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The Starkey Habitat Database for Ungulate Research: Construction, Documentation, and Use

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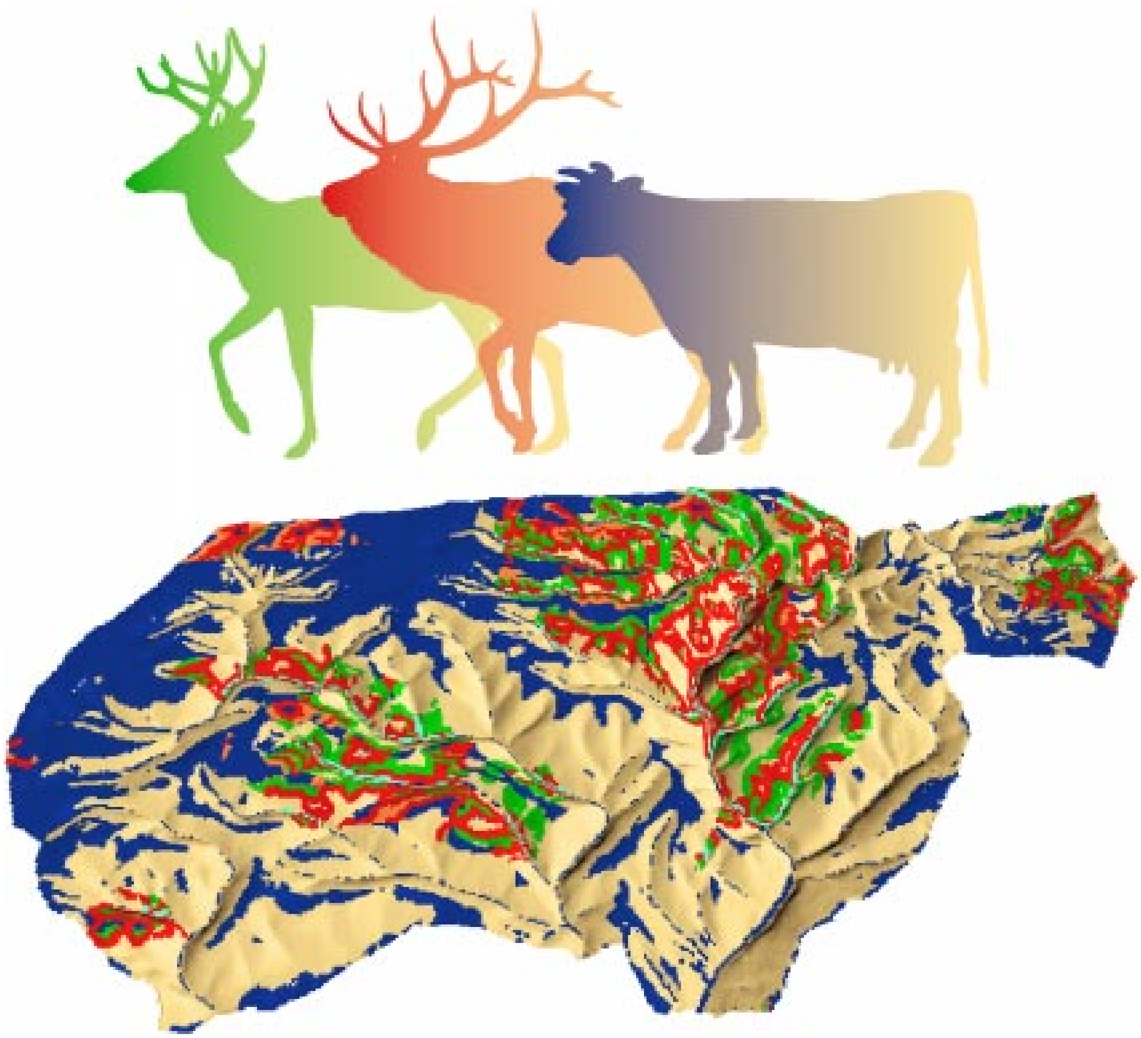

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Abstract

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The Starkey Project, a large-scale, multidisciplinary research venture, began in 1987 in the Starkey Experimental Forest and Range in northeast Oregon. Researchers are studying effects of forest management on interactions and habitat use of mule deer (*Odocoileus hemionus hemionus*), elk (*Cervus elaphus nelsoni*), and cattle. A habitat database was compiled, using GIS (geographic information systems), to examine relations of environmental variables to ungulate distribution and habitat use. The database contains over 100 variables associated with vegetation, water, soils, roads, topography, and structural features such as fences. We describe database construction and documentation of GIS layers from 1987 to 1997. Error estimates associated with each variable or layer and sample applications of the database also are presented.

Keywords: Habitat database, GIS, spatial data, ungulate, cattle, elk, mule deer, northeast Oregon, Starkey Project, accuracy assessment, Blue Mountains.

Contents

Introduction

Geographic information systems (GISs) are widely used to develop databases for modeling and analyzing wildlife habitat relations and conducting wildlife research (Butler and others 1995, Clark and others 1993, Donovan and others 1987, Duncan and others 1995, Koeln and others 1994). These systems allow efficient compilation and analysis of habitat data on a landscape scale. A habitat database was created with several GIS sources for the Starkey Project, a long-term, multidisciplinary, cooperative endeavor between the USDA Forest Service (FS) and the Oregon Department of Fish and Wildlife (ODFW). The project specifically addresses effects of forest and rangeland management on elk (*Cervus elaphus nelsoni*), mule deer (*Odocoileus hemionus hemionus*), and cattle. Several studies are underway (Johnson and others 1991, Rowland and others 1997), and hypothesis testing relies heavily on accurate assessment of environmental conditions in relation to ungulate distributions. Thus, a comprehensive, spatially explicit habitat database was needed to store environmental data in relation to elk, deer, and cattle occurrence.

Most of the study area lies within the Starkey Experimental Forest and Range (SEFR), the site of long-term range and wildlife research (Skovlin 1991; fig. 1). The term "Starkey" will be used hereafter to refer to the portion of the SEFR specifically fenced for Starkey Project research. This game-proof fence encloses 10 102 ha of historic summer range (Bryant and others 1993), with estimated post-partum populations of 850 elk, 500 mule deer, and 600 cow-calf pairs grazed annually. The area is representative of many plant communities and management activities in National Forests (NFs) of the Blue Mountains.

Radio locations of deer, elk, and cattle are recorded with an automated animal telemetry system (AATS) that can page and locate a radio-collared animal every 20 seconds (Dana and others 1989, Rowland and others 1997; see "Glossary" for terms used in this paper). The resolution of Starkey habitat data should meet or exceed that of the AATS (about 3.1 ha, 90 percent confidence interval; Findholt and others 1996), particularly in studies of ungulate-habitat interactions.

Construction of the database began in 1989. It is continually updated as better information becomes available or habitat features change (for example, road construction or changes in forest cover from insect outbreaks or timber harvest). In this report, we describe compilation of the database, including its organization and use, and sources for habitat variables as established from 1987 to 1997. Accuracy assessment and the need for better error estimates also are addressed. Appendix tables provide more detail, including a complete listing of variables now in the database and associated codes (appendix 1), documentation of creation of the database (appendix 2), and applicable software (appendix 3).

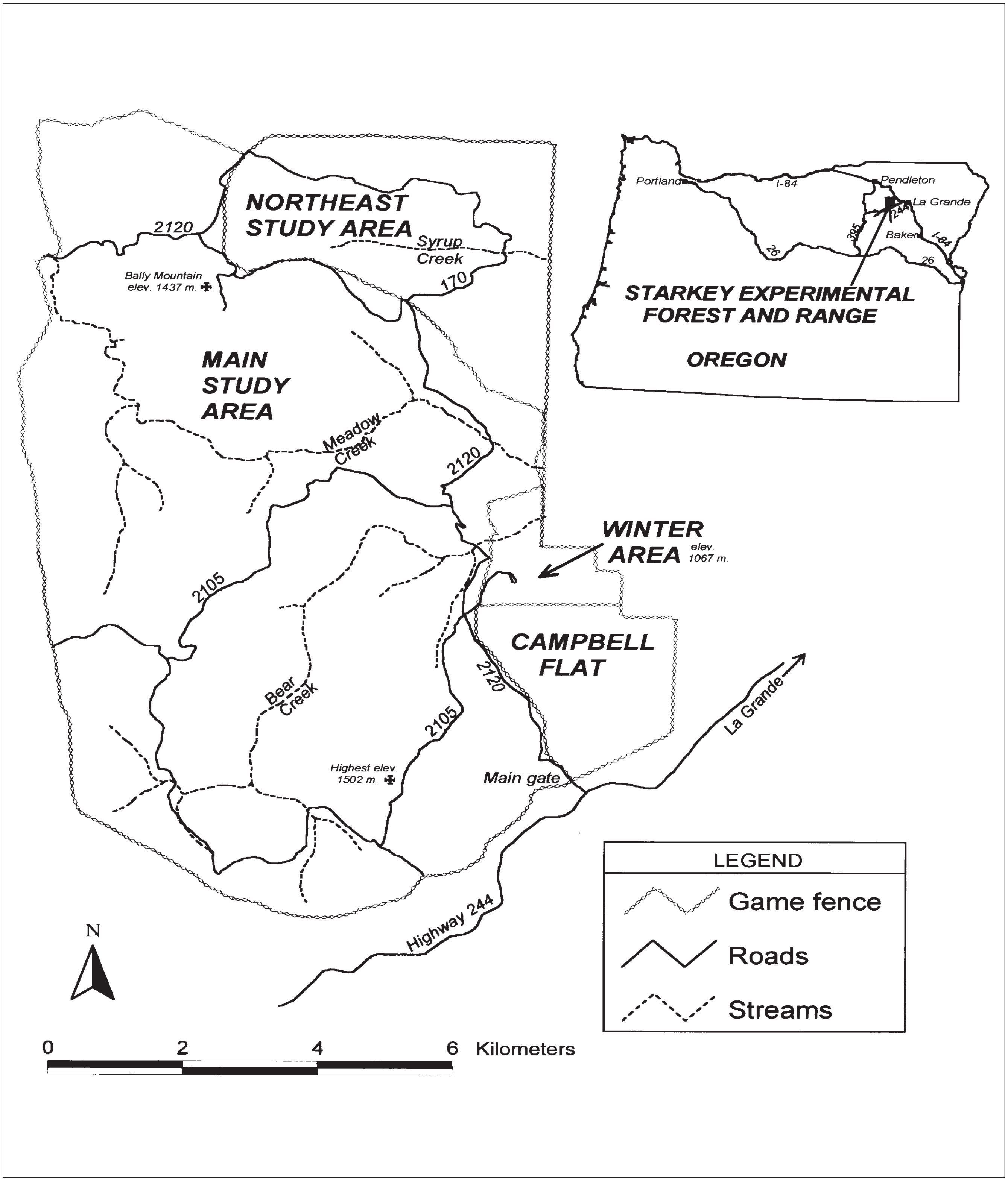

Figure 1—The Starkey Project is located within the Starkey Experimental Forest and Range in the Blue Mountains, northeast Oregon.

Database Construction and Organization

The habitat database contains maps for all major resource themes (vegetation, fences, topography, water, soils, and roads) and more than 100 variables related to distribution of deer, elk, and cattle at Starkey (table 3, appendix 1). Many sources and techniques were used to create the database, depending on the habitat resource (tables 8-11, appendix 2). The database exists in two principal platforms: UTOOLS and Arc/Info[1] (see appendix 3). The UTOOLS portion is primarily raster based, whereas the Arc/Info portion is predominately vector based. Because the UTOOLS database is most often used for exploration and analysis, this platform is emphasized in our paper. Arc/Info, however, is superior for its display capabilities and analysis of certain types of vector data, such as area perimeters or road networking and routing.

Source maps for the habitat database were created with several mapping techniques (see tables 9 and 10) that use input programs such as GeoBased STRINGS, LTPlus, or Trimble Pfinder GPS (global positioning system) software (appendix 3). These layers were output in MOSS import-export format, which was the GIS used by the FS when the Starkey database was constructed. Starkey staff converted the MOSS files to Arc/Info, where they are currently stored. Data acquisition techniques for base maps include remote sensing (satellite imagery and aerial photography), on-the-ground mapping with GPS, and digitizing from topographic maps and orthophoto quadrangles. Base maps exist in two formats, vector and raster; most variables are accessible in both formats.

The main archival storage for all digital maps of the Starkey Project is the FS GIS, which uses both Arc/Info GIS and Oracle database programs residing on the IBM RS6000 (see table 9, appendix 2). Oracle elements are used primarily to qualify map characteristics. The only geographic data not stored in Arc/Info are animal telemetry observations, which are in Oracle. There are several data structures, or models, supported by Arc/Info. Most Starkey maps are stored in the vector data model of Arc/Info, but a few are stored in the raster data model. Some vector map layers have never been rasterized for use in UTOOLS (table 11, appendix 2), primarily because they contain features recorded in too few pixels to warrant conversion to a raster database, or they are used for display only, rather than analysis.

The primary software used to build the raster portion of the database is UTOOLS, a DOS-based collection of spatial analysis programs for the PC (Ager and McGaughey 1997; McGaughey 1995). The UTOOLS programs combine raster, vector, and attribute data that are then stored as spatial databases in Paradox software, where they can be analyzed in several ways (fig. 2). By using Paradox, many complex operations in GIS, such as unions and overlays, can be completed with simple queries. Spatial operations in UTOOLS, such as routines for buffers, rasterization, slope and aspect, and landscape diversity, are performed with UCELL5 (appendix 3; Ager and McGaughey 1997). UTOOLS also includes a visualization program, UVIEW, that constructs two- and three-dimensional images of attribute data, vegetation patterns, and elevation. This analysis and display tool creates depictions of such combinations as elk and deer locations in relation to roads and topography (see "Using the Habitat Database—Sample Applications").

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[1] The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

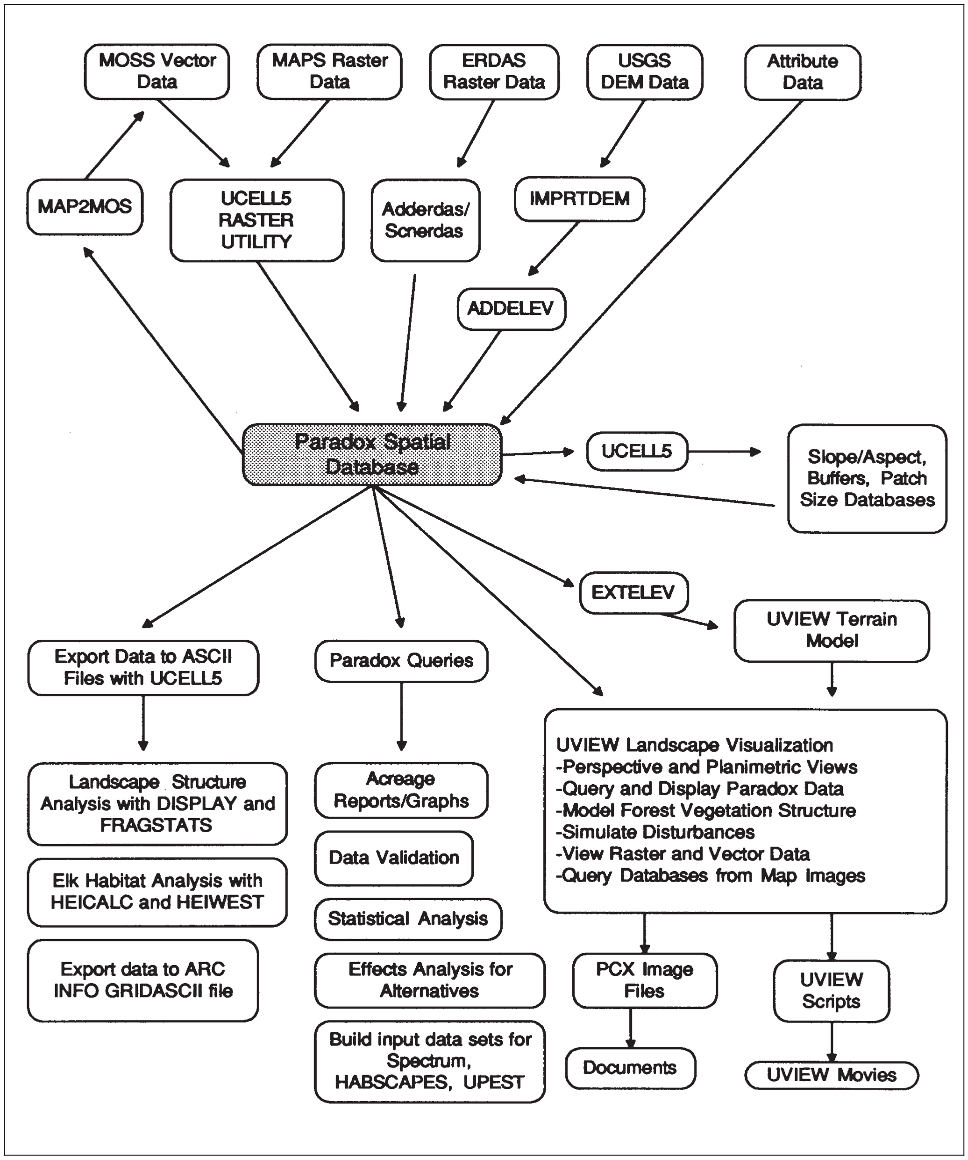

Figure 2—Data operations with UTOOLS software.

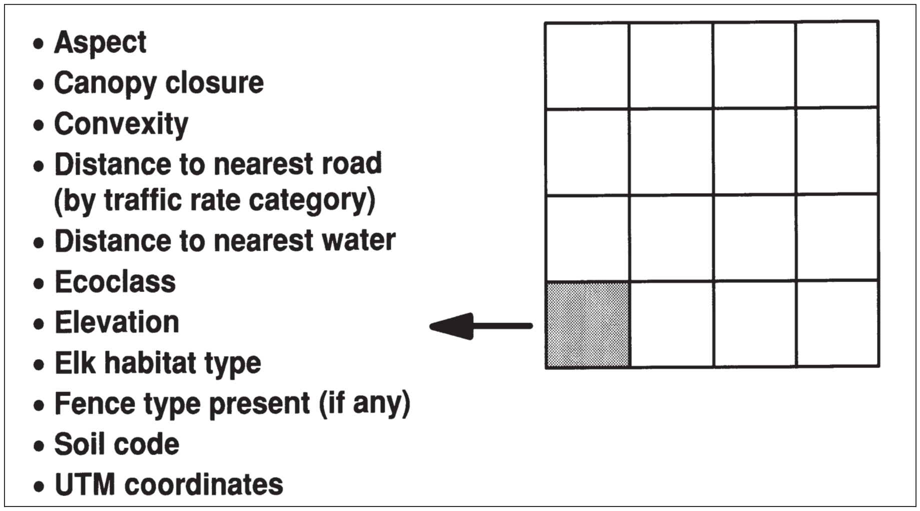

Figure 3—Sample of environmental variables recorded for each 30- by 30-m pixel in Starkey.

All spatial variables in the database except elk habitat categories and elevation were originally recorded in vector format. Vector data were converted in UCELL5 to raster format, creating a spatial database in Paradox with 112,246 records for the Starkey area. Each record in the Paradox database represents a single 30- by 30-m pixel within Starkey, with corresponding fields for each map layer or attribute associated with that pixel (fig. 3). Pixels in a buffer about 0.8 km wide around the perimeter of the Starkey Project area also are included in many analyses; this buffer contains an additional 50,725 pixels. The UTM (Universal Transverse Mercator) coordinates for the center of each pixel (variable "UTMGrid") comprise the key field linking tables together in the database (table 3, appendix 1). All locations at Starkey are recorded in NAD83 (a geographic datum; see "Glossary").

Each primary resource group is associated with lookup tables in Paradox that contain the codes (and their descriptions) that correspond with each variable: AREACODE.DB, TOPOCODE.DB, WATRCODE.DB, ROADCODE.DB, PICODE.DB, HARVCODE.DB, TRAFCODE.DB, ECOCODE.DB, SPECCODE.DB, LNSTCODE.-DB, and SOILCODE.DB (table 1). Similar code descriptions also are presented in tables 4-7 (appendix 1). To accommodate changes in habitat variables, such as roads, portions of the database are updated yearly. Such updates permit more accurate evaluation of habitat variables in relation to ungulate locations.

Vegetation

Aerial photointerpretation—Dave Motanic (Umatilla NF) interpreted two sets of aerial, natural color photographs (1:15,840) from 1987 to 1988 and 1993 specifically for the Starkey Project, by using standard Pacific Northwest Region (FS) guidelines for photointerpretation (USDA Forest Service 1992). Variables from this work are in the "STKYPI" directory (tables 1 and 3). Stands were delineated on aerial photographs, transferred to 1:24,000 orthophotos, and scanned and edited in LTPlus. Stand identification numbers and polygon boundaries associated with these variables are identical to those from earlier, intensive field data collection in the Starkey area by the La Grande Ranger District (LGRD), known as the existing vegetation database. The stand number serves as the key field linking information among the vegetation databases.

Table 1—Organization of primary tables in the Paradox portion of the Starkey habitat database (NEWHAB)

Directory	Paradox tables	Remarks
STKYAREA	AREAAFTR.DB, AREAB4.DB AREACODE.DB	Entries are assigned to a table based on whether they apply before or after construction of the Campbell Flat fence in September 1992.
STKYHARV	STKYHARV.DB, HARVCODE.DB	Timber harvest data from the La Grande Ranger District.
STKYPI	1987PI.DB, 1993PI.DB, PICODE.DB, LNSTCODE.DB, LANSAT91.DB, SPECCODE.DB	Contain vegetation data from interpretation of aerial photographs in 1987 and 1993; additional tables refer to elk habitat classified from a Landsat Thematic Mapper scene.
STKYROAD	88.DB, 89.DB, 90.DB, 91.DB, 92.DB, 93-95.DB, 88DIST.DB, 89DIST.DB, 90DIST.DB, 91DIST.DB, 92DIST.DB, 9395DIST.DB, ROADCODE.DB, COUNTERS.DB; TRAFFIC	Roads data differentiated by year, as road upgrades and construction occur; distance tables were created from buffering routines in UTOOLS. The TRAFFIC directory will contain temporary databases created as needed for derived variables of distance to nearest road of a given traffic rate, for day and night categories.
STKYSOIL	STKYSOIL.DB, SOILCODE.DB	Soil polygons and codes.
STKYTOPO	STKYTOPO.DB, TOPOCODE.DB	All topographic variables (for example, slope and convexity) and codes.
STKYWATR	STKYWATR.DB, CDISTB4.DB, CDISTAFT.DB, EDISTB4.DB, EDISTAFT.DB, WATRCODE.DB	Includes tables with distance to water for elk versus cattle, before and after construction of the Campbell Flat fence.
STKYEVG	ECOCLASS.DB, ECOCODE.DB, FORPROD.DB	Vegetation data from the La Grande Ranger District "EVG" database; more variables to be added later.

Satellite interpretation—An unsupervised classification of a 1991 Landsat Thematic Mapper (TM) scene was completed to produce a digital map of elk habitat categories and canopy defoliation in the SEFR (Noyes and others 1994). This classification was performed jointly by personnel from the LGRD (Wallowa-Whitman NF), ODFW, and the Forestry and Range Sciences Laboratory (Pacific Northwest Research Station, FS), using PC-based image processing programs. Previously, much of the Blue Mountains province had been classified into elk habitat categories from 1979 and 1980 Landsat scenes (Leckenby and others 1985). Also, a 1988 Landsat TM scene was classified into initial spectral groupings, but no further classification was completed. Severe defoliation of trees has since occurred, however, primarily because of outbreaks of western spruce budworm (*Choristoneura occidentalis* Freeman; Wickman 1992). Thus, a more current classification of elk habitat was needed.

Landsat TM data were recorded in 28.5-m pixels (raster format) and resampled to 30-m resolution (Noyes and others 1994). The Landsat data were originally used to define six categories of elk habitat, based primarily on percentage of canopy cover: forage in natural openings with less than 10 percent canopy cover; forage in clearcuts with less than 10 percent canopy cover; timbered forage (10 to 39 percent canopy cover); marginal cover (40 to 69 percent canopy cover); marginal-satisfactory cover (40 to 69 percent canopy cover, but would equal at least 70 percent if defoliation had not occurred); and satisfactory cover (at least 70 percent canopy cover). In a second classification, the three forage classes were combined, and marginal-satisfactory cover was combined with satisfactory, producing three elk habitat categories (forage, marginal cover, and satisfactory cover; see Thomas and others 1988). These habitat categories can be used to calculate habitat effectiveness for elk on winter ranges in the Blue Mountains (Hitchcock and Ager 1992).

Ground-truthing of selected sites confirmed the fit of spectral classes with elk habitat categories and that canopy height was adequate for marginal and satisfactory cover, as defined by Thomas and others (1988). Currently the only variable entered in the Starkey habitat database from this classification is “Lansat91,” the three categories of elk habitat type (table 3). However, the original classification data for canopy defoliation and other elk habitat categories can be incorporated as needed.

The Integrated Satellite Vegetation Mapping Project (ISAT) used the same 1991 Landsat scene to classify vegetation across the Pacific Northwest Region (Pacific Meridian Resources [1997]). Five layers (25- by 25-m cells) were produced, stored by 1:24,000 U.S. Geological Survey (USGS) topographic maps: canopy cover class, size-structure, tree species class, species groups, and nontree range and understory class. These cell layers may be entered into the Starkey habitat database in the future to supplement photointerpreted and other vegetation data.

Intensive field data collection—Vegetation variables from the EVG (existing vegetation) database of the LGRD, with the exception of “ecoclass,” have not been physically transferred into the Starkey database but are accessed as needed over the network (fig. 4). Attributes such as cover (tree, browse, and herbaceous), forage condition, and site index are available and represent on-site field interpretation for most stands.

The CIMS (continuous inventory and monitoring survey; USDA Forest Service 1994) information being compiled by NFs in the Blue Mountains also may be used by project staff. The 1-ha, permanent sampling plots have been visited in the last 3 years and represent the most comprehensive vegetation data in this area. There are 15 CIMS plots within Starkey, either 2.7 km or 5.5 km apart.

Starkey staff have sampled vegetation as well, including transects in the northeast study area (Northeast) of Starkey (see Rowland and others 1997). Vegetation phenology data have been collected at 11 sites within Starkey (table 11, appendix 2; Rowland and others 1997). These data will probably not be incorporated into the Starkey habitat database but be used in forage allocation models for specific years (Johnson and others 1996).

Roads

Field personnel from the Grande Ronde Engineering Zone (GREZ) and LGRD recorded locations of roads at Starkey by walking or driving along all roads with a hand-held GPS receiver. Locations at road junctions were differentially corrected and averaged (at least 120 data points were collected); sections between road junctions were only differentially corrected (table 2). Road locations were entered in the habitat database by road segments, which are defined by intersections of roads. Each road segment was assigned a unique identification number (RoadSeg#), which is the key field for the roads database. Attribute data for roads were then assigned to each segment.

All roads tables in the STKYROAD directory are distinguished by year, because road attributes may change or new roads may be built (table 1). Road segments were placed in one of seven categories, according to level of use (“ROAD USE,” table 4, appendix 1). Portions of the roads data are stored either in the transportation management system (TMS) database of the Pacific Northwest Region or the GREZ roads database. Some variables, such as “WIDTH” and “ALIGNMNT,” were created specifically for the Starkey roads database.

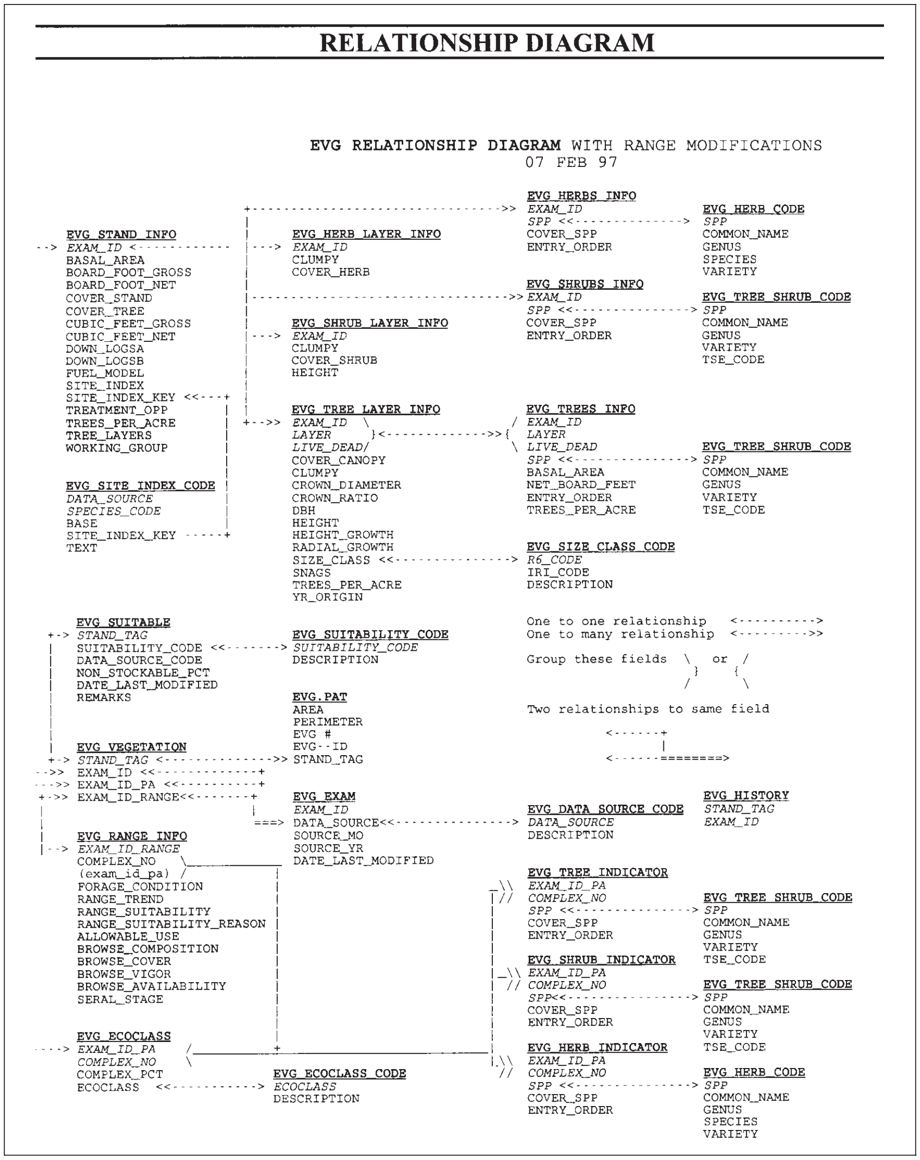

Figure 4—Variables and their relations in the existing vegetation (EVG) database for the Wallowa-Whitman National Forest.

The distance-to-roads tables are created with buffering routines in UTOOLS that calculate the distance to specific types of roads, in a given season and year, from each pixel (table 1). Roads in the buffer zone outside the perimeter fence also were mapped and categorized because of their potential influence on animal distribution within the fence.

Table 2—Accuracy of principal variables and vector layers in the Starkey habitat database

Variable or layer[a]	Source(s) of error	Error type	Estimated error or % accuracy	Remarks
Fences:				
FENCGPS3	DGPS[b]	Spatial	± 5 m	All fencelines walked or driven and mapped with portable GPS unit.
	Convert3,[c] convert2[d]	Spatial	Unestimated	
Fenccode	Human	Classification	100%	Assignment of fence type (barbed wire or elk fence).
ElkFence, CowFence	Rasterization	Spatial	9 m average	Fields in the spatial (rasterized) database.
Roads:				
TRN2OBT, TRN2INT, TRN2EXT	DGPS	Spatial	± 5 m	Road segments mapped as vector layer with portable GPS units and assigned unique 12-digit numbers.
	Convert3, convert2	Spatial	Unestimated	
RoadSeg#	Rasterization	Spatial	9 m average	Road segment ID number in the spatial database.
ROAD USE, LENGTH, SURF	Human	Classification	90%[e]	Field names in the database; description of road use (for example, green dot or closed), segment length, or surface type assigned by engineer may be incorrect, or entered incorrectly in database.
Soils:				
SOILS3	Human	Inherent	Unestimated	Soil polygon boundaries mapped as vector layer on aerial photographs and transferred to USGS quads. Boundary location could be wrong.
	Scanning,[f] Convert1,[g] convert2	Spatial	Unestimated	Polygon boundaries scanned and edited (WAW SO, Baker City).
SoilCode	Human	Classification	Unestimated	Field in spatial database; wrong soil type could be assigned to polygon (map unit). Starkey was mapped as a 2d-order (intensive) survey, that is, about 75% of polygons were visited in the field, and the remainder mapped from aerial photographs.
	Rasterization	Spatial	9 m average	
Topography:				
TOPOGSTK	Human	Inherent	Unestimated	Vector layer produced by digitizing 20-ft contour lines on USGS acetate overlays.
	Digitizing	Spatial	0.0025 cm	
	Convert4,[h] convert2	Spatial	Unestimated	
	Rasterization	Spatial	9 m average	
DEMSTKWI	Source map	Inherent	RMSE[i]<7 m	Original raster map, a level 1 DEM,[j] produced by FS Geometronics Service Center by digitizing 20-ft contour lines on 7.5-min USGS maps (see Thompson 1987 for map accuracy standards). Rasterized to 30- by 30-m cells. Accuracy may be less in areas of steep slope or along ridge tops.
	Digitizing	Spatial		
	Rasterization	Spatial		
Elev				Field in spatial database for elevation, from DEMSTKWI.
% slope	DEM	Classification	See Skidmore 1989	Field in spatial database; derived from DEM with AVERAGE method in UTOOLS (see USDI Bureau of Land Management 1990). Accuracy depends in part on DEM accuracy.
Aspect	DEM	Classification	Proportional to slope error	Field in spatial database; calculated in UTOOLS with AVERAGE method (see USDI Bureau of Land Management 1990 and Skidmore 1989). No additional error introduced through aspect calculation.
Convex3	DEM	Classification	= DEM error	Field in spatial database; calculated in UTOOLS (see Kvamme 1988 for details). No additional error introduced through convexity calculation.

Table 2—Accuracy of principal variables and vector layers in the Starkey habitat database (continued)

Variable or layer[a]	Source(s) of error	Error type	Estimated error or % accuracy	Remarks
Water:				
STRSTK2	Human	Inherent	Unestimated	Vector layer of streams; streams and crenulations were hand manu-scripted on 7.5-min maps and then scanned at Umatilla SO (cell size about 6.1 by 6.1 m). (See Thompson 1987 for national map accuracy standards.)
	Scanner	Spatial	Unestimated	
	Convert1, convert2	Spatial	Unestimated	
StrmSeg#	Rasterization	Spatial	9 m average	Vector maps rasterized in UTOOLS software; each stream segment assigned a unique ID number.
StrmClas	Human	Classification	Unestimated	Possible misclassification of stream class and other attribute data. Stream class accuracy for all of Starkey was coded as "B," that is, estimates used information that is less than complete (at least 1 value between "best" and "worst," or no knowledge of domestic use).
WATERPT4	DGPS	Spatial	± 5 m	Vector layer of water points mapped in field with portable GPS units.
	Convert3, convert2	Spatial	Unestimated	
Waterpt6	Rasterization	Spatial	9 m average	Water points rasterized in UTOOLS. Type of water source (for example, spring or seep) could be incorrectly assigned.
	Human	Classification	Unestimated	
Vegetation:				
Lansat91	Image resolution	Classification	82%	Originated as raster map. Elk habitat categories assigned from an unsupervised classification of a Landsat Thematic Mapper scene; field and map testing for accuracy assessment (Noyes and others 1994).
	Image placement	Spatial	0.87 pixels	Scene georectified with ground control points using UTM coordinates on 7.5-min USGS quads (Noyes and others 1994).
MRISTK3	Human	Inherent	90%[k]	Vegetation stand boundaries delineated by hand on aerial photographs, transferred to orthophoto quadrangles, and then digitized by scanning at Umatilla SO using half-quads (see USDA Forest Service 1992 for vegetation mapping standards). Cell size was about 2.4 m in LTPlus.
	Scanner	Spatial	Unestimated	
	Convert1, convert2	Spatial	Unestimated	
STANDID	Rasterization	Spatial	9 m average	Vegetation stand ID numbers; polygons rasterized in UTOOLS. All other vegetation variables are attributes assigned to these stand numbers.
Ecoclass, Veg Code, Total CC, #Layers, LYRCODE1-3, others	Human	Classification	70-75%[k]	May have incorrectly assigned vegetation attributes to stand polygons; all vegetation variables entered from photointerpretation only, except ecoclass (from LGRD EVG database). EVG_EXAM contains information about what type of exam was used for the LGRD vegetation variables.

[a] Variable names are described in table 3, appendix 1; vector layer names are in table 9, appendix 2.
[b] Differentially corrected Global Positioning System; all locations differentially corrected to at least 5 m CEP (circular error probable; see glossary). Locations of road junctions and traffic counters were differentially corrected and averaged (reference base station in Portland), resulting in potential 2-m accuracy.
[c] Conversion routine for Trimble Pathfinder Standard Storage Format to MOSS Export Format.
[d] Conversion routine for MOSS Export Format to Arc/Info binary format.
[e] Estimate provided by Richard Collins, formerly engineer with the Grande Ronde Engineering Zone.
[f] IDEAL monochrome scanner, Wallowa-Whitman and Umatilla NF SO; resolution for most images is 150 dots per inch.
[g] MOSS binary vector format to MOSS Export format.
[h] STRINGS export format to MOSS Export format.
[i] Root-mean-square error.
[j] Digital elevation model.
[k] Estimates for vegetation accuracy provided by Glenn Fischer, Umatilla NF.

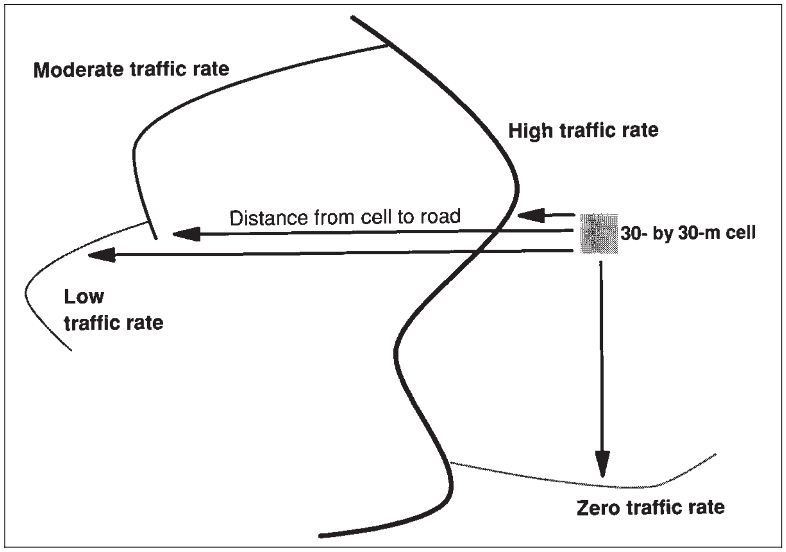

Figure 5—Distance to the nearest road characterized by a given traffic rate is recorded for each pixel in Starkey.

Traffic—Extensive data on traffic frequency have been gathered in the SEFR since 1988 with traffic counters on over 90 road segments (Cimon and others 1996, Rowland and others 1997). Counter locations are stored in a separate table (COUNTERS.DB; see table 1). Cameras at two sites also record vehicle type. Traffic frequencies have been analyzed from these counters for each season. Count data was summed for each counter for a given season. A moving window analysis (with one-half hour shifts) was conducted to determine the day-night combination that yields the highest ratio of day to night vehicle counts. The highest ratio was used to define the day and night periods for that season and year for any traffic-ungulate analysis of interest.

Each traffic counter was then characterized as belonging to a specific category of traffic frequency during the day and night periods for a given season and year. For example, each traffic counter was characterized as belonging to one of five traffic rate categories (very high, high, medium, low, or zero) during the day and one of two categories during the night (zero or nonzero). This designation of traffic categories, one for day and one for night for each counter, was then assigned to the applicable road segments, and corresponding pixels, near each counter. Buffering routines in UTOOLS created new derived variables for distance from a pixel to each of the road traffic categories for day and night (for example, distance to nearest pixel with "high" daytime road use; fig. 5, table 1). Vectors of use for deer and elk for these traffic categories, distinguished by day and night within a season, were then calculated and compared against random vectors of use under a multivariate analysis of variance (Wisdom 1998). Results indicate ungulates are selecting areas disproportionately far or close to roads of a specified traffic rate, in contrast to random use of the study area. Further studies will manipulate traffic to test these results.

Fences

An 8-foot-high game-proof fence encircles the perimeter of the SEFR (Bryant and others 1993). This fencing also separates the main study area (Main) and the winter feeding and handling area and its pastures, Campbell Flat research pasture, several game-proof exclosures, and Northeast. Barbed wire fences create additional grazing pastures for cattle within Main (fig. 6). (Cattle are grazed in the SEFR, except for the winter feeding and handling area, from June-October.) Fenceline locations were recorded with a portable GPS unit. Each pixel at Starkey is assigned to one of four elk pastures defined by the game-proof fence (MAIN, NORTHEAST, FEEDGROUND, and CAMPBELL), as well as to one of seven cattle pastures (table 3, appendix 1). Before construction of the Campbell Flat fence in fall 1992, Campbell was a cattle pasture in Main. This distinction is reflected in the "AREAB4.DB" and "AREAAFTR.DB" tables in the STKYAREA directory (table 1).

Soils

Soils information was abstracted from a database begun in 1986 by the Wallowa-Whitman NF (WAW). Data were compiled by mapping soil polygons on aerial photographs and transferring these polygons to 1:24,000 USGS topographic maps for digitizing. The Starkey soils information was collected with a second-order survey.[2] These mapping sites were classified from the following sources: 20 percent delineated only on aerial photographs; 15 percent determined from transects run at intervals (10 observations per transect, with 3 transects per map unit); 40 percent from traverses; and 25 percent from field observations (less standardized sampling than traverses or transects). Minimum size delineation for a second-order survey is about 2.4 ha. The Starkey area encompasses 37 map units (table 5, appendix 1). Additional information about each soil series can be accessed through the series number in the WAW soils database (table 10, appendix 2).

Water

Streams and rivers in the SEFR were mapped as line vectors by WAW personnel following mapped watercourses and also using contour lines and crenulations on USGS topographic maps (table 9, appendix 2). Streams were merged into sub-watersheds to simplify coding; cell size was about 6.1 m. Mapped streams were then scanned (Umatilla NF), edited in LTPlus, and later rasterized in UTOOLS. Each stream segment was assigned a unique identification number; at a minimum, stream segments end at confluences (USDA Forest Service 1991). A subset of the WAW stream variables is used in the Starkey habitat database (table 3, "STKYWATR.DB"; see the Tri-Forest Data Dictionary, USDA Forest Service 1991, for a complete listing). Locations of water sources other than streams, such as stock ponds or springs, were mapped with GPS recorders or by digitizing these features from FS grazing allotment maps (enlarged 7.5-minute topographic quadrangles).

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[2] Personal communication. 1995. Art Kreger, soil scientist, Wallowa-Whitman National Forest, P.O. Box 907, Baker City, OR 97814.

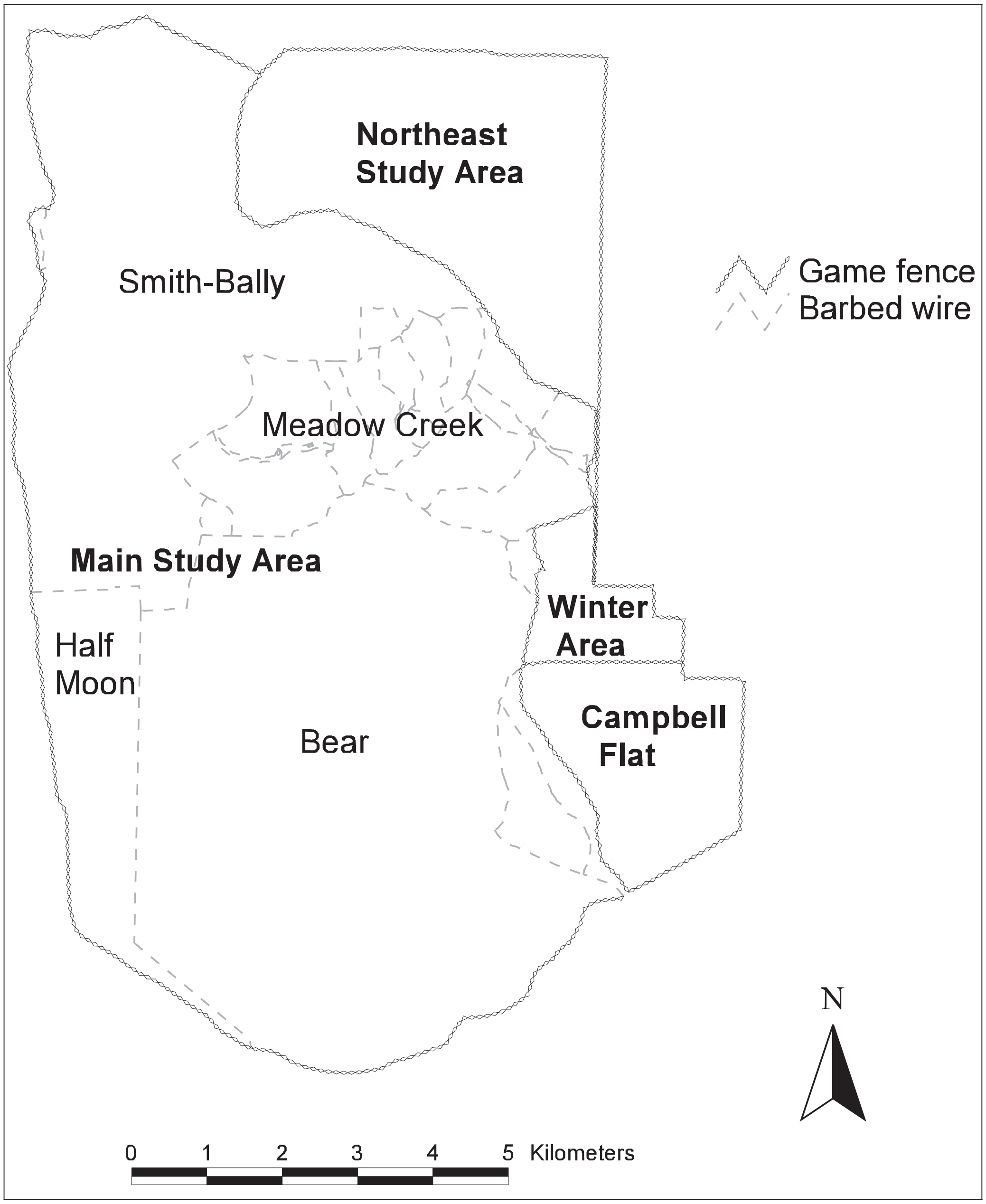


Figure 6—A combination of barbed wire and game-proof fences divides Starkey into pastures for more efficient management and research.

In calculating derived variables for distance to nearest water (for example, to nearest class II stream), ungulate species, pasture fencing, and year had to be accounted for. For example, cattle in Bear pasture do not have access to water in Smith-Bally pasture, even though some water in Smith-Bally may be closer to those cattle. Similarly, elk in Northeast cannot reach water in Main. It is assumed, however, that deer and elk cross cattle fences to reach water. Derived variables for distance to water have been created for elk and cattle thus far. In the future, a "generic" distance to water variable likely will be created that reflects the closest water source (regardless of type or order of stream) for a deer or elk, before and after the Campbell fence was built.

Topography

Elevation data for the SEFR were transferred from a digital elevation model (DEM) produced by the FS Geometronics Service Center. The DEM covering Starkey was created by digitizing contour lines on 7.5-minute USGS quadrangles; output is in 30- by 30-m raster format.[3] Slope, aspect, convexity, and other topographic variables (table 3) were derived from the DEM with routines in UCELL5. These programs use the "AVERAGE" method to calculate percentage of slope and aspect for the home pixel (Skidmore 1989) by using a roving 3- by 3-cell matrix. Convexity, which conveys variety in terrain, is derived by calculating the difference between elevation in the home pixel and an imaginary plane some specified distance above the surrounding pixels (Kvamme 1988).

Other Variables

Additional features have been, or will be, located with GPS units and entered in the habitat database. One is a subset of salt block sites that have been consistently used in the SEFR, partially mapped in December 1993. (These sites are not necessarily current salting locations). Another GIS layer maps the locations of microwave relay towers at Starkey. In the Northeast, perimeters of former timber sale units will be mapped with GPS. Additional data for possible inclusion in the habitat database are weather records, thermal neutrality zones, edge calculations (for example, between cover and forage areas), and forage productivity or biomass. A new set of digital orthophoto quadrangles also is available (see "orthophoto quadrangle" in the "Glossary").

Sources of Error and Accuracy Assessment

Interest in accuracy of spatial databases has burgeoned in recent years (Mowrer and others 1996), as users need to assess the reliability of analyses using databases constructed with GIS applications. All GIS products should present error rates to warn the user of potential pitfalls when making decisions based on these products (Goodchild and Gopal 1992). The following discussion highlights sources of error in the Starkey database as it now exists and offers suggestions for accuracy assessment that will ensure the legitimacy of the database as the foundation of the Starkey analyses (see Rowland 1996 for further elaboration of accuracy assessment of the Starkey habitat database).

[3] Personal communication. 1995. Rodney Dawson, geometronics engineer, Pacific Northwest Region, USDA Forest Service, 333 SW First Avenue, P.O. Box 3623, Portland, OR 97208.

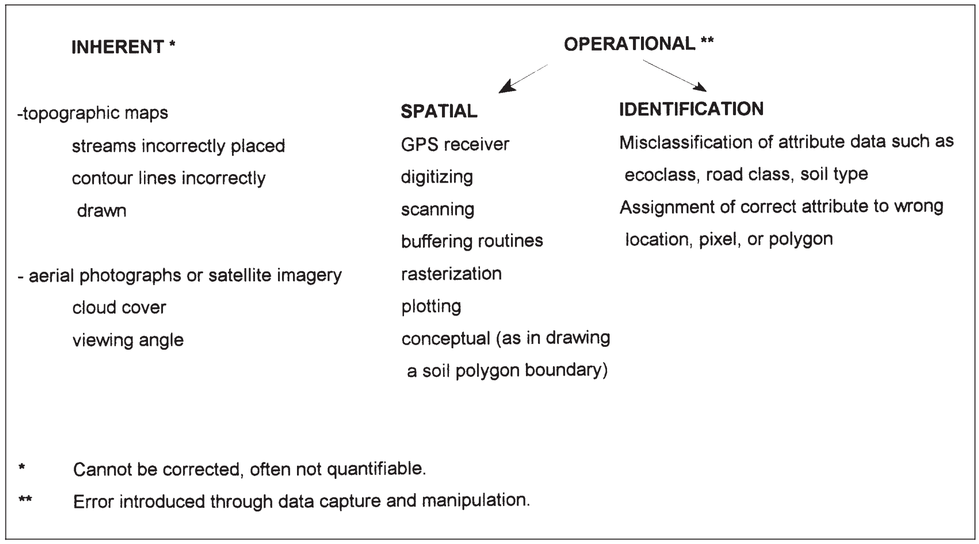


Figure 7—Types of error typical in GIS products (adapted from Goodchild and Gopal 1992 and Walsh and others 1987).

Types of Error

Experts in GIS classify and partition error in several ways (Goodchild and Gopal 1992); however, the following terminology is commonly used. **Inherent error** is error present in source materials, such as topographic maps or aerial photos (fig. 7). Inherent error can sometimes be quantified (for example, national mapping standards exist for U.S. maps [Thompson 1987]) but often remains unknown and uncorrectable**.** **Operational error** is error introduced through data capture and manipulation. It has two distinct components—**spatial** (positional, locational) **error** and **identification** (classification) **error** (Walsh and others 1987). Spatial error refers to geographic accuracy of data in a GIS, or the horizontal or vertical placement of boundaries. Digitizing, GPS, plotting, and scanning errors are types of spatial error introduced through data capture. Spatial error introduced through data manipulation includes errors from rasterizing vector data or using buffering routines to calculate distance to various features (for example, roads, water). Identification error refers to the misclassification of attribute data in the database, such as soil type or ecoclass. These errors are generally unknown but presumed to be negligible in most analyses.

Accuracy of Starkey Data

Most layers in the database were originally entered as vector maps, including vegetation, roads, streams, soils, fences, and some elevation data. Vector maps of features located with differentially corrected GPS (fences, roads, and water points) are accurate to about 2 to 5 m (see table 2 and Trimble 1992). In addition to the error inherent in this technique, software conversion routines add an unknown error (table 2). Finally, rasterization of these vector maps to create spatial databases adds an average spatial error of 9 m (see following discussion of rasterization errors). Vector maps not created using GPS (vegetation and soils polygons, streams, and elevation) were produced by first digitizing, and editing, these features (manually or by scanning) on orthophotos or aerial photographs. Again, conversion routines and rasterization add spatial error when these layers are converted to spatial databases in Paradox. In addition, any delineation of lines or polygon boundaries includes human or conceptual error in deciding where to draw lines. Attributes assigned to polygons also may be incorrect (table 2).

The UTM grid that underlies the row-column structure of the spatial database was created by rasterizing all vector maps in UTOOLS to a 30- by 30-m grid structure. The maximum error associated with this process is half the diagonal length of a pixel (or about 21 m), with an average error of 7.5 to 10.5 m. For the relative distance between two objects, the maximum error introduced through the raster process is 37 m. The maximum error associated with buffering routines (specifically, the distance between a pixel center point and some fixed feature such as a road) in UTOOLS is about 17 m.[4] Because some objects will in reality be closer than recorded in the database, and others farther away, average buffering error is likely around 0 m. Positions of features commonly buffered (fences, roads, water points, and salt locations) have all been determined with differentially corrected GPS (DGPS) and thus are as accurate as possible with any technology now in use at Starkey.

The scale of analysis influences acceptable levels of error by determining the compatibility of the habitat data with the questions being posed (Donovan and others 1987). The habitat database is used primarily with analyses that incorporate animal location data. Because the current error polygon for AATS locations is about 3.1 ha (90 percent confidence interval; Findholt and others 1996), resolution of habitat variables at this scale is likely adequate for most Starkey studies. Cumulative error may occur when combining map layers, however, justifying collection of habitat data at a finer scale.

"Veg code" (life form of vegetation) is one of several vegetation variables in the database that have never been field checked but were based entirely on photointerpretation. Another variable, ecoclass (from the LGRD vegetation database), is used extensively in the animal-unit-equivalencies study and forage allocation modeling (Johnson and others 1996). Although ecoclass was determined mainly from stand examinations, both ecoclass and "veg code," as well as some of the canopy cover variables, are priorities for field verification because of their prominent role in future analyses.

Accuracy Assessment Ongoing or Completed

Some accuracy assessment of the habitat database has been accomplished by Starkey Project and LGRD personnel:

- The Landsat scene used to classify elk habitat was georectified to UTM coordinates with orthophoto points; the resulting root-mean-square error (RMSE) was 0.87 pixels, within the recommended error of less than 1.0 pixel (Noyes and others 1994). Verification of elk habitat categories (satisfactory cover, marginal cover, or forage areas) derived from classification of this scene was completed in 1993 (table 2; Noyes and others 1994). Classification accuracy (82 percent) was typical for vegetation classification from Landsat TM scenes.

[4] Features are buffered relative to the center point of the pixel in question. Thus, the maximum distance between a center point and a feature in an adjacent pixel is 47 m (distance from center point of one pixel to the far corner of an adjacent pixel). The buffered feature will be assigned to the center point of its pixel (30 m from the center point of the home pixel); therefore the maximum error is 47 - 30 = 17 m.

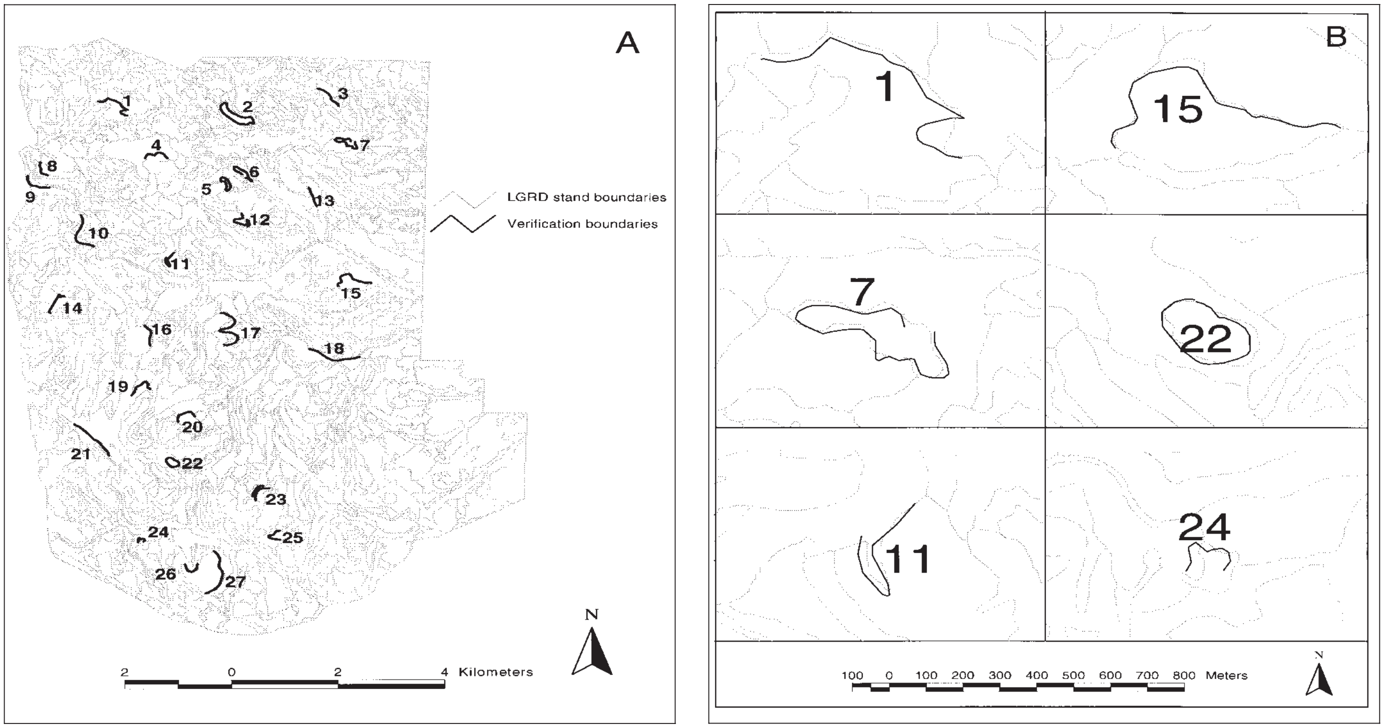


Figure 8—Verification of La Grande Ranger District vegetation stand boundary map by locating and digitizing obvious boundaries on orthophoto quadrangles (**A**); close-up view of 6 of the 29 segments compared (**B**).

- Twenty vegetation polygons in Starkey were visited in fall 1996 for validation of vegetation variables. Test polygons were randomly selected, outlined on aerial photographs, and stratified by ecoclass. Data collected included canopy closure, downed wood, and primary vegetation species.
- Forty-seven vegetation macroplots have been established in Northeast (Coleman and Bobowski 1991) and were sampled in 1991 and 1995. These data will be used for validation of some of the photointerpreted vegetation variables, such as canopy cover and primary and secondary species by layer.
- Twenty-nine plots were sampled in summer 1995 for accuracy assessment. The circular plots (30-m diameter) were centered on points 50 m north of 29 traffic counters, which have known UTM coordinates from DGPS readings (see Rowland 1996 for further details).
- Spatial accuracy of some vegetation polygon boundaries at Starkey was checked by delineating obvious stand boundaries (29 segments total) on orthophotos (1:24,000) and digitizing them (STRINGS software). These segments were visually compared to the original boundaries mapped by the FS (figs. 8A, B); correspondence was generally less than 50 m. A similar comparison was made of locations along fences mapped with GPS receivers versus those visible on orthophotos.

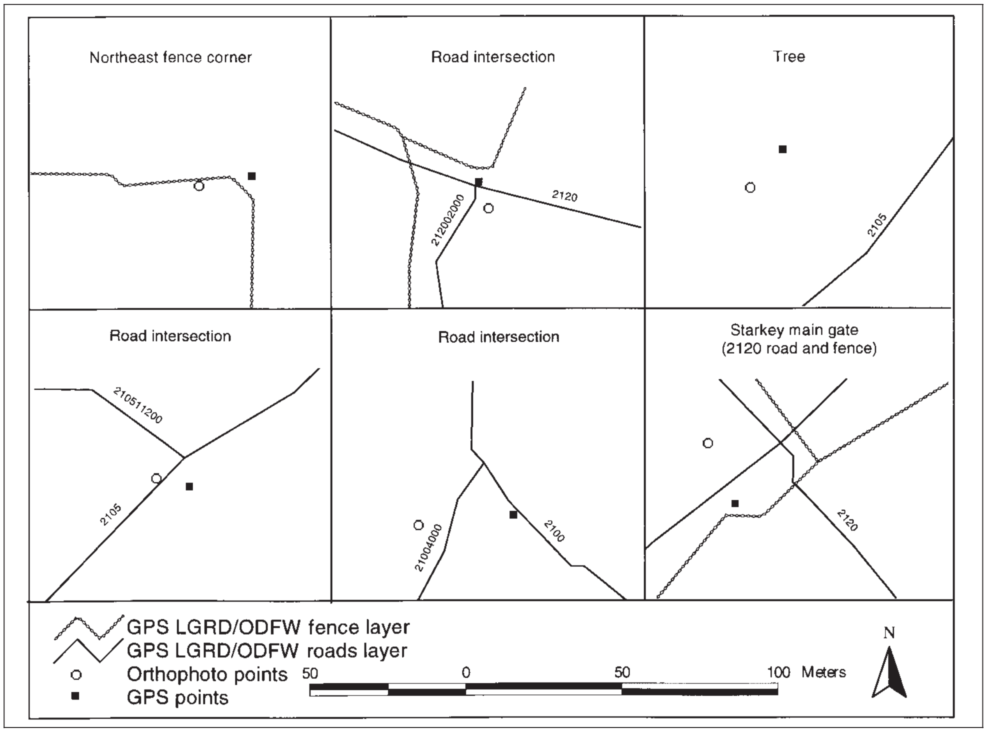


Figure 9—Comparison of locations for points mapped individually with GPS, points visible on orthophoto quadrangles, and road and fence layers in the habitat database.

- Most of the map layers provided by the FS for the habitat database were digitized from orthophotos. To test the accuracy of digitizing from orthophotos, a comparison was made between six locations digitized from USGS orthophotos and the same locations mapped with DGPS (fig. 9; see Rowland 1996). Mean offset was 16 m (easting) and 9 m (northing).

Suggestions for Future Accuracy Assessment and Monitoring

The requirement for accuracy assessment of the database is not uniform and depends on such factors as the probability that the data are erroneous, how often a variable will be used in analyses, what assumptions or further estimates will be based on the value recorded for a variable, the cost involved in verification, and the consequences of using erroneous data. In essence, some risk assessment is necessary. Although formal, quantitative verification and monitoring of the habitat database should be conducted, a more informal, qualitative review also will help eliminate errors from the database. Nugent (1995) lists several basic techniques to follow for quality control.

One data set collected previously that could be used to verify portions of the database is the soil survey and habitat type classification delineated on aerial black-and-white photographs taken in 1955 (Burr 1960). Another data set that may be used in verification of photointerpreted vegetation variables is the CIMS information (see “Vegetation,” above). If the elk habitat categories are used extensively in future habitat analyses, a more accurate rectification of the Landsat scene may be necessary. Recent work has shown that Landsat scenes rectified using GPS receivers at ground control points (versus points identified on 7.5-minute quadrangles) may be far more accurate (Cook and Pinder 1996).

To summarize:

- The accuracy of the Starkey habitat database is within the commonly used standards for error in GIS and likely is better described than most (Rowland 1996).
- Of the variables for which error rates are unknown, those related to vegetation probably should be tested first, especially ecoclass and species in the understory layer(s) that may provide forage for ungulates.
- Data collected in the macroplot studies in Northeast should be used for comparison with database vegetation variables wherever such comparisons are valid. These data have been collected twice and represent intensive field work at Starkey.
- A regular schedule of sampling and monitoring at random sites within the Starkey Project area would provide periodic checks on the accuracy of the database.

Using the Habitat Database—Sample Applications

Road Densities and Elk Habitat Effectiveness

One objective of the Starkey Project is to develop and validate an elk habitat effectiveness (HE) model for summer range. The road component of such a model is being tested by evaluating elk locations in relation to road densities and traffic frequencies within Starkey. Two road models are now used in forest planning in the Blue Mountains (Edge and others 1990): the curve in Thomas and others (1988), which in turn was derived from Lyon (1983); and the multifunction curve in Thomas and others (1979), developed with pellet count data collected by Perry and Overly (1977) in the Blue Mountains of Washington. Most road models present elk HE (dependent variable) as a linear function of open road density.

To validate these road models, open road densities and distribution at Starkey were first explored in several ways through the habitat database (Rowland 1997). One method was to calculate the road density in a square mile (2.6 km^2) centered on each of the 86,000 pixels in Main study area by using a moving window procedure ("Average Pixels" routine) in UCELL5 (McGaughey 1995). (Roads in a 0.8-km buffer surrounding Main were included in the database where this calculation was performed.) Any pixel with an open road present (defined as all road use categories except ZERO or CLOSED; see table 4) was counted as a "hit" in this procedure. Total "hits" were then multiplied by a constant for the average length of a road segment in a single pixel within Starkey, generating a new map layer of pixel-by-pixel road densities on a square mile basis. These density values were then joined in categories (for example, between 2 and 3 miles [3.2 and 4.8 km] of open road per square mile) and plotted as isopleths in UVIEW, providing a graphic depiction of areas with very low, as well as high, open road densities (fig. 10).

This portrayal of road densities on a fine scale aided subsequent delineation of analysis units, by spanning a range of road densities, for validating the road model within Main study area. The 15 units, averaging 506 ha, were created as a spatial database in Paradox with a series of queries on the UTM coordinates. Before unit boundaries were drawn, however, Main was first subdivided by subwatersheds to give the boundaries more biological credence and conform with current NF management and planning schemes. Thus, analysis units were delineated within the three primary subwatersheds (that is, unit boundaries did not cross subwatershed boundaries). Actual length of open roads in each unit was then calculated by overlaying a roads map with a vector (polygon) map of the analysis units. Further analysis to calculate proportion of elk use in each habitat analysis unit is underway.

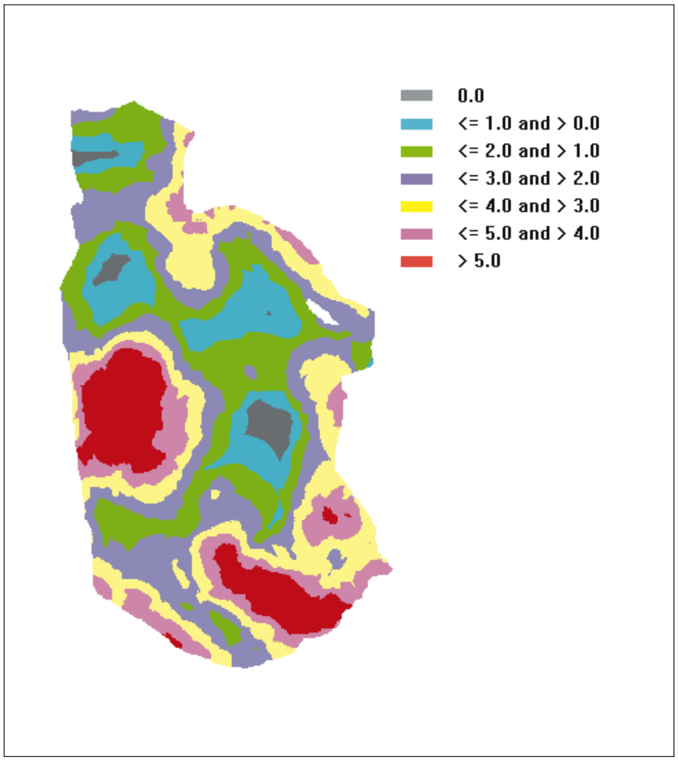
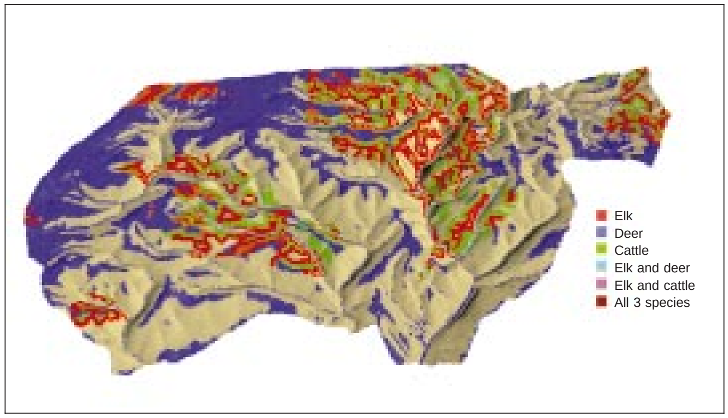


Figure 10—Open road densities (in miles per square mile) for Main study area, Starkey, calculated with an averaging procedure in UCELL5 and displayed in density isopleths. Open roads include all road use categories except "ZERO" or "CLOSED."

Forage Allocation Modeling

Predicting distributional relations and allocating forage among elk, mule deer, and cattle is a primary goal of the Starkey Project (Rowland and others 1997). To meet this goal, a forage allocation model was developed by using linear programming (Johnson and others 1996) to test modeling assumptions and develop methods for spatially displaying modeling results. The model was designed to track, on a monthly time-step, forage quality and quantity in four generalized habitat types: riparian, grasslands, open-canopy forests (10 to 40 percent canopy cover), and closed-canopy forests (greater than 40 percent canopy cover). These habitat types were derived from the habitat database as follows. Riparian areas were any pixels within 90 m of a class I stream. "Veg code," or life form of vegetation, was used to derive the grasslands and forested types, combined with canopy cover in vegetation layer 1 (see table 3, appendix 1) to distinguish between open- and closed-canopy forests. Forage quality and quantity values were obtained from previously published studies conducted within the SEFR or nearby sites and were assigned to the appropriate habitat types (Johnson and others 1996).

Modeled distributions of ungulates within all of Meadow Creek and Main study areas (fig. 6) were based on species-specific animal responses to five environmental variables in the habitat database: slope, distance to water, distance to roads, distance from cover into forage, and distance from forage into cover. Variables were



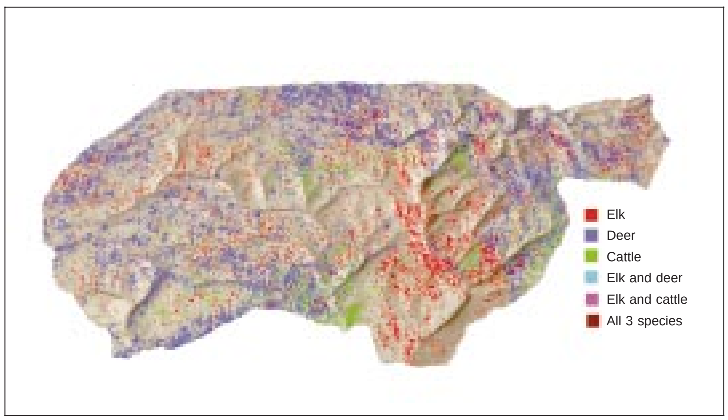


Figure 11—Predicted distribution of elk, mule deer, and cattle within the Starkey Experimental Forest and Range, using the "max preference" model for September (**A**; see text), and actual distribution from the automated animal telemetry system in September 1992-93 (**B**).

divided into several categories (for example, three slope categories of 0-15, 16-35, and greater than 35 percent); each category was then assigned a habitat preference score from 0.0 to 1.0. Variable selection and scores were developed from published studies (McInnis and others [1990] for cattle and Thomas and others [1979] for deer and elk).

The habitat database was then queried to identify and create polygons that contained unique combinations of the various categories of the five environmental variables. Habitat type was linked to those polygons, and the associated forage and environmental data were used in the model to predict elk, mule deer, and cattle distributions based on forage production and utilization constraints. Three model variates were tested (see Johnson and others 1996 for details); in the "max preference" model, species grazed in preferred habitats first (based on nonforage variables) and then moved to less preferred habitats. Results from the "max preference" model were then linked with the DEM to illustrate areas where the three species were predicted to forage in September (fig. 11A). Observed distributions of the three ungulate species in September 1992 and 1993 also are displayed (fig. 11B). The model assumes that all Main and Meadow Creek study areas are available to all three species, which was not true. Radio-telemetered cattle were excluded from Meadow Creek and a portion of Main. Consequently, comparisons of observed and predicted distributions for cattle must allow for this discrepancy.

Deriving Variables of Traffic Rate

How deer and elk are distributed in relation to roads having different rates of motorized traffic is a fundamental question on which the Starkey traffic study is based (see earlier description of this study). To answer this question, the rate of traffic (number of vehicles per unit time) is being summarized by season and year, for both Main and Northeast, from 1989 to the present. Following is a description of how variables of traffic rate were estimated for spring 1994, as an example of how data on traffic frequency are brought into the habitat database for analysis in relation to ungulate distributions.

Traffic counters, placed at nearly every road intersection at Starkey, provide summaries of traffic counts on 15-minute intervals, 24 hours a day, from spring through fall each year. For spring 1994 (April 15 to June 13), we first assigned each traffic counter to an associated section of road. Because counters are placed along roads just after their intersection with other roads, each counter estimates the frequency of traffic unique to an associated section of road.

After assigning counters to road sections, we used a moving window analysis to explore and estimate differences in rate of traffic during day versus night. We did this by (1) summing the frequency of traffic at each counter for two 12-hour periods, one for day and one for night; (2) calculating the ratio of traffic counts for the daytime 12-hour period to the traffic counts for the nighttime 12-hour period; and (3) shifting the daytime and nighttime periods successively 1 hour until all unique 12-hour periods of the day were encompassed. The resulting ratios indicated the 12-hour period of greatest difference in day versus night traffic frequency for each counter, as well as across all counters. The 12-hour period exhibiting the strongest difference in day versus night traffic across all counters was then identified and used to define daytime and nighttime. Distributions of daytime estimates of traffic frequency were plotted for all counters, and categories established based on obvious groupings or “breaks” in the data.

These groupings were defined as intervals of traffic rate, with daytime variables having five rates, based on a 12-hour interval: (5) high, 10 or more vehicles; (4) moderate, 4 to less than 10 vehicles; (3) low, 1 to less than 4 vehicles; (2) very low, more than zero but less than 1 vehicle; and (1) zero vehicles. Similar variables of low, very low, and zero traffic rates were identified for nighttime periods. Daytime and nighttime rates were then assigned to their respective traffic counters, and in turn, to the roads associated with each counter.

We then measured the distance of each 30- by 30-m pixel to the nearest road of each day and night rate, by using UTOOLS software (Ager and McGaughey 1997). For each pixel, we derived eight variables related to traffic rate for spring 1994: distance to nearest high, moderate, low, very low, and zero vehicle roads per 12-hour daytime period; and distance to nearest low, very low, and zero vehicle roads per 12-hour nighttime period (fig. 5). These variables are being analyzed in relation to deer and elk distributions for predefined seasons (fig. 12).

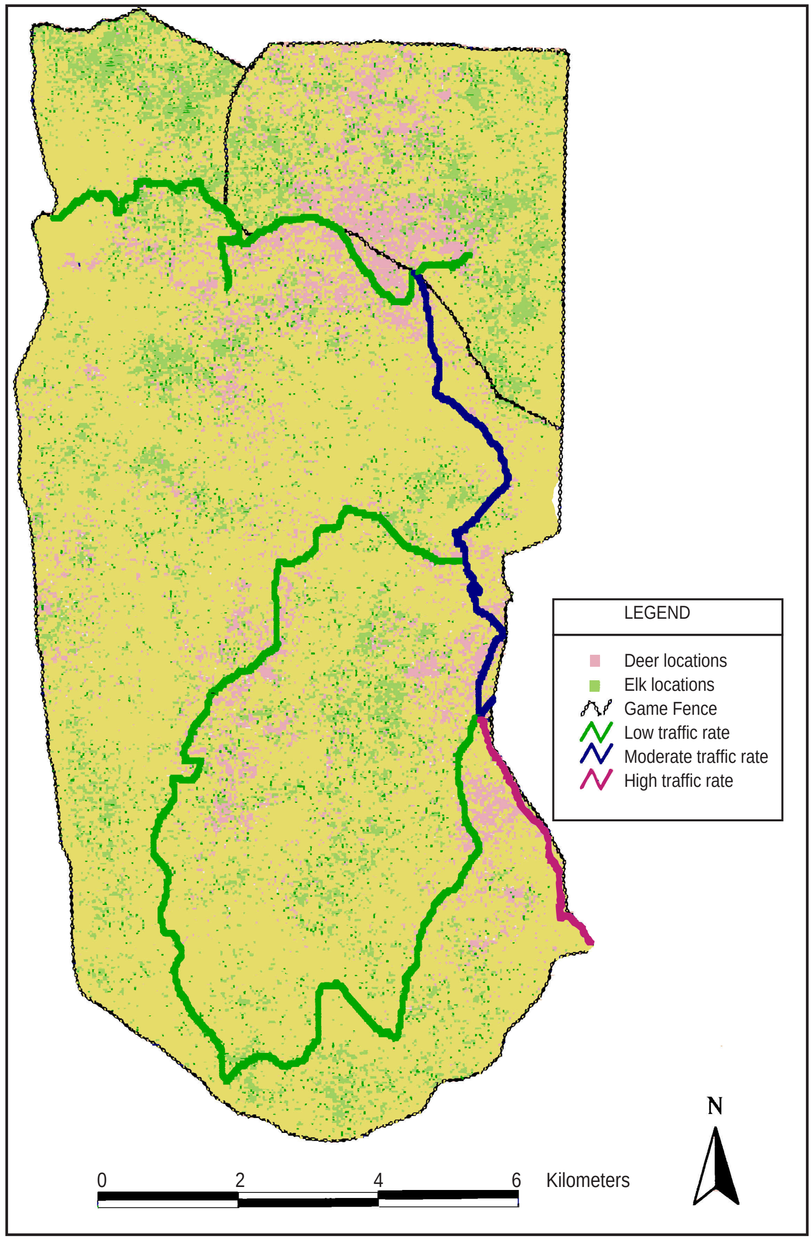


Figure 12–Elk and deer distribution in May 1994 in relation to roads in Starkey, categorized by rate of daytime traffic during spring 1994. Traffic rates, in number of vehicles per 12 hours, are as follows: low–1 to less that 4 vehicles; moderate–4 to less than 10 vehicles; and high–10 or more vehicles.

Recommendations

Users of the habitat database should be fully aware of variable definitions before undertaking analyses. These are found in lookup tables for each resource (table 1). For example, the variable "Total CC," or total canopy cover, was derived from photo-interpretation and represents all vegetation cover present in all layers, including grasslands; it does not represent only tree canopy closure. If only tree cover is needed for analysis, the user needs to construct a query combining other vegetation variables, such as "Canclos1" and "Size1."

Documentation of information in a GIS, including the data source(s), personnel involved in map creation, dates of creation, and methods used, is strongly recommended, primarily to guide future users and architects of the database. Without adequate records, it may be impossible to re-create portions of the database if necessary. In long-term research like the Starkey Project, new hypotheses will be developed and tested; the habitat database must be dynamic and flexible to accommodate future research. As new layers or variables are added to the database, their creation and construction should be described as in tables 8-11 (appendix 2), including any known or potential sources of error. Accuracy should be evaluated for those variables that are most used in analysis. This may require field sampling or sampling from aerial photographs or other sources.

Acknowledgments

Jack Ward Thomas first broached the Starkey research, designed and wrote the initial proposals for the traffic effects and intensive timber management studies, and obtained Forest Service funding for the research. Larry D. Bryant was instrumental in designing and procuring the automated telemetry system for tracking animals, overseeing construction and management of Starkey facilities, and in coordinating timber studies and livestock use within Starkey. Many of the ideas later put in practice in the creation of the Starkey habitat database were first suggested by Donavin Leckenby. Catherine Poppenwimer took over development of the database for 2 years (1988-90) while Priscilla Coe was on leave. Leonard Erickson, Jim Noyes, Catherine Poppenwimer, and La Grande Ranger District GIS personnel worked many hours digitizing. Dennis Isaacson, Donavin Leckenby, Cecilia Noyes, and Barbara Wales provided expertise in classification and accuracy assessment of the 1991 Landsat scene. Nathan Armburst, Dale Borum, Richard Collins, Brett Cooper, Ryan Kennedy, and Roanna Ruston collected GPS data in the field. Brian Fischer (LGRD GIS coordinator), Anne Kramer (Wallowa-Whitman GIS coordinator), and Art Kreger (Wallowa-Whitman soil scientist) maintain the vegetation, streams, and soils portions, respectively, of the FS databases used in the Starkey Project. Dave Motanic (Umatilla NF) photointerpreted vegetation characteristics at Starkey for 2 years.

Richard Collins and Randall Nielsen (GREZ) were instrumental in establishing and maintaining the roads portion of the database. Joan Vaughan provides networking assistance in connecting to these databases for updates. Robert McGaughey, with coauthor Alan Ager, developed the UTOOLS software used to create the raster-based portion of the database. We appreciate additional information provided by Brian Fischer, Glenn Fischer, Art Kreger, and Roanna Ruston, and editing by Scott Findholt, Brian Fischer, John Kie, and Donavin Leckenby.

Equivalents

1 kilometer (km) = 0.62 mile

1 meter (m) = 1.09 yards

1 meter (m) = 3.28 feet

1 centimeter (cm) = 0.39 inch

1 square kilometer (km^2) = 0.39 square mile

1 square kilometer (km^2) = 247.1 acres

1 hectare (ha) = 2.47 acres

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Appendix 1

Variables in the Starkey Habitat Database, Their Definitions, and Codes

Table 3—Variables in the raster (UTOOLS) portion of the Starkey habitat database, grouped by resource in Paradox tables[a]

Variable acronym[b]	Definition	Variable type	Paradox table or directory	Units or codes
UTMGrid	Universal Transverse Mercator coordinate grid; identifies center-point of each 30- by 30-m pixel	Discrete	All tables	UTM coordinates[c]
IN-OUT	Specifies whether pixel is inside or outside the Starkey perimeter fence	Categorical, binary	STKYAREA[d]	IN or OUT
ElkFence	Elk fence; pixels containing game-proof fence	Categorical, binary	STKYAREA	1, 0[e]
CowFence	Cattle fence; pixels containing fences that enclose a cattle pasture	Categorical, multiple	STKYAREA	0 or 2[f]
DistEFnc	Distance to nearest game-proof fence	Continuous	STKYAREA	Meters
NrstEFnc	UTM coordinates of nearest pixel containing game-proof fence	Continuous	STKYAREA	UTM coordinates
ElkPast	Elk pastures; areas separated by game-proof fence	Categorical, multiple	STKYAREA	MAIN, NE, CAMPBELL[g] HANDLING, EXCLOSURES
DistCFnc	Distance to nearest cattle fence	Continuous	STKYAREA	Meters
NrstCFnc	UTM coordinates of nearest pixel containing cattle fence	Categorical, multiple	STKYAREA	UTM coordinates
CowPast	Cattle pastures; separately fenced cattle pastures	Categorical, multiple	STKYAREA	SMITH-BALLY, HALFMOON, CAMPBELL, STRIP,[g] BEAR, HORSE, NE
Salt1293	Salt sites located in 12/93 (incomplete)	Categorical, binary	STKYAREA	1, 0[e]
Random	1,000 randomly selected pixels	Categorical, binary	STKYAREA	1 = point present; 0 = no point
RoadSeg#	Road segment number, created with GIS	Categorical, multiple	STKYROAD[h]	Unique 12-digit number; first 7 digits are road number; last five (incl. decimal point) are milepost at beginning of segment
BEG_DATE	Beginning date; year that a given set of attributes begins that apply to a road segment	Discrete	STKYROAD	Year (last 2 digits)
END_DATE	Ending date; year that a given set of attributes ends for a road segment	Discrete	STKYROAD	Year (last 2 digits)
ROADNO	FS road number; first part of RoadSeg# variable	Categorical, multiple	STKYROAD	Unique 7-digit number; first 2 digits are arterial route number, next 2 are collector number; last 3 are local designation of road

Table 3—Variables in the raster (UTOOLS) portion of the Starkey habitat database, grouped by resource in Paradox tables[a] (continued)

Variable acronym[b]	Definition	Variable type	Paradox table or directory	Units or codes
MP	Milepost at the beginning of each segment	Discrete	STKYROAD	5-digit number, including decimal point
LENGTH	Length of road segment as calculated by GIS	Continuous	STKYROAD	Miles
TERMINI	Beginning and ending points of each road segment, usually at a road junction	Discrete	STKYROAD	Road numbers to "end," milepost, or different road number
ROAD USE	Major categories of road use in SEFR	Categorical, multiple	STKYROAD	Coded (table 4, appendix 1)
RDPRIOR	Road priority; created to assign road use categories when >1 road segment occurs in the same pixel. Lowest number is used.	Categorical, multiple	STKYROAD	Coded (table 4, appendix 1)
DistOPEN	Distance to nearest pixel containing a greendot or open road	Continuous	STKYROAD	Meters
NrstOPEN	UTM coordinates of nearest pixel containing an open or greendot road	Categorical, multiple	STKYROAD	UTM coordinates
DistRSTR	Distance to nearest pixel containing a restricted road (administrative, possible, or N/A codes)	Continuous	STKYROAD	Meters
NrstRSTR	UTM coordinates of nearest pixel containing a restricted road	Categorical, multiple	STKYROAD	UTM coordinates
DistCLSD	Distance to nearest pixel containing a closed road (coded zero or closed)	Continuous	STKYROAD	Meters
NrstCLSD	UTM coordinates of nearest pixel containing a closed road	Categorical, multiple	STKYROAD	UTM coordinates
FENCE	Describes whether a given road segment is inside or outside the perimeter fence at Starkey	Categorical, dichotomous	STKYROAD	IN or OUT
OPML	Operational maintenance level of a road	Categorical, multiple	STKYROAD	Coded (table 4, appendix 1)
OBML	Objective maintenance level of a road	Categorical, multiple	STKYROAD	Coded (table 4, appendix 1)
MILES	"True" length of a road segment measured on the ground	Continuous	STKYROAD	Nearest 0.01 mile
DITCH	Indicates whether a drainage ditch abuts road segment	Categorical, dichotomous	STKYROAD	Y = yes, N = no
ID	Year of last road inventory for a given road segment	Categorical, multiple	STKYROAD	Last 2 digits of year, or N/A (road never inventoried)
SURF	Type of road surfacing	Categorical, multiple	STKYROAD	Coded (table 4, appendix 1)
F_CL	Functional classification of roads	Categorical, multiple	STKYROAD	Coded (table 4, appendix 1)
DV1	Design vehicle for alignment and strength	Categorical, multiple	STKYROAD	Coded (table 4, appendix 1)
DV2	Design vehicle for surfacing (smoothness)	Categorical, multiple	STKYROAD	Coded (table 4, appendix 1)

Table 3—Variables in the raster (UTOOLS) portion of the Starkey habitat database, grouped by resource in Paradox tables[a] (continued)

Variable acronym[b]	Definition	Variable type	Paradox table or directory	Units or codes
CVH	Critical design vehicle; type of vehicle that must be able to traverse the road on a limited basis	Categorical, multiple	STKYROAD	Coded (table 4, appendix 1)
S_LVL	Service level; significant traffic characteristics	Categorical, multiple	STKYROAD	Coded[k]
STRE	Existing management strategy for a road	Categorical, multiple	STKYROAD	Coded (table 4, appendix 1)
STRF	Future management strategy for a road	Categorical, multiple	STKYROAD	Same as above
CLASS	Road classification; includes number of travel lanes followed by design speed (miles/hr)	Categorical, dichotomous	STKYROAD	S = single lane; values for Starkey are S05, S10, S15, and S25
POSITION	Position of road on the slope	Categorical, multiple	STKYROAD	Coded (table 4, appendix 1)
GRADE	Average percentage of grade, categorized by risk factors	Categorical, multiple	STKYROAD	Coded (table 4, appendix 1)
WIDTH	Road width	Continuous	STKYROAD	Feet
ALIGNMNT	Horizontal alignment of road	Categorical, multiple	STKYROAD	Coded (table 4, appendix 1)
Soils	Soil types	Categorical, multiple	STKYSOIL.DB	Coded (table 5, appendix 1)
Elev	Elevation; distance above sea level	Continuous	STKYTOPO.DB	Meters
%Slope	Percentage of slope	Continuous	STKYTOPO.DB	Percent (0-∞)
Aspect	Direction a slope faces; direction of maximum downward slope	Continuous	STKYTOPO.DB	Degrees (-1 to 359)[m]
Convex3	Convexity index (gulch index); topographic measure of terrain surrounding a pixel	Continuous	STKYTOPO.DB	Meters
SINAspct	Sine of aspect	Continuous	STKYTOPO.DB	-1.00 to 1.00
COSAspct	Cosine of aspect	Continuous	STKYTOPO.DB	-1.00 to 1.00
#Towers	Number of loran-c towers visible from a pixel	Categorical, multiple	STKYTOPO.DB	0-8
StrmSeg#	Stream segment number	Categorical, multiple	STKYWATR.DB	Unique 21-character identifier, including subwatershed,[n] stream number, and milepost
StrmClas	Stream class; subjective description of the relative value of a stream based on its uses or on the potential of the stream to affect beneficial uses of streams lower in the watershed	Categorical, multiple	STKYWATR.DB	Coded (table 6, appendix 1)
Order	Stream order; relative position of stream segment in a watershed	Categorical, multiple	STKYWATR.DB	Coded (table 6, appendix 1)
Flow	Stream flow; proportion of year that water flows or is ponded in a segment	Categorical, multiple	STKYWATR.DB	Coded (table 6, appendix 1)
FlowAcc	Accuracy of stream flow measurements	Categorical, multiple	STKYWATR.DB	Coded (table 6, appendix 1)

Table 3—Variables in the raster (UTOOLS) portion of the Starkey habitat database, grouped by resource in Paradox tables[a] (continued)

Variable acronym[b]	Definition	Variable type	Paradox table or directory	Units or codes
WaterPt6	Water point; water sources other than streams	Categorical, multiple	STKYWATR.DB	Developed and undeveloped springs; pond, reservoir, or well
Lansat91	Elk habitat categories	Categorical, multiple	LANSAT91.DB (in STKYPI)	1=forage, 2=marginal cover, 3=satisfactory cover
Ecoclass	Plant association	Categorical, multiple	STKYEVG	Coded (table 7, appendix 1)
STANDID	Unique identifier of vegetation stands larger than 5 acres	Categorical, multiple	STKYPI[o]	12-digit number-letter combination
Veg code	Life form of vegetation	Categorical, multiple	STKYPI	Coded (table 7, appendix 1)
TOTAL CC	% vegetated or % canopy closure (cover); sum of cover in all vegetation layers	Continuous	STKYPI	0-100%
#Layers	Number of vegetation layers	Discrete	STKYPI	1, 2, or 3
LYRCODE1-3	Layer type of vegetation layers 1-3	Categorical, multiple	STKYPI	Coded (table 7, appendix 1)
LYR1SPC1-3	Primary, secondary, and tertiary plant species in layer 1	Categorical, multiple	STKYPI	Coded[n]
SIZE1-3	Average size class of trees in layers 1-3	Categorical multiple	STKYPI	Coded (table 7, appendix 1)
CanClos1-3	% canopy closure of all species in layers 1-3	Continuous	STKYPI	0-100%, in 5% increments
Crndia1-3	Average crown diameter of vegetation in layers 1-3	Continuous	STKYPI	Feet
LYR2SPC1-3	Primary, secondary, and tertiary plant species in layer 2	Categorical, multiple	STKYPI	Coded[n]
LYR3SPC1-3	Primary, secondary, and tertiary plant species in layer 3	Categorical, multiple	STKYPI	Coded[n]
MgmtActiv	Timber harvest management activity	Categorical, multiple	STKYPI	Coded (table 7, appendix 1)

[a] Many of these variables also are accessible in the Arc/Info platform of the database, especially the roads and vegetation variables. Variable names may be somewhat different, however.
[b] Name of field in the database tables.
[c] Composed of 6-digit easting and 7-digit northing coordinates in the UTM grid system, North American Datum 1983, zone 11.
[d] STKYAREA contains two tables, AREAAFTR.DB and AREAB4.DB; these correspond to time periods after and before the Campbell Flat elk fence was constructed in September 1992.
[e] A "1" indicates habitat feature present in that pixel; a "0" indicates feature absent.
[f] A "0" indicates no fence; a "2" indicates barbed wire fence.
[g] CAMPBELL is not an ElkPast option in the AREAB4.DB table, which applies to the time before the Campbell elk fence was erected; likewise, STRIP is not a CowPast option in this table. In AREAB4.DB, CAMPBELL is a cattle pasture in Main, and STRIP is part of CAMPBELL.
[h] STKYROAD contains 12 tables, based on year. See table 1, main text.
[k] C = interrupted by limited passing facilities, or slowed by road construction; D = flow is low or may be blocked by an activity, such that 2-way traffic is difficult and may require backing to pass.
[m] -1 = no slope or aspect (flat); 0 = north.
[n] See Tri-Forest Data Dictionary (USDA Forest Service 1991; p. 32-1 to 32-15 for subwatershed codes; p. 13-51 to 13-55 for plant species codes). For vegetation entered by layers (for example LYR1SPC1, 2, or 3), species are listed in decreasing order of canopy closure, and each must comprise at least 20 percent of the canopy closure.
[o] STKYPI contains two tables, 1987PI.DB and 1993PI.DB, that correspond to the two sets of aerial photographs interpreted.

Table 4—Codes and descriptions for variables in the roads portion of the Starkey habitat database[a]

Field or variable name[b]	Code	Description
ROAD USE:		
Inside fence	Zero	Barricaded or otherwise known to have no traffic
	Possible	Not open to public and rarely used; not physically closed
	Administrative	Receives only administrative use
	Green dot	Open to public from May 1 until mid-December; moderate to heavy use
Outside fence	Closed	Closed to all traffic by gate, windfall, or barricade
	Open	Open to public; moderate to heavy use
	N/A	Not inventoried; no information available
RDPRIOR	1	Green dot
	2	Open
	3	Administrative
	4	Possible
	5	N/A
	6	Zero
	7	Closed
OPML, OBML	0	Obliterated, to be returned to full resource production; usually ripped, seeded, and drainage removed
	1	Closed; annual culvert-drainage check; clean as necessary
	2	Maintain for high clearance vehicles; brush out, check drainage
	3	Lowest level maintained for low clearance vehicles (passenger cars); brush out, check drainage, blade as needed
SURF	2	Open crushed or high-quality pit run
	3	Dense graded crushed rock
	4	Dirty pit run
	6	Native or less than 25% spot rocked
F_CL:		
LTCC		Long term (permanent road), constant service (open for use on a continuous or recurrent basis each year); collector (connected to public or forest arterial road)
LTCL		Long term, constant service, local (connects terminal facilities, landings, campgrounds, buildings, etc., with arterial, collector, or other local roads)
LTIL		Long term, intermittent use (road closed for >1 year between periods of use), local
ST		Short term, temporary roads with limited life, to be returned to resource production
DV1, DV2, CVH	7A	Loader-yarder (width at least 3.7 m)
	7B	Standard log truck
	7C	Lowboy configuration
	7D	14-m chip van
	7E	8.5-m truck with trailer
	7F	High clearance = 25 cm
	7G	Low clearance = 10 cm
	7H	Not applicable

Table 4—Codes and descriptions for variables in the roads portion of the Starkey habitat database[a] (continued)

Field or variable name[b]	Code	Description
STRE, STRF	OTPT	Open to passenger car, public use (always use with maintenance levels 3, 4, and 5)
	ACC	Accept use (used mostly)
	ELST	Eliminate; all use eliminated
	ELLT	Eliminate; all use inactivated
	ENC1	Encourage high clearance vehicle use; used mostly when a destination sign is used or planned for use
	ENC2	Encourage project use
	DIS1	Discourage low clearance vehicle; rarely used on level 2 roads
	DIS2	Discourage public use
	DIS3	Discourage snowmobile use
	DIS4	Discourage all use
	PRO1	Prohibit dispersed recreation
	PRO2	Prohibit public use
	PRO3	Prohibit snowmobile use
POSITION	5	Draw bottom (within 46 m of drainage bottom)
	4	Lower 1/3 of slope, but farther than 46 m from drainage bottom
	2	Middle 1/3 of slope
	1	Upper 1/3 of slope including ridge top
GRADE	5	Road grade exceeds 10%
	4	Road grade is between 8 and 10%
	3	Road grade is between 5 and 7%
	1	Road grade is less than 5%
	NA	Road grade unknown (not inventoried)
ALIGNMNT	E	Excellent
	G	Good
	F	Fair
	P	Poor
	C	Primitive (alignment that is impassable by logging trucks)

[a] These codes also are found in the database table ROADCODE.DB.
[b] Variable names defined in table 3, appendix 1.

Table 5—Codes and descriptions for the variable "SoilCode" in the rasterized portion of the Starkey habitat database[a]

Symbol	Map unit name
1A[b]	Vitrandic Xerochepts-Typic Vitrixerands frigid-Aquic Udorthents complex, 0-5% slopes
5A	Typic Argixeroll-Mollic Palexeralf complex, 0-5% slopes
165C	Getaway-Threecabin-Rock outcrop complex, 30-60% slopes
170A	Syrupcreek-Limberjim complex, 0-15% slopes
170B	Syrupcreek-Limberjim complex, 15-30% slopes
170C	Syrupcreek-Limberjim complex, 30-60% slopes
171A	Limberjim-Syrupcreek complex, 0-15% slopes
171B	Limberjim-Syrupcreek complex, 15-30% slopes
171C	Limberjim-Syrupcreek complex, 30-60% slopes
174A	Syrupcreek-Lowerbluff complex, 0-15% slopes
174B	Syrupcreek-Lowerbluff complex, 15-30% slopes
175A	Klicker-Syrupcreek complex, 0-15% slopes
175B	Klicker-Syrupcreek complex, 15-30% slopes
175C	Klicker-Syrupcreek complex, 30-60% slopes
176C	Klicker-Limberjim complex, 30-60% slopes; includes former code 166C
181A	Downeygulch-Lowerbluff complex, 2-15% slopes
181B	Downeygulch-Lowerbluff complex, 15-30% slopes
182A	Syrupcreek-Tamarak complex, 0-15% slopes
190A	Anatone-Bocker-Fivebit complex, 0-15% slopes
190B	Anatone-Bocker-Fivebit complex, 15-30% slopes
190C	Anatone-Bocker-Fivebit complex, 30-60% slopes
191A	Albee-Bocker complex, 2-15% slopes
191B	Needham-Parsnip moist-Bocker complex, 15-30% slopes
192A	Bunchpoint-Bocker complex, 2-15% slopes
192B	Fivebit-Bocker-Kamela complex, 15-30% slopes; formerly 192C
195A	Fivebit-Klicker-Anatone complex, 0-15% slopes
195B	Klicker-Thirstygulch-Anatone complex, 15-30% slopes
195C	Klicker-Thirstygulch-Anatone complex, 30-60% slopes
195D	Klicker-Fivebit-Anatone-Rock complex, 60-90% slopes
196A	Klicker-Fivebit-Kamela complex, 0-15% slopes
196B	Klicker-Fivebit-Kamela complex, 15-30% slopes
196C	Klicker-Fivebit-Kamela complex, 30-60% slopes
196D	Klicker-Fivebit-Kamela complex, 60-90% slopes
197A	Bocker-Anatone-Rock outcrop complex, 2-15% slopes
197B	Bocker-Anatone-Rock outcrop complex, 15-30% slopes
197C	Bocker-Imnaha south-Rock outcrop complex, 30-60% slopes
198A	Snell-Bocker-Anatone complex, 0-15% slopes

[a] These codes also are found in the Paradox database SOILCODE.DB.
[b] 1A and 5A are alluvium, meadows, or miscellaneous land types. All other codes are basalt, andesite, hard rhyolite, or hard tuff.

Table 6—Codes and their descriptions for variables related to streams[a]

Variable name[b]	Code	Description
StrmClas	1	Class I—perennial or intermittent stream segments that have one or more of the following characteristics:
		—used by sensitive, threatened, endangered, or large numbers of other (nonlisted) fish
		—direct source of water for domestic use
		—flow enough water to be a major contributor to the quantity of water in a class 1 stream
	2	Class II—perennial or intermittent stream segments that have one or more of the following characteristics:
		—used by fish but does not satisfy class I criteria
		—flow enough water to be a major contributor to the quantity of water in a class II stream
	3	Class III—all other stream segments that do not meet higher class criteria, and are perennial or have bankside riparian shrubs or both
	4	Class IV—all other stream segments that are intermittent but do not meet higher class criteria
	5	Category E—all stream segments that have ephemeral flow duration
Order	0	Ephemeral draw channels
	1	Small, unbranched tributaries with a defined scour channel
	2	Produced by the junction of two first-order streams
	3	Produced by the junction of two second-order streams
	4-6	As above
FlowAcc	C	Good information, obtained from flow designations shown on USGS 7.5-min quadrangles
	D	Guess, based on the geomorphic setting of the segment
Flow	E	Ephemeral; water flows only during and immediately after precipitation or snow melt
	N	Intermittent; no riparian vegetation. Water flow ceases during dry season
	P	Perennial; water flows yearlong in stream segment except in periods of extreme drought

[a] These codes also are found in the Paradox table WATRCODE.DB.
[b] Variable names are explained in table 3, appendix 1.

Table 7—Codes and their descriptions for vegetation variables

Variable name[a]	Code	Description
Size1-3	1[b]	Seedlings—trees less than 1 inch d.b.h.[c]
	2	Seedlings and saplings mixed
	3	Saplings—trees 1.0 to 4.9 inches d.b.h.
	4	Saplings and poles mixed
	5	Poles—trees 5.0 to 8.9 inches d.b.h.
	6	Poles and small trees mixed
	7	Small trees—9.0 to 20.9 inches d.b.h.
	8	Small trees and medium trees mixed
	9	Medium trees—21.0 to 31.9 inches d.b.h.
	10	Medium and large trees mixed (large trees—32.0 to 47.9 inches d.b.h.)
VegCode	CX	Coniferous forest
	GM	Moist grassland in forest zone
	GX	Other grassland
	MM	Moist meadow
	SM	Shrubland
	SX	Other shrubland
LYRCODE1-3	H	Only one herb layer in stand
	S	Only one shrub layer in stand
	T	Only one tree layer in stand
	1	First tree layer in stand
	2	Second tree layer in stand
	3	Third tree layer in stand
MgmtActiv	HCPH	Regeneration harvest, clearcutting, patch
	HITH	Intensive harvest method and other changes, thinning
	HPRC	Regeneration harvest, partial removal
	HROS	Regeneration harvest, removal cut, overstory
	HSST	Regeneration harvest, seed cut, seed tree
	HSSW	Regeneration harvest, seed cut, shelterwood
Ecoclass	AB	Buildings, structures, roads
	CD-G1-11	Ponderosa pine-Douglas-fir-elksedge; A 29[d]
	CD-G1-21	Douglas-fir-pinegrass; B 332
	CD-S6-11	Ponderosa pine-Douglas-fir-snowberry-oceanspray; A 30
	CD-S6-22	Douglas-fir-common snowberry; B 358
	CD-G1-21	Douglas-fir-pinegrass; B 332
	CD-S6-34	Douglas-fir-spirea; B 352
	CD-G1-11	Ponderosa pine-Douglas-fir-elksedge; A 29
	CD-S7-11	Ponderosa pine-Douglas-fir-ninebark; A 31
	CD-S6-11	Ponderosa pine-Douglas-fir-snowberry-oceanspray; A 30
	CJ-G1-11	Juniper-bunchgrass; A 16
	CJ-S8-11	Juniper-stiff sage scabland; A 17
	CL-S5-11	Lodgepole-big huckleberry; A 35
	CL-S4-11	Lodgepole-grouse huckleberry; A 36
	CL-G2	Lodgepole-pinegrass; C 77
	CL-G2-11	Lodgepole-pinegrass-grouse huckleberry; A 34
	CL-S4-16	Lodgepole-pinegrass-grouse huckleberry; C 79
	CL-F2-11	Lodgepole-twinflower; B 305

Table 7—Codes and their descriptions for vegetation variables (continued)

Variable name[a]	Code	Description
	CP-G1-11	Ponderosa pine-wheatgrass; A 25
	CP-G1-12	Ponderosa pine-fescue; A 26
	CP-G1-31	Ponderosa pine-Idaho fescue; B 378
	CP-S5-22	Ponderosa pine-common snowberry; B 372
	CW-G1-12	Mixed conifer-pinegrass-ash soils; A 33
	CW-G1-11	Mixed conifer-pinegrass-residual soil; A 32
	CW-S3-21	Grand fir-spirea; A 315
	CW-S2-11	White fir-big huckleberry; A 38
	CW-S8-11	White fir-grouse huckleberry; A 39
	CW-F3-11	White fir-twinflower-forb; A 37
	GB-91-11	Bluegrass scabland; A 8
	GB-49-11	Bunchgrass on shallow soil, gentle slopes; A 9
	GB-49-12	Bunchgrass on deep soil, gentle slopes; A 10
	GB-49-13	Bunchgrass on shallow soil, steep slopes; A 11
	GB-49-14	Bunchgrass on deep soil, steep slopes; A 12
	GB-59-11	Idaho fescue-prairie junegrass (ridgetops); B 33
	MD	Dry meadow; A 4
	MM	Moist meadow; A 5
	MW	Wet meadow; A 6
	NR	Rocky land with minimal vegetation potential
	SD-19-11	Low sagebrush-bunchgrass; A 14
	SD-91-11	Stiff sage scabland; A 13
	WR	Running water-streams, creeks, rivers, ditches

[a] Variable names are explained in table 3, appendix 1.
[b] Codes are from the Integrated Resource Inventory (IRI); see USDA Forest Service 1991, p. 13-48.
[c] Diameter at breast height.
[d] Letters and numbers refer to reference in which the ecoclass is defined and corresponding page number; A = Hall 1973; B = Johnson and Simon 1987; C = Johnson and Clausnitzer 1992.

Appendix 2

Documentation and Creation of Variables, Source Maps, and Tables in the Starkey Habitat Database

Table 8—Creation of variables in the UTOOLS portion of the Starkey habitat database

Variable acronym	Type	Method of creation	Source[a]
UTMGrid	NA[b]	UCELL5[c]; data conversion of MOSS vector map to Paradox table	NA
ElkFence	Base[d]	UCELL5; data conversion of MOSS vector map to Paradox table	FENCGPS3
DistEFnc	Derived[e]	UCELL5; spatial operations, buffer all pixels	ElkFence
NrstEFnc	Derived	UCELL5; spatial operations, buffer all pixels	ElkFence
ElkPast	Base	UCELL5; data conversion of MOSS vector map to Paradox table	ELKPAST
CowFence	Base	UCELL5; data conversion of MOSS vector map to Paradox table	FENCGPS3
DistCFnc	Derived	UCELL5; spatial operations, buffer all pixels	CowFence
NrstCFnc	Derived	UCELL5; spatial operations, buffer all pixels	CowFence
CowPast	Base	UCELL5; data conversion of MOSS vector map to Paradox table	COWPAST
Salt1293	Base	UCELL5; data conversion of MOSS vector map to Paradox table	SALTD93
Random	Derived	UCELL5; create database of random pixels	UTMGrid
RoadSeg#	Base	UCELL5; data conversion of MOSS vector map to Paradox table	TRN2OBT, TRN2INT, TRN2EXT
BEG_DATE[f]	Attribute[g]	Paradox join of rasterized MOSS road maps with STKROADS.DB roads database	STARKEY.DB
MP	Derived	Paradox join of rasterized MOSS road maps with STKROADS.DB roads database	STARKEY.DB
LENGTH	Derived	Paradox join of rasterized MOSS road maps with STKROADS.DB roads database	STARKEY.DB
ROAD USE	Attribute	Paradox join of rasterized MOSS road maps with STKROADS.DB roads database	STARKEY.DB
DistOPEN[h]	Derived	UCELL5; spatial operations, buffer all pixels using “green dot” and “open” roads	ROAD USE
SoilCode	Base	UCELL5; data conversion of MOSS vector map to Paradox table	SOILS4
Elev	Base	UCELL5; data conversion of MOSS/MAPS SPSS file to Paradox table	DEMSTKWI
%Slope	Derived	UCELL5; spatial operations; slope	Elev
Aspect	Derived	UCELL5; spatial operations; aspect	Elev
SINAspct	Derived	UCELL5; spatial operations, sine of aspect	Aspect
COSAspct	Derived	UCELL5; spatial operations, cosine of aspect	Aspect
Convex3	Derived	UCELL5; spatial operations, convexity; search distance = 129 m; elevational differential = 500 m	Elev

Table 8—Creation of variables in the UTOOLS portion of the Starkey habitat database (continued)

Variable acronym	Type	Method of creation	Source[a]
StrmSeg#	Base	UCELL5; data conversion of MOSS vector map to Paradox table	STRSTK2
StrmClas	Attribute	Paradox join of rasterized MOSS streams map with WAWSTR.DB streams database	WAWSTR.DB
Order	Attribute	Paradox join of rasterized MOSS streams map with WAWSTR.DB streams database	WAWSTR.DB
Flow	Attribute	Paradox join of rasterized MOSS streams map with WAWSTR.DB streams database	WAWSTR.DB
FlowAcc	Attribute	Paradox join of rasterized MOSS streams map with WAWSTR.DB streams database	WAWSTR.DB
WaterPt6	Base	UCELL5; data conversion of MOSS vector map to Paradox table	WATERPT4
STANDID	Base	UCELL5; data conversion of MOSS vector map to Paradox table	MRISTK3
Lansat91	Base	UCELL5; data conversion of MOSS/MAPS SPSS file to Paradox table	SYHAB91
Veg code[i]	Attribute	Paradox join of MRISTK3.DB with 1987PI.DB and 1993PI.DB vegetation databases	1987PI.DB, 1993PI.DB
Ecoclass	Attribute	Paradox join of MRISTK3.DB with EVG1984	EVG1984

[a] May be either an SPSS or MOSS file (vector layer), a spatial database (all file names with .DB extension), or another variable.
[b] Not applicable; UTOOLS software is used to create "UTMGrid" whenever a vector map layer is rasterized.
[c] UCELL5 is a UTOOLS program.
[d] Base variables are obtained from original vector or raster map layers entered in a GIS.
[e] Derived variables are those calculated from base variables or other derived variables, usually with an algorithm or other mathematical formulation.
[f] The following road attribute variables were created in an identical manner to the "BEG_DATE" variable: END_DATE, ROADNO, TERMINI, FENCE, OPML, OBML, MILES, DITCH, ID, SURF, F_CL, DV1, DV2, CVH, S_LVL, STRE, STRF, CLASS, POSITION, GRADE, WIDTH, and ALIGNMNT. Values for the following variables should not change during the lifespan of the project: FENCE, MILES, DITCH, F_CL, S_LVL, CLASS, POSITION, GRADE, WIDTH, and ALIGNMENT. Others may change as road attributes change.
[g] Attribute variables have values assigned to them from field inventory or other sources.
[h] The following derived variables were created with similar buffering routines in UCELL5, and are derived from "ROAD USE:" NrstOPEN, DistRSTR, Nrst RSTR, DistCLSD, and NrstCLSD.
[i] The following vegetation attribute variables were created identically to the variable "Veg code:" TOTAL CC, #Layers, LayerCode1-3, LYR1SPC1-3, SIZE1-3, CanClos1-3, Crndia1-3, LYR2SPC1-3, and LYR3SPC1-3.

Table 9—Documentation of source maps used to create base variables in the Starkey habitat database

Map layer	Source map name[a]	Archived map name[b]	Date of creation	Producer	Method of creation
Fences	FENCGPS3	FENCES_ALL	Summer 1995	Starkey and LGRD staff	Fences walked or driven using DGPS
Cattle pastures	COWPAST	PASTURE_CATTL	Nov. 1995	Starkey staff	Derived from FENCGPS2
Elk pastures	ELKPAST	PASTURE_ELK	Nov. 1995	Starkey staff	Derived from FENCGPS2
Stream locations	STRSTK2	STREAMS_ALL	1993-94	LGRD,[c] WAW[d] and Starkey staff	Hand-manuscripted streams and crenulations on topographic maps,[e] then scanned at Umatilla NF; map scale 1:24,000 or 1:15,840[f]
Water points	WATERPT4	WATER_POINTS	1996	Starkey staff	Mapped with DGPS
Soils	SOILS4	SOILS	1986-present	WAW and Starkey staff	Polygons mapped on aerial photographs and transferred to 7.5-min quadrangles (1:24,000); scanned and edited at Wallowa-Whitman NF
Elevation	DEMSTKWI	ELEV_DEM	Unknown	FS Geometronics Service Center	DEM created by digitizing 20-ft contour lines on 7.5-min quadrangles (raster map) to USGS standards[g]
Roads	TRN2OBT, TRN2EXT, TRN2INT	TRN_GONE TRN_EXTERIOR TRN_INTERIOR	1993	LGRD and Starkey staff	Road locations recorded with DGPS while driving
Elk habitat categories	SYHAB91	ELK_HAB_91	1992	LGRD and Starkey staff	Unsupervised classification of 1991 Landsat Thematic Mapper scene
Vegetation polygons	MRISTK3	VEG_EVG_ID	1988-90	LGRD	Stand boundaries delineated by hand on aerial photographs (~1:12,000), then scanned at Umatilla NF at half quadrangles. Edited in LTPlus (2.4-m cell size). Combination of photointerpretation and field examination
Salt block locations	SALTD93	SALT	1993	Starkey staff	DGPS; incomplete

[a] All source maps are in Arc/Info format.
[b] Archived layers are stored in Arc/Info on the FS IBM RS6000 system. Associated tables in Oracle, also residing on the IBM, contain attribute data corresponding with the following maps: STREAMS_ALL, SOILS, TRN_GONE, TRN_EXTERIOR, TRN_INTERIOR, and VEG_EVG_ID.
[c] La Grande Ranger District.
[d] Wallowa-Whitman National Forest.
[e] USGS 7.5-min quadrangle maps covering the SEFR are Bally Mountain, Sullivan Gulch, McIntyre Creek, and Marley Creek. These maps were produced by the USGS from aerial photographs taken in 1960 and field checked in 1965.
[f] Most of the Starkey Experimental Forest and Range was recorded with 1:24,000-scale maps that were photo-enlarged to 1:15,840.
[g] Only the DEM was originally received in raster format; all other layers were vector maps that were subsequently rasterized.

Table 10—Documentation of source tables used to create attribute variables in the Starkey habitat database[a]

Database name	Owner	Contact	Reference name
STARKEY.DB, .DBF	W-W SO[b]	Anne Kramer	Transportation Management System (TMS)[c]
WAWSTR.DB, .DBF	W-W SO	Anne Kramer	Streams[c]
STKSOILS.DB, .DBF	W-W SO	Anne Kramer, Art Kreger	Soils or SRIDS
EVG1984.DB, .DBF	LGRD[d]	Brian Fischer	Existing vegetation (EVG)[c]
1987PI.DB, .DBF	Starkey Project	Dave Motanic (Umatilla SO), Starkey staff	Starkey photointerpretation, 1987 photographs
1993PI.DB, .DBF	Starkey Project	Dave Motanic (Umatilla SO), Starkey staff	Starkey photointerpretation, 1993 photographs

[a] Local archive for these tables is the Starkey Project Micron at the Forestry and Range Sciences Laboratory in La Grande and the USFS IBM RS6000 mainframe, with data on disk at the LGRD.
[b] Wallowa-Whitman Supervisor's Office; data are stored either on the Data General System or the newer IBM.
[c] Variables for these databases are described extensively in the Tri-Forest Data Dictionary (USDA Forest Service 1991).
[d] La Grande Ranger District.

Table 11—Documentation of map layers stored in the Arc/Info portion of the Starkey habitat database[a]

GIS layer	Source map name[b]	Date of creation	Producer	Method and description
NE harvest unit boundaries	SYRUP_TS (ACTIVITY_NE)	1993	Starkey staff	Digitized from USGS orthophoto quadrangles (1:24,000); hand-drawn boundaries
Relay towers	TOWERS (TELEM_TOWERS)	Summer 1991	Starkey staff	DGPS
Test sites for accuracy assessment	GPSSITES (CONTROL_GPS)	Summer 1991	Starkey staff	DGPS
Ownership boundaries	LANDSTAT (OWNERSHIP)	Summer 1991	WAW[c]	Manuscripted and digitized from 1:24,000 USGS maps; edited in LTPlus
Kill sites for elk harvested 1989-93	KILLSITE (HUNT_KILLSITE)	Spring 1994	Starkey staff	Digitized onscreen using topography as background; points are approximate sites provided by hunters who marked them on 1:15,840 topographic maps
20-foot contours	TOPOG	1988	Starkey staff	Digitized from USGS acetate layers (1:15,840) with STRINGS mapping system
100-foot contours	TOPOG100 (ELEV_CONT_100)	1988	Starkey staff	Derived by reselecting every fifth contour from"TOPOG" (1:15,840 scale)
20-foot contours inside game-proof fence only	TOPOGSTK (ELEV_CONT_20)	1988	Starkey staff	Derived by overlaying TOPOG with ELKPAS (1:15,840 scale)
Centerpoints of 1988 aerial photos	PHOTOPTS	1991	Starkey staff	Transferred to 1:24,000 orthophotos and digitized with STRINGS mapping system
Vegetation phenology	PHENPTS	1996	Starkey staff	DGPS; plots are located along 11 transects in 3 habitat types
Vegetation plot locations	MRIPLOTS (VEG_EVG_PLOT)	1988-90	Starkey staff	Points mapped on aerial photographs and transferred to 7.5-min orthophotos

[a] These layers are not stored in the UTOOLS platform.
[b] If applicable, name of equivalent archive file on the IBM RS6000 follows in parentheses.
[c] Wallowa-Whitman National Forest.

Appendix 3
Computer Software Used

Various GIS software was used to develop the Starkey habitat database, primarily UTOOLS, MOSS, and Arc/Info. A brief description of the software programs used and their specific application to the Starkey habitat database follows.

Arc/Info: PC Arc/Info, with digitizing, editing, analysis (vector only), and display-plotting subsystems, has been the main editing and plotting system for Starkey maps. The following maps were digitized or edited with this system: TOWERS, KILLSITE, parts of WATERPT4, and parts of FENCGPS2 and its derivatives, COWPAST and ELKPAST. The official GIS of the FS is now the workstation version of Arc/Info (UNIX Arc/Info), which brings the first vector-based GIS to FS staff since MOSS. This version of Arc/Info also has an extensive raster-based analysis system, and can access map-based information stored in Oracle. Terminals are now accessible to all Starkey staff, and training and data import have begun.

Arcview: A display-plotting system in the Windows environment. Arcview is used for some analysis (proximity-type selections), but has become essential in producing hardcopy maps that are stored in Arc/Info. It replaces the plotting subsystem of Arc/Info. The UNIX Arcview system is virtually identical to the PC version.

IDRISI: A DOS-based, primarily raster processing system. IDRISI was used extensively for the analysis of a 1991 Landsat Thematic Mapper scene and subsequent development of elk habitat classes ("Lansat91") (see "Vegetation," main text) based on that scene.

LTPLUS: This program resides at the FS District and Supervisor Offices on UNIX-based machines and is used to edit scanned, GPS-collected, or manually digitized maps before transporting them into MOSS for analysis and display.

MOSS: The Map Overlay and Statistical System resides on the USDA Forest Service Data General computer and has been the unofficial GIS for the FS since about 1985. It consists of data entry (digitizing), editing, analysis (both raster and vector), and display-plotting subsystems. The MOSS import-export format used extensively in this project is ASCII.

Paradox: Paradox for Windows is a database program that resides on all Starkey Project PCs and is used for GIS and non-GIS-based databases. As a GIS tool, Paradox is used in several ways. It is the main data storage and query device for UTOOLS maps, in which each 30- by 30-m pixel in Starkey is stored as a Paradox database record. The UTM coordinates of a pixel are the linking (key) field for each record. The querying abilities of Paradox are then used as the selection device for displaying map information and creating new maps.

On PCs that are linked to the network, we use Paradox for Windows to access, display, and download into the UTOOLS system map-based information that is stored in the FS Oracle database on the IBM system (La Grande Ranger District and Wallowa-Whitman NF.

STRINGS: This program was connected to a large digitizing table and Tektronix display terminal. Starkey staff began digitizing maps in 1987 with this system. Completed maps were digitally transferred to the Data General and imported into MOSS for analysis and display. Most of the maps digitized with the STRINGS setup were redigitized later by using GPS technology and LTPlus or Arc/Info. An exception is the 20-ft contour map "TOPOG" and its derivations, "TOPOG100" and "TOPOGSTK," which are still used for display. A map showing the center points of the 1988 photographic series, "PHOTOPTS," also was digitized in STRINGS. A description of this software can be found in Coe and Quigley (1986).

UTOOLS: This is a DOS-based collection of software developed in-house by Forest Service programmers to analyze and display raster maps (Ager and McGaughey 1997). It is being used extensively by Starkey staff to accomplish the main analysis objectives of the animal-unit-equivalencies and road and traffic monitoring studies. UTOOLS converts traditional GIS data into a spatial database in Paradox. The program imports existing digital maps and rasterizes them, if necessary, with UCELL5. Each pixel becomes a single record in the database, with fields representing map layers or attributes. The UVIEW program is used to display data in three dimensions; one can view a landscape from any perspective. Other programs in UTOOLS derive new topographic variables from elevation data (for example, convexity or slope) and use buffering routines to create distance band variables.

VGA ERDAS: This DOS version of the ERDAS Image Processing programs was used in the initial analysis of a raw 1991 Landsat Thematic Mapper image for grouping spectral values into classes. It consists of complex classification routines and superior display capabilities for images.

Glossary

AATS: Automated Animal Telemetry System; the radio-telemetry system at Starkey, comprised of radio collars on elk, mule deer, and cattle that receive loran-C navigational signals; seven remote microwave towers; a base station microwave tower; data processing center; and signals received from distant loran-C stations. The collars are paged in sequence every 20 seconds and automatically transmit their locations to a microwave tower, which retransmits the signals to the base station computer system.

Accuracy (absolute): How closely locations of objects on a map match their true geographic locations on the surface of the Earth (Corbley 1996).

Accuracy (relative): How closely distances between pairs of objects as determined from measurements on a map match their true distances (Corbley 1996).

Buffer: GIS routine that creates an area surrounding a feature, such as a point or line; the width of the buffer is generally predefined for the area of interest (for example, 100 m).

Categorical variable: One whose values fall into one or more distinct categories; that is, the data consist of names of categories, rather than quantitative measurements. Categorical variables may be binary (values coded either "1" or "0"); dichotomous (only two categories, but the values are not coded as above); or multiple (several possible categories exist).

Circular error probable: CEP; a term used in describing accuracy of GPS locations, meaning 50 percent of the collected points are within a circle of a specified radius on a horizontal plane (Trimble 1992).

Classification: Computer-assisted interpretation of remotely sensed imagery; a **supervised classification** is one in which the operators train the computer to look for surface features with similar reflectance characteristics to a set of examples of known interpretation within the image; in an **unsupervised classification**, a computer routine classifies by identifying typical patterns in the reflectance data. These patterns are subsequently identified by ground truthing selected sites (Eastman 1992).

Continuous variable: One whose values fall along a continuum, such as distance to a road or weights of calves; also called interval data. May include discrete, quantitative data that are treated as continuous.

Convexity: Quantitative measure of topography that describes the terrain surrounding a given pixel; how exposed a location is in terms of surrounding terrain. Calculated for the Starkey database as the difference between the averaged elevations of 9 pixels in a 3 by 3 matrix (search radius of about 129 m) and an imaginary plane 500 m above the home (center) pixel (Ager and McGaughey 1997). Values lower than 500 indicate valley bottoms; values greater than 500 suggest ridge tops.

Datum: Reference system for correlating results of surveys; a horizontal datum is used for position. Based on the surface of a particular earth spheroid projected beneath the land, a datum is the basis from which flat maps are produced that show coordinates from a curved earth. Most of the original source maps for Starkey were in NAD27, but have been converted to NAD83.

DEM: digital elevation model; image that stores data that can be envisioned as heights on a surface (Eastman 1992). A digitized map of elevation in standard cell format (30 by 30 m), produced by the U.S. Geological Survey on a 1:24,000 scale, is used to map elevations at the SEFR. A standard DEM has the following features: elevations referenced in the UTM system, in meters or feet above mean sea level; coverage based on the standard USGS 7.5-minute quadrangle; data ordered from south to north in profiles ordered west to east; and a spacing of 30 m along and between each profile (that is, a 30- by 30-m pixel size) (USGS 1986).

Digitizer: Term commonly used to refer to a device for encoding vector graphic data (point, line, or polygon locations) into plane (X,Y) coordinates. Also applies to scan digitizers that encode raster images (Eastman 1992). Converts images from photographic or other hard material to a numerical dataset format.

Discrete variable: Quantitative variable that consists of discrete points along a continuum, such as counts of vehicles at a traffic counter, or the number of plant species in a pixel.

Easting: The X coordinate in the UTM grid system; distance in meters east or west from the central meridian of the UTM zone (Koeln and others 1994).

GIS: geographic information system; system for the input, storage, retrieval, analysis, and display of interpreted geographic data (Eastman 1992).

GPS: global positioning system; calculates the range (distance) to a set of simultaneously viewable satellites to intersect a position according to a specified geodetic referencing system (Eastman 1992). Uncorrected GPS locations are accurate to about 100 m. **Differentially corrected GPS** (DGPS) uses readings from a base station of known location to correct positions collected from a remote (rover) GPS unit; these positions are accurate to about 5 m CEP (see “circular error probable”). If about 180 positions are recorded and averaged after differential correction, accuracy is increased to 2 m CEP. Newer GPS units are capable of even greater accuracy.

Key field: A field or group of fields in a table used to order records or maintain referential integrity by linking tables; prevents duplicate records.

NAD: North American Datum; refers to the georeferencing system used for locations in the Starkey habitat database. The telemetry system uses the most current datum for recording coordinates of animal locations (North American Datum 1983, or NAD83), whereas the habitat maps were digitized mainly from published USGS maps that used an older datum system (NAD27). Starkey staff have converted all habitat maps to NAD83 with the NADCON-USNGS routine in Arc/Info. For the Starkey area, the correction from NAD27 to NAD83 is +203 m north and -81 m west.

Northing: The Y coordinate in the UTM grid system; distance in meters north from the equator (Koeln and others 1994).

Orthophoto quadrangle: Aerial photograph corrected for geometric distortions, accurate to scale in both X and Y directions; can be used as a photographic “map.” The orthophotoquads encompassing Starkey are Bally Mountain, Sullivan Gulch, Marley Creek, and McIntyre Creek. They were produced from 1:80,000 black-and-white aerial photographs taken in August 1976. A new set of **digital orthophotoquads** also has been purchased for use at Starkey. The black-and-white photographs, produced by the National Aerial Photography Program (NAPP), were taken at 6100 m. Scale is about 1:40,000, with a pixel size of 1 by 1 m, providing excellent resolution (2 m). These raster format maps likely will be used to locate or compare positions of fixed features in the field, rather than used in analysis or entered as a spatial layer with GIS.

Pixel: Contraction of the words “picture element.” Strictly refers to a small (usually rectangular or square) portion of a raster display device, whereas a cell in a raster data grid refers to a raw data value that governs how the pixel is displayed. “Cell” and “pixel” often used interchangeably (Eastman 1992).

Raster: Describes a system of representing images, where the image is composed of small, internally uniform cells arranged in a grid. Order of image storage is typically by scanlines, progressing from left to right, and then from top to bottom (Eastman 1992).

Rectify: To make image data conform to a map projection, typically for a Landsat scene or other remotely sensed product; eliminates effects of distortion and orientation of the camera.

RMSE: Root-mean-square error. Measure of the variability of measurements about their true values; directly comparable to concept of standard deviation. Encompasses both random and systematic error. Differences between sample measurements and the "true value" are squared and summed, then divided by the number of measurements to obtain mean square deviation. The square root is taken to produce an error term in the same units as the original measurement (Eastman 1992).

Scanline: Horizontal group (row) of image cells or pixels spanning the entire image (Eastman 1992).

TM: thematic mapper; sensor used in newer Landsat satellites capable of digitally recording intensity of natural radiation in 7 spectral bands. Provides better spatial and spectral resolution than previous Landsat sensors. The resulting Landsat TM scene is a digital map with 30- by 30-m cells. Two scenes have been acquired for Starkey, 1988 and 1991.

UTM: Universal Transverse Mercator; a map projection system based on 60 east-west zones, each 6 degrees wide in longitude. X, Y coordinates in the grid are recorded in meters and are seven-digit numbers, increasing as one moves east and north (Koeln and others 1994). The Starkey area is in UTM zone 11N.

Vector: Technically, any variable quantity that can be described as having magnitude and direction and that can be resolved into components; also, all graphic data that can be ultimately decomposed into point locations described by absolute coordinates, including lines, points, or polygons; systems that make use of vector representations in data storage and analysis (Eastman 1992).

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Rowland, Mary M.; Coe, Priscilla K.; Stussy, Rosemary J. [and others]. 1998. The Starkey habitat database for ungulate research: construction, documentation, and use. Gen. Tech. Rep. PNW-GTR-430. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 48 p.

The Starkey Project, a large-scale, multidisciplinary research venture, began in 1987 in the Starkey Experimental Forest and Range in northeast Oregon. Researchers are studying effects of forest management on interactions and habitat use of mule deer (*Odocoileus hemionus hemionus*), elk (*Cervus elaphus nelsoni*), and cattle. A habitat database was compiled, using GIS (geographic information systems), to examine relations of environmental variables to ungulate distribution and habitat use. The database contains over 100 variables associated with vegetation, water, soils, roads, topography, and structural features such as fences. We describe database construction and documentation of GIS layers from 1987 to 1997. Error estimates associated with each variable or layer and sample applications of the database also are presented.

Keywords: Habitat database, GIS, spatial data, ungulate, cattle, elk, mule deer, northeast Oregon, Starkey Project, accuracy assessment, Blue Mountains.

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