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D. Geographic Information Systems (GIS) Applications

GIS-BASED MODEL TO SUPPORT PROGRAMMATIC SECTION 7 CONSULTATIONS ON THE CANADA LYNX IN COLORADO

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Abstract
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The Colorado Department of Transportation (CDOT), on behalf of the Federal Highway Administration (FHWA), is in the process of conducting programmatic section 7 consultations on the Canada lynx. CDOT divided Colorado into eight consultation units where lynx habitat and highways intersect. A programmatic is nearing completion for one of the units; others will be developed in order of priority. The programmatic builds on the idea that the highest conservation needs for lynx, such as structures that allow it to cross roads, are not necessarily located within project limits. The programmatic therefore identifies locations that form the greatest barriers to movement, develops conservation measures for those areas, and provides agreements between the U.S Fish and Wildlife Service (FWS), FHWA, and CDOT to implement those measures.

To assess barriers to movement and other conservation needs, CDOT, with the assistance of the remote sensing unit of the U.S. Bureau of Reclamation and the FWS, constructed a GIS-based model of lynx habitat. The model is designed to identify likely movement corridors and their intersection with roadways. It was assembled using detailed watershed-based vegetation maps (developed by the US Bureau of Land Management and the Colorado Division of Wildlife), digital elevation models, as wells as slope and aspect data. The process yielded several potential corridors. Their intersection with roadways was verified on the ground. CDOT then developed design recommendations for structures that connect lynx movement corridors across a highway. When constructed, these crossings will compensate for impacts associated with highway projects in the consultation unit and form the basis for a programmatic section 7 consultation.

GIS-BASED MODELING APPROACHES TO IDENTIFY MITIGATION PLACEMENT ALONG ROADS

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Abstract: Decision-making in the design of effective wildlife passage structures is hampered by the sparse information currently available. There are several reasons for this deficiency. Monitoring wildlife passages is not often anticipated after construction. There are few methodological approaches to identify the placement of wildlife passages. Finally, there is an urgent need for mitigation procedures that contemplate the broad landscape context of road systems. When used in a geographic information system (GIS) environment, regional or landscape level connectivity models of sufficient resolution can help delineate placement of wildlife crossing structures. GIS tools and applications are becoming more popular among resource managers and transportation planners. An empirically based habitat linkage model is preferred to qualitative or conceptual models based on limited data. However, in many cases, the data necessary for empirically based models are not available. As a substitute, expert information can be used to develop simple, predictive, habitat linkage models in a relatively short period of time. Banff National Park is preparing for a new Trans-Canada highway (TCH) expansion and mitigation project. We need to be able to provide park managers with an empirical assessment of the impediments posed by transportation corridors to animal movements, and recommend the placement of mitigation measures. For some species there are empirical data, while for others there are little or no data. Given this situation, we developed several GIS approaches to model animal movements across transportation corridors in the Central Rocky Mountains. For a single species, we developed three different but spatially explicit habitat models to identify linkage areas across the TCH. One model was based on empirical data, and the other two models were based on expert opinion and expert literature. We used the empirical model as a yardstick to measure the accuracy of the expert-based models. Our tests showed the expert literature-based model most closely approximated the empirical model, both in the results of statistical tests and the description of the linkages. For a similar exercise using empirical data, we developed a multi-scale GIS approach to model multiple species movements across the TCH and identify mitigation passage placement. Three steps were involved: 1) the creation of regional habitat suitability models for each of four large mammal species, 2) the development of a regional scale movement component to the models, and (3) nested within step 2, the construction of local-scale movement models of high spatial resolution within the transportation corridor. Recommendations regarding the location of potential mitigation based on the intersection of simulated pathways with transportation corridors and other human infrastructure were the result of the exercise. Our empirical and expert models represent useful tools for resource and transportation planners charged with determining the location of mitigation passages. Expert models were shown to be practical when baseline information is lacking and time constraints do not allow for pre-construction data collection. It is important to note the wide applicability of such models to other planning issues in the Central Rocky Mountains. The proposed models could be applied to other human infrastructure, such as railways, trails, or other road systems.

Introduction

Wildlife crossing structures have been designed and incorporated into road construction projects to mitigate the effects of road barriers (Foster and Humphrey 1995, Keller and Pfister 1997, McGuire and Morrall 2000). Although effective crossing structure designs have been formulated for single species and multispecies assemblages (Singer and Doherty 1985, Rodríguez et al. 1996, Clevenger and Waltho 2000), few methodological approaches to determine the placement of highway mitigation passages have been explored. Traditional road planning and mitigation designs have been site-specific and one-dimensional, i.e. linear, thus failing to incorporate the broad landscape context of road systems (Forman 1987). When used in a geographic information system (GIS) environment, regional or landscape level connectivity models of sufficient resolution can help identify potential highway crossing or linkage areas for wildlife (Servheen and Sandstrom 1993, Singleton and Lehmkuhl 1999, Clevenger et al. in press).

Within the Canadian Rocky Mountains, habitat fragmentation and physical barriers undermine the integrity of the vast ecological network. Major transportation corridors and road networks are of greatest concern and perhaps the greatest obstruction to conserving large animal populations in the entire area (Noss et al. 1996). As part of a project aimed at evaluating, designing and planning highway mitigation measures along the Trans-

Canada highway (TCH) in Banff National Park (BNP), Alberta, we have developed GIS-based approaches to modeling animal movements across transportation corridors in the Central Rocky Mountains.

Banff National Park is preparing for a new Trans-Canada highway (TCH) expansion and mitigation project. We need to be able to provide park managers with an empirical assessment of the impediments posed by transportation corridors to animal movements and recommend the placement of mitigation measures. For some species there are empirical data, while for others there are little or no data. Thus, several GIS approaches were developed to model animal movements across transportation corridors in the Central Rocky Mountains.

For a single species, we developed three different but spatially explicit habitat models to identify linkage areas across the TCH. One model was based on empirical data, while the other two were based on expert opinion and expert literature. We used the empirical model as a yardstick to measure the accuracy of the two expert-based models (Clevenger et al. in press).

For a similar exercise using empirical data, we developed a multi-scale GIS approach to model multiple species movements across the TCH and identify mitigation passage placement. Three steps were involved: 1) the creation of high-resolution, regional habitat suitability models for each of four species, 2) the development of a regional scale movement component to the models, and (3) nested within step 2, the construction of local-scale movement models of high spatial resolution within the transportation corridor. Recommendations regarding the location of potential mitigation based on the intersection of simulated pathways with transportation corridors and other human infrastructure were the result of the exercise.

Study Area

Our extensive study area encompassed Banff, Kootenay and Yoho National Parks located in the Central Canadian Rocky Mountains, Canada. Specifically, we focused on the Trans-Canada highway (TCH) transportation corridor in Banff National Park (BNP), Alberta (Fig. 1). There are probably few places in the world where the intersection of transportation corridors with wildlife corridors is as significant as in the Canadian Rocky Mountain national parks. Banff and Yoho are the only national parks in North America to have a major transportation corridor running through them. Situated approximately 120km west of Calgary, Banff is the most heavily visited national park in North America with over 5 million visitors per year. The highway also is a major commercial motorway between Calgary and Vancouver. In 1998, annual daily traffic volume at the park east entrance was 14600 vehicles per day and summer annual traffic volume was 21500 vehicles per day (Parks Canada Highway Service Centre, unpublished data).

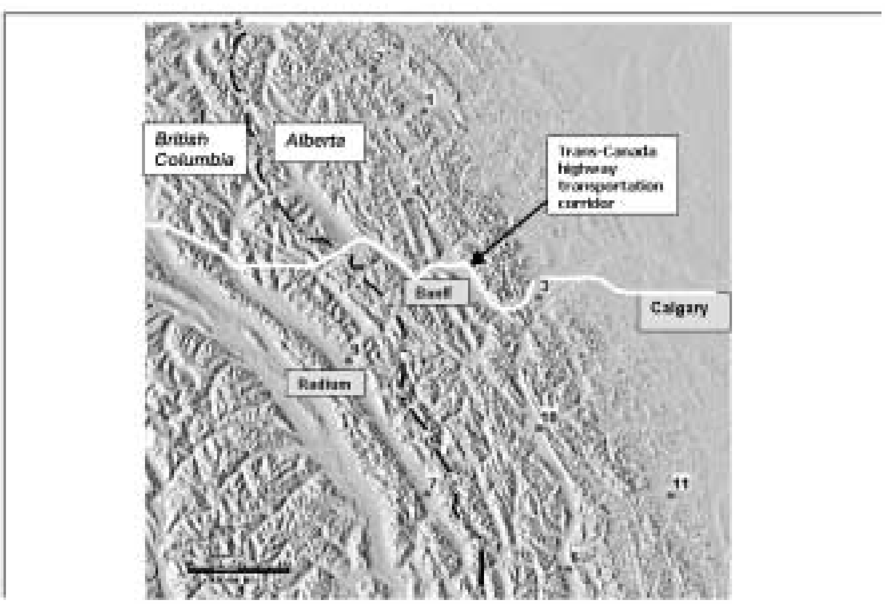

Fig. 1. The location of the Trans-Canada highway study area in relation to the entry-exit points (numbered 1 to 11) used in simulating regional scale, large mammal movements in the Central Canadian Rocky Mountains, Canada.

Major transportation corridors can seriously alter ecosystem processes. Mitigating the effect of the TCH on the park environment is an obvious necessity. Since the 1980s, fencing and 24 wildlife crossing structures (overpasses and underpasses) have been installed along the first 45 km of TCH in BNP (McGuire and Morrall 2000). The remaining 30km to the British Columbia border is currently two lanes and unfenced; however, four-lane expansion with appropriate mitigation measures for wildlife is imminent.

The Trans-Canada highway in BNP runs along the floor of the Bow Valley, sharing the valley bottom with the Bow River, the township of Banff (population 9000), several high volume two-lane highways, numerous secondary roads, and the Canadian Pacific Railway. The geography of central and eastern BNP is dictated by the geology of the Front Ranges of the Rocky Mountains. This geography influences the distribution and movement of wildlife in the park. The parallel NNW-SSE oriented limestone ridges and shale valleys create a landscape much more conducive to the North-South than the East–West movement. The few large valleys, the Bow Valley being the most prominent of them, that dissect the Front and Central Ranges are recognized as critical not only in maintaining the regional-scale East-West movements, but also in providing a vital link between the valleys nested among the Front Ranges of the park. For these same reasons, the Bow Valley is also one of the most important of the transportation corridors in the region.

Methods

Expert-Based Linkage Models

Empirical model

We selected black bears (*Ursus americanus*) to model habitat use and identify linkage areas across the TCH. Black bears were the only species for which we had sufficient empirical data to build a habitat model and enough data from crossings and mortality locations to test the model. Furthermore, we assumed that mortality locations were crossing locations although we were unable to prove that the unsuccessful crossing locations were different from successful ones.

To develop the empirical habitat model, we first determined the habitat characteristics of black bears in the study area using nine biophysical variables in the analysis. Location data were obtained from monitoring the movements of nine radio-collared bears between 1998-99. We used a probability function that ties the distribution of bear locations to the variables in the study area (Pereira and Itami 1991, Manly et al. 1993). To incorporate black bear landscape perception depth, we tied the dimensions of the kernels (= 500m radius) used to calculate landscape indices and radiotelemetry density maps with the reported black bear average daily movement rates (Garshelis et al. 1983, Alt et al. 1980). To account for the telemetry error, each location was buffered 175 meters (the maximum average error) and assigned a probability of occurrence (PO) value. To facilitate statistical analysis, we stratified the density maps into PO classes. We removed all density values less than 0.5 animals per kernel area (the null class), and calculated the 25th, 50th and 75th percentile for each of the density distributions. These percentiles were used as the cut-out values in defining four PO categories: low (<25%), moderate (25-50%), high (50-75%), and very high (>75%). A stratified random sample of points (n = 580) was generated to compare with the landscape and biophysical variables in each of the PO categories.

Our sample of marked animals was not random or large enough to represent the black bear population. Therefore we decided against the univariate selection vs. avoidance method of habitat modeling. Instead we identified directional trends in habitat selection across the full set of PO categories, supported by a statistical analysis of the observed patterns. This approach overcomes problems associated with small sample sizes and potential spatial autocorrelation of the study animals; however, it does not fully mitigate the effects of their non-random selection.

We used a multivariate discriminant function analysis (DFA) to assess the relative importance of the biophysical variables to bear habitat selection. We used the Mahalanobis distances criterion in the stepwise method for variables' entry and removal. Approximately 10% of the locations (n = 68) from the black bear telemetry database were excluded from the habitat selection analysis in order to validate the model.

Expert model

Both expert habitat models were developed as weighted linear combinations of each models' layers (landscape and biophysical variables) obtained by a) expert opinion or b) review of the literature on black bear habitat requirements. With a weighted linear combination approach, the variables were combined by applying a weight to each followed by a summation of the results to yield a suitability map. This procedure is not uncommon in GIS and has a form similar to a regression equation (Eastman et al. 1995). Further, all GIS software systems provide the basic tools for evaluating such models. However, the main issues relate to the standardization of criteria scores and the development of the weights. To do this we used the pairwise comparison method developed by Saaty (1977) in the context of a decision-making process known as the Analytical Hierarchy Process (Eastman et al. 1995, Rao et al. 1991). The comparisons concern the relative importance of the two criteria involved in determining suitability for the stated objective, in this study, black bear habitat. Ratings were provided on a nine-point continuous scale, ranging from 1/9 (extremely less important) to 9 (extremely more important), and the midpoint 1 being equally important (see Eastman et al. 1995). In developing the weights, a group of individuals (minimum of two) compared every possible pairing and entered the ratings into a pairwise comparison matrix.

Opinion-based model. The expert opinion-based model required the collaboration of experts in assessing the importance of variables influencing black bear habitat selection in the study area. Two experts committed to developing the weights for the pairwise comparison matrix. Both investigators had a combined 47 years of experience studying black bears and their habitat in the Bow River Valley. We solicited input from the experts in regard to the variables selected for building the model and how the variables should be divided up for the pairwise comparion matrix. The experts preferred to score the variables by seasons relevant to the biological needs of bears: pre-berry (den exit to 15 July) and berry (15 July to den entry). Matrix scoring was done within the variables and among the variables. Five habitat variables were used in the analysis: elevation, slope, aspect, greenness, and distance to nearest drainage. The time required to perform the pairwise comparisons (n = 12) for both seasons was 90 minutes.

Literature-based model. Expert models based on data obtained from the literature were developed like the expert opinion models. We used the available literature on black bear habitat selection to help us weight the variables and completing the pairwise comparison matrices. One of the authors (APC) and two other biologists performed this task. We searched the literature to obtain as much information as possible on black bear habitat needs; preferably within our study area if possible. We scored the same variables in a pairwise comparison procedure as for the expert opinion model. All pairwise comparisons were carried out using the WEIGHT procedure in the Idrisi geographic analysis software (Eastman 1997). The 12 pairwise comparisons took 110 minutes to complete.

Linkage Zone Identification

The linkage analysis model was based on the assumption that the probability of a bear crossing a highway increases in areas where the highway bisects high quality bear habitat, and the highest probability of crossings occur in areas where topographic and landscape features are conducive to lateral, cross-valley movements.

To create the empirical black bear habitat model we used the GIS environment to apply the DFA findings to calculate the Mahalanobis distances for each pixel of the study area, and to calculate the posterior probabilities of group membership, i.e., a probability of good black bear habitat (Clark et al. 1993, Corsi et al. 1999). To allow statistical comparisons between the empirical and expert-based models, the latter being a habitat suitability index (HSI) type of model (U.S. Fish and Wildlife Service 1980 and 1981), we reclassified the continuous empirical habitat quality surface into 20 habitat favorability (or probability) classes, indexed from low (0%) to high (100%). We applied the same rules to the expert models. The reclassification process allowed us to describe the best black bear habitat as a percentage of the maximum habitat favorability value, regardless of the unit of measurement (a probability value or HSI-type score). Prime black bear habitat was defined as areas with habitat favorability values >70% for both models.

We used the GIS environment to generate four classes of highway crossing/habitat linkage zones:

- Class I – sections of TCH crossing prime black bear habitat extending up to 100m on both sides of the highway.
- Class II - sections of TCH crossing prime black bear habitat extending over 100m on both sides of the highway
- Class III - sections of TCH, $\geq$250m away from any permanent human development, nested within the Class II linkages, and within the areas conducive to cross-valley movement. This class was interactively mapped using the ortho-photographs and the DEM of the area.
- Class IV - sections of TCH not directly crossing the prime black bear habitat but having the prime black bear habitat within no more than 700m on both sides of the highway.

Data analysis

We tested each of the linkage models using a set of empirical black bear crossing and mortality points. Crossing locations were defined as the location on the TCH connecting a straight line between consecutive radiolocations on opposite sides of the road and obtained within 24 hours. Mortality locations came from the BNP wildlife mortality database (Banff National Park, unpublished data). We tested whether black bear empirical crossing and mortality points were randomly distributed with respect to their proximity to linkage zones. We generated random highway crossings, equal in size to the empirical data, and calculated the distances from both sets of points to the Class III and IV linkage zones. We repeated the calculations for each model. We used the kappa index of agreement (KIA) to measure the similarity between models and linkage areas (Campbell 1996). The KIA is a measure of association for two map layers having exactly the same number of categories. Indices range from 0.0 (no agreement) to 1.0 (spatially identical). Between map layers, values >0.75 indicate excellent agreement beyond chance; values between 0.4-0.75 demonstrate fair to good agreement; and values <0.4 indicate poor agreement (SPSS 1998). We used SPSS version 8.0 statistical package for all analyses (SPSS 1998). The software Idrisi was used to measure the KIA (Eastman 1997).

Multi-scale, Regional Movement Models

Habitat model

We modeled regional scale movements of four large mammals species (black bear, grizzly bear *U. arctos*, moose *Alces alces*, elk *Cervus elaphus*) and identified their potential linkage areas across the TCH. These species were selected: 1) because of their long ranging movement patterns and potential for interactions with transportation corridors in the study area (Woods 1991, Noss et al. 1996, Child 1998), 2) sufficient empirical location data were available to construct predictive spatial models of habitat suitability and 3) empirical crossing and mortality data were available to independently test the models.

To develop the habitat suitability models for the four species we first characterized their habitat using fifteen biophysical variables. Telemetry points were obtained from monitoring movements of the four species between 1980 and 2000 (Woods 1991, Hurd 1999; Gibeau 2000, M. Percy, unpublished data). Habitat suitability models were developed using a resource selection function as described earlier. We stratified the radiolocation data by the season (preberry [den emergence to 15 July] and berry [16 July to den entry] seasons for bears; summer [moose: May-October; elk: April-October] and winter [moose: November-April; elk: November-March] for ungulates).

Movement model

We based the movement component of the model on the least-cost movement principle and quantified the effects of slope angle and orientation (with respect to movement direction) on movement pathway. In mountainous areas, this principle is strongly affected by topography as it differentially influences effort required to move through space. We used the habitat probability surfaces for the habitat component of the movement model. In the absence of any empirical wildlife research we used an equation relating human walk time to the magnitude of slope angle in developing the topographic component:

$$Y = [-0.031((X^2)) - .025X + 1]^f$$

where *X* is the slope angle in degrees, Y is the walk time and *f* is a decay function relating the direction of the movement (with respect to the orientation of the slope) with change in an effort to move through space (Schneider and Robbins 1996).

We simulated the four species movement pathways by generating 11 potential entry and exit points located outside the Bow Valley and TCH transportation corridor. Entry and exit points were situated in high quality, valley bottom habitat, the most likely population source areas that animals would be expected to disperse from (Fig. 1).

We simulated movement pathways from selected combinations of entry and exit points in the regional study area. For any given pair of entry-exit points there were three iterations resulting in three different pathways. The first iteration simulates the least-cost movement pathway with no obstructions imposed. In the second iteration, the first pathway is blocked forcing the creation of a new pathway distinct from the original. In the third iteration, the first two pathways are blocked and an alternative route taken. These three distinct model runs can be thought of as producing the primary, secondary and tertiary movement pathways. This multiple iteration approach allowed a broad spectrum of potential movement pathways to be generated and quantified. For each species and season we simulated a minimum of 150 movement pathways and overall more than 1000 movement routes.

Highway crossing zone analysis

We examined the juxtaposition of the TCH with respect to the location of high quality habitat patches defined as areas with habitat probability classes exceeding 50 and 70 percent. We then extracted those sections of highway that dissect habitat patches extending more than 150m on both sides. For each of the mapped potential crossing zones we then calculated the number of zone intersections with simulated movement pathways, weighted by the crossing zone length.

Our method of identifying potential crossing zones often identified long sections of highway, which may be too generalized when recommending the placement of mitigating structures. We addressed this problem by modifying the model to analyze one-km long segments of highway. We sequentially numbered the segments starting from the eastern park boundary (east gate). Because the movement simulation is partially driven by the habitat quality aspect of the landscape, we considered this method equally valid in identifying potential wildlife movement, yet providing for better spatial resolution of the results. The maximum spatial resolution of the model, however, is not defined by adopting a specified length of highway, but by the resolution of the habitat and movement components of the movement simulation model. The questions we posed in this study were of regional scope and the length of the segments used in the analysis should reflect that. Given the 120m pixel size of habitat and topography layers and the obtained fit of the habitat models, we considered one kilometer to be the minimum segment length we could safely use.

Model testing

We tested the accuracy of highway crossing zones predicted by black bear and elk movement models with a set of empirical crossing and mortality points. There were too few crossing and mortality data from grizzly bears and moose to test their models. Empirical crossing locations were defined as described earlier for testing expert models; mortality locations were obtained from the BNP wildlife mortality database. Within the unfenced, unmitigated section of TCH we tested whether empirical crossing and mortality points were randomly distributed with respect to the distance to the predicted crossing zones created by the models. We generated a random set of highway crossings/mortalities equal in size to the empirical set and calculated the distances from both sets of points to the predicted wildlife crossing zones, individually per model stratified into 1) moderate-to-high and 2) high crossing frequency zone classes.

Within the fenced part of the TCH we assessed the congruence of current crossing structure placement with respect to the predicted regional movement patterns by plotting their location on the maps with the cumulative four species crossing frequencies by one-km segments. We also plotted their position on graphs showing this information with the total number of times the four large mammal species have been detected using the crossing structures during the last four years (Clevenger and Waltho 2000, A. Clevenger, unpublished data).

From the movement simulations, we identified the potential locations for highway mitigation, such as wildlife crossing structures, on the unfenced phase 3B section of TCH by plotting the pathway crossing frequencies by one-km TCH segments. We contrasted the predicted crossing frequency patterns on the mitigated (fenced) and unmitigated (unfenced) section of TCH, and examined the spatial pattern of high frequency predicted crossing zones.

Results and Discussion

Expert-Based Linkage Models

Empirical model

We generated the most parsimonious model by using eight variables. Overall, the DFA produced a sound statistical model. The high canonical correlation coefficient (0.755) indicated that the DFA was strong and discriminated well between the groups. Also, the Wilk's Lambda was low (0.43) denoting a relatively high discriminating power of DFA. The overall cross-validated classification accuracy was 87%. The model correctly classified 79% of the radiolocations into prime black bear habitat.

Model testing

Each of the linkage models was tested using a set of 37 empirical black bear crossing and mortality points. We found no statistical difference between the empirical crossings and random locations ($P > 0.05$), suggesting that Class IV linkages were a poor predictive tool for mapping cross-highway movement. There were significant differences between the distance from the empirical points and random locations to the Class III linkages. Empirical bear crossing and mortality locations were significantly closer to Class III linkages than expected by chance for the empirical model ($P = 0.018$), the expert opinion-based berry season model ($P = 0.027$), and the expert literature-based model ($P = 0.005$). Distances from the empirical points to the Class III linkages for the expert opinion-based pre-berry season model were not significantly different from the random locations ($P = 0.10$).

Of the Class III linkages, both seasonal expert opinion-based models had more linkage zones and were on average smaller in length compared to the empirical and expert literature-based model linkage zones (Table 1). When compared to the empirical model, there was a relatively strong correlation with the expert literature-based model (KIA = 0.662). The expert opinion-based pre-berry season and berry season models were only fair (0.416) to moderate (0.569) in agreement with the empirical model.

Table 1
Description of Class III linkages[a] of empirical and expert models.

Model	n	Minimum length (km)	Maximum length (km)	Total length (km)	Average length (km)
Empirical	11	0.20	2.70	8.6	0.78
Expert literature	9	0.30	1.90	6.3	0.70
Expert opinion Preberry	17	0.13	0.93	5.7	0.33
Expert opinion Berry	18	0.08	0.72	4.7	0.26

[a] Identified as segments of Trans-Canada highway (TCH) ≥250m away from any permanent human development, found within the Class II linkages and within the areas conducive to cross-valley movement. Class II linkages were segments of TCH crossing prime black bear habitat surpassing 100m on both sides of the road.

The expert literature-based model was most similar to the empirical model, both in the results of the statistical tests and the description of the Class III linkages. We compared the expert models and empirical model in terms of the level of juxtaposition of both the prime bear habitat maps and the Class II, III and IV linkage zones (Table 2). The expert literature-based model was consistently more similar to the empirical model than either of the two expert opinion-based models. Class III linkages for all three expert models had the greatest similarity with the empirical model. Among the expert models, the literature-based model had the strongest correlation with the empirical model. Expert opinion-based models ranged in KIA measures from 0.02-0.44, while expert literature-based models varied from 0.25-0.55.

Table 2
Kappa index of agreement[a] of the empirical black bear habitat model with expert opinion-based models and expert literature-based model.

Expert models	**Empirical model**		
	Class II[b]	**Class III[b]**	**Class IV[b]**
Expert literature	0.427	0.556	0.253
Expert opinion - Berry	0.368	0.379	0.362
Expert opinion - Preberry	0.324	0.441	0.027

[a] Measure of association for two map layers with exactly the same number of categories.
Indices range from 0.0 (no agreement) to 1.0 (spatially identical) (Campbell 1996).
[b] See Table 1.

The most noteworthy result from the exercise was not the low performance of the expert opinion-based model, but the close proximity of the expert literature-based model to the empirical model. Our findings confirmed that the expert literature-based model was consistently more similar and conformed to the empirical model better than any of the expert opinion-based models. These results were based on the test of distribution of the empirical points from actual crossing and mortality locations in relation to the linkages, the descriptive characteristics of the Class III linkages, the measure of agreement between models, and measure of agreement between model linkage zones.

We explain the poor predictive power of the pre-berry expert opinion-based model being attributed to an overestimation of the importance of riparian habitat to the preberry habitat model, as compared to the opinions expressed in the literature. Another possible explanation is that the expert literature model is based on an analytical process (data collected, statistically analyzed and summarized), whereas the expert opinion model is based on information taken from how experts perceive attributes from memory and experience. Further, the fact that only 35% of the empirical black bear crossing and mortality locations were those of the preberry season may also have influenced how well it predicted linkage areas.

Multi-scale, Regional Movement Models

Habitat suitability models

Ten habitat suitability models were generated from the four species data sets. The overall cross-validated classification accuracies from the DFA and the habitat model validation tests using retained data suggest that all of the models showed a reasonably good fit with the empirical data. Overall cross-validated classification of models ranged from 66-86%. The median percent habitat probability value of tested points varied from 64-84%.

A noticeable feature of the grizzly bear berry season habitat probability maps was the assignment of the relatively low probability values to the Bow Valley and other major valleys in the study area. Although not a surprising result, this map contrasts with research that indicates valley bottoms to be of high value to grizzly bears (McLellan and Hovey 2001). We explain this discrepancy as a difference between the realized (actual use as influenced by human disturbance) and potential or unrestricted use of the landscape. We believe the distribution of aerial locations represents the former and better describes bear movements in the study area.

We could not produce a discriminating function to successfully separate grizzly bear preberry season aerial locations (canonical correlation = 0.05, cross-validated classification = 56%), therefore we focused on ground-based radiolocation data. We recognize the bias inherent with ground locations, however, compared to the spatially sparse aerial locations, ground locations more explicitly capture the pattern of habitat use around the linear infrastructures we investigated.

Model fit, sampling and uncertainties

When analyzed in conjunction with the distribution of the radiolocations used to build the discriminant functions, it becomes apparent that the predictive aspect of the nine models were inversely correlated with the spatial extents of the telemetry points, or conversely, the more spatially focused the points resulted in a higher fit of the resultant model ($R^2 = 0.658$).

The available radiolocation data more accurately depicted habitat use patterns and the locally important spatial variables were included in building the discriminant function. We recognize the apparent trade-off between the models. The theoretically more accurate, locally derived probability models may have less predictive power when applied on a regional scale, and the less accurate but more predictive regional models may be less predictive when applied locally. We considered our probability surfaces more than adequate for modeling regional-level wildlife movement patterns; however, we recommend caution if the models were to be applied to more localized issues.

Model testing and applications

Black bear and elk movement models were tested with a set of empirical crossing and mortality points. In the black bear model there was strong statistical evidence that the empirical bear crossing and mortality locations were closer to both high (Mann-Whitney U test, U = 390, $P = 0.009$) and moderate-high frequency crossing zones (U = 441, $P = 0.034$) than expected by chance. Similarly, empirical elk winter crossing and mortality locations were closer to the high frequency crossing zones than random points (U = 360, $P = 0.019$), but there was no difference between empirical points and the moderate-high frequency crossing zone locations ($P = 0.192$). We concluded that the model and empirical data correlated well.

We plotted the number of cumulative primary pathways and total pathways (primary, secondary and tertiary) in relation to the existing wildlife crossing structures. Primary pathway crossing frequencies on 0-24km of the TCH showed a close association with the empirical data for wildlife crossing structure use by the four large mammal species (Fig. 2A). The most prominent crossing locations were at 5-Mile, Cascade and East Gate underpasses. The Duthil underpass did not coincide well with the predicted crossings as there was more observed use than predicted use by the models. Predicted primary crossings were high in two locations without crossing structures: between Duthil and Powerhouse underpasses and in the Cascade area. We found a close association between total pathway crossing frequencies and observed crossing structure use on the same section of highway; however, it was not as strong as the primary pathway crossings (Fig. 2A). Greater predicted crossings than empirical crossings occurred at East Gate and Carrot Creek. High predicted total crossings in areas without crossing structures occurred between Duthil and Powerhouse underpasses, at Cascade, and west of Vermilion underpass.

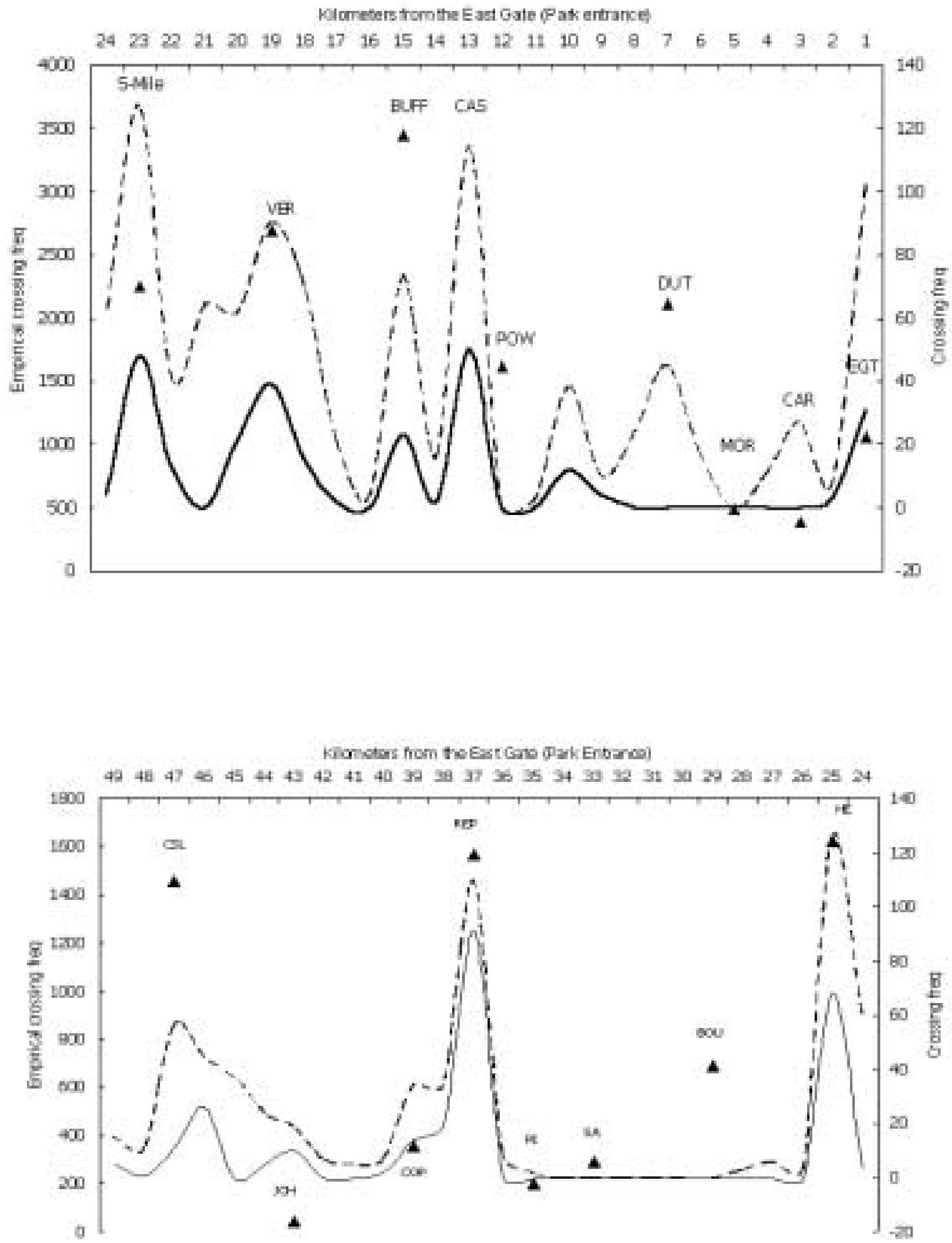

Fig. 2. The frequency of cumulative primary (solid line) and total pathways (intermittent line) in relation to empirical crossing data on wildlife crossing structure use on (A) 0-24km and (B) 25-50km, of the Trans-Canada highway in Banff National Park, Alberta. Wildlife crossing structures: EGT = East Gate, CAR = Carrot Creek, MOR = Morrison Coulee, DUT = Duthil, POW = Powerhouse, CAS = Cascade, BUFF = Buffalo, VER = Vermilion, 5-Mile = 5-Mile bridge, HE = Healy, BOU = Bourgeau, SA = Sawback, PI = Pilot, REP = Redearth overpass, COP = Copper, JOH = John, CSL = Castle.

Primary pathway crossing frequencies between 25-50km also showed a strong association with the empirical data for wildlife crossing structure use (Fig. 2B). There were no highway segments with greater predicted than empirical crossings, nor were there any high predicted crossings in areas without crossing structures. Total pathway crossing frequencies compared to crossing structure use were nearly identical to the primary pathway crossing frequencies. In the three crossing structure complex area comprised of Wolverine overpass, Wolverine and Bourgeau underpasses, there was a relatively high amount of passage by the four species although there were no predicted primary or total crossings. This suggests that the Wolverine overpass and other wildlife crossing structures can be functional and serve a vital purpose despite being located in an area with low expected highway crossings. There were no predicted crossings between Healy underpass and Redearth overpass. Thus, the lack of simulated pathways in this part of the valley might imply the highway is in a good location to minimize disturbance to wildlife movements.

The models identified several areas along the 0-50km mitigated section of highway that were outstanding in terms of their importance for wildlife movement. In order of importance, the highest predicted crossing areas based on the number of primary pathways were in the areas of Redearth overpass, Healy, Castle, Cascade underpasses and 5-Mile bridge. The number of total pathways were greatest at Healy, 5-Mile, Cascade and Redearth overpass. These predicted crossing locations were in agreement with the rank-ordered importance of wildlife crossing structures as indicated by usage by all wildlife species currently being monitored (A. Clevenger, unpublished data).

At the individual species level, the pattern of movement across the entire length of the TCH (0-86km) as predicted by the six individual species movement models (summer and winter included) was consistent, varied slightly, and overall was similar to that described above at the group level. To assess potential wildlife crossing structure placement along the unmitigated section of the TCH (50-86km) we weighted equally the four species and utilized the cumulative movement patterns generated by the models. We examined the intersection of primary and total pathways with the highway. Seven locations were indicated by high frequencies of predicted primary crossings across the highway (Fig. 3). The most prominent crossing locations were east and west adjacent to the Lake Louise townsite followed by highway 93 North junction and Wapta Lake. Nine locations were identified by the total predicted crossings on the highway. The greater number of pathways resulted in a finer resolution of key crossing zone locations and more of them. The average distance (± sd) between the nine locations was 3.3 ± 1.4 km.

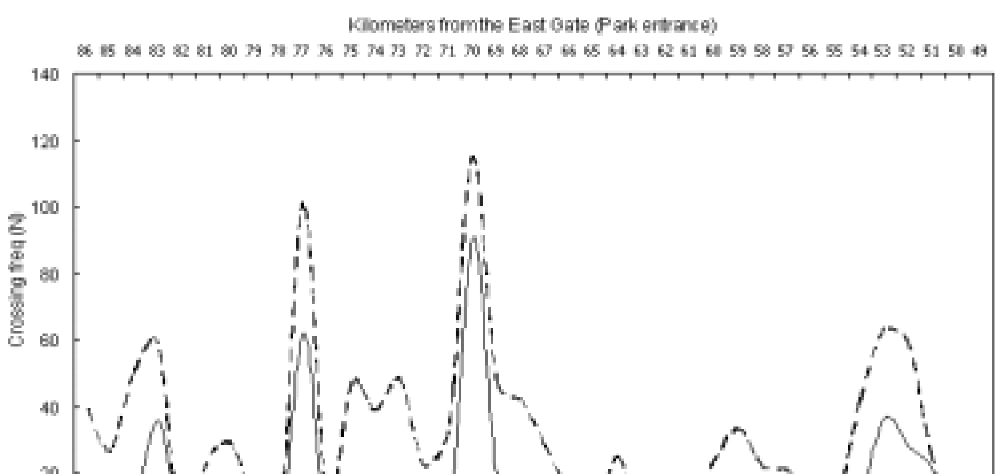

Fig. 3. Frequency and distribution of primary (solid line) and total pathways (intermittent line) generated by all movement models on the 50-86km, unmitigated phase of the Trans-Canada highway.

For comparative purposes we examined the intersection of primary and total pathways on the mitigated section of TCH (0-50km). There were a total of 13 locations indicated by high frequencies of predicted total crossings across the highway (Fig. 2A and 2B). Nine crossings were on phase 1 and 2, while four crossings were on phase 3A. The average distance (± sd) between the predicted crossing zone locations was greater on phase 3A (25-50km) than phase 1 and 2 (0-25km) (5.5 ± 5.0km vs. 2.7 ± 1.1km). The average distance between the 24 wildlife crossing structures on both phases is 2.1 ± 1.3km.

There are few methodological approaches to identify the placement of mitigation passages along road corridors and even less ways to determine spacing. Crossing structure placement has generally been related to location, i.e. riparian corridors, wildlife travel or migration routes (Reed et al. 1975, Evink 1996). Primary linkages across roads for key species such as large mammals may be spaced at wide intervals, many times wider than most small- and medium-sized terrestrial vertebrate home ranges. A variety of animals use wildlife crossing structures (Bekker et al. 1995, A. Clevenger, personal observation); however, passage planning based on our large mammal movement models would not represent the habitat connectivity needs of smaller fauna. Therefore, to enhance landscape connectivity for as many species and ecological processes as possible, we recommend that wildlife crossing structures be spaced at shorter intervals than indicated by our models.

We suggest a planning scheme that might consist of first, locating crossing structures in the area of key crossing zones as predicted by the models, and second, installing additional structures so that there is at least 1.5km between the crossing structures; this is a slightly shorter spacing between existing structures on the TCH. Our results also suggest that by providing additional crossing opportunities in areas not identified by the model output, the structures will be used if positioned and designed properly.

Conclusions

Expert-Based Linkage Models

There are several advantages to the expert-based techniques presented in our study. There are an assortment of GIS tools designed for model building purposes that are readily available today. GIS applications such as Idrisi (Clark University, Worcester, Massachusetts, USA), MapInfo Professional Software (MapInfo Corporation, Troy, New York, USA), and ArcView GIS (Environmental Systems Research Institute, Redlands, California, USA) are relatively inexpensive and easy to use. Idrisi has decision support procedures as a program module built into the geographic analysis system. Remotely sensed data, digital land cover data and habitat suitability maps are increasingly accessible, frequently updated and refined for individual users or government agencies. Further, empirical data from field studies of many wildlife species, particularly game species, are obtainable in most countries where road mitigation practices are implemented. The use of the Saaty's pairwise comparison matrix requires little training and ensures consistency in developing relative weights in the development of the expert-based models. This procedure is readily available in the Idrisi software package.

Identifying linkage areas across road corridors using both expert model types (opinion- and literature-based) we have presented can provide a useful tool for resource and transportation planners charged with determining the location of mitigation passages for wildlife when baseline information is lacking and when time constraints do not allow for pre-construction data collection. Regarding the latter, we spent approximately two months developing the four models. More than half of that time was dedicated to developing the more complex, data intensive empirical black bear habitat model. We do not advocate modeling linkage zones using exclusively expert information if empirical data are available. However, we do encourage others with empirical data for model building and testing to develop expert models concurrently so that their findings may be contrasted with ours.

Multi-scale, Regional Movement Models

We recognize the shortcomings of the movement models presented. Because of the large spatial scale (pixel size = 120m) our models were generalized and predicted crossing locations had a wide margin of error. Nevertheless, we feel they can be valuable tools for identifying locations of important bottlenecks or fracture zones at a regional scale. Once these are identified (as suggested above), smaller, local-scale features of the landscape, including possible wildlife concerns and engineering constraints, will need to be contemplated in order to select the most appropriate location for mitigation passages (Bekker 1998).

In this exercise we equally weighted the four species. However, some management strategies may give higher precedence to key species of conservation concern (Mills et al. 1993, Lambeck 1997). Adjustments can be made to the models by weighting individual species according to management priorities. An appropriate species weighting procedure is the pairwise comparison method (Saaty 1977, Eastman et al. 1995) shown earlier. Finally, we underscore the wide applicability of such models to other resource management and transportation planning issues, such as railways, trails, other road systems. The models could be applied to other human infrastructure, such as railways, trails, or other road systems.

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Biographical Sketch: Anthony Clevenger is currently directing a five-year research project addressing the ecological effects of roads on wildlife populations in the Central Canadian Rocky Mountains. The investigation focuses primarily on the Trans-Canada highway in Banff National Park, its permeability for wildlife, and effects in terms of wildlife mortality, movements, and habitat connectivity in the Bow River Valley. The study will be completed in April 2002.

Anthony Clevenger received a B.Sc. degree in Conservation of Natural Resources from the University of California, Berkeley, a M.Sc. degree in Wildlife Ecology from the University of Tennessee, Knoxville, and a Ph.D. in Zoology from the University of León, Spain. He has been an adjunct assistant professor at the University of Tennessee, Knoxville since 1989, and at the University of Calgary since 1998. In August 2001, he has become a member of the U.S. National Academy of Sciences, National Research Council committee to study the effects of highways on natural communities and ecosystems.

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ODOT'S SALMON RESOURCE AND SENSITIVE AREA MAPPING PROJECT: A HIGH-TECH PROCEDURE FOR OBTAINING BIOLOGICAL RESOURCE DATA FOR RESOURCE PROTECTION AND REGULATORY COMPLIANCE

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Abstract: In response to increasing environmental concern and regulation, the Oregon Department of Transportation (ODOT) hired Mason, Bruce & Girard, Inc. (MB&G) to develop a Geographic Information System (GIS)-based sensitive resource inventory along nearly 6,000 miles of state highway. The inventory was named the Salmon Resources and Sensitive Area Mapping (SRSAM) project. The primary purpose of the SRSAM project was to provide accurate resource protection maps to roadway maintenance crews so that their activities (e.g., mowing, pesticide applications, etc.) do not harm these resources. Some of the high-technology features used to expedite the development of a comprehensive resource inventory for such a large geographical area included: 1) ortho-rectified, color infrared digital imagery with 2-foot pixel resolution, 2) on-screen digitizing of obvious sensitive resource features, 3) road-side capture of sensitive resources using laser rangefinders linked to vehicle-mounted real-time Global Positioning System (GPS) units, and 4) sophisticated GIS modeling. We were able to accurately determine the locations and attributes of twelve sensitive resource categories or "fields" with an error rate of less than one percent. Resource data gathered through this project were tied to ODOT's Linear Referencing System (LRS) and converted to easy-to-read straight-line maps showing resource features for use in ODOT's maintenance and planning activities. A second series of straight-line maps was produced identifying Restricted Activity Zones. These maps are used to facilitate better management of sensitive resources located within Oregon's transportation corridors.

Introduction

In the wake of Oregon Governor Kitzhaber's 1995 Executive Order to Oregon state agencies to protect and recover salmon and steelhead populations state-wide, and following the listing of numerous such fish stocks as "threatened" under the Federal Endangered Species Act (ESA), the Oregon Department of Transportation (ODOT) realized that it had both an obligation and an opportunity to contribute significantly to the protection and enhancement of aquatic ecosystems. To carry this out, ODOT's Maintenance and Operations, Environment, and Transportation Inventory and Mapping Sections identified a need for the following:

- An inventory of sensitive natural resources, and
- A set of maps that describes the resources and the restrictions to maintenance activities needed to minimize impacts to them.

ODOT recognized that a traditional field-intensive natural resource inventory along the thousands of miles of highway under its jurisdiction would be tremendously expensive and time-consuming. Not having the resources available in-house, ODOT sought a contractor to acquire the needed natural resource information in a more expedited fashion.

ODOT contracted with Mason, Bruce & Girard, Inc. (MB&G) in 1999 to collect biological resource information inside the state transportation corridor along nearly 6,000 miles of highway across four ODOT regions (Regions 1, 2, 4, and 5). The methodology developed by MB&G for the SRSAM project utilizes the latest spatial data collection techniques to maximize efficiency. The project employed digital aerial orthophotography, GIS, and GPS and laser surveying technology.

Pilot Project

ODOT's first large-scale attempt at collecting natural resource data along transportation corridors occurred in 1998 with mixed results. This effort occurred along approximately 1,200 miles of highway in Region 3 (southwest Oregon), and involved biologists driving the state highways and visually assessing the presence or absence of numerous environmental features (e.g., streams, wetlands, riparian zones, sensitive species habitat, etc.) for each 52-foot (i.e., 0.01-mile) highway increment. Data were attributed directly onto ODOT's

LRS and used to generate Resource Maps showing the locations of sensitive resources that ODOT maintenance crews needed to avoid.

While these data were useful, the collection process proved problematic. The two-person crews averaged less than 20 miles per day. Additionally, since the inventory was done visually, classification of resource features that varied between the 0.01-mile markers (e.g. land cover) became a subjective interpretation of the data recorder. Indeed, quality control checks conducted by ODOT biologists found a high degree of variability among the Region 3 data, necessitating follow-up fieldwork to correct the errors. Finally, since the data were recorded in such an unconventional format, their utility and application beyond this particular project was extremely limited.

Methods

The approach employed by MB&G for the SRSAM project in Regions 1, 2, 4, and 5 was to use the latest imagery, spatial modeling, and surveying technologies to maximize data quality and collection efficiency. ODOT identified 12 natural resource features, or "fields," that MB&G was required to map for the SRSAM project. These fields varied from streams, wetlands, or other resource features that could be readily observed, to those that were dependent upon the spatial relationships of two or more variables and thus required GIS modeling to delineate. A multiphase process involving digital aerial orthophotography and GIS guided the fieldwork and the GPS verification and collection of base layers. This, in turn, supplied the spatial data used to generate more complex modeled fields.

Imagery

The acquisition of digital high-resolution imagery was integral to the approach used for this project. Imagery acquisition was subcontracted to Space Imaging, and was achieved using fixed-wing aircraft. Color infrared imagery (red, green, near infrared) was chosen for this project for its ability to clearly highlight vegetation and water. Each image consisted of 2000 x 3000 pixels, with a single pixel representing two feet on the ground. As the digital camera acquired the imagery, GPS and inertial measurement equipment on the aircraft collected exact location, attitude, and altitude information. The images could therefore be orthorectified, or geometrically corrected for terrain variation. The individual images were merged to create a geo-referenced mosaic, and incorporated into the GIS. Imagery extended a minimum of 1,000 feet out from both sides of the centerline of the highway to ensure adequate coverage for photo interpretation.

This digital imagery was used throughout the various stages of the natural resource inventory process. Primarily, the imagery allowed the team to assess the project area before going into the field. Existing features were confirmed and spatially reregistered and previously unmapped features were identified, attributed, and flagged for confirmation by the field team. Imagery was also used in the post-field processing phase to confirm and delineate new features identified by the field team.

Spatial Modeling

Base Data Generation

The SRSAM project utilized existing digital databases as a base for the mapping. ODOT maintains 1:24,000 Computer-Aided Design (CAD) files for the state. These contain detailed information on rights-of-way, landmarks, hydrology, and wetlands, among other features. Stored in quadrangles, appropriate features were extracted from these CAD maps, converted to ArcInfo GIS coverage format, and mosaiced together for each of the four ODOT regions. Recognizing that more recent and detailed resource inventories had been conducted across the state, the project team gathered all other relevant and available GIS data for the state. For example, hydrology and wetland data were acquired from the National Wetlands Inventory, Bureau of Land Management, U.S. Forest Service, and U.S. Geological Survey, among others. The data acquired through this outreach effort were collectively referred to as "auxiliary data."

After compiling the hydrology and wetlands data into GIS coverages, they were overlaid on the digital orthophotography for photo interpretation. The hydrology and wetland features were verified and reregistered to match the imagery. Features apparent on the imagery but not shown on the auxiliary data were digitized on-screen and attributed. Existing features in question were flagged for later verification by the field team.

Transportation Network

The existing GIS transportation network (i.e., the digitized highway system) was originally mapped by ODOT at a scale of 1:100,000. While the network had since been positionally corrected in most of the urban areas to a larger scale, the 1:24,000 base data still did not match properly. Consequently, GIS analysts reregistered the transportation network to match the digital orthophotography. It was crucial to duplicate the topology of ODOT's highway centerline to maintain the proper routing used for determining mileage and side of road (i.e., left or right).

As some environmental features were differentiated by their proximity to the road, the project also required detailed coverages of the "transportation corridor" and "clearzone" for modeling purposes. The transportation corridor is defined as the area extending out 500 feet on either side of the highway centerline. By contrast, the clearzone is the area along the highway where vegetation is actively managed (through mowing, spraying, etc.), and has a narrower but highly variable width.

Sensitive Species Information

One of the project's goals was to provide data that would minimize impacts to sensitive, threatened, or endangered species. To meet that goal, data from the Oregon Natural Heritage Program (ONHP) were spatially enabled from sighting records and converted into an ArcInfo coverage. ONHP maintains the state's largest database of threatened and endangered species. It contains over 20,000 records of endangered plants and animals, including historical sightings. This ONHP-derived GIS coverage of sensitive species locations was then augmented with current project-specific sensitive species information as obtained from interviews with state and federal biologists with local knowledge of the four ODOT regions. Information obtained from interviews was compared to the ONHP GIS data, and any new data were digitized into the GIS and attributed according the biologists' records.

Field Data Collection

A two-person team performed the fieldwork. The field vehicle included a laptop computer loaded with both the imagery and GIS data derived from the pre-field effort, a GPS unit, and a laser rangefinder. Using a real-time GPS feed and a customized ArcPad interface, the vehicle location could be continuously displayed on the computer screen and superimposed on the GIS data and imagery. This allowed the field crew to focus their efforts on verifying the on-screen display of GIS data that had been developed during the pre-field processing stage rather than collecting all features in the field. Thus, rather than the traditional and time-consuming role of data capture, the field crew for this project focused on data verification. Those few natural resource features that had been missed during the pre-field process were captured by the field crew using the GPS unit and the laser rangefinder. The field crew averaged more than 50 miles per day using this approach.

Feature Modeling

Prior to the project's inception, ODOT planners and biologists defined 12 specific fields of information that were to be collected for this project (Table 1). These fields were identified as being critical for determining whether ODOT's maintenance and construction activities would adversely affect sensitive natural resources. While these 12 fields were distinct, many were highly correlated. In addition, several of the fields were dependent upon the spatial relationships of one or more resource features, or upon the spatial relationship of resource features relative to the transportation system. As a result, the project team's approach was to collect and map a few key fields and derive the remaining fields through GIS modeling.

Project GIS analysts developed a preliminary set of algorithms to derive the modeled fields. These were reviewed by ODOT biologists, refined, and finalized. Ultimately, 7 of the 12 fields collected for the project incorporated GIS modeling.

Table 1
Method of Capture for the 12 Sensitive Resource "Fields", SRSAM Project.

Field Name	Method of Capture
Dominant Land Cover Type	Imagery
Fill Slope in Riparian Zone	Model
Riparian Overstory Condition	Model
Late Successional Habitat	Imagery
Riparian Zone Integrity	Model
Riparian Zone Boundary	Model
Salmonid Presence	Auxiliary Data
Sensitive Resource Areas	Auxiliary Data + Model
Spawning/Rearing Areas	Auxiliary Data + Model
Tributaries	Imagery + Field Data + Model
Wetlands	Imagery + Field Data + Model
Wildlife Trees or Snags	Field Data

Dynamic Segmentation

After deriving the 12 fields, presence/absence values for each field had to be related back to ODOT's routed transportation network. Utilizing custom programming in combination with ArcInfo's Dynamic Segmentation model, point, line, and polygon features associated with each field were related back to ODOT's routed transportation network in 0.01-mile increments. Presence/absence values for sensitive resource features were generated separately for both the transportation corridor and the clearzone. Data were exported in an ASCII format for use in ODOT's custom straight-line mapping program to produce the Resource Maps and Restricted Activity Zone (RAZ) Maps.

Accuracy/Quality Control

The project team conducted field tests throughout the course of the project. Accuracy was assessed at two levels: whether or not features were missed, and the positional accuracy of recorded features. Presence/absence determinations of sensitive resource features were at least 99 percent accurate. Actual positional accuracy of features in the GIS was within 10 feet at least 95 percent of the time. This far exceeded the contract requirement of $\pm$ 52 feet (i.e., 0.01 mile).

Project Deliverables

Resource Maps

ODOT's Inventory and Mapping Section converted the ACSII text files into Resource Maps, which utilized the standard straight-line presentation format. These maps indicated, by 0.01-mile segments, where sensitive resources were present and whether they were on the left and/or right side of the road. These maps were prepared for ODOT biologists, planners, and maintenance managers.

Restricted Activity Zone Maps

ODOT's Inventory and Mapping Section also converted the ACSII text files into RAZ maps. These maps also utilized the straight-line presentation format. However, as opposed to the Resource Maps, the RAZ maps used a simple color-coding scheme of green and red to indicate, for each major -class of maintenance activity (e.g., surface and shoulder work, vegetation management, snow and ice removal, etc.), whether or not that activity should be restricted along the left and/or right side of a given 0.01-mile segment of highway. These maps were prepared for the ODOT maintenance crews and did not require any biological understanding to interpret.

GIS Data
The final GIS data generated from this project included coverages of hydrology, wetlands, land cover, old growth, wildlife trees/snags, and sensitive species locations. These GIS data were corrected with respect to position using the high-resolution imagery, and were field-verified. Additional GIS fields were generated thorough modeling of the spatial relationships of the fields to each other or to the transportation system. The resulting library of GIS data is a detailed environmental inventory of ecological resources throughout four of ODOT's five regions. In addition to their use in generating the Resource and RAZ Maps, these GIS data serve as a tremendous resource available to ODOT biologists, engineers, and planners who can more easily consider and address sensitive natural resource features when planning and designing transportation system improvements.

Imagery
The imagery acquired for this project consists of a series of ortho-corrected, high-resolution, color infrared images mosaiced together to create a region-wide network. This imagery has wide utility within ODOT for project planning and environmental scoping purposes. For example, from their computers ODOT biologists will be able to access the imagery and GIS data for a given highway segment 300 miles away and perform "virtual environmental scoping" to assess the extent to which various environmental resources or permitting requirements may affect a certain project.

Conclusions
The data and ancillary products from the SRSAM project have enabled ODOT to minimize the potential for violations of the Federal ESA and the Clean Water Act. Agreement to produce the Resource and RAZ Maps was key to ODOT negotiating a programmatic ESA permit for standard maintenance operation activities with the National Marine Fisheries Service (NMFS). Specifically, ODOT received an exemption under 4(d) of the ESA allowing crews to perform routine road maintenance without having to consult with NMFS on individual actions.

For approximately the same cost as a traditional field-intensive natural resource inventory, ODOT has used a more modern, high-tech approach with numerous benefits over the traditional approach, including:

- Better Quality Data: Compared to the pilot project, the SRSAM project resulted in fewer classification errors. The method is repeatable and much less subject to individual interpretation.
- Larger Analysis Area: The imagery provided the project team with a lookdown view. Sensitive resources could therefore be assessed as far as 1,000 feet from the centerline without concern for access/trespass issues.
- Ancillary Products: As described in the preceding section, the GIS data and imagery will have many uses to ODOT beyond the scope of the SRSAM project.
- Easy Updates: With the imagery now in hand, the GIS base data already compiled, and the modeling routines written, future updates can be easily made.

The limits to this high-tech approach to natural resource inventory are still being explored. Already in development by MB&G and Space Imaging is an Internet-based application to deliver these data to the desktop. A likely future application is the integration of these data into maintenance vehicles where, for example, herbicide application would be controlled by a computer accessing the SRSAM data with a real-time GPS feed, which would automatically turn the spray boom on and off as needed to avoid impacting sensitive resources such as streams, wetlands, or rare plant populations.

As these technologies continue to improve and become integrated into everyday life, the call for improved data will only increase. Endangered species, wetlands, and other environmental permitting issues continue to drive the need for better resource data. With constrained budgets, agencies will be called upon to do more with fewer resources. The adoption of innovative techniques and emerging technologies will only aid in meeting mission statements.

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Biographical Sketches: Robert Carson is the manager of the Environmental Services Group at Mason, Bruce, & Girard, Inc. He holds a B.S. degree in Forestry and a M.S. degree in Wildlife Resources, and has more than 20 years of experience conducting environmental studies and assisting clients with regulatory compliance and environmental permitting. The focus areas of Bob's practice include wildlife biology, wetland ecology, and Endangered Species Act and wetland permitting. A majority of his project experience has been with local, state, and federal transportation agencies.

Jason Neil is the manager of the ODOT Project Coordination Unit, which is responsible for NEPA compliance and environmental permitting for ODOT projects statewide. Prior to his current management position, he served as a senior environmental project manager for ODOT. Jason has also worked for the U.S. Forest Service and the Colorado Division of Wildlife. He received his Bachelor of Science degree in Natural Resource Management, and has over eight years of natural resource management experience.

Robert Kirkman has nine years of experience in GIS and Remote Sensing in both Environmental Sciences and Urban Planning. He has his Bachelor of Arts degrees in Geography and Environmental Science. Prior to joining MB&G, Robert was a GIS Specialist at the Metropolitan Regional Government (Metro) in Portland, Oregon. He has also conducted wetland research for the National Wetlands Research Center in Lafayette, Louisiana. Robert currently serves as GIS analyst and manages the GIS department at Mason, Bruce, & Girard, Inc. He provides expertise on integrating GIS in field efforts, database development, and environmental modeling.

USE OF A GEOGRAPHIC INFORMATION SYSTEM TO IDENTIFY ENVIRONMENTAL CONSTRAINTS FOR LARGE-SCALE PROJECTS: INTERSTATE 70 TRANSPORTATION CORRIDOR

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Abstract: The Missouri Department of Transportation (MoDOT) employed ArcView 3.1 software from ESRI through an enterprise-wide Geographic Information System (GIS) to identify environmental constraints to expanding I-70. Geographic information on historic buildings and bridges, archaeological sites, cemeteries, roads, wetlands and streams, floodplains, public lands, and sensitive biological resources was used to produce a series of coverages along I-70 from Kansas City to St. Louis. While documenting the feasibility of improving I-70, MoDOT considered the following issues: the availability of resources for geographic data, the level of detail and extent of coverage needed for the project study area, and the techniques for updating topographic map information. MoDOT produced a map in 36 plates to cover the project study area and found two areas along the facility with a concentration of environmental constraints. GIS and the resulting feasibility study were used to help MoDOT determine that a tiered environmental document was needed to evaluate alternatives to expanding I-70.

Introduction

The Missouri Department of Transportation (MoDOT) conducted a feasibility study of Interstate 70 (I-70) to investigate and evaluate the deficiencies in the existing interstate facility and to recommend strategies for eliminating those deficiencies. Comments from the traveling public about congestion and pavement conditions on I-70 made it apparent that the facility is not adequate as it exists today. MoDOT studied and assessed the conditions of the pavement, bridges, and interchanges; traffic patterns and projections; and the socioeconomic conditions and cultural and environmental resources. The goals of the study were to 1) project the future needs of I-70, 2) analyze a range of possible solutions to deficiencies, and 3) make recommendations on viable alternatives that provide transportation service commensurate with social, economic, and environmental impacts. MoDOT is reporting on the portion of the study involving the use of an enterprise-wide Geographic Information System (GIS) to identify environmental and cultural constraints for this large-scale project.

I-70 Background

I-70 crosses ten states, beginning in Maryland and ending in Utah. One of the longest interstate routes in the country, the facility connects St. Louis with Kansas City. The Missouri portion of I-70 is 251 miles long. Missouri began work on I-70 in August 1956 (completing it in 1965) as the first state to start construction on the interstate system. I-70 carries more traffic daily than any other roadway in the state and has far exceeded the expectations of a twenty-year design life. Excepting the reconstructed portions, the Missouri section of I-70 is between 34 and 43 years old.

Methods

MoDOT studied a 194-mile corridor extending from the eastern boundary of Kansas City to the western boundary of St. Louis. For the through lanes on the majority of the facility, MoDOT's environmental and cultural teams looked at a study area extending 100 feet from the outer edge of the pavement. This distance was believed to be adequate to expand I-70. The teams extended the study area width to accommodate the latest design safety standards for reconstructing the interchanges. MoDOT identified standard environmental and cultural resources typically considered for National Environmental Policy Act (NEPA) documents and environmental permits. These included historic bridges and buildings, cemeteries, archaeological sites, hazardous waste sites, wetlands and streams, sensitive biological species, floodplains, public lands, and socioeconomic conditions.

MoDOT used ArcView 3.1 software, a product of ESRI, to produce a map in 36 plates. MoDOT selected a GIS-based project for the savings in time and the ability to use the final product as a base for future environmental documents for I-70. In addition, the GIS product can be queried during the permitting and design phases of the project.

Geographic data sets and digital information were verified and customized to meet specific applications required for the project. The final map was projected in Universal Transverse Mercator (UTM) North America Datum (NAD) of 1983.

MoDOT used a 1:24,000 scale (24K) digital raster graphic (DRG) files created by the U.S. Geological Survey (USGS) as backgrounds for the plates. Originally created in NAD 27 by the USGS, the DRG were projected in NAD 83 in 1998 by the Transportation Management System at MoDOT. DRG maps are used as the source image during digitizing for spatial accuracy and control. Digitizing is a process whereby features from a paper map are converted into a digital format.

For cultural resource sites, GIS themes were created from point-source resources for archaeological sites, historic buildings and bridges, and other cultural sites. MoDOT used heads-up digitizing techniques on 24K DRG maps. Cemeteries were partially derived from Geographic Names Information System (GNIS), a 24K geodata set describing specific places of Missouri. The original information data set consisted of USGS Level 1 GNIS that was converted to NAD 83 by the Missouri Spatial Data Information Service (MSDIS). Cemeteries indicated on the DRG maps but not included in the GNIS coverage were added to the original GNIS data set using heads-up digitizing techniques.

MoDOT derived the water body data for this project from a 100K digital line graph (DLG) containing hydrography of Missouri counties. The original data were converted to ARC/INFO using the Spatial Data Transfer Standard and from NAD 27 to NAD 83 by MSDIS. The roadway data set was derived from TIGER/Line Files and modified by MoDOT in 1995.

MoDOT created the wetland layer from a 24K data set, National Wetland Inventory, available from the U.S. Fish and Wildlife Service. Data were available as 7.5ft by 7.5ft blocks containing ground planimetric coordinates of wetland point, line, and area features and wetland attributes. Original data were available in NAD 27 and converted to NAD 83 by MoDOT in 1999. Floodplain information, in a 24K data set known as Q3 flood data, was created from Flood Insurance Rate Maps published by the Federal Emergency Management Agency 1996 to present.

MoDOT used a 100K data layer first published by the Missouri Resource Assessment Partnership (MoRAP) to identify lands owned and leased by federal and state governments. MoDOT used a 24K data set containing point locations for threatened, endangered, or otherwise sensitive species and their habitats. This information, known as Heritage Database Information, is provided to MoDOT through a Memorandum of Agreement with the Missouri Department of Conservation.

MoDOT Tools

MoDOT uses a high-end GIS workstation, GPS receiver and data logger, and plotter on these types of projects. In addition, digital cameras, scanner, CD writer, and laptop computers are used for GIS projects. MoDOT uses ESRI's ARC/Info and ArcView 3.1 for GIS development and Pathfinder Office for field data processing. Microstation of Bentley Systems, Inc., and a photo editing software are also employed for map development.

MoDOT uses a variety of data sets, which can be classified as "canned," "fresh," or "reconstituted." Canned or existing data sets are good screening tools over large areas. These are widely available from universities, government agencies, and businesses. The drawbacks to canned data sets are that the data are static and the accuracy must be verified by other means.

Fresh data are collected with GPS when no existing data are available for a location. This affords up-to-date accuracy and allows precise delineation of features. Since fresh data sets may require field collection, creating them can be very time consuming.

Reconstituted data are created from existing data sets and updated for specific locations or features. Reconstituting data allows for up-to-date accuracy, allows precise delineation of individual features, and requires less time than fresh data collection. Producing reconstituted data may limit the use of a data set to only a specific project.

Results

MoDOT's use of GIS provided information on cultural and environmental parameters identified as important in assessing the feasibility of I-70 improvements. Thirty previously recorded archaeological sites were identified within the study area. A record search of the National Register of Historic Places revealed two architectural resources. A record search and field survey revealed 21 bridges 50 years or older. These bridges were generally part of the old Route 40, portions of which were incorporated into the "new" interstate as outer roadways. Three species listed as federally protected and two candidate species were identified. Two locations within the project corridor have a concentration of environmental constraints and are described next.

I-70 Crossing of Missouri River at Overton Bottoms

Overton Bottoms is in the Missouri River floodplain 10 miles west of Columbia, Missouri, where I-70 crosses the river on two, two-lane bridges. The remaining I-70 crossing within the floodplain at Overton Bottoms is on a fill section. During the floods of 1993 and 1995, considerable sand deposits and scour holes formed within the floodplain near the river crossing. The U.S. Army Corps of Engineers (USACE) subsequently purchased land in this floodplain and adjacent to the I-70 crossing with the intent of establishing wetlands and a wildlife refuge.

MoDOT has had formal contact with the USCAE and the land-managing agencies, the U.S. Fish and Wildlife Service and the Missouri Department of Conservation. These agencies are aware of the potential expansion of I-70 through the floodplain and indicate that this action could be acceptable. However, acquiring right-of-way at this location will involve compensatory wetland mitigation, public land purchase, and compliance with Section 4(f) of the Department of Transportation Act.

One federally protected and two candidate fish species are potentially found at the I-70 crossing (MDC 1999). The pallid sturgeon (*Scaphirhynchus albus*) is listed as endangered, and the sturgeon chub (*Macrhybopsis gelida*) and sicklefin chub (*Macrhybopsis meeki*) are candidate species. Informal consultation with the U.S. Fish and Wildlife Service will be required to determine whether any of these listed species could likely be affected by any proposed actions.

MoDOT identified one historic building in the area of the Missouri River crossing that is potentially eligible for listing on the National Register of Historic Places (NRHP). Although probably not yet 50 years old, the Les Bourgeois Winery may be culturally significant to the area and will require further investigation in subsequent studies.

The KATY Trail State Park, a rails-to-trails project developed by the Missouri Department of Natural Resources, will extend from Kansas City to St. Louis when it is finished. The trail is protected by Section 4(f) of the Department of Transportation Act. However, the trail is located under the bridge near the high bluff and the impact resulting from the expansion of I-70 would likely be minimal.

I-70 at Graham Cave State Park

The Graham Cave State Park area in Montgomery County, approximately 40 miles east of Columbia, Missouri, is also of concern to the expansion of I-70. A large rock commonly referred to as "slave rock" is located in the median of I-70. It is a widely held belief that the rock was once the site of slave auctions. Extensive research (MoDOT 1998) on the subject revealed no written evidence for this belief. The rock was used for picnics and social gatherings beginning in the late nineteenth century and continuing through the mid-twentieth century. During that time, it was know as "picnic rock" or "Graham Rock." In 1951, U.S. Route 40 was constructed through the area and the land surrounding the rock was designated as a roadside park. In 1963, additional lanes were added to Route 40 to create Interstate 70 and the roadside park became inaccessible. At present, it is unknown what implication there might be to an interstate project that has impacts on this rock. Although there is no documentary evidence for slave sales at the rock, there is a consistent body of folklore that has evolved since the mid-twentieth century saying sales did occur there.

The Graham family, after whom Graham Cave State Park is named, settled south of the slave rock area in 1816. Their house, constructed in 1828, is located within sight of the rock and is still occupied by descendants of the Grahams. This farmstead, located adjacent to I-70, should be considered potentially eligible for the NRHP. Graham Cave State Park lies adjacent to and just north of I-70. Within this 82-acre park is a natural resource designated by the Missouri Natural Areas Committee as the Graham Cave Glades Natural Area. The natural area is a complex of sandstone- and limestone-glade community types, with dry sandstone forest and dry sandstone cliffs. The close proximity of some of the sandstone and limestone glades allows some dolomite glade species to occur alongside sandstone glade species (Reese 1986).

Graham Cave State Park has been invested with improvements made possible through funding from the Land and Water Conservation Fund Act. Permanent taking from properties improved or acquired with these funds must be replaced with land of at least equal monetary value and recreational utility, as determined by the U.S. Department of the Interior.

Conclusions

The use of GIS is often discussed in terms of its power to analyze spatial data. GIS is also used as a production tool for visual point and area locations. With this project, MoDOT used GIS to analyze spatial data and integrate non-spatial data to produce a map showing environmental point and area locations. GIS cannot be discounted for mapping when previously collected data are available or are easily converted into digital format. In this case, GIS is a powerful tool that considerably reduced the number of hours needed to produce information in a visual format. Using GIS also produced project-specific information that has been subsequently used and expanded upon during the data collection for a tiered Environmental Impact Statement (EIS). MoDOT used its GIS system to identify cultural and environmental constraints and used the feasibility study to investigate and evaluate the deficiencies in the existing interstate facility. As a result of the completed work, two strategies appeared to be the most feasible solutions for the capacity problems for I-70. Adding capacity to the existing interstate facility is one of the strategies. Adding capacity in the median, with future widening capability on the outside, is one alternative to this strategy. Another alternative would be to add capacity on the outside leaving the median for any future widening. The second strategy for the I-70 corridor is to construct a new, parallel interstate facility or provide a public transportation alternative such as high-speed rail. MoDOT concluded that a tiered environmental document would be the appropriate tool to achieve the extensive public, community, and agency involvement needed before a preferred strategy for the improvement of I-70 can be developed. At this time, the first tier draft EIS has been completed and is available for viewing at http://www.i70study.org. Selecting a preferred alignment and determining logical termini for construction staging will be the foci for the second tier EIS.

Biographical Sketch: Gayle A. Unruh is the Wetland Coordinator for the Missouri Department of Transportation's (MoDOT) wetland specialists team. Employed with MoDOT for eight years, she does wetland delineation, Section 404 permitting, and wetland mitigation and banking development. Gayle works on wetland mitigation development teams with the U.S. Army Corps of Engineers and Missouri Department of Conservation to provide compensatory mitigation projects under the management of those agencies. Ms. Unruh was an author of a Memorandum of Understanding (MOU) between MoDOT and the Section 401 Water Quality Certification issuing agency, Missouri Department of Natural Resources. Under recent legislation and this MOU, Missouri has streamlined the process of water quality certification and conditioning for all MoDOT projects authorized by Nationwide permit. Prior to her work with MoDOT, Gayle worked for consulting companies as an avian toxicology researcher, wildlife specialist, and technical writer. She received a Masters of Science in biology with an emphasis in avian ecology from Western Illinois University, Macomb, Illinois, and a Bachelors of Arts in environmental science from McPherson College, McPherson, Kansas.

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