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An Object-oriented Decision Support System for Black-tailed Deer on Vancouver Island

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Abstract

The evolution of computer systems and methods has led to the development of an object-oriented decision support system for black-tailed deer (*Odocoileus hemionus columbianus*) on Vancouver Island. To better understand the winter habitat requirements of black-tailed deer, personal computers were used to develop expert systems to investigate the relationships between black-tailed deer food and cover quality and the interspersion of these two life requisites. A more rigorous approach was adopted through the use of a geographic information system, but limitations soon became apparent. Most significantly, the system required many days to reevaluate the model. By using high-powered workstations and an object-oriented modeling structure, we were able to reduce the time for model reevaluation to minutes, thereby greatly increasing our ability to perform sensitivity analysis on our model.

Résumé

L'évolution des systèmes et méthodes informatiques a mené à l'élaboration d'un système d'aide à la décision orienté-objet relatif au cerf à queue noire (*Odocoileus hemionus columbianus*) de l'île de Vancouver. Pour mieux comprendre les besoins du cerf à queue noire en ce qui a trait à son habitat hivernal, les chercheurs se sont servis d'ordinateurs personnels pour concevoir des systèmes experts en vue d'étudier les relations entre la nourriture du cerf à queue noire et la qualité de la couverture et la façon dont ces deux éléments essentiels à la vie sont agencés. L'utilisation d'un système d'information géographique a permis l'adoption d'une approche plus rigoureuse, mais les limites de ce système n'ont pas tardé à se manifester. Plus particulièrement, il lui fallait de nombreux jours pour réévaluer le modèle. Grâce à des postes de travail de haute puissance et à une structure de modélisation orientée-objet, nous sommes parvenus à réduire le temps de réévaluation du modèle à quelques minutes seulement, ce qui accroît largement notre capacité d'effectuer des analyses de sensibilité par rapport à notre modèle.

Introduction

To achieve objectives for wildlife management in increasingly modified landscapes, integrated habitat management has had to increase in scope and scale. In coastal British Columbia, for example, approximately 100 000 black-tailed deer (*Odocoileus hemionus columbianus*) died from lack of suitable winter habitat during the severe winter of 1968–69 (Smith 1973). Rapid and widespread harvesting of winter habitat was believed to have contributed to the catastrophic event. Consequently, to maintain long-term viability of black-tailed deer populations, managers needed a better understanding of the seasonal habitats required by deer over large areas. In response to the immediate need for management action, harvesting of old-growth forests was temporarily deferred in some areas on Vancouver Island.

Resolution of conflict between forest managers, who wanted to maximize wood fiber production, and wildlife managers, who wished to maximize wildlife habitat values, required the initiation of black-tailed deer research. Two decades of research has led to many habitat modeling efforts. B.C. Ministry of Forests Research Branch models, for example, have evolved from simple word models, through binary and geographic information system (GIS) models, to sophisticated spreadsheet models that are object-oriented decision support systems.

We present a brief review of this modeling evolution leading to development of an object-oriented model (OOM). In doing so, we introduce some key concepts of object-oriented programming and discuss its application in modeling wildlife habitat.

Our review is based on an investigation of habitat use by 31 radio-collared, black-tailed deer that were located weekly (n=7 623 re-locations) in a 225 km^2 area of the Nanaimo River watershed on southeastern Vancouver Island (McNay and Doyle 1987). Once entirely old growth, this area is presently a mixture of old growth, second growth, and recent clear-cuts. Steep U-shaped valleys are oriented east to west providing favorable topography for deer winter range.

The main components of the model were the availability of nutritious forage (in all seasons) and the proximity of winter cover. That emphasis was derived from the knowledge that deer survival is limited by their ability to over-winter in a healthy state (Harestad 1979, Bunnell 1985). In winter, forest cover provides snow interception, which maintains both forage availability and thermal protection. The accessibility and quantity of winter cover becomes critical during severe winters when the energetic costs of movement escalate (Parker et al. 1984), and the quality of forage declines (Rochelle 1980).

The value of food and cover varies with season and topography following seasonal trends in soil moisture and nutrients and as modified by elevation and aspect. The need for food and cover also varies seasonally, and with sex and age (Parker et al. 1993). The seasonal variations are complicated because winter weather in coastal British Columbia is unpredictable, with severe winters occurring approximately every 18 years. As a result, the suitability of a particular site varies between years, depending on winter conditions. Expansion of site-specific habitat characteristics into temporally dynamic conditions has led to the need to model summer habitats and both mild and severe-winter habitats. Also, three different migration tactics have been associated with these seasonal habitats, each with its own specific patterns for use of space (McNay 1995). Hence, spatial constraints at two scales (i.e., between seasonal ranges, and between food and cover within a seasonal range) have been recognized as important aspects of black-tailed deer ecology.

Models of wildlife habitat are an attempt to explain the spatial and temporal variations in animal behavior in terms of biotic and abiotic components. Some modeling difficulties arise because processes occur at a variety of temporal and spatial scales. Also, habitat use is affected by several behavioral and population regulating factors such as inter- and intra-specific competition, population structure, recruitment, dispersal, predation, and site fidelity. Lags in responses to habitat changes may hide evolutionary stable habitat-use tactics through a variety of climatic fluctuations such as cyclical severe winters. Simplification of these complex relationships that affect black-tailed deer are necessary to understand and integrate their habitat needs into the management of forested lands.

Model History

Binary Models

An expert system called Prospector II (Campbell et al. 1982) was used to quantify, in a binary format, word model rules that had been developed over time by wildlife managers. Five characteristics of winter habitat for deer were considered: food, cover, suitable aspect, proximity to food, and proximity to cover. Habitat types were assigned a 1 or 0 based on whether or not they were suitable for deer. Spatial needs of black-tailed deer were incorporated in the model by including the proximity-to-food and proximity-to-cover variables thus altering the value of a habitat unit based on proximity of a habitat patch to food or cover (McNay et al. 1987). For each habitat patch a final score was generated by summing up the binary variables for the five habitat categories.

GIS Models

With ever-increasing computer power, a more rigorous approach to habitat interspersion could be pursued to better represent the relationships among individual habitat polygons. GIS-based models expanded the binary variable technique (Eng et al. 1989) by assigning expert-derived habitat scores to the habitat categories.

Food and cover are required on a daily basis and must be available in close proximity. The closer together these habitat types are, the higher quality that area is for black-tailed deer. The ability of a specific site to provide quality food and cover is constrained by elevation and aspect. Higher altitude northern slopes retain snow for longer periods, and at greater depths, decreasing the quality of those sites.

Polygons representing different ecosystem types were classified according to the successional stage of the vegetation. A scoring system, based on expert knowledge, between 0.0 and 1.0 was applied to the sites to describe forage and cover qualities under different weather conditions. The resulting map contained the scores of mild winter food and cover, and severe winter food and cover for each polygon. Maps of distance buffers were generated around favorable food and cover polygons. The quality ratings of these buffers was related to the likelihood that a deer would move a certain distance under different seasonal conditions as indicated by previous research (Kremsater and Bunnell 1992).

Aspect and elevation polygons for the study area were manually delineated on 1:50 000 topographic maps. Field biologists scored combined aspect/elevation polygons from 0 to 1.0 based on expected heat loading for each polygon. Maps of each of the scored habitat categories were combined in the GIS to generate a composite map. The resulting data was rated in each habitat

polygon for severe [1] and mild [2] winter scenarios:

$$Qsev = (((1-(1-F)^{1}(1-C)^{1})^{.5})^{1.5} * SFD^{.75} * SCD^{.75})^{.333} * AE \quad [1]$$

$$Qmild = (((1-(1-F)^{1.6} * (1-C)^{.4})^{.5})^{1.5} * MFD^{.75} * MCD^{.75})^{.333} * AE^{.5} \quad [2]$$

where:

Qsev = habitat quality value in severe winter conditions;
Qmild = habitat quality value in mild winter conditions;
F = the winter food quality rating;
C = the winter cover quality rating;
SFD = the rating for proximity to quality food severe winter rating;
SCD = the proximity to quality cover severe winter rating ($C \geq 0.7$);
MFD = proximity to quality food mild winter rating;
MCD = proximity to quality cover mild winter rating ($C \geq 0.1$); and,
AE = the combined aspect/elevation rating.

The exponents used to weight the equation components are based on expert knowledge.

To clarify the model equation, if both the food and cover rating for a habitat polygon are high, then the location has the potential to be of high quality to black-tailed deer, as expressed by the inverse geometric mean of the food score and the cover score. Alternatively, if a habitat polygon has high quality black-tailed deer cover and is in proximity to a polygon with quality food, then it too would be scored as high quality deer habitat. Similarly, a habitat polygon would be scored high if it has high quality food and is close to quality cover. This compensatory relationship is calculated in the modeling equation by using the weighted geometric mean of scores for: a) the value for food and cover, b) the distance to food, and c) the distance to cover. Aspect and elevation are limiting factors, therefore, we multiplied the weighted geometric mean of food and cover and their interspersion by a combined aspect and elevation score to generate the final score. The model of black-tailed deer mild winter habitat use weighted food as more important than cover, allowed greater distances between habitats, and weighted topography less than the model of severe winter habitat use.

Model Limitations

In trying to validate the habitat model, we encountered several problems that limited the potential usefulness of the model. For example, the radio-collared black-tailed deer that we studied did not experience the extreme winter conditions that can kill adult deer, making it impossible to properly validate our predicted habitat use under severe winter conditions. Furthermore, time lags in responses to habitat or climatic change can hamper validation by individuals surviving with poor habitat choices when not all biotic/abiotic effects act against them during the time of the study.

A synthesis in a GIS of landscape factors affecting deer, produces a mosaic of data that is difficult to interpret. The detail must be reduced to generate a product more readily understandable to a manager. However, arbitrary decisions made to simplify the data, and the thresholds between simplified classes can affect the interpretation of the results. Another confounding factor is that predicted future habitats may not exist in the present (e.g., 60-year-old second-growth). This makes it impossible to evaluate black-tailed deer habitat response to projected forests.

When conducting use/availability analysis of telemetry data to validate the model in our study, we partitioned the data into different categories. Each of the deer were classified into one of three behavioral groups: obligatory migrators, facultative migrators, and residents. We did comparisons of use parameters and their relation to factors of interest including behavior, season, and sex (McNay 1995). For example, we looked at how habitat use patterns shifted seasonally for the different behavioral groups of deer. Resident deer stay in moderate quality summer habitat that is also moderate quality winter habitat. Whereas migrators move from high quality summer to high quality winter habitat. However, the reduced sample size in some categories caused instability in the data analysis. A model with a lot of noise may not fail a test of validation, or conversely it may not reveal habitat selection or avoidance. If the telemetry data had not been initially partitioned, the sample size problem could have been overcome. By using an individual-based model, the variation between individuals and among groups could have been more rigorously evaluated.

Further refinement of the model may be possible by adopting an empirically based model of habitat use. The Mahalanobis distance statistic could be used to develop a habitat model. This statistic measures the dissimilarity, based on the standard squared distances, between an ideal habitat, as determined by telemetry locations, and the habitat that is available in each map cell (Clark et al. 1993). This technique would generate a map of Mahalanobis distances that can be recoded to probabilities that reflect the habitat selection of deer. The results of this analysis could then be compared and incorporated with the expert-based habitat scoring.

Some unfortunate limitations became obvious with the standard GIS approach to wildlife modeling. A lot of effort was required to modify the model to respond to changes in any of the input data. For example, if a habitat score needed adjustment, new maps had to be generated, overlays re-done, and new evaluations made, re-

quiring many days. Any "game playing" to investigate model sensitivity was severely limited by the time required to assess any results. As well, successive overlays resulted in very complex maps so any mistakes made with the input data were usually hidden.

Object-oriented Modeling

The rules of previous models were translated into an object-oriented modeling (OOM) environment to reduce the effort required in adjusting model parameters. Parameter adjustment was deemed the next step in improving the model's reflection of the natural history of black-tailed deer.

Objects in Habitat Modeling

Objects in habitat modeling can take on a variety of forms. A single piece of data such as elevation at a point, or collections of data such as deer telemetry locations, or maps of deer cover can be represented as objects. Functions can be applied to data to generate new objects (e.g., buffers around habitat units). Elaborate formulas, such as habitat models, can be applied to a series of maps to create more complex objects.

Object-oriented Modeling Environment

We used a tool for application development based on OOM called Facet (Facet Decision Systems Inc., Vancouver, BC). Facet operates much like a traditional spreadsheet. The habitat model described above, and all of its components, were treated as one complex object. Cells of the spreadsheet contained objects, such as numbers, data, formulas, images, maps, nested spreadsheets, and modeling expressions. Facet provides more flexibility in analyses than traditional spreadsheet programs because its cells can be examined as numeric data, maps, or graphs simultaneously. Changes in the spreadsheet update the data, maps, and graphs automatically, similar to a traditional spreadsheet. As one cell in the spreadsheet changes other cells dependent on it are re-calculated. Processing time is improved by only updating the data, maps, and graphs currently displayed, other nested spreadsheets or maps are updated only when they are invoked.

Deer and their Habitat as Objects

Each map layer (quality of food, quality of winter cover, distance to food, distance to cover, aspect/elevation) was encapsulated as an object within its own spreadsheet. It could be displayed as a map or as habitat polygon scores. The main spreadsheet accessed the underlying objects and combined them with severe and mild winter modeling equations.

Generic maps were created for habitat polygons, elevation, and aspect by converting the original GIS vectors into polygonal rasters in the Facet system. A matrix data structure was used to represent the polygonal raster, where a matrix position corresponded to an individual raster position within the study area. Specific thematic maps were generated by using a look-up table (LUT) to access a remote database containing the thematic scores for specific polygons. The LUT uses the spatial coordinates for polygon identity codes as the link to the database. Matrix values, for a particular theme, were derived by assigning the value at the study area raster position to a corresponding matrix position. Figure 1 shows the results of a LUT that was used to access a database containing food scores to generate a food quality map.

Food scores could be changed and compared with the original scores in graphs and maps to examine relationships and thresholds and adjusted (Fig. 2). Habitat model results changed simultaneously so that the influences of score modifications could be assessed. In this way, food scores could be interactively fine tuned and model sensitivity examined. Similar operations were performed on aspect and elevation.

Maps representing the distance to high quality food and cover habitat were generated by using a linear decay function from the boundary of a high quality polygon to the assumed maximum movement based on season and snow depth. These "distance to" maps inherited data from the cover or food maps, so that when they changed, they immediately affected the proximity maps because they were subclasses of the food and cover maps.

Finally, black-tailed deer locations were also modeled as objects. Season-specific telemetry data were used to calibrate the Facet model. Deer locations were compared with habitat availability within the study area to examine the relationship of habitat use and availability. Figure 3 shows the results of the original model equation used to assess the components in the object-oriented programming spreadsheet format.

Advantages of Object-oriented Models

To summarize, the habitat model could be presented as real world constructs, reducing its apparent complexity and hence increasing its accessibility to those not trained in the technical aspects of GIS operation. Among the specific advantages we found working with OOP are the following: a library of methods and objects can be maintained for future projects; data can be updated and extended, facilitating maintenance of the model; new data can be used in the model with a minimum of adjustment necessary; and, since the model is contained within a single programming environment, future work will not

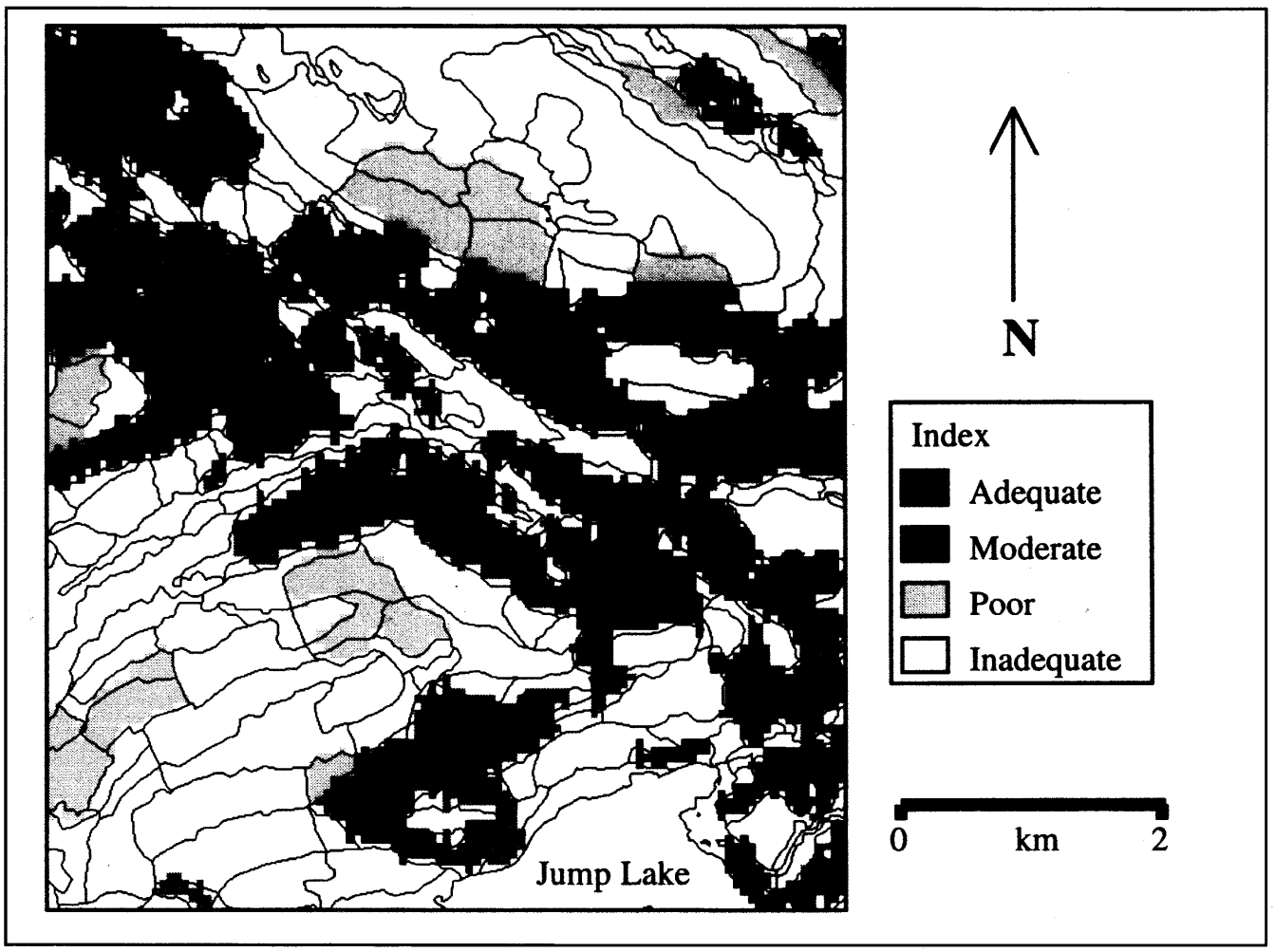

Figure 1. Black-tailed deer food quality map in the Nanaimo River watershed.

require a paper chase to try and determine the steps taken to generate the model, thus promoting reusability.

Associated with these clear advantages is a higher initial development time for the object-oriented model than with traditional GIS approaches. However, there is a lower maintenance cost resulting in a better user interaction with the habitat model. Validation and updating of the model are far more efficient. Models can be modified to incorporate dynamic programming goals, sensitivity analysis, and adaptive management.

Model Use and Future Directions

Currently our research focus is on Woodland caribou (*Rangifer tarandus caribou*). We are using composition analysis (Aebischer et al. 1993) to determine if caribou select certain landscape features and to evaluate differences among animals and herds. We are also developing an HSI (habitat suitability index) based on Clark et al. (1993). To incorporate cover and food interspersion

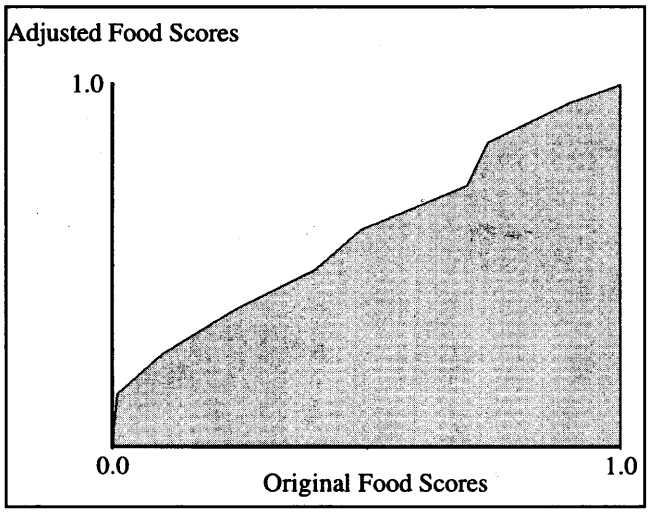

Figure 2. Comparison of original scores of food quality and adjusted scores.

into the HSI we will use a kernel that is applied to a cover map to assign a resulting value to a cell based on what cover is in proximity. By using the object-oriented techniques that we developed for black-tailed deer, we will be able to combine the data-derived habitat values from the HSI and adjust the HSI values based on expert knowledge of caribou natural history. This procedure will be used to evaluate the sensitivity of the model to various landscape effects. We are also incorporating the use of a modified harvest scheduler to schedule caribou habitat supply over time by optimizing the caribou HSI. By constraining the scheduler by forest harvest targets, we can then evaluate the impact of different management scenarios on caribou habitat supply. In the future, we will be applying similar habitat modeling techniques to grizzly bears (*Ursus arctos*) and spotted owls (*Strix occidentailis*).

Conclusions

Since we began our black-tailed deer research in 1980, our methods of analysis have evolved. There has been an increase in capability of the technology, with more processing power and access to high capacity data storage devices. Software has become increasingly sophisticated with more complex data structures and problem description. There is greater ability to game with scenarios and manipulate data classes. In the future, with even more capable technology, more detailed representations of the problem will be possible. It will be possible to study larger areas at higher resolutions. We will be able to integrate with other decision support systems to evaluate management decisions. With simpler interfaces and more realistic data representation, the audience of decision support tools will expand allowing for greater public access and involvement.

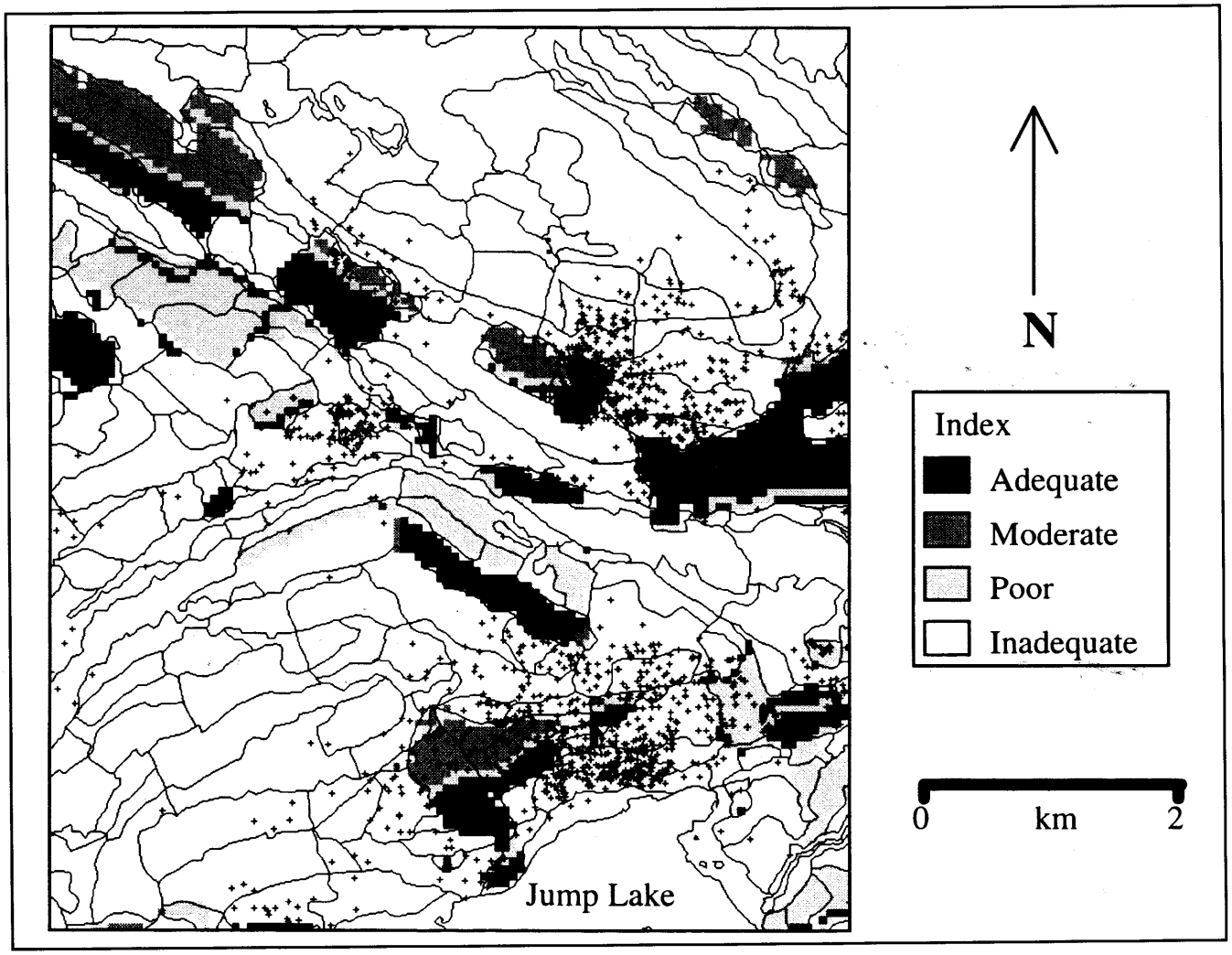

Figure 3. Summer and winter telemetry locations (+) superimposed on severe winter habitat suitability for black-tailed deer.

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