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A rule-based model for mapping potential exotic plant distribution

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A RULE-BASED MODEL FOR MAPPING POTENTIAL EXOTIC PLANT DISTRIBUTION[1]

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ABSTRACT.—Wildland managers need a method to predict which portions of the lands under their stewardship are susceptible to invasion by exotic plants. We combined a database listing exotic plant species known to occur in major environmental types (habitat types) throughout the northern Rocky Mountains with a digital vegetation map of environmental types for a major national park in the region (Yellowstone National Park) to produce maps of areas potentially threatened by major exotic species. Such maps should be helpful to managers concerned with monitoring and controlling exotic plants.

Key words: maps, exotics, weeds, GIS, Yellowstone National Park, modeling, Centaurea, Cirsium, Melilotus, Phleum.

More than 100 exotic plant species occur in Yellowstone National Park (Whipple 2001), and others will undoubtedly become established in the future. Many of these are likely to undergo range expansion. An ability to predict the areas threatened by expanding exotics should be of great value to park managers trying to minimize dispersal to susceptible areas and eradicate new colonies of these areas.

Information needed to predict the potential extent of a species includes knowledge of which environments are susceptible to invasion by the species and the location and extent of susceptible environments.

Both are available for Yellowstone National Park. First, we have a map of environmental types (Despain 1990a). Students of vegetation have pointed out that plant communities provide a good indicator for site conditions (Holdridge 1947, Whittaker 1975, Huschle and Hironaka 1980). In our area Daubenmire identified major environmental types (habitat types) for eastern Washington and northern Idaho and demonstrated the relationship of indicator species to both environmental qualities (Daubenmire 1952, 1956) and plant performance (Daubenmire 1976). His environmental types have been extended into southern Idaho, Montana, and Wyoming (Pfister et al. 1977, Mueggler et al. 1980, Hironaka et al. 1983, Steele et al. 1983), and their relationships to environment have been reviewed by Weaver et al. (2001). We use environmental type as a synonym for Daubenmire's habitat type, but prefer environmental type because it unambiguously refers to physical environment and excludes confusing factors in animal "habitat" such as characteristics of a community temporarily occupying the site (e.g., species composition or structure of a seral community). Daubenmire recognized and regretted this confusion (Weaver et al. 2001).

Second, exotic species' potentials to invade environmental types representing segments of the altitudinal gradient of the northern Rocky Mountains have been identified by Weaver et al. (2001). In their treatment the environmental range of a species is expected to be wider in disturbed sites (where competition is less) than in late seral communities (where competition is intense; Daubenmire 1968, Grime 1979, Huschle and Hironaka 1980), and this has been demonstrated (Weaver et al. 2001). Thus, we expect geographic ranges of exotic species in undisturbed vegetation to be narrower than, and nested in, ranges of the same species occupying disturbed vegetation.

This paper has 5 objectives: (1) to demonstrate a method for mapping potential plant distribution, (2) to illustrate it with 4 exotic plant species of Yellowstone National Park, (3) to publicize maps of 24 other exotics, (4) to compare the mapped ranges of each species on undisturbed and disturbed sites, and (5) to

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evaluate the method by comparing predicted distributions with actual distributions recorded by Yellowstone National Park's weed management staff.

METHODS

Working in Glacier National Park, Yellowstone National Park, Grand Teton, and areas between, Weaver et al. (2001) studied the distribution of exotic plants in 16 environmental types representing altitudinal zones of the northern Rocky Mountains. To determine which exotics invade disturbed and undisturbed vegetation in these environmental types, they recorded presence at 7–10 sites in each environmental type. To test susceptibility, they examined sites long exposed to diverse seed sources, i.e., sites near major highways. Their inspection of each site was concentrated in two 4 × 25-m plots running parallel to the road. Entry into disturbed sites was examined with a plot on the roadcut (inslope) bordering the highway. Entry into near-climax vegetation was examined with another plot in adjacent undisturbed vegetation. They listed all species present in the plot (and in similar areas around it), recorded presence in five 4 × 5-m segments of the plot as an index of ubiquity, and estimated cover with 75 points located near the central axis of the plot. They reported both constancy values (the percentage of plots in an environmental type where the species occurred) and cover for each species. For a more complete description of their methods, refer to Weaver et al. (2001).

We used Weaver et al.'s (2001) constancy value as a measure of a species' ability to establish in an environmental type. Our maps indicate areas where a species was present at more than half the sites, at less than half the sites, and where they were capable of invading the climax community.

Two details require elaboration. First, because Weaver et al. (2001) did not encounter all environmental types that occur in Yellowstone National Park, we predicted exotic plant species occurrence, in those Yellowstone National Park types for which they had no data, from the most similar type for which data were available. A type was judged to be similar if it was in a similar moisture range of the same series. Resultant assignments are shown in Table 1. Exotic plant species presence in the known type was assigned to other types in its group.

TABLE 1. Environmental types of Yellowstone National Park with Weaver et al. (2001) equivalents.

Weaver et al.[a]	Yellowstone environmental type[b]
DECA/CARX	alpine tundra
FEID/AGCA	FEID/DECA POFR-ARCA/DECA ARCA/FEID ARTR/FEID-GEVI FEID/STRI FEID/AGCA-GEVI FEID/AGCA
ARTR/FEID	ARTR/FEID
ABLA/ARCO	PIAL/VASC PIAL/CAGE
ABLA/VASC	ABLA/LIBO-VASC ABLA/VAGL-VAGL ABLA/THOC ABLA/VASC-VASC ABLA/VASC-PIAL ABLA/VASC-CARU ABLA/CAGE ABLA/CARU
ABLA/ARCO	ABLA/CARO PICO/CAGE PICO/CARO PICO/PUTR
PSME/PHMA	PSME/PHMA
PSME/SYAL	PSME/SYAL PSME/CARU PSME/SPBE-SPBE
AGSP/BOGR	FEID/AGSP ARTR/AGSP
STCO/AGSP	AGSP/POSA-STCO

[a]Environmental types are named for 2 species, including a dominant overstory species and an indicator species. Names of these species are abbreviated with a 4-letter code including 2 letters from the genus name and 2 from the specific epithet: ABLA = *Abies lasiocarpa*, AGCA = *Agropyron caninum*, AGSP = *Agropyron spicatum*, ARCA = *Artemisia cana*, ARCO = *Arnica cordifolia*, ARTR = *Artemisia tridentata*, BOGR = *Bouteloua gracilis*, CAGE = *Carex geyeri*, CARO = *Carex rossii*, CARU = *Calamagrostis rubescens*, CARX = Carex spp., DECA = *Deschampsia caespitosa*, FEID = *Festuca idahoensis*, GEVI = *Geranium viscosissimum*, LIBO = *Linnaea borealis*, PHMA = *Physocarpus malvaceus*, PIAL = *Pinus albicaulis*, PICO = *Pinus contorta*, POFR = *Potentilla fruticosa*, POSA = *Poa sandbergii*, PSME = *Pseudotsuga menziesii*, PUTR = *Purshia tridentata*, SPBE = *Spirea betulifolia*, STCO = *Stipa comata*, STRI = *Stipa richardsonii*, SYAL = *Symphoricarpos albus*, THOC = *Thalictrum occidentale*, VAGL = *Vaccinium globulare*, VASC = *Vaccinium scoparium*.

[b]Weaver et al. (2001) did not encounter all environmental types that occur in Yellowstone National Park. Thus, Yellowstone types (Despain 1998) were grouped with the Weaver type to which they were most similar. Blocking in this table indicates the correspondences. Yellowstone types for which there are no equivalent Weaver types include hot springs vegetation, sedge bogs, willow/sedge, wet forests, talus, and water.

Second, Despain's (1990a) habitat type map sometimes uses mosaic mapping units that contain 2 dominant types, such as a matrix of grasslands with numerous islands of trees or vice versa. In these cases we averaged the constancy values of the 2 component types to derive a value for the mosaic units. If a species could invade the climax vegetation of either of the types, the entire map unit was considered to be susceptible to that species.

The resultant database was combined with the vegetation map using GIS to create 28 maps, one for each species studied. Four species are used as illustrations. Canadian thistle (*Cirsium arvense* [L.] Scop.) and spotted knapweed (*Centaurea maculosa* Lam.) are classed as noxious weeds by the surrounding states. Yellow sweetclover (*Melilotus officinalis* [L.] Lam.) and timothy (*Phleum pratense* L.) are crop plants that have become widely established in nonagricultural areas of the region. All 4 are of special concern to Yellowstone National Park managers.

To evaluate the success of our model, we compared locations we mapped for 3 species with actual locations mapped by Yellowstone National Park's staff: Canadian thistle, spotted knapweed, and yellow sweetclover (data for timothy were not available).

RESULTS

Potential ranges of 28 exotic species found repeatedly in northern Rocky Mountain vegetation (Weaver et al. 2001) were mapped. Maps are available from the Geographic Information and Analysis Center, Montana State University, Bozeman, website (http://www.giac.montana.edu) in raster format at 50-m resolution, which should be useful for field purposes.

Centaurea maculosa is classified as a noxious weed in the Greater Yellowstone Ecosystem. The potential range of spotted knapweed mapped for disturbed sites (Fig. 1) includes the drier portions of the park, i.e., dry grasslands/shrublands and drier Douglas-fir forests. We mapped no areas where knapweed would have an expected constancy >50%. It is expected to invade climax vegetation only in dry grasslands predominantly at low elevations. In contrast to our predictions, actual Yellowstone National Park data showed many locations along park roads outside our predicted areas. Thus, more data are required to determine how threatening this species is in Yellowstone National Park. Unpredicted locations may be either transient occurrences that would disappear without constant seeding from the outside

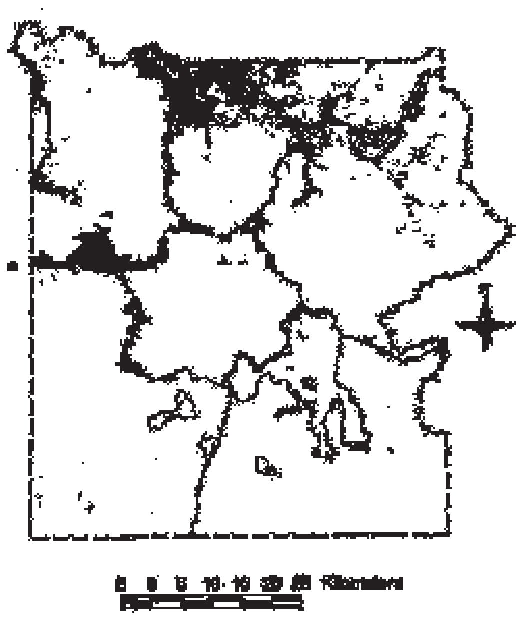

Fig. 1. Potential distribution of *Centaurea maculosa* (spotted knapweed) in Yellowstone National Park. Gray areas show the distribution of disturbed areas where it is expected to occur in less than half a series of study plots. No areas occurred where it would be capable of occurring in more than half the study plots. Black areas show distribution of those sites where it is capable of invading climax vegetation. Roads are indicated (solid line) for reference. Actual locations recorded by Yellowstone's weed management staff are shown by triangles.

or an indication that knapweed enters environments not predicted by this model and is thus a serious threat over a much larger area than that mapped. While it does not appear to pose a serious threat to the majority of the park, it should be closely monitored as a potential threat especially in the Yellowstone River valley along the north boundary.

Cirsium arvense is a 2nd noxious weed of the Greater Yellowstone Ecosystem. The potential range mapped for it (Fig. 2) includes disturbed areas primarily in sparsely vegetated forest types and montane and subalpine grasslands/shrublands. We map no potential for entry into dry grasslands/shrublands. Because it does not invade climax vegetation, colonies established on disturbed sites are expected to die out as succession progresses to climax. No areas occurred where Canadian thistle would have an expected constancy >50%. Our map is

Cirsium arvense

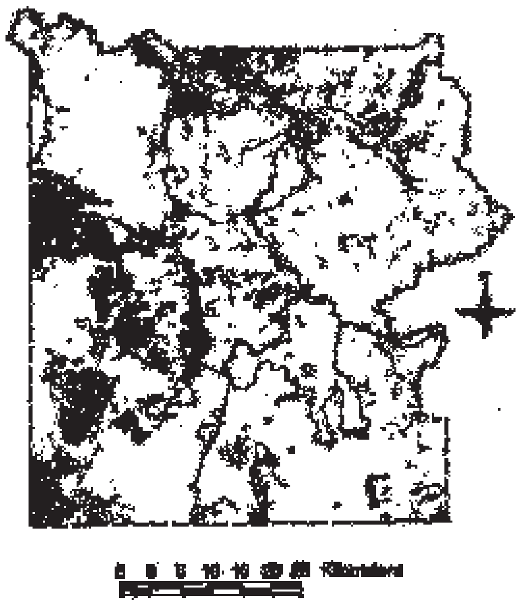

Fig. 2. Potential distribution of *Cirsium arvense* (Canadian thistle) in Yellowstone National Park. Gray areas show the distribution of disturbed areas where it is expected to occur in less than half a series of study plots. No areas occurred where it would be capable of occurring in more than half the study plots. Black areas show distribution of those sites where it is capable of invading climax vegetation. Roads are indicated (solid line) for reference. Actual locations recorded by Yellowstone's weed management staff are shown by triangles.

Melilotus officinalis

Fig. 3. Potential distribution of *Melilotus officinalis* (yellow sweetclover) in Yellowstone National Park. Gray areas show the distribution of disturbed areas where it is expected to occur in less than half a series of study plots. No areas occurred where it would be capable of occurring in more than half the study plots. Black areas show distribution of those sites where it is capable of invading climax vegetation. Roads are indicated (solid line) for reference. Actual locations recorded by Yellowstone's weed management staff are shown by triangles.

validated by noting that the majority of locations mapped by the Yellowstone National Park weed management staff are within the areas we mapped as potential habitat. Anomalous colonies in dry grassland/shrubland units may be located within inclusions of wetter environmental types.

Melilotus officinalis is a plant of special concern because it tends to dominate grasslands. The potential range mapped for yellow sweetclover on disturbed sites (Fig. 3) includes areas from drier grassland/shrubland sites in the northern part of the park to moist subalpine meadows. Our map predicts that *Melilotus* is capable of invading open climax communities across the same range. In the higher-elevation forest zone it can invade disturbed areas. No areas were mapped where yellow sweetclover would have an expected constancy >50%. Most locations recorded by the weed management staff did not correspond to predicted locations. More data must be gathered to determine the threat posed by yellow sweetclover. This species could become a serious problem if it displaces native climax species in sites to which it is well adapted.

While *Phleum pratense* is less obvious than the forbs just discussed, it has a significant tendency to dominate Yellowstone National Park vegetation (Weaver et al. 2001). The potential range mapped for timothy (Fig. 4) includes disturbed areas in most of the park. The map indicates that it can invade climax communities in a smaller range of environmental types, i.e., moister grasslands/shrublands and lower forest communities. It is more common than spotted knapweed, Canadian thistle, and yellow sweetclover on disturbed sites; i.e., it had a constancy >50% over large portions of the park. Because weed management staff

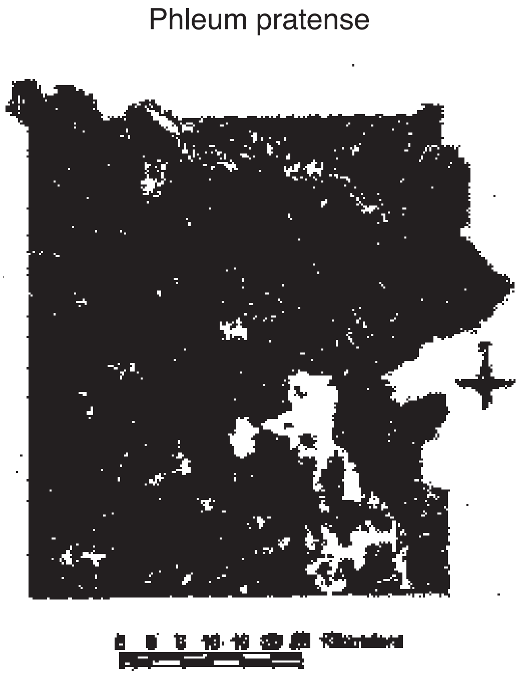

Fig. 4. Potential distribution of *Phleum pratense* (timothy) in Yellowstone National Park. Light gray areas indicate where it is expected to occur in less than half a series of study plots. Dark gray indicates areas where it is expected to occur in more than half the study plots. Black areas show distribution of those sites where it is capable of invading climax vegetation. Roads are indicated (solid line) for reference.

members do not map it, actual location data for this widespread species are not available for validation of our maps. While it is of little concern in the forested types because it would be greatly reduced at canopy closure, it could be of major concern in moister grassland/shrubland environments, which are the major source of forage for native ungulates.

DISCUSSION

This exercise has demonstrated a method for producing maps showing the potential ranges of exotic plant species in disturbed and undisturbed environments. Some general patterns are seen in the maps: (1) potential ranges of some species are limited while others are extensive; (2) most invader species are adapted to colonize disturbed sites, and thus species ranges are broader on disturbed than undisturbed segments of an environmental type; (3) where colony locations are known, constancies are usually highest in or near the potential range predicted. We attribute near-misses to interfingering of environmental types in ecotonal areas, unmapped islands of one type in a matrix of another, or inexact records of invader colony locations made by the weed team.

The certainty of our maps could be increased by adding more observations, particularly in those types where Weaver et al. (2001) have no data. The most extensive of these in Yellowstone are the wetland types and high-elevation forests.

For simplicity we have mapped ranges in successional extremes of severely disturbed roadside cuts and near-climax conditions. Roadcuts are typically void of developed soil and are usually in the early stages of primary succession. Gathering more data relating to more moderate disturbances, such as wildland fire, could usefully extend the work. For example, while Canadian thistle has been shown to increase after forest fire (Turner et al. 1997), this is not reflected (Fig. 2). The persistence of this species as the community succeeds, after fire, to climax vegetation deserves study. Thus, it would be useful to gather exotic species distribution data across successional stages within each of the environmental types (Despain 1990a) to allow a broader and more accurate evaluation of the threat posed by a particular species.

We recommend that managers gather the data necessary to use this method to further their efforts in monitoring and controlling the establishment and spread of these exotic plants, especially those that are most likely to cause extensive ecological and economic problems.

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