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Weed Invasion Susceptibility Prediction (WISP) Model for Use with Geographic Information Systems

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The Weed Invasion Susceptibility Prediction (WISP) model was developed as an extension of the ArcView Geographic Information System to predict potential risk of invasion by individual weed species in rangelands. Existence potential was determined by comparing growth requirements of each weed species with respect to nine site characteristics obtained from geographic data layers: distance from water and disturbance sources, elevation, annual precipitation, soil texture and pH, aspect, slope, and land cover. Disturbance is important for predicting weed infestations; an innovative aspect of the WISP model is that we use data layers for transportation and energy development as an estimate of disturbance. Data from weed surveys

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conducted at the Jack Morrow Hills Study Area in southwestern Wyoming, USA, were used to test WISP model predictions for the occurrence of Hyoscyamus niger *(black henbane),* Cardaria draba *(hoary cress), and* Lepidium latifolium *(perennial pepperweed). Data acquired from the U.S. Department of Interior, Bureau of Land Management were used to test model predictions for the occurrence of* Euphorbia esula *(leafy spurge) and* Centaurea maculosa *(spotted knapweed) for four counties in northwestern Wyoming, USA. The model accuracy, based on false-negative errors where a species was present but was predicted not to occur, averaged 89% for the five weed species. The WISP model allows land managers to predict more easily and accurately the potential for weed invasions in order to prioritize areas for detailed monitoring.*

Keywords invasive species, habitat suitability, GIS, Wyoming, rangelands, black henbane, *Hyoscyamus niger*, hoary cress, *Cardaria draba*, perennial pepperweed, *Lepidium latifolium*, leafy spurge, *Euphorbia esula*, spotted knapweed, *Centaurea maculosa*

A major difficulty facing natural resource management is locating and monitoring weed invasions over vast western rangelands. Noxious weeds degrade the economic value of these sparsely populated lands, and can be devastating to livestock and wildlife (DiTomaso 2000; Masters & Sheley 2001; Olson 1999). Geographic Information System (GIS) technology allows better data organization and visualization, and simulation of complex environmental interactions, thus enabling more informed decisions (Longley et al., 1999). Global positioning systems (GPS) allow survey data of weed infestations to be accurately entered into a GIS, which facilitates these analyses (Johnson 1999; Lass & Callihan 1993).

With the expansion of GIS, prediction of the geographic distribution for a given organism is an important area of research and management (Franklin, 1995). Higgins et al. (1996, 2000) and Collingham et al. (1997) present theoretical weed spread models within a GIS. These models are designed to predict weed population growth and dispersion based on biological attributes and environmental interactions. Habitat suitability models for potential weed existence are difficult within a GIS because one of the most important environmental predictors for invasion is the frequency and extent of disturbance (Hobbs & Huenneke, 1992).

The goal for this study was to develop a model of potential weed existence for semiarid rangelands. We used commonly available geographic data layers, and either the literature or expert opinion, to predict locations that are favorable for weed infestation. The resulting algorithm was incorporated into GIS software and is called the Weed Invasion Susceptibility Prediction (WISP) model. One of the innovative aspects of this model is the use of transportation and energy data layers as an estimate of disturbance. The objectives of this article are the description of the WISP model's algorithm and its validation using two weed survey studies in Wyoming.

WISP Model Description

The WISP model was written as an automated extension within the GIS program, ArcView version 3.2a, with the Spatial Analyst Extension version 2.0 (Environmental Systems Research Institute, Inc., Redlands, California, USA). It was developed using the Avenue programming language and incorporates commonly available geographic data layers, with a database table of biological parameters. The open design of the WISP allows future enhancements because the user can incorporate new data layers and add new species to the weed species database table.

Version 1.0 (alpha) of the WISP model is available as a CD-ROM from the University of Wyoming. An internet site has been established for information or for requesting an order form (http://w3.uwyo.edu/~annhild/WISP.html). Detailed WISP documentation and other model features are available on the CD-ROM.

Weed Species Database Table

A database table, called the weed species matrix, defines the environmental requirements for establishment and growth. Parameters for five weed species are listed for the following geographic data layers: soil texture, soil pH, distance from direct water sources, distance from disturbances, annual precipitation, associated land cover, elevation, slope, and aspect (Table 1). Database entries were determined from available literature (Lacey et al., 1995; Leitch et al., 1994; Mitich 1992; Sheley et al., 1998; Whitson et al., 1996), reasonable values from expert opinion, and field observations. When a species is not strongly related by distance to either water or disturbance, the parameters for distances to these features were set to an arbitrarily high value. The parameters may be updated by the model user.

Geographic Data Layer Input

Nine geographic data layers were selected to be a compromise between public availability and the important factors for establishment and survival. The first set of data layers are soil characteristics, texture and pH, developed at the University of Wyoming (http://www.sdvc.uwyo.edu/24k/soil100.html). Land cover was determined from the Wyoming Gap land cover dataset (Driese et al., 1997; http://www.sdvc.uwyo.edu/24k/landcov.html). The precipitation layer was developed at the University of North Dakota Regional Weather Information Center (http://www.umac.org/climate/database.html). The elevation layer was acquired from the National Elevation Dataset (http://www.sdvc.uwyo.edu/24k/dem.html). Slope and aspect were calculated from the gridded elevation data layer.

Two important data layers are usually available in vector formats—roads and surface water. The WISP model assumes that roads and other transportation corridors disturb the landscape and create high potential for some weed species. Energy data layers may also indicate disturbance, such as pipelines and fossil-fuel wells. Lakes, rivers and streams are the preferred habitat for some species because of water availability requirements. The calculations for both distance to disturbance and water require parameter values from the weed species database table. Distance to water was calculated from a streams and lakes data layer (http://www.sdvc.uwyo.edu/24k/hydro100.html). Distance to disturbance was calculated from a transportation layer (http://www.sdvc.uwyo.edu/24k/road.html) and an oil-and-gas-development layer (http://wogra.wygisc.uwyo.edu/misc/wograindex.html). All geographic data layers were projected to a Lambert Conformal Conic Projection for North America with the Clark 1866 datum, and gridded to 30-m raster cells. In this study, the size of the grid cells was selected on the basis of values in the weed species matrix (Table 1) rather than the uncertainty of the data layers.

Predicting Existence Potential

Once a weed species has been introduced into the area and if the biological requirements are fulfilled at a site, we assumed that species would be able to establish and grow successfully. For each species, a score-based "Existence Potential" layer is created within the user-defined area. For each raster grid cell, the geographic data are compared to the weed parameters (Figure 1). If the data of the geographic layer

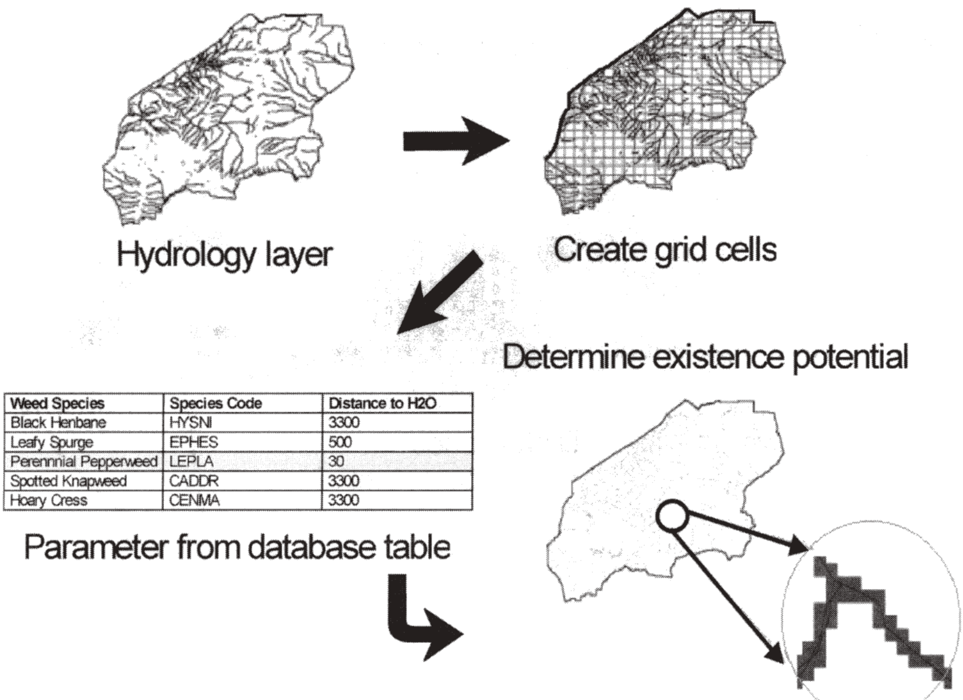
TABLE 1 Weed Species Database Table used to Define Susceptibility Parameters in WISP Model for Five Weed Species

Parameter	*Hyoscyamus niger*	*Lepidium latifolium*	*Cardaria glabra*	*Centaurea maculosa*	*Euphoriba esula*
Species Code	HYSNI	LEPLA	CADDR	CENMA	EPHES
Distance to water (m)	3300	30	3300	3300	500
Distance to disturbance (m)	30	3300	30	300	400
Elevation range (m)	1500–2800	300–2600	1200–2900	600–3100	1200–2400
Landcover class[a]	SG,GL,ST,NV	SG,RP,RS	SG,GL,ST,RP, RS,NV	SG,GL,ST,NV, RP,RS,OS,FR	RP,NV,GL,SG RS,RF,ST,PN,AP
pH range	7.7–8.2	7.6–8.7	7.5–8.7	6.5–8.4	6.8–8.4
Soil texture class[b]	SL	CL,SL,C	SCL,SL,CL	S,L,CL,SL,STCL	L,SL,CL,STL
Maximum slope (°)	36	36	36	36	36
Aspect class[c]	S,W	E,S,W	E,S,W	S,W	E,S,W
Precipitation (mm)	100	80	80	200	200

[a]Landcover classes are: SG sagebrush; RP riparian grass; RS riparian shrub; RF riparian woodland; GL grasslands; ST short grass; NV nonvegetated; OS other shrubs; PN pine woodlands; AP aspen woodlands.

[b]Soil texture classes are: C clay; S sand; L loam; SL sandy loam; CL clay loam; SCL sandy clay loam; STCL silty clay loam; STL silt loam.

[c]Aspect classes are: N (315°–45°), E (45°–135 °), S (135°–225°), and W (225°–315°).



Weed Species	Species Code	Distance to H2O
Black Henbane	HYSNI	3300
Leafy Spurge	EPHES	500
Perennnial Pepperweed	LEPLA	30
Spotted Knapweed	CADDR	3300
Hoary Cress	CENMA	3300

FIGURE 1 Weed Invasion Susceptibility Prediction (WISP) model algorithm for calculating the existence potential for a single geographic data layer. In this example, a vector-based hydrology data layer (streams, rivers, and lakes) is bounded by a user-defined area (Jack Morrow Hills Study Area). In step 1, the user-defined area is divided into 30-m by 30-m grid cells. In step 2, the allowable distance from a water source for a given species is looked up in a database table. In step 3, grid cells within the specified distance from the vector water source are given the value 1 (marked in gray); the other grid cells are given the value 0 (marked in white).

meet the criteria set by the parameters for that layer, one point is added to the total score for that raster cell. The final prediction for invasion is a new geographic data layer where each raster cell with a possible high score of nine (from nine data layers) is displayed. Lower total susceptibility scores, indicating less potential for invasion, can also be displayed as geographic contours in the ArcView view window.

To explain this process better, an example prediction for *Lepidium latifolium L.* (perennial pepperweed) is systematically described for a single weed characteristic, distance to water sources (Figure 1). The weed species database entry for *L. latifolium* is based on observations that it is not likely for *L. latifolium* to establish more than about 30 meters from a direct water source (Table 1). The model evaluates each cell individually on the environmental map and determines the distance of an individual cell to a water source based on the hydrology data layer. If any part of the cell is within the database table value for distance to a water source, then that cell is given a value of one (Figure 1). The model repeats this step, scoring each cell as it proceeds through the hydrology data layer. After all cells in the user-defined area have been scored for water availability, the model evaluates the other requirements (soil texture, disturbance, and so forth). After all cells in the selected area have been scored for each environmental parameter, total scores are determined for each raster cell (Figure 2). Because there are nine

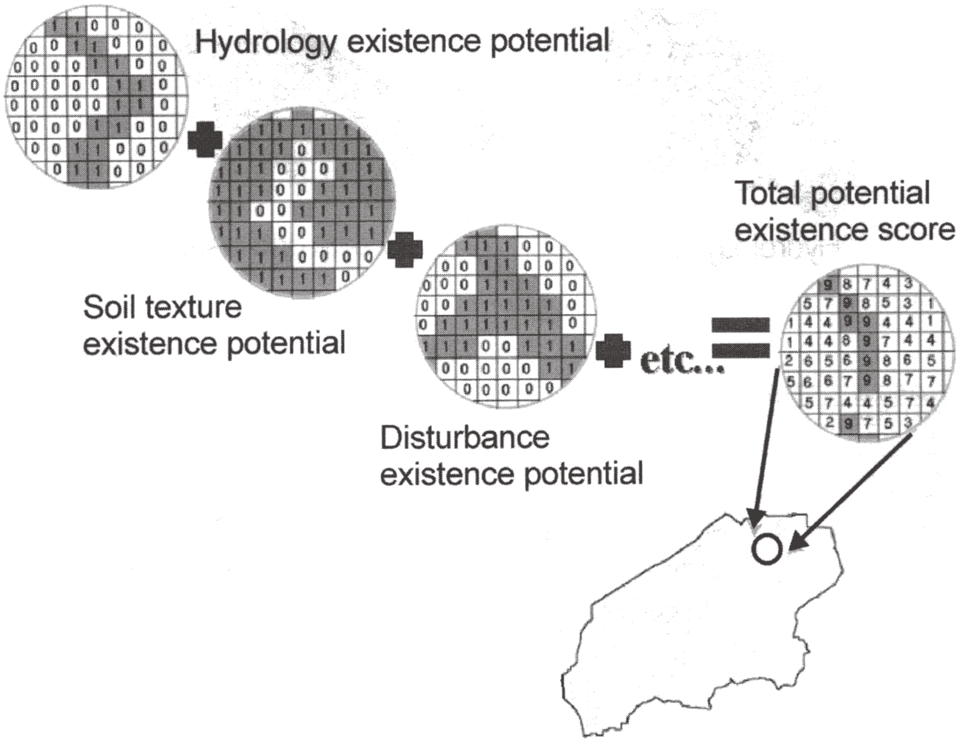


FIGURE 2 The total potential existence score in the WISP model is calculated for each grid cell from the potential existence calculated with the individual data layers. In this example, the existence potential for 30-m by 30-m grid cells from the hydrology data layer (Figure 1) are added with the existence potentials for soil texture, disturbances, and other data layers. Grid cells with a total score of 9 (determined by the maximum number of data layers) indicate the areas with the highest potential for weed occurrence.

data layers used within this version of WISP, a total score of 9 is used to predict the occurrence of a species in a given grid cell.

Methods

Accuracy Assessment

The WISP model was parameterized and tested for five weed species: *Hyoscyamus niger* L. (black henbane), *Cardaria draba* (L.) Desv. (hoary cress), *Euphorbia esula* L. (leafy spurge), *Lepidium latifolium* L. (perennial pepperweed), and *Centaurea maculosa* Lam. (spotted knapweed). Model predictions were tested by comparing susceptibility predictions to known locations of weed infestations for two areas in Wyoming. We did not attempt to predict the initial introduction of weeds to an area.

Map layer uncertainty may be a significant source of error between predictions and observations (Stine & Hunsaker, 2001). Therefore, point locations of weed infestation were surrounded by a 50-meter buffer to account for map misregistration. The 50-meter value was calculated from the accepted error on standard topographic maps (the thickness of a line approximately 0.5 mm), multiplied by the map scale (1:100,000).

There are two types of errors which affect the overall accuracy: (1) locations where weeds were observed but were predicted not to occur (false negative, or error of omission) and (2) locations where weeds were predicted to occur but were not observed (false positive, or error of commission). Accuracy for each species was calculated:

$$\text{Accuracy} = (\text{Observed infestations} - \text{False negatives})/\text{Observed infestations}$$

because false-positive errors cannot be distinguished from areas where the weed species could indeed occur, but simply have not yet been introduced. Other commonly used statistics for accuracy assessment require estimates of the false-positive error rate (Congalton & Green 1999; Fielding & Bell 1997).

Weed Survey at the Jack Morrow Hills Study Area

The Jack Morrow Hills Study Area is located in Fremont and Sweetwater counties in southwestern Wyoming, USA (Figure 3). The site has a total area of 250,000 ha and ranges in elevation from 1980 m to 2440 m. The mean annual precipitation is

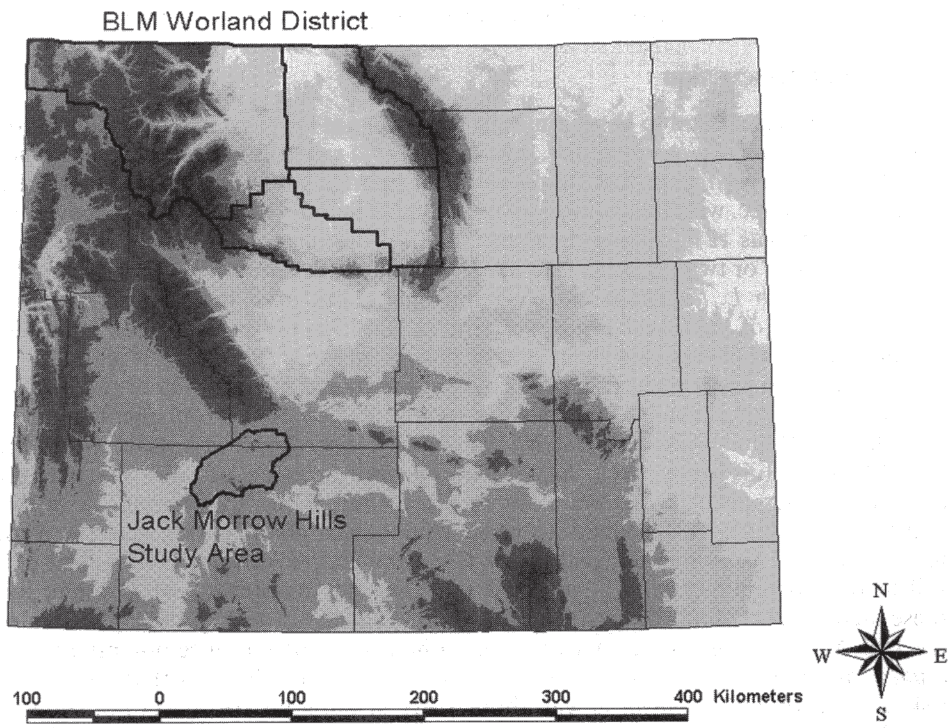


FIGURE 3 Locations of two WISP validation sites in Wyoming, USA, shown on a digital elevation map. The southern and northern borders are latitudes of 41° N and 45° N, respectively, and the eastern and western borders are longitudes 104° W and 111° W, respectively. The Jack Morrow Hills Study Area was used to assess prediction accuracy for black henbane (*Hyoscyamus niger*), hoary cress (*Cardaria draba*), and perennial pepperweed (*Lepidium latifolium*); leafy spurge (*Euphorbia esula*) and spotted knapweed (*Centaurea maculosa*) were not observed to occur there. The U.S. Department of Interior Bureau of Land Management (BLM) Worland District Office provided survey data of *E. esula* and *C. maculosa* in northwestern Wyoming to assess prediction accuracy.

210 mm, with a high of 35 mm falling in May. Ecosystems found within the study area include sagebrush steppe, desert sand dunes, and riparian streams and marshes.

Data were collected for three weed species: *H. niger*, *C. draba*, *L. latifolium* during the summer of 1999. A handheld GeoExplorer II GPS (Trimble Navigation, Ltd., Sunnyvale, California, USA) was used to record locations at the center of weed patches. The GPS data were differentially corrected to remove errors caused by selective availability using a BLM base station near Casper, Wyoming, to achieve a final accuracy under 5 meters.

Riparian drainages, marshes, railroad tracks, and pipelines were traveled by foot. The bottom and embankments were covered for 8 to 13 km depending on the drainage. Paved and unpaved roads, two-track vehicle trails, and gas wells were surveyed from a slow-moving vehicle (25–30 km h^{-1}), stopping whenever a weed patch was observed. The total distance covered was 1100 km.

Additional Weed Survey Data

The Department of Interior, Bureau of Land Management Worland District Office (Worland, Wyoming) provided survey data for *E. esula* and *C. maculosa* from a four-county area in northwestern Wyoming (Figure 3) for use in testing model predictions. The four counties are Big Horn, Hot Springs, Park, and Washakie, and the data were obtained over a four-year period by agents of the county Weed and Pest Districts.

Results and Discussion

Three species were found to have minimal infestations at the Jack Morrow Hills Study Area: *L. latifolium*, *C. draba*, and *H. niger*. *Euphorbia esula* and *C. maculosa* were not found. *Lepidium latifolium* was found solely in riparian areas within 30 meters of a direct water source, with the majority of occurrences within 10 to 20 m. Total coverage of this species was 12 ha spreading along 18 km of drainage. Densities of infestation ranged from one or two plants m^{-2} to over 50 plants m^{-2}. *Cardari. draba* occasionally co-occurred with *L. latifolium* along stream banks, but most infestations occurred along the sides of well-used roads, usually within 15 m of the disturbed roadside. *Cardaria draba* had densities from one or two plants m^{-2} to over 100 plants m^{-2}. Finally, *H. niger* was observed to occur only along roadsides with 1 ha of this species mapped over 9 km of roads. The densities were low from one to four plants m^{-2}.

The WISP model predicts that *E. esula* and *C. maculosa* could occur within the Jack Morrow Hills Study Area. *Euphoriba esula* and *C. maculosa* were less strongly related to either disturbance and water sources, than were *L. latifolium*, *C. draba*, and *H. niger* (Table 1). Distances to water sources and disturbances were the most limiting factors for potential existence of *E. esula* (Figure 4). Four factors, soil pH, soil texture, precipitation, and slope did not limit the distribution of *E. esula*, but these factors would limit the distribution of other invasive weed species. The area of the Jack Morrow Hills Study Area that has a high score of existence potential for *E. esula* is about 8.2% of the total area (Figure 5). Similarly, the area that has a high risk of invasion by *C. maculosa* was about 1.2% of the total area (data not shown).

Only about 0.8% of the area in the Jack Morrow Hills Study Area was predicted to have a high score of existence potential for *H. niger*, *C. draba*, and *L. latifolium* (Table 2). This small area was primarily caused by strong limitations imposed by distances to either disturbances and water sources (Table 1). Using a score of 9 for total existence potential, accuracies were 86%, 90%, and 97% for *L. latifolium*, *C. draba*, and *H. niger*, respectively (Table 2).

For the 4-county Worland District of the Bureau of Land Management, about 25% and 10% of the area was predicted to have high existence potential for *E. esula* and *C. maculosa*, respectively (Table 2), due to fewer limitations caused by distances to disturbance and water sources (Table 1). The WISP predictions for *E. esula* and *C. maculosa* had accuracy levels of 85% and 88%, respectively (Table 2).

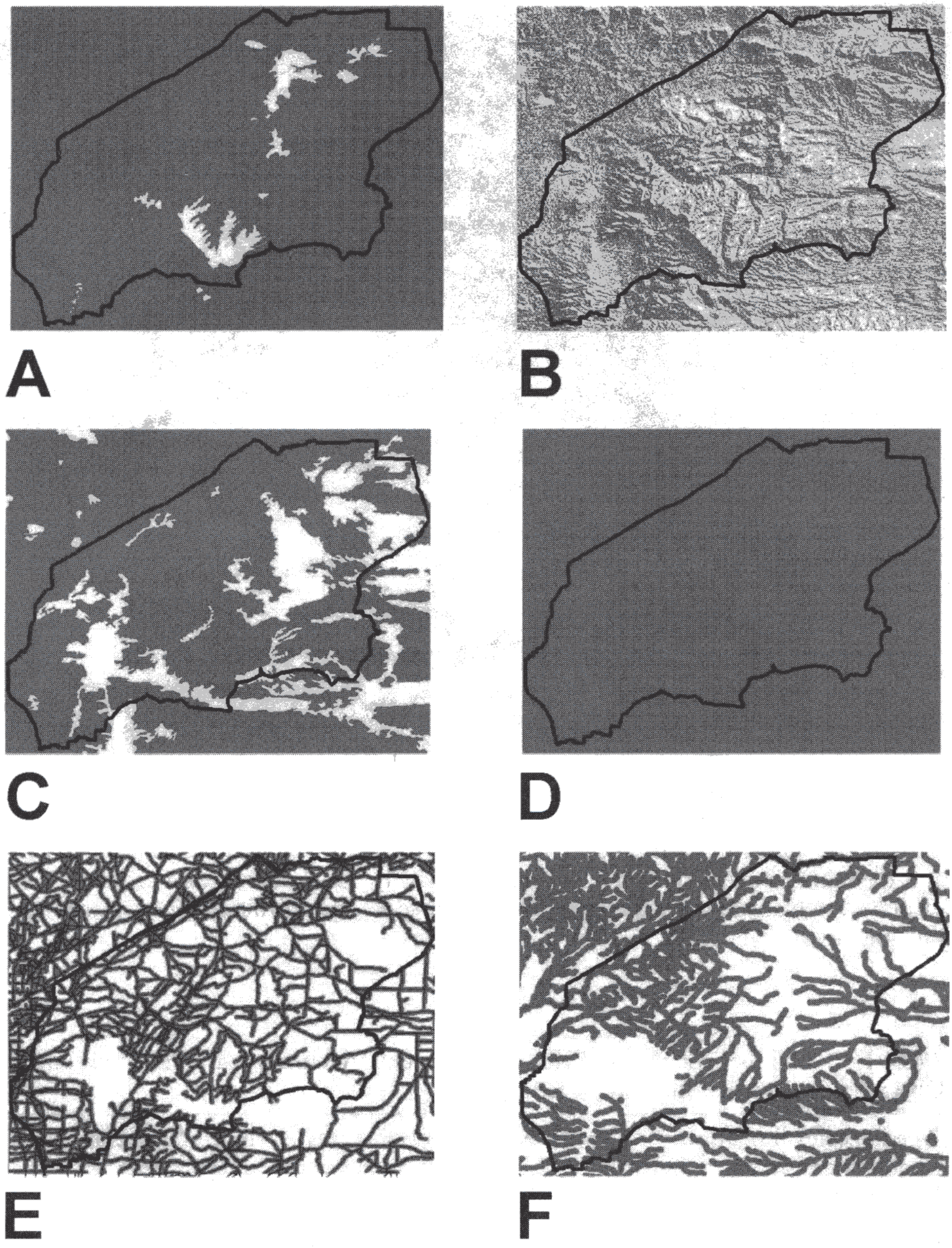


FIGURE 4 WISP scores of potential existence for *Euphorbia esula* (leafy spurge) from various geographic data layers at the Jack Morrow Hills Study Area: A, elevation; B, aspect; C, land cover; D, various other layers; E, disturbances from roads and pipelines; and F, streams and lakes. White and gray areas are defined in the caption for Figure 1. In D, other data layers were soil pH, soil texture, slope, and precipitation.

Hyoscyamus niger, *C. draba*, and *L. latifolium* were predicted to occur, but data for these species were not provided. The accuracies between the data collected during this study and the data provided by the Bureau of Land Management were similar, even though the weed growth requirements are considerably different.

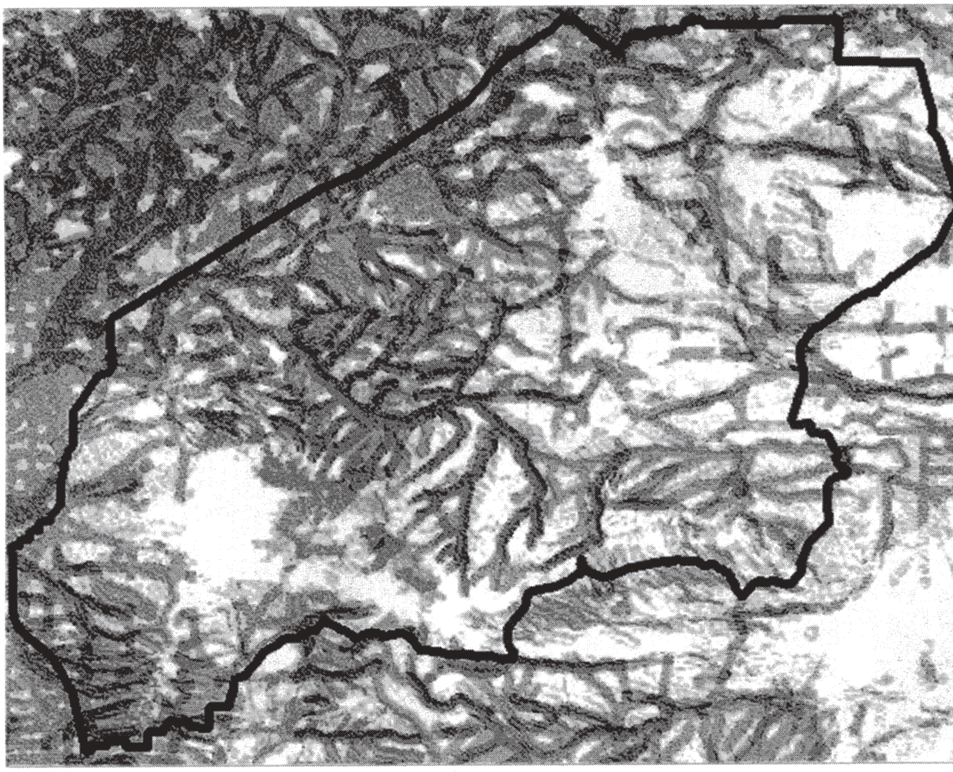


FIGURE 5 Total potential existence for *Euphorbia esula* (leafy spurge) at the Jack Morrow Hills Study Area. Grid cells of white indicate total potential existence scores of 6 or less, indicating little chance for the occurrence for *E. esula*. Grid cells of light and dark gray have scores of 7 and 8, respectively. Grid cells with a score of 9 are displayed in black and are the most likely to have *E. esula* if this species is introduced into the area.

TABLE 2 Number of Grid Cells and Percent Accuracy of Predicted and Observed Occurrence for Five Weed Species.

Weed species	Location	Predicted	Area (%)[a]	Infested	Errors[b]	Accuracy (%)
L. latifolium	Jack Morrow Hills	21548	0.78	518	74	85.7
C. draba	Jack Morrow Hills	23884	0.86	1935	200	89.7
H. niger	Jack Morrow Hills	23556	0.85	375	13	96.5
E. esula	Worland District	7550190	25.4	5617	844	85.0
C. maculosa	Worland District	3066326	10.7	5016	602	88.0

[a]Total numbers of 30-m grid cells were 2,776,106 for the Jack Morrow Hills Study Area, Wyoming USA, and 29,708,878 for the four counties in the Bureau of Land Management Worland District, Wyoming USA. Each 30-m grid cell covers an area of 900 m^2 or 0.09 ha.

[b]False-negative errors are grid cells predicted to not be infested, but weeds were present.

A site may have high susceptibility for weed invasion but weeds are not present, because the weed species have not yet been introduced to that site. Thus, false-positive errors cannot be distinguished from lack of introduction. Therefore, the average accuracy of 89% is biased because the false-positive errors were not included. Standard techniques for accuracy assessment cannot be used without a reasonable measure of the rate of false positives (Congalton & Green, 1999; Fielding & Bell 1997). Whereas the use of accuracies based on false-negative errors can be optimistic for the reasons above, it is logical to conclude the results show initial validation of the WISP modeling approach.

One of the most important features of the WISP model is that we simplified the ecologically-important process of disturbance for weed invasion by using commonly available vector transportation and energy data layers. The use of transportation and energy data layers enabled high accuracies of predicted existence for *H. niger* and *C. draba* at the Jack Morrow Hills Study Area, both of which are very sensitive to disturbance. Some disturbances are more variable over space and time, such as wild fires and soil erosion, both of which can be incorporated into additional data layers through the use of remote sensing.

Transportation and hydrology layers also represent corridors for seed dispersal, making these data layers important for the prediction of invasive potential. Other data layers such as precipitation, soil texture, soil pH, and slope were not predictive for invasive potential for the five weed species in the two locations presented here. These environmental factors have been shown to be important for other invasive weed species (Whitson et al., 1996), and so were included here for generality. Other geographic data layers may become available with the emphasis on GIS in all aspects of management, so the open design of WISP will facilitate inclusion of these new data layers.

Even though *Euphorbia esula* (leafy spurge) and *Centaurea maculosa* (spotted knapweed) were not yet found in the Jack Morrow Hills Study Area, these species may have the potential to invade. With a larger area of potential occurrence predicted for *E. esula* and *C. maculosa*, the potential economic impact may be greater compared to *Hyoscyamus niger* (black henbane), *Cardaria draba* (hoary cress), and *Lepidium latifolium* (perennial pepperweed). Therefore, one of the values of the WISP model may be to provide guidance for a tradeoff between eradication of current infestations and prevention of possible future infestations.

Few GIS models have dealt with noxious weed invasions and spread (Collingham et al., 1997; Higgins et al., 1996, 2000). The WISP model allows natural resource managers to predict likely locations of noxious weed invasions so that monitoring can be done more efficiently. Other tools in the WISP model allow a resource manager to generate numeric estimates needed in developing alternative management proposals. The WISP model was designed for semiarid rangelands in Wyoming, and should be evaluated for applicability to other natural resource areas and evaluated with other invasive weed species.

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