1. INTRODUCTION

Natural resource managers need maps of invasive plant distribution to most effectively address their impacts. Prevention, eradication, and containment efforts depend upon spatial information. Tracking the spread of a species over time, and evaluating the effectiveness of management, depends on landscape-scale maps that can be updated regularly. However, the number of invasive plant species and their broad distribution make full regional mapping impracticable using typical ground-based occurence reporting alone.

To address this need, Cal-IPC initiated a statewide effort specifically designed to produce complete landscape-scale distribution maps that can be updated regularly. These "risk maps" are necessarily coarse in resolution and depend on expert opinion as much as on field-mapped GIS datasets. The maps support regional prioritization for goals and approaches addressing particular species in particular areas.

This report presents risk maps developed for 43 species selected to be of special importance for the Sierra Nevada region of California. (Approximately 100 plants on the Cal-IPC Inventory (Cal-IPC 2006) occur in the Sierra Nevada; we chose a representative set for the scope of this project.) From the risk maps, priorities are determined for the region as a whole and for each of the 14 Weed Management Areas (WMAs) in the region. These recommendations consider three types of strategic management opportunities: eradication, containment, and surveillance.

As part of this project, Cal-IPC modeled suitable climatic range for 29 of the study species. The resulting maps, overlaying current distribution and suitable range, show uninvaded areas that are most vulnerable to spread. In addition, this modeling lends itself to assessing future suitability based on climate change projections.

The goal of this project is to enhance the long-term effectiveness of strategic invasive plant detection and control in the Sierra Nevada. The results of this project can help natural resource managers secure funding by clearly showing invasive plant distribution to funders and providing a rationale for project strategy. The results also provide a foundation for collaboration on efforts that span the entire region.

Using this Report

This report includes recommendations for the Sierra Nevada region as a whole (chapter 2), recommendations for the 14 WMAs (chapter 3), and species profiles (including statewide risk maps) for each of the 43 species studied (chapter 4). The risk map for a given species shows its abundance, spread trend, and management status by 7.5-minute USGS quadrangles. Many of the maps also show climatic suitability.

For the region as a whole and for each WMA, the report provides statistics and an assessment of management opportunities. Statistics include:

- percent of the quads in the area that are infested with a given species,
- percent of the quads with suitable habitat in that area that are infested with that species,
- percent of the infested quads in the area in which infestations of that species are spreading,
- percent of the infested quads in the area where that species iscurrently under active management,
- percent of the quads in the area in which the species has been eradicated,
- percent of the overall area that is currently suitable for the species,
- percent of the overall area that is expected to be suitable in the year 2050, and
- change in suitability in the overall area between 2010 and 2050.

Management opportunities are identified in three categories – eradication, containment, and surveillance – with the strategic potential for each of these opportunities rated as high, medium or low. Ratings depend on factors such as the impact and invasiveness of the species, whether the particular infestation is spreading, whether the species has a CDFA weed rating, and the evaluation of land managers. In addition, each type of opportunity has spatial factors that help determine its rating:

- **Eradication** – these opportunities entail complete removal of an infestaion, and result from infestations in a small number of quads isolated from other infestations. Strategic potential for eradication opportunities depends on how many contigous quads are infested, how isolated they are, and the suitability of adjoining areas. (The extent of infestation within a quad will dictate the feasibility of eradication; such judgements must be made by local natural resource managers.)
- **Containment** – these opportunities entail limiting spread from an existing infestation, and result from larger areas of infested quads. Strategic potential depends on the geography of the infestation, how isolated it is, and the suitability of adjoining areas.
- **Surveillance** – these opportunities entail regular surveys to detect new infestions of a species that is thought to be absent from an area. Strategic potential depends on the proximity of nearby infestations and the suitability of the area.

For each WMA and the region as a whole, we identify species as top priorities for strategic management based on these ratings. Our recommendations are meant to complement the many management efforts already underway in the region and to aid in planning future efforts. This report can be used to find opportunities to combine new efforts with those that already exist. For example, efforts to contain invasive plant species climbing the foothills from the Centeral Valley may be able to coordinate with the existing Leading Edge Project working to prevent the spread of yellow starthistle to higher elevations (CDFA 2011). A region-wide coordinating body can use these risk maps to establish goals for eradication, containment and surveillance in support of early detection.

This report is meant to be a beginning. As online risk mapping tools are developed to support strategic management in California, it will become simpler to update and improve this information and the recommendations that they inform. Details on development of online tools can be found on the mapping pages of the Cal-IPC website (www.cal-ipc.org). Natural resource managers who collect GIS data are encouraged to help statewide efforts by contributing these datasets to Calflora (www.calflora.org).

Methods

California has historically had few statewide maps of invasive plant distribution beyond those maintained by the state's Department of Food and Agriculture for A-rated noxious weeds. In 2006, Cal-IPC initiated an effort to produce statewide maps that would support strategic management decisions. Cal-IPC surveyed WMAs in California for expert knowledge in order to map the distribution of 35 species by county and floristic region. Cal-IPC also used an ecological niche modeling approach to predict suitable range based on climatic factors. Current efforts build upon this basic approach, with the resolution of distribution mapping increased to the USGS quad level and suitability modeling based on a more robust methodology.

Study Area and Species: The study area is the Sierra Nevada ecoregion (see map). We chose the study species by surveying natural resource managers in the region regarding their species of concern from the California Invasive Plant Inventory (Cal-IPC 2006). The final list represents plants with a range of distribution and impacts in the Sierra Nevada; it is not a comprehensive list of all plants invading the region.

Current Distribution: To determine the current distribution of each species, we interviewed WMA participants and other local botanical experts in small group meetings around the state. Experts were chosen based on recommendations from our existing contacts in each county and included county agricultural agents, federal, state and local agency biologists, University of California Cooperative Extension personnel, land preserve stewards, environmental consultants, and knowledgeable amateur botanists. We recorded data by USGS 7.5-degree quadrangle ("quad") because it represents a standardized, widely recognized grid that is familiar to many natural resource managers and lends itself to statistical comparisons. For each species, we recorded in which quad it occurs; at what level of abundance; whether populations are stable, increasing, or decreasing in each quad; and whether populations are currently managed. We augmented expert opinion data with GIS datasets. We have not yet interviewed experts in the San Francisco Bay Area, so that area is based on GIS data only.

Suitable Range: We modeled suitable range for each species in California using current distribution and climate data for the state. We used Maxent, free software developed by a team at Princeton University that has become increasingly popular in habitat modeling, biodiversity research, and invasive plant prediction (Loarie et al. 2008, Strahlberg et al. 2009). Maxent predicts where a species can grow based on known locations combined with environmental variables (Elith et al. 2006, Phillips et al. 2006). It requires precise location data and complete representation of the range of areas where a species currently grows; consequently we needed to compile multiple data sources for each species. We downloaded data from the Calflora (2010) and Consortium of California Herbaria (2010) online databases, and collected additional datasets from agencies and individuals. More than 25 datasets were combined for the final analysis. Because some of our study species are not widely distributed, they necessarily have fewer data available on which to base the models.

For environmental data in the models, we used 19 climatic variables from Bioclim based on temperature and precipitation in a raster grid of 30 arc seconds which is roughly 800 m x 920 m in California. This set of variables is commonly used in ecological modeling and is available at www.worldclim.org. Our results show areas that have the highest statistical probability of being suitable. We used a threshold of 0.10 to define suitable areas. This was chosen so that 90% of all occurrence points fall in an area that is determined as suitable.

Our modeling relied exclusively on data for infestations in California. Thus, suitability maps are most complete for species that are already widespread and for which a significant number of data points have been collected.

From our initial list of 43 species, we chose 29 with sufficient data to develop the models. Suitability maps were reviewed by a panel of statewide invasive plant mapping experts. As part of future efforts, we plan to expand our approach to include information from populations outside of California, which can provide broader information on the full climatic range of a particular species. In addition, we will consider including additional environmental variables such as soil type in our analysis.

Climate Change: The Sierra Nevada is likely to be heavily impacted by climate change (Knowles and Cayan 2002, Cayan et al. 2008, Coats 2010). Suitable habitat for some native plants may shrink, with some areas becoming refugia for particular species (Kueppers et al. 2005, Loarie et al. 2008). Some plants have shifted to higher elevations in recent years, possibly as a response to climate change (Kelly and Goulden 2008). At the same time, invasive plants, which tend to be generalist species with broad ecological tolerances, may be able to colonize new locations (Pauchard et al. 2009). Of course, many invasive plants are still expanding their ranges regardless of climate change.

We based our assessment of future suitability under climate change on scenarios for 2050 because land managers indicated this date would be more useful to them than predictions farther into the future. For this report we used the A2 emission scenario, which is widely used for the assessment of climate change effects informing today's policy decisions (IPCC 2007). Climate change projections for California do not vary widely in temperature predicted for the mid-21st century but do diverge in their precipitation predictions. For this report, we based our suitability modeling on downscaled General Circulation Model (GCM) output from the Canadian Centre for Climate Modeling and Analysis (CCCMA) representing a wetter scenario. We received guidance and support in using this model from the Geospatial Innovation Facility at UC Berkeley. In the future we plan to integrate more models and downscaling algorithms to better address uncertainty.

The results of this report provide an opportunity to collaborate with other projects addressing climate change and conservation. For example, the Southern Sierra Partnership (2010) identified conservation priorities for the Southern Sierras and Tehachapis based on biodiversity, ecosystem services, land use, and projected climate change. PRBO Conservation Science (2011) examined the potential consequences of climate change for wildlife (Strahlberg et al. 2009).

Management Opportunities: Opportunities for the strategic management actions of eradication, containment, and surveillance are based on the risk maps showing current distribution, spread, and suitability. Regional invasive plant experts from the Sierra Nevada reviewed the risk maps and provided guidance for rating the opportunities. We present ratings for the Sierra Nevada region in chapter 2. Ratings are organized by WMA in chapter 3 and by species in chapter 4.

Limitations

This report represents a milestone in a larger effort that covers all regions of California, and all species listed by Cal-IPC as invasive. Cal-IPC lists some 200 plants as invasive in California, so the recommendations for 43 species in this report are by no means a comprehensive assessment of all invasive plant threats in the Sierra Nevada.

The resolution of the risk mapping approach used in this work is necessarily coarse. It is useful for tracking distribution of a given species at a landscape scale. It is not, however, sufficient for planning the details of on-the-ground management, which requires field mapping at a much higher resolution.

The data sources for the maps are not expected to be 100% accurate. Data from expert knowledge has the benefit of drawing on the extensive experience of individual local resource managers, but their best estimates can be incorrect. The online system that will house the data and maps will allow experts to update data, which is expected to improve accuracy significantly over time. Data that we have drawn from GIS datasets, though of higher precision, may not always be accurate, either. Those conducting the mapping may have misidentified the species, the location may not be captured correctly, or the dataset may be out of date.

Mapping climatic suitability for a given plant species is an inexact science. The maps are based on existing distribution as evidence of the climatic range of the species. Some species may be able to grow in climates beyond where they currently grow in California, either because they adapt or because they have not yet been transported to a region.

These are all innate challenges of providing useful information at the scale and breadth we are addressing, and we believe this approach takes a significant step forward by aggregating existing information into a useful structure.