J Raptor Res. 35(4):378–384

DEVELOPMENT OF A HABITAT SUITABILITY INDEX MODEL FOR BURROWING OWLS IN THE EASTERN CANADIAN PRAIRIES

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ABSTRACT.—Recent efforts to sustain Burrowing Owl (*Athene cunicularia*) populations in Manitoba have been unsuccessful, and the species is now effectively extirpated from the province. Although specific causes of the decline remain unknown, loss, fragmentation, and degradation of suitable habitat have likely been major contributors to this decline. We developed a habitat suitability index model to determine suitability of Burrowing Owl nesting habitat in southwestern Manitoba and southeastern Saskatchewan. Model parameters were obtained using a modified Delphi technique to solicit expert opinions. An interactive, adaptive learning approach was used in model development, iteratively refining the model until acceptable levels of accuracy and robustness were achieved. Application of the model to historical Burrowing Owl breeding sites in Manitoba indicated that habitat suitability is often reduced by the presence of tall vegetation at former nest burrows. A management approach involving moderate grazing to maintain low vegetation height at all nest burrow sites is recommended.

KEY WORDS: *Burrowing Owl*; Athene cunicularia; *habitat*; *habitat suitability index*; *modeling*; *grazing*; *Manitoba.*

Desarrollo de un modelo de indice de aptitud del Hábitat para los Búhos Cavadores en las praderas orientales canadienses

RESUMEN.—Recientes esfuerzos por sostener las poblaciones del Búho Cavador (*Athene cunicularia*) en Manitoba no han tenido éxito, y la especie esta ahora efectivamente extirpada de la provincia. Aunque las causas especificas del declive permanecen sin conocerse, la perdida, fragmentación y degradación de la aptitud del hábitat han probablemente sido los mayores contribuidores a este declinación. Nosotros desarrollamos un índice de aptitud del hábitat para determinar la idoneidad del hábitat de anidación del Búho Cavador en el sudoeste de Manitoba y el sudeste de Saskatchewan. Los parámetros del modelo fueron obtenidos usando una técnica Delphi modificada para solicitar opiniones expertas. Un acercamiento interactivo, de aprendizaje adaptativo fue usado en el desarrollo del modelo, refinando iterativamente el modelo hasta lograr niveles aceptables de exactitud y robustez. La aplicación del modelo a sitios históricos de reproducción de Búhos Cavadores en Manitoba indicó que la aptitud del hábitat a menudo se reduce por la presencia de vegetación alta en las antiguas cuevas nido. Se recomienda un enfoque de manejo que involucre un pastoreo moderado para mantener la altura de la vegetación baja en los antiguos sitios de los nidos cueva.

[Traducción de Victor Vanegas y César Márquez]

Declines of Burrowing Owl (*Athene cunicularia*) populations in Canada (Haug and Oliphant 1990, James et al. 1997) have resulted in the species being designated as endangered (Wellicome and Haug 1995). Population declines have been accompanied by a contraction of the Canadian Burrowing Owl range, with the most pronounced range reduction occurring in the eastern Canadian prairies (Hjertaas 1997). Recently in Manitoba, the species has become effectively extirpated (De Smet 1997, Rothfels et al. 1999). Although many factors

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could be responsible for these changes, reductions in the quality and availability of grassland habitat are believed to be the major factors that have impacted Burrowing Owl populations (Zarn 1974, Haug and Oliphant 1990, Millsap and Bear 1997).

Because wildlife-habitat modeling often facilitates an improved understanding of the impacts of habitat alterations on wildlife populations (Morrison et al. 1998), we developed a habitat suitability index (HSI) model for Burrowing Owl populations in their former range of southwestern Manitoba. Habitat suitability index modeling was originally developed by the U.S. Fish and Wildlife Service (1981) as part of their Habitat Evaluation Procedures. HSI models evaluate habitat in relation to environmental factors that are deemed most important in influencing the presence, distribution, and abundance of a given species (Morrison et al. 1998). Such models can provide a repeatable assessment procedure for identifying changes in habitat suitability over time (U.S. Fish and Wildlife Service 1981, Schamberger and O'Neil 1986, Morrison et al. 1998). Our objective was to develop an HSI model that could be used to determine whether grasslands of southwestern Manitoba provide the habitat conditions required to sustain Burrowing Owl populations.

METHODS

Modified Delphi Data Collection. Little information has been published on the site-specific, qualitative habitat requirements of Burrowing Owls in the eastern Canadian prairies. To obtain this information, we used a modification of the Delphi technique (Dalkey 1969, Crance 1987) to solicit opinions from regional Burrowing Owl researchers (Crance 1987). The Delphi technique originally used anonymous questionnaires to obtain information from experts and facilitate consensus building, but was subsequently modified to include group discussions among experts (Crance 1987). For the purpose of this study, the Delphi technique incorporated both a group discussion and a questionnaire component.

Five researchers, who had conducted studies on Burrowing Owls in southwestern Manitoba and southeastern Saskatchewan, participated in a workshop on 13 June 1997 in Regina, Saskatchewan. The workshop began with an overview of HSI models and the principles driving their development. Participants were then asked to identify nesting and foraging habitat requirements of Burrowing Owls in southwestern Manitoba and southeastern Saskatchewan based on their research experiences. As each habitat requirement was identified, participants collectively developed a suitability-index (SI) curve displaying the relationship between the habitat variable and the index of suitability. Participants considered each of the identified habitat components, and used a secret ballot voting method to select 10 components they believed

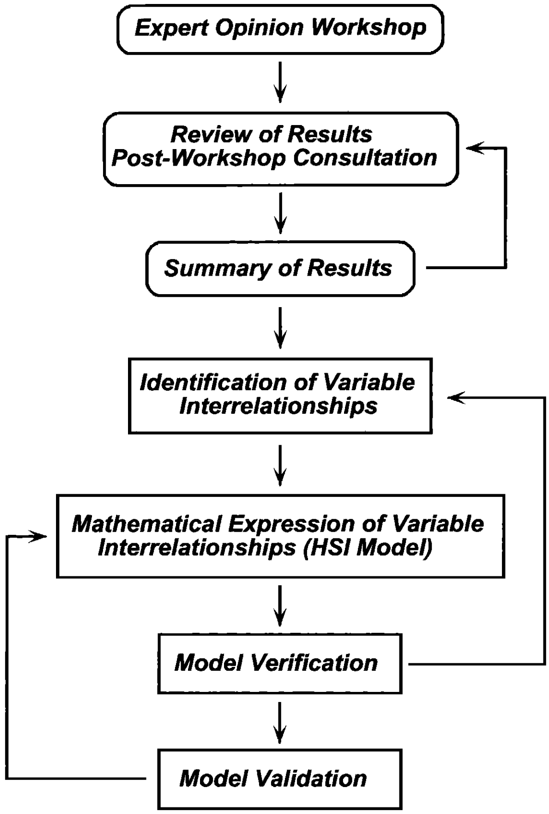

Figure 1. Flow diagram summarizing the development of the Burrowing Owl Habitat Suitability Index (HSI) model. Curved boxes represent the Delphi expert workshop stage, rectangles the numerical model development stage.

were most important in determining Burrowing Owl habitat suitability. Votes were displayed and workshop participants then collectively modified these results as required to achieve group consensus.

Participants were then asked to consider interrelationships among the 10 habitat components as they related to Burrowing Owl habitat suitability and reproductive success. Individually, participants ranked each component by considering its importance for suitability of Burrowing Owl habitat. In addition, participants were asked to assign relative weights (scaled from 0.0–1.0) to habitat components, resulting in a mathematical description of the interrelationships functioning within the habitat. Equal ranking and weightings among two or more variables were permitted. Results of this secret ballot were subsequently displayed. Participants then reviewed and critiqued the component rankings and weights until consensus was reached.

Results of the workshop were later summarized and mailed to the participants for comments (Fig. 1). Participants were asked to approve or modify the results and provide clarification where necessary. Comments and suggestions from this questionnaire were incorporated into the workshop results and again forwarded to participants for their final approval.

Field Data Collection. To examine present-day habitat suitability of historical Burrowing Owl nest sites in southwestern Manitoba, fieldwork was undertaken in the vicinity of Melita (49°10′N, 101°00′W) within the mixed-grass prairie ecoregion of Manitoba (Scott 1996). In early-June 1998, proximate habitat was examined at 13 historical nest sites used by Burrowing Owls between 1987–97. Records of fledging success between 1987–97 (De Smet 1997, K. De Smet unpubl. data) were used to classify historical nest sites as successful (70% of broods fledged), marginally successful (30–50% of broods fledged), or unsuccessful (0 broods fledged). Of the 13 sites, six were classified as successful, two as marginally successful, and five as unsuccessful. The historical nest sites were located in present-day cattle pastures subjected to a variety of grazing intensities. Sites were interspersed among cereal and forage crops, haylands, summer fallow, and other grassland habitat types.

Because most Burrowing Owl activity occurs in habitats located ≤600 m of the nest burrow (Haug and Oliphant 1990), this study assessed habitat located within a 600-m radius of each nest site. Nest and forage vegetation heights, burrow availability, topography, perch availability, and openness were assessed at each nest site.

We assumed that Burrowing Owls select forage habitats consistent with optimum-foraging theory (Stephens and Krebs 1986). Therefore, potential Burrowing Owl forage habitat was examined within 600 m of the nest site using information provided by the workshop participants. Vegetation structure and composition were visually assessed by looking outward while walking a 50-m radius circle centered on the nest site. Roadside habitat within 600 m of the nest site was also assessed visually using information provided by workshop participants. Each distinct habitat was classified and assigned a suitability index (SI) based upon the workshop rankings. The areal extent of each habitat class was also estimated. Vegetation sampling was then undertaken, beginning with forage habitat having the highest SI and proceeding to habitats having lower SI values until a total forage habitat area of 9 ha or more was achieved for each nest site. Within each habitat type, vegetation height was measured at 10-m intervals along three randomly-positioned, 100-m transects, and mean forage vegetation height was calculated.

Nesting activity of Burrowing Owls is restricted primarily to habitat located within 50 m of the nest burrow (Haug and Oliphant 1990). To identify habitat suitability within this area, vegetation height was measured in each of the four cardinal directions 1 m from the nest, and also at 10-m intervals along a circle with a 10-m radius centered on the nest burrow. At all sample locations, height of vegetation was recorded to within 1 cm by using a meter stick.

Burrowing Owls on the Canadian prairies rarely excavate their own nesting burrows (Haug et al. 1993), relying instead on abandoned badger (*Taxidea taxus*) and Richardson's ground squirrel (*Spermophilus richardsonii*) burrows (Wellicome and Haug 1995). Participants of the modified Delphi process indicated that Burrowing Owls typically use holes having an entrance diameter of 8–35 cm. To determine burrow availability at each site, the number of natural and artificial burrows with entrance diameters of 8–35 cm were counted within a 10 × 10 m random plot located between 10–50 m from the nest burrow. In addition, perch availability and habitat openness were determined at each nest site by counting the number of perches and trees, respectively, within a 50-m radius of the nest. Site topography was assessed visually using incremental rankings from flat to moderately rolling.

Model Development. Information obtained from the modified Delphi process was used to develop an HSI model. To ensure that the identified habitat components were appropriate indicators of habitat suitability, the HSI compatibility of each variable was assessed using criteria developed by Schamberger and O'Neil (1986). In addition, the SI curves generated by the Delphi process were fitted to mathematical functions using regression analysis and statistical modeling (Jeffers 1982).

Model construction. Construction of the HSI model began by formulating model objectives and assumptions Variables considered to be inappropriate to the modeling objectives were excluded from consideration. Exploratory data analysis was used to summarize interrelationships among the remaining variables, and variables were each identified as limiting, cumulative, or compensatory factors using guidelines established by the U.S. Fish and Wildlife Service (1981). A mathematical expression of habitat suitability was generated (Fig. 1) using an adaptive learning process of combining habitat variables. Both arithmetic and geometric means of variables were considered in formulating habitat suitability. A multiplicative application was considered appropriate for limiting variables, as it ensured that the HSI would equal zero should any of the variable SI values equal zero. Cumulative variables were incorporated into the model additively, while compensatory variables were incorporated using either an arithmetic or geometric mean as deemed appropriate, recognizing that geometric means were more sensitive to individual low SI values than were arithmetic means. Variable weights identified by workshop participants were applied to compensatory variables to express their relative importance in identifying suitable habitat (U.S. Fish and Wildlife Service 1981).

Model verification. An interactive computer program was developed to verify the function, accuracy, and robustness of the HSI model (Fig. 1). Empirical habitat measurements were entered into the program to explore the multi-variable behavior of the HSI model, and to ensure that the computed HSI values reflected expert opinion. If the model behavior was deemed suboptimal, refinements were made iteratively until acceptable levels of accuracy and robustness were achieved.

Model validation. The HSI model was validated using field data from known Burrowing Owl habitat at Moose Jaw, Saskatchewan, and from historical Burrowing Owl habitat in southwestern Manitoba (Fig. 1). The Saskatchewan data were used to confirm that the model produced high HSI values for currently occupied habitat, while the Manitoba data were used to assess the suitability of historical Burrowing Owl nest sites for future populations

Table 1. Primary habitat variables, variable priorities, and variable importance weights (range of possible weights: 0.0–1.0), as determined by habitat-modeling workshop participants.

PRIORITY	PRIMARY HABITAT VARIABLE	IMPORTANCE WEIGHT
1	Burrow availability	1.0
2	Forage availability	1.0
3	Vegetation at nest site	0.8
4	Openness	0.8
5	Habitat fragmentation	0.7
6	Forage habitat quality	0.9
7	Inter-nest distance	0.5
8	Areal extent of nest pasture	0.2
9	Topography of nest area	0.2
10	Perch availability	0.2

RESULTS

Model Construction. Workshop participants individually identified 19 habitat components thought to affect the suitability of Burrowing Owl breeding habitat in the eastern Canadian prairies. Participants then reduced this to 10 components thought to be the most important in determining Burrowing Owl habitat suitability (Table 1).

Nine of the 10 habitat components identified by workshop participants were specific to habitat proximate (<50 m) to nest burrows, while the tenth addressed landscape-level habitat fragmentation. Given that the objective of this study was to develop an HSI model for small-scale, proximate habitat, the fragmentation measure was excluded. The remaining nine habitat components were redefined as variables for the purpose of model construction.

The contribution of the nine remaining variables to the HSI model was determined by considering the variable interrelationships identified by workshop participants. Number of burrows was deemed to be a limiting factor in identifying suitable nesting habitat because Burrowing Owls rarely excavate their own burrow. Because species survival is dependent upon the availability of suitable prey habitat, the quality and availability of foraging habitat were also deemed limiting factors. Inter-nest distance, openness and vegetation height at the nest burrow were identified as compensatory factors because high suitability levels for these variables were expected to offset low suitability levels of other variables. Topography at the nest site, areal extent of nest pasture, and perch availability were considered to have minimal influence on site suitability individually, but collectively, these variables were determined to be important. Topography at the nest site, areal extent of nest pasture, and perch availability were therefore considered to be cumulative factors.

An initial model was produced that included all nine variables in a weighted geometric mean, using the variable weights suggested by the workshop participants. The resulting model proved cumbersome and was insensitive to changes in variable values. To improve model function, the three variables weighted lowest by workshop participants were removed. Two additional variables were incorporated indirectly into the model as stipulations guiding model application. Specifically, the HSI was automatically set to zero under either of the following conditions:

(1) Openness: tree or tall shrub encroachment within 50 m of the nest site.
(2) Forage availability: no forage habitat located within 600 m of the nest site.

Subsequent model construction and verification focused on the four remaining variables.

HSI models are intended to be general indicators of habitat suitability that are easily and repeatably applied under field conditions. Minimizing the number of variables in the HSI model served two purposes: the model became more easily applied, and the likelihood of model overfitting was reduced (Jeffers 1982).

Model Verification. Model verification was undertaken by creating an interactive computer program to determine individual variable SI values and a composite HSI value for a specific set of habitat parameters. Approximately 500 sets of habitat parameters were generated to explore the utility and robustness of the model. An iterative process was used to modify model parameters until a suitable model was achieved. The final model took the form:

$$HSI = [(S_1)(S_2)(S_3^{0.8})(S_4^{0.5})]^{1/3.3}$$

where S_{1-4} are SI values for the following habitat variables:

S_1 = burrow availability
S_2 = forage vegetation height
S_3 = nest vegetation height
S_4 = inter-nest distance

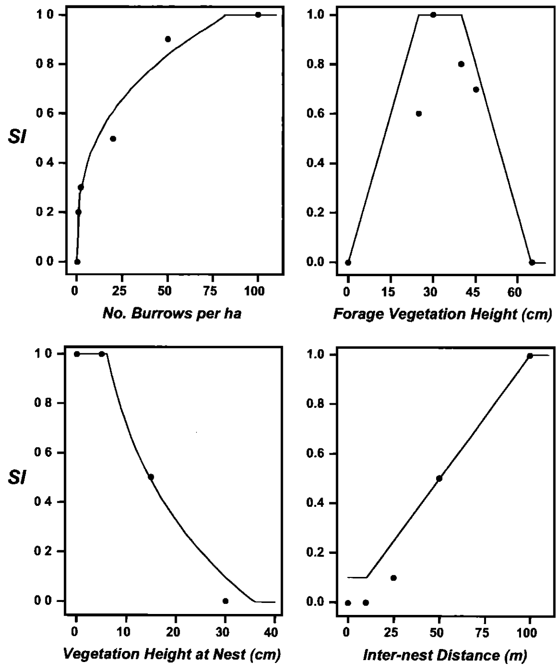

Figure 2. Suitability Index (SI) curves for the four habitat variables used in the Habitat Suitability Index (HSI) model. Fitted curves (solid lines) and variable values from the Delphi workshop participants (circles) are shown.

Variable weights incorporated into the model are provided in Table 1, and suitability index values for the four variables are presented graphically in Fig. 2.

A simpler model, excluding inter-nest distance, was developed for nest sites where Burrowing Owls were not present:

$$HSI = [(S_1)(S_2)(S_3^{0.8})]^{1/2.8}$$

Model Validation. Burrowing Owls have nested successfully in Moose Jaw, Saskatchewan for a number of years (E. Wiltse pers. comm.). The suitability of breeding habitat was assessed at nest sites located within two distinct study areas, the track infield of the Moose Jaw Exhibition Grounds and on land adjacent to the Lynbrook Golf Course. Eight nest sites were examined at the Moose Jaw Exhibition Grounds study area while an additional eight nest sites were assessed on the Lynbrook study area. Burrowing Owls were nesting on both study areas when the assessment was conducted. The HSI values for each of the study areas equaled 1.0, indicating that the model successfully recognized habitat that was being used by Burrowing Owls.

Of the 13 historical Manitoba nest sites examined, nine artificial nest burrows and four natural nest burrows were used. All historical nest sites were located on pastures that varied in the frequency and intensity of cattle grazing. Four historical sites were being grazed during the sampling period, while four others had remained ungrazed for a number of years. At the remaining five sites, grazing had occurred in the recent past, although historical grazing regimes were based solely upon supposition. Discussions with landowners indicated that these pastures were being subjected to rotational grazing practices at the time sampling occurred. Although other forms of habitat management can be used to suppress vegetation height (e.g., mowing, prescribed burning), only grazed sites were available for this study.

Individual SI values were determined at each of the Manitoba nest sites for three variables: burrow availability, vegetation height at the nest, and forage vegetation height. Inter-nest distance was not included because the sites were not occupied by Burrowing Owls when sampling occurred. SI values for burrow availability were >0.8 for 11 of the 13 sites, but two sites had low SI values (<0.5) due to a shortage of available burrows. Forage vegetation height SI values were all >0.8, and in 10 of the 13 historical nest sites maximum suitability values of 1.0 were achieved. SI values for vegetation height at the nest showed the greatest variation, ranging from 0.19 to 1.0. Together, these results indicate that forage habitat quality and burrow availability were close to maximum at most sites. By contrast, SI values for vegetation height at nest sites were often low, particularly in ungrazed pastures.

HSI values for the 13 sites ranged from 0.58 to 1.0, and were correlated with historical nest site success ($r^2 = 0.33$, $P < 0.05$; Fig. 3). HSI values of unsuccessful historical sites ranged from 0.58 to 0.79, with highest values occurring in pastures grazed when sampling occurred. By contrast, HSI values for successful historical sites ranged from 0.7 to 1.0, with smallest values occurring in sites that had not been grazed for some time. These results suggest that moderate cattle grazing of nest sites may be critical to the maintenance of suitable Burrowing Owl breeding habitat in southwestern Manitoba.

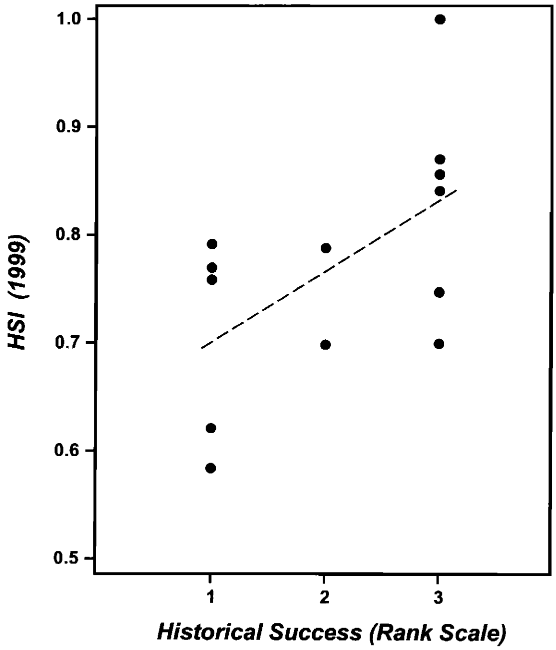

Figure 3. The relationship between brood-rearing success (1987–97) and Habitat Suitability Index (HSI) values (June 1999) for 13 historical Burrowing Owl breeding sites in southwestern Manitoba. Success codes are 1 = unsuccessful, 2 = moderately successful, and 3 = successful. The dashed line was fitted using linear regression.

DISCUSSION

The HSI model developed in this study incorporated directly four habitat variables considered critical in evaluating the suitability of Burrowing Owl habitat in southwestern Manitoba. An additional two variables were incorporated indirectly as stipulations guiding model application. During the early model development phase up to nine habitat variables were included; however, these more complex models proved to be cumbersome and produced unstable results. Similar results were obtained by O'Neil et al. (1988). Simpler models have the advantages of being tractable mathematically and easily applied under field conditions.

Application of the HSI model to historical Burrowing Owl nest sites in Manitoba suggested that habitat suitability was most strongly compromised by the presence of tall vegetation at the nest burrow. In southwestern Manitoba, native mixed-grass prairie and tame grasses may exceed 10 cm in height by early-June, particularly in wet years. By contrast, vegetation height in the drier mixed-grass prairies of southwestern Saskatchewan rarely exceeds 5–10 cm, even in the absence of grazing. In the Canadian prairies, annual precipitation increases from west to east and results in taller grass and forb species in southern Manitoba (Scott 1996).

In Manitoba, moderate grazing appears to be critical to maintaining an optimal (≤6 cm) vegetation height at nest burrows. Historical nest sites subjected to cattle grazing during habitat sampling were identified as having greater habitat suitability than ungrazed sites, indicating that grazing may enhance the suitability of Burrowing Owl habitat. In historically successful breeding habitat, cessation of grazing resulted in degraded habitats consisting of tall and lush grasses. De Smet (1997) identified over 700 pastures in southwestern Manitoba as potentially suitable habitat for Burrowing Owls; however, the quality of these habitats has not been formally assessed. The HSI model developed in this study can be used to assess these pastures, and identify the variables that compromise habitat suitability.

Population declines in Manitoba have been attributed previously to vehicular mortality and recent inclement, wet spring weather (De Smet 1997). Based on our analysis, we suggest that habitat deterioration at historical nest sites may have contributed to the effective extirpation of Burrowing Owls from Manitoba. Vegetation management at historical nest sites, such as regular grazing or mowing and either mechanical or fire management directed toward the removal of encroaching woody plants, should be implemented to improve Burrowing Owl habitat by maintaining consistently low vegetation height at nest burrow sites.

ACKNOWLEDGMENTS

This research was funded by Manitoba Hydro, Manitoba Conservation, and the Manitoba Raptor Foundation. The authors are indebted to T.I. Wellicome, D G Hjertaas, P.C. James, K.D. De Smet, K. Clayton, M. Shoesmith, R. Bukowsky, C. Johnson, and J. O'Neil for their advice and assistance. Thanks to K.D. De Smet, of Manitoba Conservation, for providing unpublished data on historical fledging success and to E. Wiltse, of Saskatchewan Environment and Resources Management, for providing a personal communication. We also thank K.D. De Smet, L. Takats, and an anonymous reviewer for their helpful suggestions. This study and its field research could never have been accomplished without the assistance and encouragement of the adventurous and perseverant V. Uhmann.

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