

Effects of applying deicing salt to roads in protected areas of the Bohemian Forest region[†]

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Abstract

The effects of deicing salt have been studied with the same monitoring methods in three protected areas of the Bohemian Forest. More than ten years monitoring data set from the Šumava National Park and the Šumava Protected Landscape Area (since 2003) together with repeated monitoring conducted in the Bavarian Forest National Park (in 2011, 2012, and 2015) offer an unique opportunity for studying long-term trends and different sensitivities of various habitats occurring in the Bohemian Forest region. The same methodology for monitoring the effect of deicing salt is applied both in the Bavarian Forest NP (9 permanent sites) and the Šumava NP & PLA (12 permanent sites). Soil conditions have been recorded and samples of soil are collected at the study sites annually. The mixed soil samples for each site are analysed by the certified laboratory. Two five-meter long transects for phytoindication run parallel with the road at each site. The first one is located just at the edge of the asphalt road surface and the second one meter from the road edge. Transects are characterised by the percentages of halophytes, sub-halophytes and glycophytes. More statistical analyses are necessary; however, preliminary results have already shown growing concentrations of chlorides and high proportions of halophytic species (>60%) in some locations. The long-term monitoring using a proven methodology was found to be a very important tool for better understanding of the ecological impacts of road salting on surrounding ecosystems in the Bohemian Forest, the area of high conservation value.

Key words: road salting, halophytes, national park, ecosystem monitoring

INTRODUCTION

The negative effects of applying of deicing salts to ecosystems are well known and documented for many countries, both in urban and natural areas (FINDLAY & KELLY 2011). In cold regions, deicing salts applied to roads are a major contributor to local and regional contamination, while salts from water softeners and septic systems are less important. There is emerging evidence that simple salt (NaCl), the most often used deicing salt, contrary to what was previously thought is not transported rapidly through the soil and groundwater. This can

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affect the living conditions of water organisms, especially their most sensitive developmental stages. Several studies documented the negative cumulative effects on amphibians breeding in vernal pools near roads (KARRAKER et al. 2008). High concentrations of salt affect competition and predation and, also cause significant changes in plant composition (i.e. ANGOLD 1997, RICHBURG et al. 2001, WROBEL et al. 2006) and soil invertebrate communities (RUSEK & RUSEK 1999).

The effects of NaCl can be summarized as follows: (i) soil liquids (with Na⁺) on the leaves of plants reduce assimilation, dehydrate and irreversibly destroy plant tissues resulting in the leaves/needles turning yellow; (ii) the increasing concentration of ions (Na⁺, Cl⁻) in soil stresses plants by making more difficult for them to take up and transport water by osmosis and transpiration; (iii) changes in species composition – local gaps in vegetation cover, later also an increase in halophytes and sub-halophytes, which produce many seeds and invade neighbouring plant communities; in forests the killing of trees can decrease the stability of the forest; (iv) species diversity of soil microorganisms is affected; and (v) contamination of waterbodies has a negative effect on amphibians, pearl muscles etc.

In some countries, e.g. the Czech Republic, the application of deicing salts to roads in large protected areas is prohibited by the law. The Šumava National Park (Šumava NP) and the Šumava Protected Landscape Area (Šumava PLA), which plays a role of a buffer zone of the Šumava NP, are the largest protected areas in the Czech Republic with high conservation value (KŘENOVÁ & HRUŠKA 2012, KŘENOVÁ & KINDLMANN 2015). There are special exceptions for several main roads, where deicing salts can be applied but only when particular conditions prevail. The monitoring of the effects of deicing salt on ecosystems in the Šumava NP & PLA was started in 2003 and data are recorded annually.

No legislation regulations of applying of deicing salt are implemented in Bavaria. A main road (Nationaparkstrasse) in the eastern part of the Bavarian Forest National Park (Bavarian Forest NP) and several other bigger roads are regularly cleaned by salt.

The main aims of monitoring projects conducted in this area were similar: (1) To survey the ecological conditions along the main roads in protected areas (the Šumava NP & PLA, the Bavarian Forest NP) and identify suitable study sites for monitoring the effects of deicing salt. (2) To establish the permanent study sites. (3) To test the methodology and make the first analyses of the vegetation, soil structure and soil chemistry. (4) To repeat the monitoring during several years and learn more about seasonal variability and trends in effect of deicing salt.

MATERIALS AND METHODS

Project duration

The monitoring of the effects of deicing salt on ecosystems in the Šumava NP and PLA started in 2003, but the first monitoring was carried out already in the 1990s (PYŠEK & ZÝVAL 1993, ZÝVAL & PYŠEK 1999a–c). Data are recorded annually.

There has been only little detailed information on the effects of deicing salts on ecosystems in the Bavarian Forest NP till 2011, when the first preliminary study was carried out (KŘENOVÁ 2011). The monitoring was repeated in 2012 (KŘENOVÁ 2012) and 2015 (ZÝVAL et al. 2015).

Site and method description

In the Šumava NP & PLA the effect of deicing are annually studied since 2003. Six permanent sites were established in locations where special exceptions agreed by the Šumava NP Authority have allowed applying of deicing salts (Table 1). Two permanent sites were estab-

lished in locations where deicing salts have been allowed only in high risk of icy road. The last permanent site was established in the location, where deicing salt has not been allowed at all. In this location, the road no. I/39 is passing through the Velká Niva nature reserve, where sensitive peat and marshland habitats are protected. Only gravel can be used to maintain two kilometres long section of this road. Three more sites (Table 1) have been established in 2012–2014 to learn more about the effect of deicing salt on the state border (site BD, monitored since 2012), in a small river above the location of very rare pearl mussel (*Margaritifera margaritifera*; site BL, since 2013) and in a stream, which is going to be renaturalised soon (site UH, since 2014). All sites were provided with blue permanent markers, photographed and have their GPS positions recorded.

In Bavaria the first survey of the study area was done during the summer of 2011. After a discussion with the Bavarian Forest NP Authority, the Nationalparkstrasse road and two others running perpendicularly from it towards Waldhäuser and Racheldienesthütte in the eastern part of the Bavarian Forest NP were chosen for this project. Nine permanent study sites (Table 1) were established in this study area, seven of which were located along roads, where deicing salts are regularly applied (the main road Nationalparkstrasse and the road to Waldhäuser). Two of the study sites were along roads that were not salted and they were used as control sites. Also these sites were provided with blue permanent markers, photographed, and have their GPS positions recorded.

The same methodology for monitoring the effect of deicing salt is applied both in the Bavarian Forest NP and the Šumava NP & PLA.

Soil, snow, and water sampling and analyses

Soil structure and horizons were recorded at all the study sites at distances of 5 and 10 meters from the road edge. Samples of soil are collected from the upper (0 m to -0.1 m) and lower soil layers (> -0.1 m) at four sample points and then samples from each soil horizon mixed for each site.

The mixed soil samples for each site are analysed by the certified laboratory in Klatovy (The Health Institute Pilsen, Laboratory Klatovy). The following parameters are measured: $\text{pH}_{\text{H}_2\text{O}}$, Na^+ , Cl^- , SO_4^{2-} , conductivity (after water extraction); pH_{KCl} (after KCl extraction); and Ca^{2+} , Mg^{2+} , K^+ , Na^+ (after Mehlich 2 extraction).

If possible also snow samples are collected with a standard snow tube, 10 cm in diameter in distances 5 m and 10 m from the road edge. Also snow depth is measured in all sampled sites. The snow samples are melted and pH, Eh, and conductivity are measured. Later the samples are sent for chemical analyses, which are done again by the certified laboratory in Klatovy (The Health Institute Pilsen, Laboratory Klatovy). The following parameters are measured: Na^+ , Ca^{2+} , Mg^{2+} , K^+ , Cl^- , NO_3^- conductivity, and $\text{pH}_{\text{H}_2\text{O}}$.

Twenty new dataloggers were installed in summer 2015 to improve monitoring of impact of deicing salt on water environment. The dataloggers were installed in streams crossed by the roads maintained by the salt and they can continuously measure water level, temperature and conductivity.

Vegetation

Five-meter long transects were laid out at each site in order to identify the plants occurring there. These transects run parallel with the road: the first one is located just at the edge of the asphalt road surface and the second one meter from the road edge. In addition, if necessary, another transect has been established to record the vegetation at a distance five meters from the road edge.

The standard method, based on five levels of abundance for each species (BRAUN-BLAN-

Table 1. The study sites and their geographical characteristics.

Site code	Name	GPS	Altitude (m a.s.l.)	Road nr.	Road maintenance	Since
Šumava NP & PLA						
AR	Arnoštka	N 49 00.069 E 13 46.098	917	I/4	salt	2003
BL	Blanice	N 48 57.024 E 13 56.594	754	II/141	salt but only in ice cond.	2003
CH	Chlum	N 48 51.554 E 13 55.384	740	I/39	salt but only in ice cond.	2003
KH	Kubova Hut'	N 48 58.150 E 13 45.661	915	I/4	salt	2003
KS	Kúsov	N 49 04.919 E 13 38.407	872	III/14514	salt	2003
SM	Soumarský Most	N 48 54.666 E 13 50.141	772	I/39	salt	2003
ST	Strážný	N 48 54.532 E 13 44.006	830	I/4	salt	2003
VL	Valná	N 48 53.369 E 13 43.205	820	I/4	salt	2003
VN	Velká Niva	N 48 55.261 E 13 49.018	762	I/39	no salt, only gravel	2003
BD	Celnice	N 48 53.180 E 13 42.470	876	I/4	salt	2012
BZ	Blažejovice	N 48 57.335 E 13 57.137	763	II/141	salt but only in ice cond.	2013
UH	Uhlíkovský Potok	N 48 49.852 E 13 57.338	738	I/39	salt	2014
Bavarian Forest NP						
S1	Mauth–main road	N 48 53.118 E 13 34.522	772		salt	2011
S2	Mauth–control	N 48 53.218 E 13 34.551	773		no salt	2011
S3	Racheldiensthütte	N 48 55.401 E 13 24.644	773		no salt	2011
S4	Grosse Ohe–west	N 48 55.416 E 13 24.862	765		salt	2011
S5	Grosse Ohe–east	N 48 55.406 E 13 24.817	764		salt	2011
S6	Waldhäuser	N 48 56.237 E 13 27.288	847		salt	2011
S7	Grosse Filz	N 48 55.338 E 13 25.210	777		salt	2011
S8	Guglöd	N 48 55.388 E 13 25.106	769		salt	2011
S9	Atschöna	N 48 54.664 E 13 27.977	748		salt	2011

QUET 1951), is used for the transects. Also percentage cover of mosses, herbaceous plants, shrubs, and trees are recorded along all transects. Floristic terminology follows KUBÁT et al. 2002. The species occurrences and their salt-tolerance are studied.

Three categories of species are distinguished (ELLENBERG et al. 1992): halophytes – species that tolerate and thrive on substrates with a high salinity; sub-halophytes – species that can tolerate moderate salinity but not a high salinity; and glycophytes – species that are easily damaged by saline conditions. Transects are characterised by the percentages of halophytes, sub-halophytes, and glycophytes. Necrosis, leaf senescence, and other forms of damage are recorded too.

RESEARCH OUTPUTS

The project reports with results of monitoring are annually delivered to the Šumava NP Authority and the official regional authority responsible for maintaining the roads (ZÝVAL & CHOCHOLOUŠKOVÁ 2003–2005, ZÝVAL & CHOCHOLOUŠKOVÁ 2006a,b–2008a,b, ZÝVAL et al. 2009a,b–2014a,b). The reports from the monitoring projects conducted in the Bavarian Forest NP have been delivered to the National Park Authority (KŘENOVÁ 2011, 2012, ZÝVAL et al. 2015).

Only the results of the pilot project conducted in the Bavarian Forest NP already have been published (KŘENOVÁ et al. 2012). We found that some parts of the study area are strongly affected due to long term applying of deicing salt. Significant differences in the concentrations of Cl^- and Na^+ ions among different study sites were recorded. The highest concentrations of both ions were measured in samples from site S4 – Grosse Ohe west. Especially samples, which were collected at a distance of ten meters from the road edge, showed high concentrations of ions. The same trends were recorded also using the Mehlich 2 Na^+ testing method. Also results of the vegetation survey showed that high numbers of halophytes and sub-halophytes occurred near the Grosse Ohe stream and also several other sites have very high proportion of halophytes (Fig. 1).

All other data from monitoring projects remain unpublished up to date. Preliminary results of ten-year monitoring in the Šumava NP & PLA have been presented at several conferences and also popularised in the Šumava journal (KŘENOVÁ et al. 2015). With preliminary results, not yet published, we can summarise that the studied sites differ in environmental conditions and their answers to applying of deicing salt. However the main trends in growing amount of Cl^- ions in soil samples (Fig. 2) and increasing proportions of halophytes (Fig. 3) are common for most of the studied sites in the Šumava NP & PLA, despite the fact that winters of the last decade have been rather mild. Growing concentrations of chlorides were recorded also at the permanent site VN, where applying of salt has not been allowed by the Šumava NP authority. Nevertheless, there is a high risk that the salt can affect this section surrounded by sensitive wetlands. Salt is probably imported on car tires from salted parts of the road or sometimes the road managers may forget about the regulation.

CONCLUSIONS

The effects of deicing salt have been studied with the same monitoring methods in three protected areas of the Bohemian Forest. More than ten years monitoring data set from the Czech Republic (Šumava NP & PLA, since 2003) together with repeated monitoring conducted in Bavaria (Bavarian Forest NP, in 2011, 2012, 2015) offer an unique opportunity for studying long-term trends and different sensitivities of various habitats occurring in the Bohemian Forest region. More statistical analyses are necessary; however, preliminary re-

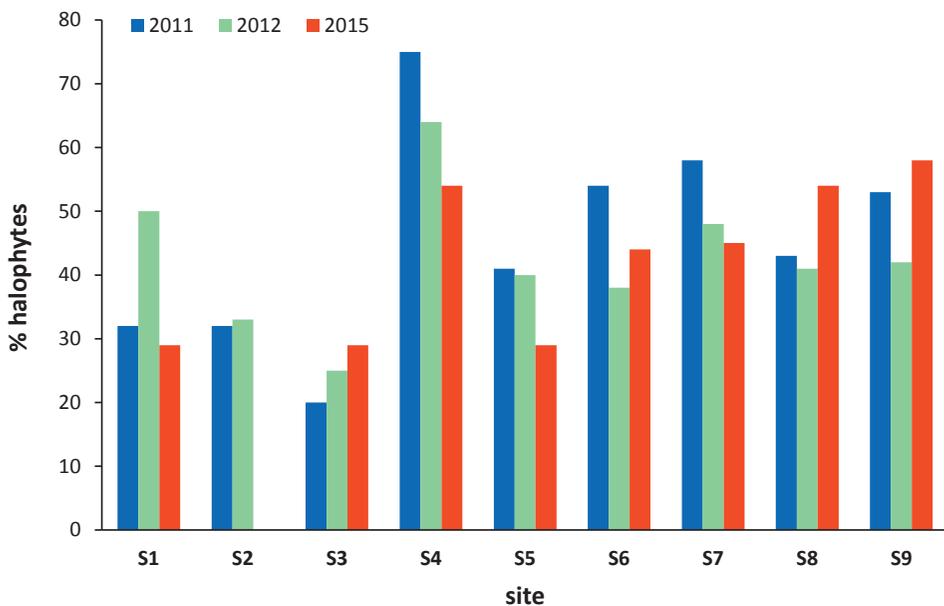


Fig. 1. Percentages of halophytes recorded in transects at the edges of the roads in the Bavarian Forest NP.

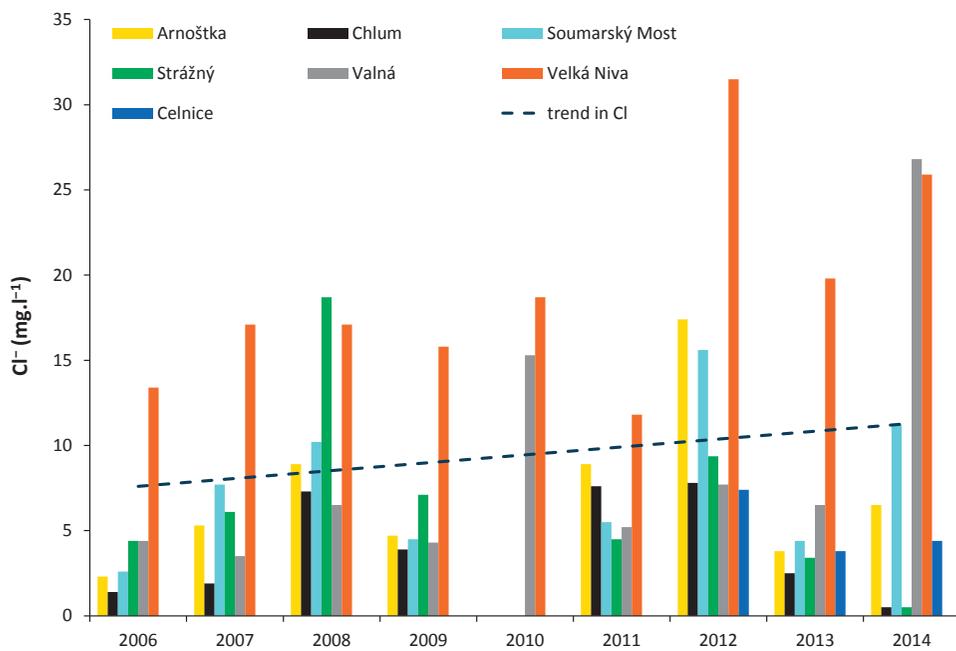


Fig. 2. Concentrations of Cl^- ions recorded in soil samples in the Šumava NP & PLA in the years 2003–2014.

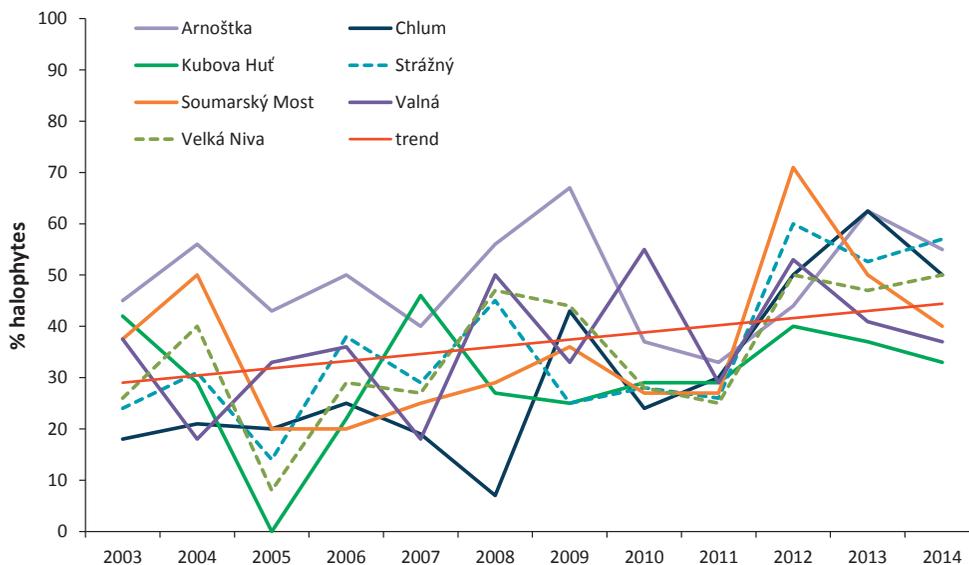


Fig. 3. Percentages of halophytes recorded in transects at the edges of the roads in the Šumava NP & PLA.

sults already show growing concentrations of chlorides and high proportions of halophytic species in some locations. Also more detail information about annual differences in weather conditions and amount of deicing salt applied in different locations (not only a total amount of salt for a whole road) could help to interpret our data.

We believe that the long-term monitoring using a proven methodology is a very important tool for better understanding of the ecological impacts of road salting on surrounding ecosystems in the Bohemian Forest, the area of high conservation value. The transboundary cooperation can offer excellent opportunity to learn more about impacts of different technologies used for the road maintenance in two neighbouring countries.

The results of the project also offer important arguments in the debate about recently started novelization of the Czech Nature Conservation Act, in which maintenance of class I roads passing through the national parks without any regulations has been proposed. Our results show that impacts of deicing salt in some sensitive habitats can be significant.

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REFERENCES

- ANGOLD P.G., 1997: The impact of a road upon adjacent heathland vegetation: effects on plant species composition. *Journal of Applied Ecology*, 34: 409–417.
- BRAUN-BLANQUET J., 1951: *Pflanzensoziologie. Grundzüge der Vegetationskunde*. 2. Aufl. Springer-Verlag, Wien, 631 pp.
- ELLENBERG H., WEBER H.E., DULL R., WIRTH V., WERNER W. & PAULISSEN D., 1991: Zeigerwerte von Pflanzen in Mitteleuropa. *Scripta Geobotanica*, 18: 1–248.

- FINDLAY S.E.G. & KELLY V.R., 2011: Emerging indirect and long-term road salt effects on ecosystems. *Annals of the New York Academy of Sciences*, 1223: 58–68
- HORKÝ J., SOUKUP J. & DNEBORSKÝ L., 1980: Problematika zimního solení komunikací ve vztahu k zelení a technologie zimní údržby komunikací [Challenges of winter salting of roads in relation to green technologies and winter road maintenance]. *Ochrana a tvorba životního prostředí*, 2: 7–87 (in Czech).
- KARRAKER N.E., JAMES P.G. & JAMES R.V., 2008: Impacts of road deicing salt on the demography of vernal pool-breeding amphibians. *Ecological Application*, 18:724–734.
- KŘENOVÁ Z., 2011: Effects of deicing salts in the Bavarian Forest National Park. Ms., project report, 42 pp. (deposited in the Bavarian Forest NP Authority, Grafenau)
- KŘENOVÁ Z., 2012: Effects of deicing salts in the Bavarian Forest National Park. Ms., project report, 40 pp. (deposited in the Bavarian Forest NP Authority, Grafenau)
- KŘENOVÁ Z., CHOCHOLOUŠKOVÁ Z. & ZÝVAL V., 2012: Effects of applying deicing salt to roads in protected areas: a preliminary study in the Bavarian Forest National Park. *European Journal of Environmental Sciences*, 2: 50–55.
- KŘENOVÁ Z. & HRUŠKA J., 2012: Proper zonation – an essential tool for the future conservation of the Šumava National Park. *European Journal of Environmental Sciences*, 2: 56–66.
- KŘENOVÁ Z. & KINDLMANN P., 2015: Natura 2000 – Solution for Eastern Europe or just a good start? The Šumava National Park as a test case. *Biological Conservation*, 186: 268–275.
- KŘENOVÁ Z., ZÝVAL V. & CHOCHOLOUŠKOVÁ Z., 2015: Sůl nad zlato? Jak solení silnic ovlivňuje okolní přírodu [Salt above gold? How deicing salt effect environment along the roads]. *Šumava*, 2015 (1): 6–7 (in Czech).
- KUBÁT K., HROUDA L., CHRTEK J. JUN., KAPLAN Z., KIRSCHNER J., ŠTĚPÁNEK J. (eds), 2002: *Klíč ke květeně České republiky [Key to the Flora of the Czech Republic]*. Academia, Praha, 928 pp.
- PYŠEK A. & ZÝVAL V., 1993: Vliv zimní údržby silnice I/4 na okolní přírodní ekosystémy [Effect of winter maintenance road I/4 on the surrounding ecosystems]. Ms., project report, Gekon Praha, 28 pp. (in Czech). (deposited in the GeoVision Plzeň)
- PYŠEK A. & ZÝVAL V., 1999a: Silnice I/4, I/27 a II/141. Hodnocení vlivu zimní údržby na kontaktní ekosystémy v NP a CHKO Šumava (I. část – půdy) [Roads I/4, I/27 and II/141. Effect of winter maintenance on the surrounding ecosystems in the Šumava NP & PLA (Part I – soils)]. Ms., project report, GeoVision Plzeň, 31 pp. (in Czech). (deposited in the GeoVision Plzeň)
- PYŠEK A. & ZÝVAL V., 1999b: Silnice I/27. Hodnocení vlivu zimní údržby na kontaktní ekosystémy v NP a CHKO Šumava (II. část – vegetace) [Road I/27. Effect of winter maintenance on the surrounding ecosystems in the Šumava NP & PLA (Part II – vegetation)]. Ms., project report, GeoVision Plzeň, 31 pp. (in Czech). (deposited in the GeoVision Plzeň)
- PYŠEK A. & ZÝVAL V., 1999c: Silnice II/141. Hodnocení vlivu zimní údržby na kontaktní ekosystémy v NP a CHKO Šumava (I. část – vegetace) [Road II/141. Effect of winter maintenance on the surrounding ecosystems in the Šumava NP & PLA (Part II – vegetation)]. Ms., project report, GeoVision Plzeň, 18 pp. (in Czech). (deposited in the GeoVision Plzeň)
- RICHBURG J.A., PATTERSON W.A. & LOWENSTEIN F., 2001: Effects of road salt and *Phragmites australis* invasion on the vegetation of a Western Massachusetts calcareous lake-basin fen. *Wetlands*, 21: 247–255.
- RUSEK J. & RUSEK J., 1999: Impact of winter road salting on soil Collembola and other microarthropods. In: *Proceedings of the 5th Central European Workshop on Soil Zoology*, TAJOVSKÝ K., & PIŽL V. (eds) Institute of Soil Biology CAS, České Budějovice: 261–268.
- WROBEL M., TOMASZEWCZ T. & CHUDECKA J., 2006: Floristic diversity and spatial distribution of roadside halophytes along forest and field roads in Szczecin lowland (West Poland). *Polish Journal of Ecology*, 54: 303–309.
- ZÝVAL V. & CHOCHOLOUŠKOVÁ Z., 2003: Monitoring kontaktních ploch podél komunikací v NP a CHKO Šumava [Monitoring of environmental conditions along roads in the Šumava NP and PLA]. Ms., project report, GeoVision Plzeň, 48 pp. (in Czech). (deposited in the GeoVision Plzeň)
- ZÝVAL V. & CHOCHOLOUŠKOVÁ Z., 2004: Monitoring kontaktních ploch podél komunikací v NP a CHKO Šumava [Monitoring of environmental conditions along roads in the Šumava NP and PLA]. Ms., project report, GeoVision Plzeň, 48 pp. (in Czech). (deposited in the GeoVision Plzeň)
- ZÝVAL V. & CHOCHOLOUŠKOVÁ Z., 2005a: Monitoring kontaktních ploch podél komunikací I. tř. v NP a CHKO Šumava [Monitoring of environmental conditions along class I roads in the Šumava NP and PLA]. Ms., project report, GeoVision Plzeň, 39 pp. (in Czech). (deposited in the GeoVision Plzeň)
- ZÝVAL V. & CHOCHOLOUŠKOVÁ Z., 2005b: Monitoring kontaktních ploch podél komunikací II. a III. tř. v NP a CHKO Šumava [Monitoring of environmental conditions along class II and III roads in the Šumava NP and PLA]. Ms., project report, GeoVision Plzeň, 18 pp. (in Czech). (deposited in the GeoVision Plzeň)
- ZÝVAL V. & CHOCHOLOUŠKOVÁ Z., 2006a: Monitoring kontaktních ploch podél komunikací I. tř. v NP a CHKO

- ZÝVAL V., CHOCHOLOUŠKOVÁ Z., ZÝVAL V. JUN. & KŘENOVÁ Z., 2014a: Monitoring kontaktních ploch podél komunikací I. tř. v NP a CHKO Šumava [Monitoring of environmental conditions along class I roads in the Šumava NP and PLA]. Ms., project report, GeoVision Plzeň, 45 pp. (in Czech). (deposited in the GeoVision Plzeň)
- ZÝVAL V., CHOCHOLOUŠKOVÁ Z., ZÝVAL V. JUN. & KŘENOVÁ Z., 2014b: Monitoring kontaktních ploch podél komunikací II. a III. tř. v NP a CHKO Šumava [Monitoring of environmental conditions along class II and III roads in the Šumava NP and PLA]. Ms., project report, GeoVision Plzeň, 28 pp. (in Czech). (deposited in the GeoVision Plzeň)
- ZÝVAL V., KŘENOVÁ Z. & CHOCHOLOUŠKOVÁ Z., 2015: Effects of deicing salts in the Bavarian Forest National Park. Ms., project report, GeoVision Plzeň, 42 pp. (deposited in the Bavarian Forest NP Authority, Grafenau)

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