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The proposal of biotic hazard zones in selected spruce dominated regions in Slovakia

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ABSTRACT: Biotic agents driven spruce decline has been observed over several regions in Europe. We studied the spatial pattern of spruce stands mortality due to biotic agents in three spruce dominated regions in Slovakia – the Kysuce, Orava and Low Tatras regions. Regularly reported data on sanitary felling were used for the analysis. Geostatistical techniques and other spatial modelling tools were used to design the zones of biotic hazard for each region. Zone A stands for the totally disintegrated stands with extremely elevated activity of biotic agents. Zone B represents the buffer zone around the zone A. Its width depends on the spreading potential of biotic agents and related stand mortality observed during the last years. Zone C stands for the background areas, with more or less healthy stands. Zone-specific forest protection measures are proposed. Such a system allows for the priority rating of unnatural spruce stand conversion and optimal allocation of forest protection measures.

Keywords: bark beetle; biotic hazard zones; fungal pathogens; Slovakia; spruce decline

Declining spruce stands are distributed over the spacious areas in Central Europe. Biotic agents driven decline occurs in Slovakia prevailingly at the lower limit of spruce distribution (400–800 m a.s.l.), such as the Beskydy Mts. Destructive (wind-driven) decline is typical of the mountainous regions in the central part of Outer and in the northern part of Inner Western Carpathians. Bark beetle (*Ips typographus* mainly) and fungal pathogens (*Armillaria* mainly) are the most aggressive biotic agents in spruce stands, causing heavy damage to forests. Recently, their activity, population dynamics and mutual relationships have received a great deal of attention (Jakuš 2001; Čermák et al. 2004; Boddy, Jones 2008).

Spatial patterns of tree mortality and tree infestation by biotic agents have been studied rarely (Franklin, Grégoire 1999; Otto, Schreiber 2001; Taylor, MacLean 2007). Such a study allows for a profound understanding of their ecology (Grodzki 2004; Hlásny, Turčáni 2009), proposing forest protection measures (Capecki 1981; Turčáni, Hlásny 2007) and prioritization of forest conversions (Kulla, Hlásny 2009).

Data on accidental felling is an effective proxy for the analysis of the forest disturbance regime. We used it for the identification of biotic hazard zones in selected regions in Slovakia stricken by massive spruce decline. The results could be effectively used for the planning of unnatural spruce stand conversion as well as for forest protection purposes. In particular, we focused on:

(1) Introduction of the methodology allowing for the design of biotic hazard zones;

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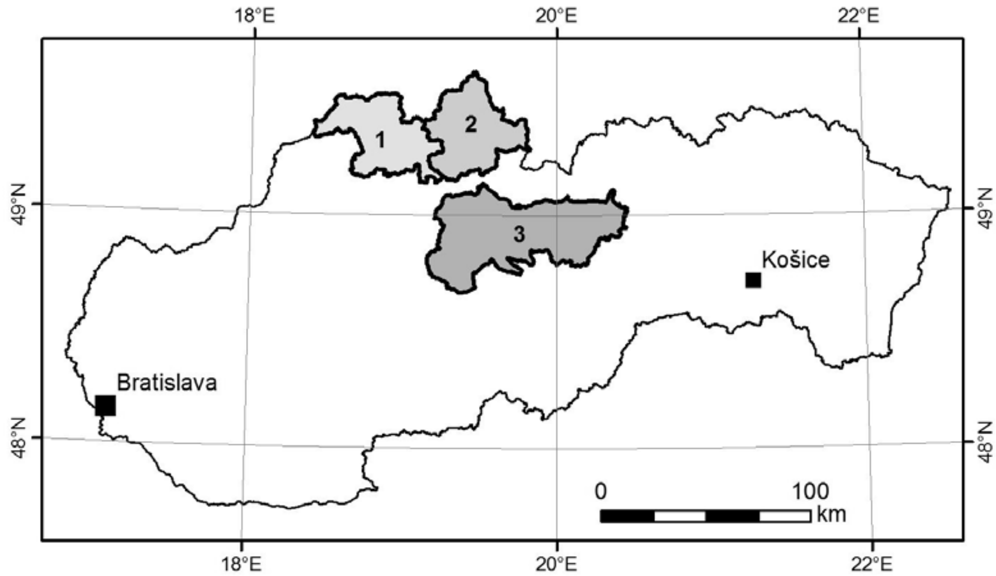

Fig. 1. The position of study regions in Slovakia: 1 – Kysuce region, 2 – Orava region, 3 – Low Tatras region

(2) Identification and evaluation of biotic hazard zones in three spruce dominated regions in Slovakia;
(3) Proposal of zone-specific forest protection measures.

Study regions

Three regions with different kind of spruce decline have been investigated (Fig. 1). Biotic agents driven decline is typical of the Kysuce and Orava regions. In the Orava region, the decline was accelerated by windstorm in 2004, causing heavy damage to forests. In contrast to the other two regions, the exponential increase of fungal pathogen activity has been observed there since approximately 2004. Destructive kind of decline is typical of the Low Tatras region. Frequent windstorms followed by local bark beetle outbreaks primarily disintegrate the stands. Fungal pathogen activity is negligible there, therefore this data has not been used for the analysis.

MATERIAL AND METHODS

Data on accidental felling regularly reported by forest users was used to design the zones. The data is spatially referenced to forest compartment centres. Source data descriptive statistics are given in Table 1.

The methodology consists of three steps:

(1) Maps of bark beetle and fungal pathogen activity were produced by means of an ordinary kriging procedure (Isaaks, Srivastava 1989; Wackernagel 2003). Such maps were developed for both agents and for all years listed in Table 1.
(2) Subsequently, produced temporal series of maps were aggregated to produce a single map, indicating the total activity of biotic agents in all study regions during the respective period. Although various weighed schemes were tested to aggregate the maps, simple summation produced the most reliable result (in comparison with field observations and remote sensing data).
(3) Biotic hazard zones were produced using the aggregated data (map). Zone A was delimited by the isoline of the highest amounts of infested volume. It represents dead forest or highly disintegrated stands. It is a focal area of decline.
Zone B represents the buffer zone between zone A and the rest of the region. It was modelled by the technique of spatial spreading (e.g. Tomlin 1990). In this procedure, zone A stands for the source feature. Recent biotic activity accelerates/decelerates the spreading outwards the A zone. In this way we forced the varying width of this zone, reflecting the activity of biotic agents in recent years (the higher the activity, the broader the zone). In the Kysuce and Orava region, the maximum zone width was 11 km, which is estimated to be the ten-year spreading range of bark beetle in these regions (Zumr 1985; Hlásny, Turčáni unpublished). Bark beetle spreading was much less intensive in the Low Tatras region during the studied period, thus the average zone width is only 5 km. It corresponds to the one-generation regime of bark beetle spreading that is typical of this region.

Table 1. Descriptive statistics of data on accidental felling of spruce (m^3 of felled volume) used for the proposal of biotic hazard zones in three investigated regions

Region	Agent	Year	*N*	Mean	Min.	Max.	Med	25%	75%	Sum
Kysuce	bark beetle	2000	775	40	1	499	11	3	45	31,006
		2001	757	29	1	691	5	2	31	22,159
		2002	658	29	1	629	7	2	36	19,478
		2003	1,012	50	1	600	21	6	63	50,970
		2004	1,782	120	1	1,782	50	19	131	138,013
	fungal pathogens	2001	345	19	2	944	41	15	99	27,164
		2002	456	84	1	607	48	20	113	38,509
		2003	843	134	1	1,802	60	18	152	113,038
		2004	919	229	1	3,002	78	25	250	210,811
Orava	bark beetle	2002	731	15	1	829	3	1	11	11,238
		2003	612	21	1	559	3	2	14	12,605
		2004	785	69	1	1,279	19	2	66	54,082
	fungal pathogens	2002	87	111	6	912	65	29	125	9,663
		2003	125	97	3	673	51	21	130	12,086
		2004	249	148	4	1,969	91	38	191	36,948
Low Tatras	bark beetle	2001	978	21	1	506	5	2	20	20,554
		2002	998	27	1	507	6	3	26	26,675
		2003	638	43	1	1,066	7	3	34	27,338
		2004	1,372	65	1	1,775	20	5	68	88,895
		2005	931	100	1	1,451	26	6	100	93,035

Zone C represents the rest of the area, with more or less healthy stands. Bark beetle infestation is just local and no massive decline has been observed yet.

RESULTS

The Kysuce region

Zone A covers 12% of the total area of the region and 17% of spruce stands in the region. It is composed of two parts (Fig. 2; Table 2). The main part spreads over the central part of the Kysucké Beskydy Mts., while the smaller one covers the Javorský Beskyd Mts.

Zone B stretches to an approximate distance of 11 km around the zone A. Its width varies from 5 km in the E-W direction in the eastern part to 12 km in the N-S direction in the southern part. It is significantly prolonged in the N-S axis, as a result of the intensive spreading of bark beetle infestation in recent years in this direction. The infestation is supposed to continue in this direction to the near future.

Table 2. The areas of biotic hazard zones and spruce stand proportions within the zones in the Kysuce region

Zone	Zone area (ha)	Proportion in total area of the region (%)	Proportion of spruce stands (ha)	Proportion of spruce stands (%)
A	16,519	12	9,115	17
B	54,299	38	16,537	33
C	72,601	50	26,315	50
Sum	143,419	100	51,967	100

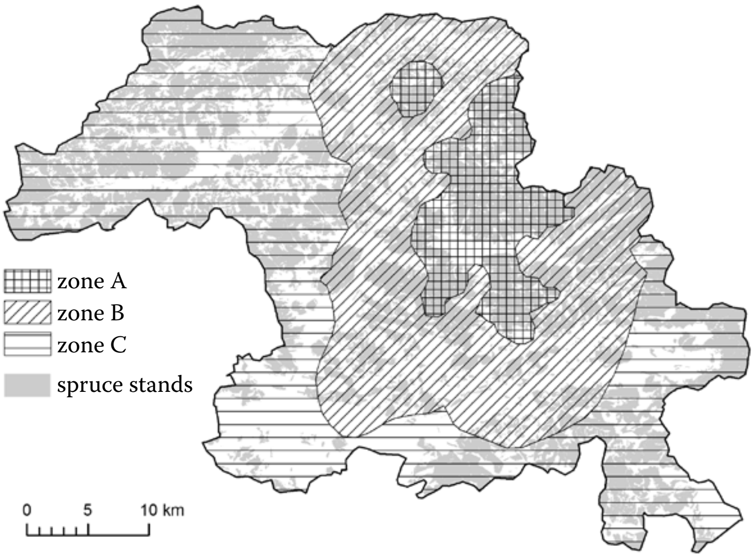

Fig. 2. Biotic hazard zones in the Kysuce region

Background zone C covers 50% of the region. The activity of biotic agents was low during the studied period, except for several foci in the eastern part. These appeared mainly in 2002–2003.

The Orava region

Zone A covers 23% of the total area of the region and 21% of spruce stands in the region (Fig. 3; Ta-

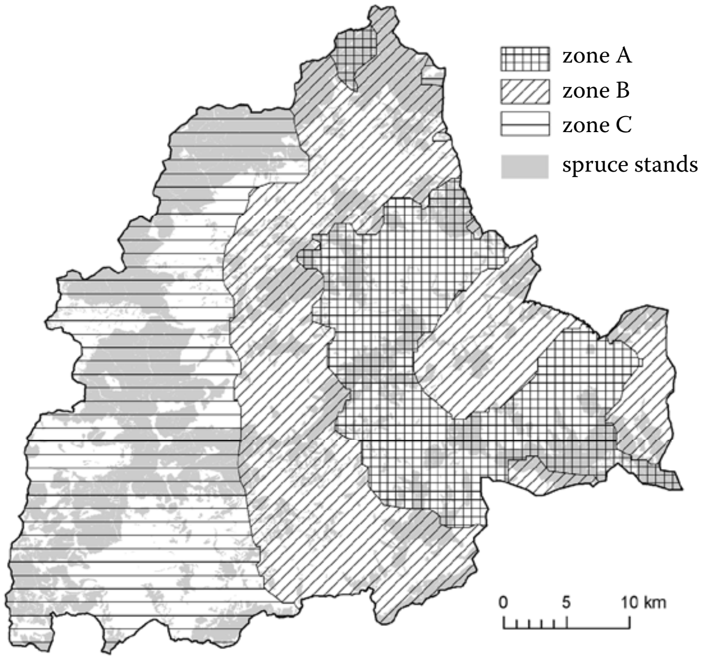

Fig. 3. Biotic hazard zones in the Orava region

Table 3. The areas of biotic hazard zones and spruce stand proportions within the zones in the Orava region

Zone	Zone area (ha)	Proportion in total area of the region (%)	Proportion of spruce stands (ha)	Proportion of spruce stands (%)
A	36,010	23	10,763	21
B	62,105	39	17,462	34
C	59,233	38	23,127	45
Sum	157,348	100	51,352	100

ble 3). The main part has a semi-arch shape and it spreads in the surroundings of the Oravská kotlina and adjacent lower massifs of Skorušina, Oravská Magura and Podbeskydská vrchovina Mts. The second part is located northerly at the Slovak-Polish frontier. It covers highly disintegrated stands in the lower parts of the Oravské Beskydy Mts., between Piľsko and Babia hora Mts.

Zone B covers 39% of the area of the region and 34% of spruce stands in the region. The zone width is approximately 11 km in the N-S direction and 5 km in the perpendicular direction. It reflects the strong anisotropic pattern of bark beetle infestation, with prolonged axis in the N-S direction (for more details see Hlásny et al. 2009).

The background C zone covers 38% of the area of the region and 45% of spruce stands. It spreads over the Paráč massif and crest of the Oravské Beskydy Mts., westerly from Piľsko Mt.

The Low Tatras region

Fungal pathogen activity is negligible in this region, thus the zone proposal is based only on bark beetle data. In contrast to the Kysuce and Orava regions, zone A is fragmented and it is distributed in several separated regions (Fig. 4; Table 4). It covers only 3% of the area of the region and 5% of spruce stands. It is distributed in the Spišské Bystré – Kozie chrbty Mts. and Malužiná-Javorinka.

Bark beetle horizontal spreading was much less intensive than in the preceding regions, thus the zone average width is 5 km. It covers 14% of the total area of the region and 15% of spruce stands.

The background zone C covers 83% of the total area of the region and 80% of spruce stands. Despite there has been observed minimal activity of bark beetle, the zone cannot be considered as "safe", because of stochastic impacts of windstorms and related bark beetle outbreaks.

Zone-specific forest protection measures

Spatial differentiation of forest management techniques is the primary benefit of the proposed zones. Although natural conditions and disturbance regime differ between the regions, we suggest the following zone-specific forest protection principles. Region-specific adjustments are needed to apply the measures in the field.

In the central (focal) zone A, with the highest level of pest activity, the control measures should prima-

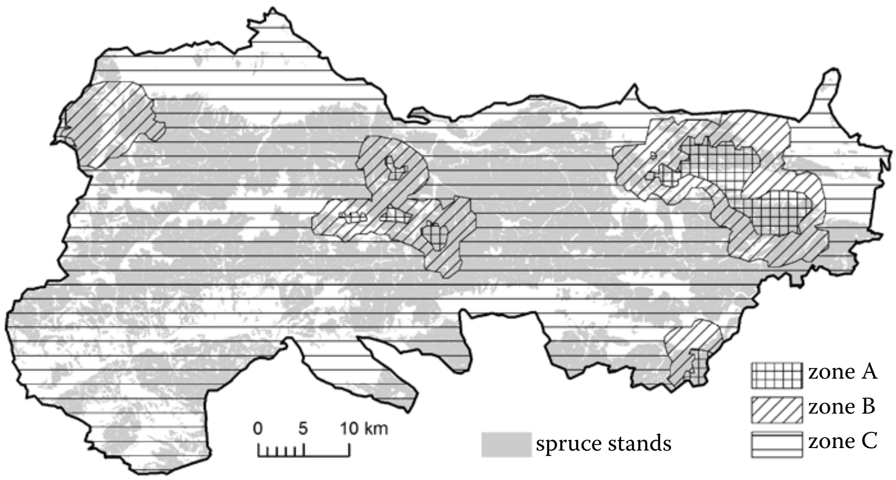

Fig. 4. Biotic hazard zones in the Low Tatras region

Table 4. The areas of biotic hazard zones and spruce stand proportions within the zones in the Low Tatras region

Zone	Zone area (ha)	Proportion in total area of the region (%)	Proportion of spruce stands (ha)	Proportion of spruce stands (%)
A	9,972	3	5,503	5
B	37,669	14	16,182	15
C	228,878	83	86,260	80
Sum	276,519	100	107,945	100

rily eliminate the abundance and infestation power of biotic agents. Extensive felling of heavily infested mature spruce stands, stressing on the outer marginal areas of the zone, should be carried out to prevent the infestation from spreading to zone B. We also recommend the rests of non-infested stands to remain as a source of attractive material on the margins of the A zone. The allocation of chemically treated trees baited by pheromone traps on stand edges and their subsequent felling should help concentrate the bark beetle population to the minimal volume of trees. The problem is the enormous volume of trees which should be felled in the next years to control the decline. In the Kysuce region, it is estimated to be approximately 120,000·m^{-3} annually during the next 2–3 years if the decay remains constant. To reduce the losses, we recommend intensive felling mainly in the first 1–3 years to eliminate the bark beetle population. The intensity of felling may decrease later.

The primary goal in zone B is to minimize/eliminate the impacts on zone C and to reduce the losses within the zone. We recommend selective sanitary cutting (removing infested trees individually, even under the threat of increased costs) and mass use of trap trees (classic ones, chemically treated classic and standing trees baited by pheromone dispenser, chemically treated tripods, barriers of pheromone traps). Like in zone A, extreme amounts of trees are supposed to be felled to prevent the infestation from spreading outside the zone. This could limit the efficiency of control measures.

The primary purpose in zone C is to minimize the initiation of infestation. Control measures reducing the abundance/infestation pressure without or with minimal sanitary felling (immediate cutting of infested trees, mass trapping by pheromone traps, introduction of entomopathogenous fungi, etc.) should keep the agents under control and thus allow for the continuous forest conversion to a more stable ecosystem. In fact, the size of the zone and heterogeneous forest ownership could hinder such management.

DISCUSSION AND CONCLUSIONS

In this study we developed a methodology allowing for the proposal of biotic hazard zones on the basis of the recent activity of biotic agents. The system yields from the generally accessible forest enumeration data, thus it is transferable to any other region with a functional reporting system. Subsequently, we demonstrated its use in three spruce dominated regions in Slovakia, covering approximately 70% of spruce forests of this country. Almost all declining spruce stands in this country were embraced.

The relevance of the proposed zones was proved by extensive field observations of forest damage conducted in 2004–2006 (unpublished). In the Orava and Kysuce regions, the zones also spatially well complied with the observed pattern of decline in the adjacent regions in Poland (Grodzki 2005, 2006). The zones may be primarily used in two ways:

(1) as an indicator of biotic hazard in complex risk assessment models,

(2) as a spatial framework for the differentiated pest control and other forest management techniques.

As far as the first point is concerned, the zones were a significant explanatory variable in the logistic risk rating model designed for the Kysuce and Orava regions (Kulla, Hlásny 2009). As for the differentiated application of pest control measures and other forest management techniques, we proposed some general principles in this paper.

The feasibility and effectiveness of proposed measures are limited in several ways. First of all, extreme amounts of trees are supposed to be felled to control the decline, which is not technically feasible to such an extent. Anyway, the allocation of control measures based on the proposal of zones could largely improve their effectiveness.

Secondly, legal regulations in natural reserves and protected areas, which cover some parts of the studied regions, limit the proposed zone-specific management. In contrast, the observed patterns of infestation often reflect such regulations. For example, the northern part of zone A in the Orava region is located just in the Babia hora natural reserve, and massive decline there is supposed to be just a reason of such limitations.

Thirdly, high dynamics of decline needs annual updates of the zone proposal to optimize the next year measures. However, source data availability is rather delayed and the reporting system is not working properly in all regions at all.

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