiyakii* is also a Ni hyperaccumulator, based on a population near Çamlık that showed a mean Ni concentration exceeding 8000 mg kg^{-1} of dried leaf material. Several other members of the Brassicaceae at the same site–species of *Alyssum* L., *Pseudosempervivum* (Boiss.) Grossh. (formerly in *Cochlearia* L.) and Thlaspi L.–also act as Ni hyperaccumulators.

Key Words: *Bornmuellera*, nickel, hyperaccumulation

Bornmuellera kiyakii Aytaç & Aksoy Türünde Nikel Hiperakümülasyonu ve Kızıldağ'dan (Derebucak, Konya-Türkiye) Brassicaceae Familyası Bitkileri

Özet: Son yıllarda Türkiye'nin güneybatısında ultramafik bir alanda yapılan araştırmada, yeni bir tür olan *Bornmuellera kiyakii* Aytaç & Aksoy (Brassicaceae) keşfedilmiş ve tanıtılmıştır. Bu küçük cins içinde yer alan diğer altı taksonun (Arnavutluk, Yunanistan ve Türkiye'den) nikel hiperakümülasyonunun daha önce belirlenmiş olmasından dolayı, bu yeni tür özel olarak ilgimizi çekmiştir. Bu makalede, *Bornmuellera kiyakii*'nin de bir nikel hiperakümülatör olduğu; kuru yaprak materyalinde ortalama 8000 mg kg^{-1} üzerinde nikel konsantrasyonu gösteren Çamlık yakınında bir populasyonu rapor edilmektedir. Aynı alanda, Brassicaceae familyasının diğer birkaç üyesinden *Alyssum* L., *Pseudosempervivum* (Boiss.) Grossh. (daha önce *Cochlearia* L.'da) ve *Thlaspi* L.– cinslerinin türleri de nikel hiperakümülatör olarak davranmaktadır.

Anahtar Sözcükler: *Bornmuellera*, nikel, hiperakümülasyon

Introduction

The accumulation of nickel to concentrations exceeding 1000 mg kg^{-1} of dry matter by plants growing on Ni-rich serpentine soils has been found in about 360 plant species since its first discovery in *Alyssum bertolonii* Desv. in Italy (Minguzzi & Vergnano, 1948). The term hyperaccumulation was introduced, and definitions refined to describe this behaviour (Jaffré et al., 1976; Brooks et al., 1977; Reeves, 1992). Ni concentrations of 1000-10,000 mg kg^{-1} or more found in hyperaccumulating plants are about 100-fold greater than those normally found in plants on serpentine, and 1000-fold greater than those found in most plants on substrates with normal Ni concentrations.

* E-mail: adiguzel@gazi.edu.tr

More than 100 of the Ni-hyperaccumulating species are plants of the Mediterranean region and Turkey. Most of these are in *Alyssum* L. (Brooks et al., 1979) and several other genera of the Brassicaceae (Reeves & Baker, 2000; Reeves & Adıgüzel, 2004), although some examples are known from other families, such as *Centaurea* L. (Asteraceae) in Turkey (Reeves & Adıgüzel, 2004). Other Ni hyperaccumulators in the Brassicaceae of this region include the monospecific *Leptoplax emarginata* (Boiss.) O.E.Schulz (syn. *Peltaria emarginata* Boiss.) from Greece (Reeves et al., 1980), and the Turkish species *Pseudosempervivum aucheri* (Boiss.) Pobed. and *P. sempervivum* (Boiss. & Bal.) Pobed., formerly in *Cochlearia* L. (Reeves, 1988).

The small genus *Bornmuellera* Hausskn. was discussed by Greuter (1986), who recognised 3 species in Europe and 3 in Turkey. Further accounts are given in *Flora Europaea* (Tutin et al., 1964; updated by Akeroyd, 1993) and *Flora of Turkey* (Cullen, 1965). Several *Bornmuellera* species are very rare; several are known from Ni-rich ultramafic (serpentine) soils and are probably endemic to such areas. Reeves et al. (1983) reported extremely high Ni concentrations in *B. tymphaea* (Hausskn.) Hausskn. from northern Greece, in the subspecies of *B. baldaccii* (Degen) Heywood from Greece and Albania, in the sterile hybrid *B. x petri* from northern Greece, and in *B. glabrescens* (Boiss. & Bal.) Cullen & T.R.Dudley from Masmeneu Mountain (Niğde) near Kayseri in Turkey. Ni concentrations in leaf dry matter reached 31,200 mg kg^{-1} in *B. tymphaea*, 27,300 mg kg^{-1} in *B. baldaccii*, 11,400 mg kg^{-1} in *B. x petri*, and 19,200 mg kg^{-1} in *B. glabrescens.* Two of the Turkish species, *B. cappadocica* (DC.) Cullen & T.R.Dudley and *B. angustifolia* (Hausskn. & Bornm.) Cullen & T.R.Dudley, have not been found on serpentine and have only very low Ni concentrations in their leaves (Reeves et al., 1983).

In 1997 and 1998 a new species of *Bornmuellera* was discovered and collected by Z. Aytaç et al. on Kızıldağ Mountain (Konya) near Çamlık in southern Anatolia, where it was observed growing on serpentine rocks in a *Pinus nigra* Arn. forest. A full description was given by Aytaç and Aksoy (2000). From our knowledge of the behaviour of *Bornmuellera* species on serpentine elsewhere, and from our recent experience with collecting and analysing plants from Turkish serpentine (Kruckeberg et al., 1999; Reeves et al., 2001; Adıgüzel & Reeves, 2002; Reeves & Adıgüzel, 2004), it appeared very likely that the new species would also prove to be a hyperaccumulator of Ni. The aims of the present study were to test this hypothesis and to examine the Ni-uptake behaviour of other species growing in the same area.

Materials and Methods

In early June 2003 two of the authors (RDR, NA) travelled north from Manavgat and Akseki (Antalya) to Cevizli on the road towards Çamlık. The ultramafic massif of Kızıldağ ('red mountain') is visually prominent from a distance because its colour stands out from the largely limestone landscape. The study site was about 2 km before the village of Çamlık (1360 m; 37°21.86´ N, 31°40.30´ E). On grassy ground close to the foot of a hill slope we found *B. kiyakii* and several other crucifers (e.g. species of *Alyssum* and *Thlaspi*). Higher up the hill on rockier ground was *Pseudosempervivum sempervivum*. About 100 m up the rocky hill slope, which was mostly covered with open *Pinus nigra* forest, were damp places in which *B. kiyakii* was particularly abundant. In the meadow about 500 m further up the stream was *Aethionema spicatum* Post. We collected many plants from the hill slope and foot of the hill (herbarium specimens of 23 species and material for analysis).

The species listed below were collected as herbarium specimens, and for analysis when there was sufficient material (collection numbers in parentheses; 2000-series are RDR numbers; 4000-series are NA numbers). The specimens were collected for the herbaria of Gazi University, Ankara (GAZI), and for the Massey University Metallophyte Herbarium, Palmerston North, New Zealand. The latter collection, since mid-2006, has been housed at the herbarium of the Royal Botanic Garden, Edinburgh, Scotland (E).

ASTERACEAE: *Anthemis aciphylla* Boiss. var. *discoidea* Boiss. (2679, 4636); *Centaurea reuterana* Boiss. var. *phrygia* Bornm. (2680, 4637); *Leontodon crispus* Vill. subsp. *asper* (Waldst. & Kit.) Rohl. (2676, 4633); *Helichrysum pallasii* (Sprengel) Ledeb. (2681, 4638)

BRASSICACEAE: *Aethionema spicatum* Post (2687, 4644); *Alyssum mouradicum* Boiss. & Bal. (2673, 4630); *A. murale* Waldst. & Kit. subsp. *murale* var. *murale* (2688, 4645); *A. peltarioides* Boiss. subsp. *peltarioides* (2684, 4641); *Bornmuellera kiyakii* Aytaç & Aksoy (2671, 4628); *Pseudosempervivum sempervivum* (Boiss. & Bal.) Pobed. (2685, 4642); *Thlaspi elegans* Boiss. (2677, 4634)

CARYOPHYLLACEAE: *Minuartia leucocephaloides* (Bornm.) Bornm. (2689, 4646); *Petrorhagia alpina* (Habl.) Ball & Heywood (2674, 4631); *Silene spergulifolia* (Desf.) Bieb. (2686, 4643); *S. tunicoides* Boiss. (2690, 4647)

CISTACEAE: *Fumana aciphylla* Boiss. (2683, 4640)

EUPHORBIACEAE: *Euphorbia anacampseros* Boiss. var. *anacampseros* (2675, 4632); *E. petrophila* C.A.Meyer var. *petrophila* (2672, 4629)

LEGUMINOSAE: *Lathyrus nissolia* L. (2682, 4639); *Lotus aegaeus* (Gris.) Boiss. (2678, 4635)

SCROPHULARIACEAE: *Scrophularia lucida* L. (2692)

PTERIDOPHYTA: *Ceterach officinarum* DC. (2691); *Cheilanthes persica* (Bory) Kuhn (2693)

Four soil samples were taken from a depth of 0-10 cm; 2 from the *B. kiyakii* specimen collection sites, 1 from where a *Pseudosempervivum* specimen was collected, and 1 from the site of abundant *Thlaspi elegans* in a grassy area at the foot of the slope. In all, 15 samples of leaves for analysis were taken from 10 different plants of the *Bornmuellera.*

Laboratory investigation involved analysis of plant material, both from field collections made by the authors and from a herbarium specimen of *B. kiyakii* kindly provided by Dr. Aytaç. Soil samples were analysed by plasma emission spectroscopy (ICP) for about 20 elements in order to establish the general nature of the substrate. In particular, it is possible to determine the ultramafic origin of soils from the characteristic combination of high Mg, Fe, Ni, Cr, and Co concentrations, and high Mg:Ca ratio. The soil analysis procedures used in the present study have been described in more detail elsewhere (Reeves et al., 1999).

For plant analysis, leaf samples of field and herbarium specimens were washed with careful agitation in deionised water for 2 min, followed by air drying at 40 °C. In general, 0.03-0.07-g samples were weighed out for analysis. When data for a limited range of elements were sought (e.g. Ni, Co, Fe, and Zn), atomic absorption spectrophotometry was used after dry ashing for 4 h to a maximum temperature of 500 °C and dissolution of the ash in a suitable volume (usually 5.0 ml) of 2 M HCl. Some specimens were analysed using inductively coupled plasma emission spectrometry (ICP) of a more comprehensive range of 12-20 elements.

Results and Discussion

Results of the soil analyses are shown in Table 1. The soils were of typical ultramafic composition, with the expected high concentrations of Mg, Fe, and the other characteristic trace elements (Ni, Cr, and Co). Fe and Cr concentrations were not as high as are sometimes found in such soils. The soils were low in the nutrients K and P, although not as deficient in these elements as is sometimes the case. The combination of unusually high Mg and characteristic low Ca concentrations in the tested ultramafic soils resulted in a very low Ca/Mg quotient between 0.018 and 0.060 on a weight basis (mole ratio between 0.011 and 0.037). The soils contained normal concentrations of Cu and Zn.

Table 1. Total element concentrations (mg kg^{-1} or %, where indicated) and Ca/Mg quotient in serpentine soils of Kızıldağ, near Çamlık (Konya).

Site[a]	1	2	3	4
Ni	2833	2655	2404	2765
Cr	470	561	448	404
Co	177	181	123	146
Mn	1540	1615	1313	1225
Cu	21	22	30	60
Zn	109	114	124	214
P	331	532	1053	414
Fe (%)	8.99	8.72	7.28	8.30
Mg (%)	18.36	14.81	10.14	16.43
Ca (%)	0.34	0.69	0.61	0.31
K (%)	0.58	0.74	1.04	0.55
Al (%)	2.26	2.22	3.13	2.42
Ca/Mg	0.0185	0.0466	0.0602	0.0189

[a]Plants at sites. (1, 2): *Bornmuellera kiyakii*; (3): *Pseudosempervivum sempervivum*; (4): *Thlaspi elegans.*

Analysis of a specimen of *B. kiyakii* provided by the plant's discoverers showed Ni concentrations of 7410 mg kg^{-1} in leaves and 5420 mg kg^{-1} in other plant fragments (mainly stems). The results of an additional 15 analyses of the leaves from the plants collected in this work showed that the Ni concentration range was 4490-12,590 mg kg^{-1} (median: 7320 mg kg^{-1}; mean: 8490 mg kg^{-1}). Results of the analysis of various parts of *B. kiyakii* plants and of the Ni-accumulating *Thlaspi elegans* that grew nearby are shown in Table 2. *T. elegans* is well known from earlier work as a Ni hyperaccumulator (Reeves, 1988; Reeves et al., 2001; Reeves & Adıgüzel, 2004). Ni levels in *B. kiyakii* found in the present study clearly mark this species as a hyperaccumulator of Ni, with behaviour comparable to that of the other serpentine endemic species of the genus.

The results of the analysis of leaf material from a range of plants collected from the Kızıldağ site are shown in Table 3.

Since earlier work on Ni hyperaccumulation in *Bornmuellera* species, one of the authors (RDR) has made additional collections and analyses of *B. tymphaea* and *B. baldaccii* subsp. *rechingeri* from the areas of the Katara Pass and Tsouka Rossa in the Pindus Mountains of northern Greece. Current knowledge of Ni accumulation in *Bornmuellera* species is summarised in Table 4, which includes all species of the genus, except *B. dieckii* Degen, a plant known from serpentine pastures of Ostrovica Mountain, south-east of Prizren in the Kosovo province of Serbia (Stevanović et al., 2003). To the best of our knowledge this species has never been analysed, but we predict that it will prove to be another Ni hyperaccumulator.

Several other points may be made about the data in Table 3, particularly in relation to *Centaurea* and members of the Brassicaceae. A number of *Centaurea* species that occur on serpentine in Turkey hyperaccumulate Ni (Reeves et al., 2001; Reeves & Adıgüzel, 2004). This behaviour has not been observed in *C. reuterana*. In addition to the *C. reuterana* var. *phrygia* specimen from Çamlık, with a Ni concentration of 77 mg kg^{-1}, we analysed a specimen from serpentine in Antalya province (161 mg kg^{-1}) and a *C. reuterana* var. *reuterana* specimen from serpentine on Sandras Mountain, Muğla province (38 mg kg^{-1}). These values are at the upper end of the range for 'normal' plants on serpentine.

In the genus *Alyssum* only members of sect. Odontarrhena have been observed to act as Ni hyperaccumulators. *A. mouradicum*, found at Çamlık (12 mg kg^{-1}), is a member of sect. Alyssum of this genus, and is expected to have rather low Ni concentrations, even when growing in serpentine soil. Other records for this species include those of Brooks et al. (1979)–3 values for herbarium specimens ranging from < 1-12 mg of Ni kg^{-1}– and a specimen (Reeves 1983) collected from serpentine east of Hamidiye (Seyhan province) in July 1998, which had a Ni concentration of 29 mg kg^{-1}.

The case of *A. peltarioides* is particularly interesting. Brooks et al. (1979) gave 3 Ni concentration values in the range of 2-17 mg kg^{-1} for herbarium specimens of this species and stated that this appeared to be the sole non-accumulating species of sect. Odontarrhena subsect. Samarifera. Those specimens were probably collected from non-serpentinitic locations. An update by Reeves et al. (1983) reported another low Ni value for subsp. *peltarioides*, but Ni hyperaccumulation by subsp. *virgatiforme* (Nyár.) T.R.Dudley (values of 5300 and 7600 mg kg^{-1} for specimens from serpentine in Erzurum and Burdur provinces). From our own recent collection and analysis of plants from serpentine locations, we can now add the following:

Table 2. Elemental analysis of various parts of *Bornmuellera kiyakii* and *Thlaspi elegans* from Kızıldağ near Çamlık (all concentrations in mg kg^{-1} of dry matter).

Sample	Ni	Co	Zn	Fe
B. kiyakii				
leaves (16)	4490-12,590	3.6-25.3	8-53	39-408
fruit/stem (3)	3510-5020	4.0-6.0	14-35	61-100
T. elegans				
rosette leaves (2)	8960-13,340	8.1-12.9	59-154	591-1110
stem leaves	17,380	11.9	96	1140
fruit/stem	7920	1.3	30	82

Table 3. Element concentrations in the leaves of plants collected from serpentine in Kızıldağ (Çamlık, Konya). Data refer to individual plants with RDR collection numbers cited in the text.

Family and Species	Element Concentrations (mg kg^{-1} or %, where shown)										
	Ni	Ca (%)	Mg (%)	K (%)	Co	Cr	Cu	Fe	Mn	P	Zn
ASTERACEAE											
Anthemis aciphylla var. *discoidea*	62	1.10	0.39	0.93	3.8	4.7	1.8	1320	91	1940	21
Centaurea reuterana var. *phrygia*	77	3.97	0.45	1.52	3.1	3.4	2.7	1040	61	658	14
Helichrysum pallasii	14	0.37	0.38	1.34	0.3	0.8	13.8	241	18	2670	27
Leontodon crispus subsp. *asper* var. *asper*	45	1.47	1.18	2.48	0.6	1.3	5.6	303	34	2340	22
BRASSICACEAE											
Alyssum mouradicum	12	3.82	0.39	0.25	0.7	0.9	0.5	281	22	775	3
A. murale subsp. *murale* var. *murale*	7890	2.90	1.05	0.49	5.8	2.0	1.3	371	16	1710	10
A. peltarioides subsp. *peltarioides*	19270	2.58	0.91	1.31	9.6	1.7	2.1	451	43	2380	30
Bornmuellera kiyakii	9020	1.84	1.56	0.94	4.1	1.7	1.6	408	52	1740	26
Pseudosempervivum sempervivum	30030	1.81	0.45	1.90	8.5	1.3	4.6	98	43	1580	113
Thlaspi elegans	13340	1.00	0.28	0.47	8.1	3.4	1.8	1110	35	862	59
CARYOPHYLLACEAE											
Minuartia leucocephaloides	5	0.30	0.49	1.17	0.3	0.5	1.6	96	68	1170	15
CISTACEAE											
Fumana aciphylla	6	0.65	0.44	0.62	0.1	0.4	3.5	97	39	2130	43
EUPHORBIACEAE											
Euphorbia anacampseros var. *anacampseros*	101	1.25	0.71	1.93	3.1	0.8	3.7	189	34	1030	28
E. petrophila var. *petrophila*	37	0.75	0.43	0.96	1.1	0.4	3.8	56	22	2200	24
LEGUMINOSAE											
Lotus aegaeus	37	0.84	0.95	0.77	1.4	2.3	2.0	682	17	2340	15
SCROPHULARIACEAE											
Scrophularia lucida	7	1.05	0.66	1.32	0.1	0.7	2.5	270	14	712	11
PTERIDOPHYTA											
Ceterach officinarum	32	0.40	0.32	1.05	0.6	1.5	2.4	712	24	2500	31
Cheilanthes persica	19	0.11	0.13	0.93	0.1	0.5	1.3	101	10	2120	23

Table 4. Ni concentrations in the leaves of *Bornmuellera* species (ranges in mg kg^{-1}) and number of samples (n). Data from this work, Reeves et al. (1983), and additional unpublished analyses from collections by R.D. Reeves in Greece in 2002.

Species	Location	Ni	n
B. angustifolia	Turkey (Erzincan)	33-57	2
B. baldaccii			
subsp. *baldaccii*	N Greece (Mt. Smolikas, Pindus Mts.)	6670-21,300	6
subsp. *markgrafii*	SE Albania (Kamja)	27,300	1
subsp. *rechingeri*	N Greece (Pindus Mts.)	6480-18,200	5
B. cappadocica	Turkey (Van, Bitlis, Gümüşhane)	< 2-48	5
B. glabrescens	Turkey (Niğde)	14,800-19,200	3
B. kiyakii	Turkey (Konya: Çamlık)	4490-12,590	16
B. x petri	N Greece (Pindus Mts.)	3420-11,400	2
B. tymphaea	N Greece (Pindus Mts.)	1590-31,200	11

A. peltarioides subsp. *peltarioides*: (i) Konya province, Çamlık (Reeves 2684) (Table 3): 19,270 mg kg^{-1}; (ii) Erzincan province, 25 km east of Refahiye, near Sakaltutan Pass (Reeves 2281): 3810 mg kg^{-1}.

A. peltarioides subsp. *virgatiforme*: (i) Tunceli province, 1.5 km S of Pülümür Pass (Reeves 2225): 34,690 mg kg^{-1}; (ii) Erzincan province, 27 km west of Refahiye (Reeves 2298): 3130 mg kg^{-1} ; (iii) Erzincan province, 27 km west of Refahiye, road to Kayınboğazı (Reeves 2302): 12,140 mg kg^{-1}.

It is therefore now clear that both taxa are Ni hyperaccumulators on serpentine, but that subsp. *peltarioides* is also found on a wider variety of substrates, with low Ni concentrations in both soils and plants.

A. murale, found at Çamlık (7890 mg kg^{-1}), requires little additional explanation, as the majority of its occurrences, from the Balkans to the Caucasus, appear to be in serpentine soils, from which it reliably accumulates Ni to levels over 1000 mg kg^{-1}, as it has been recorded in many places during the last 50 years (Doksopulo, 1961; Brooks & Radford, 1978; Reeves et al., 2001).

Hyperaccumulation of Ni was reported in 2 Turkish species of *Cochlearia–C. aucheri* and *C. sempervivum*–by Reeves (1988). These species, now among those transferred to the genus *Pseudosempervivum*, have been recorded from many serpentine sites in Turkey by Reeves and Adıgüzel between 1998 and 2003. These species often contain Ni at concentrations exceeding 1%, and the values of more than 3% for specimens of *P. sempervivum* from Çamlık (Table 3) and from Hazar in Elazığ province (noted below) are among the highest recorded for any plants on serpentine in Turkey. Other recent analyses of these species include:

P. sempervivum: (i) Seyhan, E of Hamidiye (Reeves 1987): 8360 mg kg^{-1}; (ii) Niğde, Pozantı-Çamardı (Reeves 2004B, 2009A): 10,320 mg kg^{-1} and 12,540 mg kg^{-1}; (iii) Elazığ, 5 km west of Hazar (Reeves 2217): 34,130 mg kg^{-1} (mature leaves), 5080 mg kg^{-1} (rosette leaves); (iv) Kayseri, Pınarbaşı-Pazarören (Reeves 2306): 2210 mg kg^{-1}; (v) Kayseri, Pınarbaşı-Sarız (Reeves 2314): 2510 and 3220 mg kg^{-1}.

P. aucheri: (i) Tunceli, 1.5 km south of Pülümür Pass (Reeves 2224): 3030 mg kg^{-1}; (ii) Tunceli, Pülümür Pass (Reeves 2242): 14,210 mg kg^{-1}; (iii) Erzincan, Kurutelek-Karataş (Reeves 2260): 14,870 and 19,080 mg kg^{-1}; (iv) Erzincan, 25 km east of Refahiye (Reeves 2272): 21,550 mg kg^{-1}; (v) Erzincan, 19 km west of Refahiye (Reeves 2291): 9560 and 10,990 mg kg^{-1}; (vi) Erzincan, 25 km west of Refahiye (Reeves 2297): 14,720 mg kg^{-1}.

In the light of these data, we could also predict that the species described by Contandriopoulos and Quézel from the Amanus mountains as *Cochlearia amana* Contrandr. & Quézel (Contandriopoulos J & Quézel P, 1976) and now reclassified as *Pseudosempervivum amanum* (Contrandr. & Quézel) Al-Shehbaz, Mutlu & Dönmez (Al-Shehbaz et al., 2007) is also likely to prove to be a hyperaccumulator of Ni.

The Ni data for *Thlaspi elegans* from Çamlık (Tables 2 and 3) are consistent with those reported for this species from other Turkish serpentine sites. Ni concentrations of 8800-20,800 mg kg^{-1} were reported by Reeves (1988) from the analysis of 5 herbarium specimens, and Ni concentrations of 9220-16,740 mg kg^{-1} were given for samples from İçel province, 5 km south of Fındıkpınarı (Reeves et al., 2001). A specimen (Reeves 1995) from near Gerdibi, Seyhan province, contained a Ni concentration 10,810 mg kg^{-1}. It appears that *T. elegans*, together with several other Turkish species in this genus noted by Reeves (1988), can be classified as a serpentine-endemic Ni hyperaccumulators. Accumulation of Ni in European species of *Thlaspi* was reported by Reeves and Brooks (1983).

Aethionema spicatum occurs on serpentine in Turkey, and high-Ni specimens have been recorded (Reeves et al., 2001) from the Hamidiye-Gerdibi region of Seyhan province (the specimens Reeves 1986 and 1988 had Ni concentrations of 764 mg kg^{-1} and 1111 mg kg^{-1}, respectively); therefore, this species can be regarded as marginally Ni hyperaccumulating. There was insufficient material for analysis of the specimen collected at Çamlık, but any future work there should include additional collection and analysis of this species. This little-known species may prove to be endemic to scattered serpentine localities in Turkey and northern Syria.

The Cr levels in the plant specimens from Çamlık were all below 5 mg kg^{-1}, indicating that soil contamination of the plant material was extremely unlikely: suspicion of contamination only arises when Cr levels are > 15 mg kg^{-1}, especially when accompanied by high Fe (> 1500 mg kg^{-1}), high Ni, and high Co. Levels of Co in the Ni hyperaccumulator plants from Çamlık were higher than in the other plants, but the Ni hyperaccumulators showed a remarkable selectivity for Ni over Co. For total element concentrations in soils the Ni/Co quotient was in the range

of 14-20 (Table 1), but Ni/Co in the Ni hyperaccumulator plants was in the range of 1300-3600.

As is usual on serpentine, the Ca/Mg quotients of all the plants analysed (Table 3) covered a wide range, from 0.6 to almost 10; however, the median of 1.67 is typical of plants of a serpentine flora, and is considerably lower than that observed in plants growing in non-serpentine soils (median Ca/Mg usually 5-10). The highest Ca concentrations were in the species of *Alyssum* and *Centaurea*; the ability of *Alyssum* species to accumulate Ca to very high concentrations, even from Ca-deficient serpentine soils, has been reported elsewhere (Reeves et al., 1997).

Interest is increasing in the potential practical applications of metal hyperaccumulation (Angle et al., 2001). Uses for plants that are reliable Ni hyperaccumulators include the following: (i) Locating, defining, or delimiting the extent of ultramafic soils; (ii) Remediation of soils contaminated by Ni from smelting and related activities; (iii) Phytomining, in which a hyperaccumulator can be developed as an agronomic crop plant, whose ash can be used to enrich Ni smelter feedstocks. There exist in Turkey several species with good biomass production, combined with strong Ni uptake (to levels exceeding 1% in dry matter and 10%-15% in ash), which therefore have potential for use in the last 2 applications listed. These include *Alyssum murale* and *A. corsicum* Duby, *Centaurea ptosimopappa* Hayek, and *C. ensiformis* P.H.Davis.

Certain areas of ultramafic soil in Turkey, such as the one visited for the present study near the boundary of Konya and Antalya provinces, have been floristically studied in less detail than many others, at least until recently, and deserve much more attention. The Çamlık site of Kızıldağ is especially remarkable because it is possible to see representatives of all the genera in the Brassicaceae that exhibit hyperaccumulation in Turkey (*Aethionema*, *Alyssum*, *Bornmuellera, Pseudosempervivum*, and *Thlaspi*) growing together in a very small area (about 1 ha). The entire mountain requires additional close study during several seasons of the year.

It seems certain that more serpentine endemic species remain to be discovered in Turkey (whether Ni accumulators or not). Further exploration of some of the lesser known serpentine areas should be conducted before there is any further habitat modification for agriculture, forestry, conventional mining, urban development, or other activities. Furthermore, it is essential that the exact distribution of *B. kiyakii* and other rare Turkish Ni hyperaccumulators, including *B. glabrescens*, should be fully documented, to allow appropriate decisions to be made regarding their conservation, whether or not their Ni-accumulating properties prove to be suitable for exploitation. In the meantime, we note that Aytaç & Aksoy (2000) recommended that *B. kiyakii* be graded as LR(cd) in the IUCN nomenclature (1994). Because this species is presently only known from one locality and as a small population, we recommend that its IUCN category be transferred to CR (2001).

Acknowledgements

The authors thank Dr. Z. Aytaç for providing information about the locality of the population of *Bornmuellera kiyakii* studied, and for providing material from his own collection for analysis. Assistance with some of the ICP analysis was kindly provided by Augustine Doronila.

References

Adıgüzel N & Reeves RD (2002). A new nickel-accumulating species of *Alyssum* (Cruciferae) from western Turkey. *Edinburgh J Bot* 59: 215-219.

Akeroyd JR (1993). *Bornmuellera* Hausskn. In: Tutin TG et al. (eds.), *Flora Europaea*, 2nd ed., Vol. 1, p. 52. Cambridge: Cambridge Univ. Press.

Al-Shehbaz IA, Mutlu B & Dönmez AA (2007). The Brassicaceae (Cruciferae) of Turkey, updated. *Turk J Bot* 31: 327-336.

Angle JS, Chaney RL, Baker AJM., Li Y, Reeves RD, Volk V, Roseberg R, Brewer E, Burke S & Nelkin J (2001). Developing commercial phytoextraction technologies: practical considerations. *S Afr J Sci* 97: 619-623.

Aytaç Z & Aksoy A (2000). A new species of *Bornmuellera* Hausskn. from south Anatolia, Turkey. *Bot J Linn Soc* 134: 485-490.

Brooks RR & Radford CC (1978). Nickel accumulation by European species of the genus *Alyssum*. *Proc Roy Soc Lond* B200: 217-224.

Brooks RR, Lee J, Reeves RD & Jaffré T (1977). Detection of nickeliferous rocks by analysis of herbarium specimens of indicator plants. *J Geochem Explor* 7: 49-57.

Brooks RR, Morrison RS, Reeves RD, Dudley TR & Akman Y (1979). Hyperaccumulation of nickel by *Alyssum* Linnaeus (Cruciferae). *Proc Roy Soc Lond* B203: 387-403.

Contandriopoulos J & Quézel P (1976). Contribution à l'étude de la flore du Taurus et de l'Amanus. *Bull Soc Bot Fr* 123: 415-432.

Cullen J (1965). *Bornmuellera* Hausskn. In: Davis PH (ed.), *Flora of Turkey*, Vol. 1, Edinburgh Univ. Press, Edinburgh, pp. 358-359.

Doksopulo EP (1961). Nickel in rocks, water and plants adjacent to the talc deposits of the Chorchanskaya group. Izdatel Tbiliskovo Unversitet, Tbilisi.

Greuter W (1986). Some notes on *Bornmuellera* in Greece, and an interspecific hybrid in the *Alysseae (Cruciferae)*. *Candollea* 30: 13-20.

IUCN (1994). *Red List Categories*. Gland, Switzerland: IUCN Species Survival Commission.

IUCN (2001). *IUCN Red List Categories*. *Version 3.1*. IUCN Species Survival Commission. Gland, Switzerland and Cambridge, UK.

Jaffré T, Brooks RR, Lee J & Reeves RD (1976). *Sebertia acuminate*, a hyperaccumulator of nickel from New Caledonia. *Science* 193: 579-580.

Kruckeberg AR, Adıgüzel N & Reeves RD (1999). Glimpses of the flora and ecology of Turkish (Anatolian) serpentines. *Karaca Arbor Mag* 5: 67-86.

Minguzzi C & Vergnano O (1948). Il contenuto di nichel nelle ceneri di *Alyssum bertolonii* Desv. *Atti Soc Tosc Sci Nat, Mem Ser A* 55: 49-77.

Reeves RD (1988). Nickel and zinc accumulation by species of *Thlaspi* L., *Cochlearia* L. and other genera of the Brassicaceae. *Taxon* 37: 309-318.

Reeves RD (1992). Hyperaccumulation of nickel by serpentine plants. In: Proctor J, Baker AJM & Reeves RD (eds.) *The Vegetation of Ultramafic (Serpentine) Soils*, pp. 253-277. Andover, UK: Intercept Ltd.

Reeves RD & Adıgüzel N (2004). Rare plants and nickel accumulators from Turkish serpentine soils, with special reference to *Centaurea* species. *Turk J Bot* 28: 147-153.

Reeves RD & Baker AJM (2000). Metal accumulating plants. In: Raskin I & Ensley B (eds.), *Phytoremediation of Toxic Metals: Using Plants to Clean Up the Environment*, pp. 193-229. New York: John Wiley and Sons.

Reeves RD & Brooks RR (1983). European species of *Thlaspi* L. (Cruciferae) as indicators of nickel and zinc. *Journal of Geochemical Exploration* 18: 275-283.

Reeves RD, Brooks RR & Press JR. (1980). Nickel accumulation by species of *Peltaria* Jacq. (Cruciferae). *Taxon* 29: 629-633.

Reeves RD, Brooks RR & Dudley TR (1983). Uptake of nickel by species of *Alyssum, Bornmuellera* and other genera of Old World Tribus Alysseae. *Taxon* 32: 184-192.

Reeves RD, Baker AJM & Kelepertsis A (1997). The distribution and biogeochemistry of some serpentine plants of Greece. In: Jaffré T, Reeves RD & Becquer T (eds.), *Écologie des milieux sur roches ultramafiques et sur sols métallifères*. Documents Scientifiques et Techniques No. III/2, ORSTOM, Nouméa. pp. 205-207.

Reeves RD, Baker AJM, Borhidi A & Berazaín R (1999). Nickel hyperaccumulation in the serpentine flora of Cuba. *Ann Bot* 83: 29-38.

Reeves RD, Kruckeberg AR, Adıgüzel N & Krämer U (2001). Studies on the flora of serpentine and other metalliferous areas of western Turkey. *S Afr J Sci* 97: 513-517.

Stevanović V, Kit Tan & Iatrou G (2003). Distribution of the endemic Balkan flora on serpentine. I. Obligate serpentine endemics. *Plant Syst Evol* 242: 149-170.

Tutin TG, Heywood VH, Burges NA, Valentine DH, Walters SM & Webb DA (1964). *Flora Europaea*, Vol. 1, pp. 306-307. Cambridge: Cambridge Univ. Press.