# TEMPORAL AND SPATIAL VARIABILITY OF FIRE OCCURRENCE IN WESTERN OREGON, A.D. 1200 TO PRESENT

by

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A THESIS

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Understanding past fire regimes in the Pacific Northwest enables a better assessment of current forest conditions and management practices. Possible synchroneity in historic fire occurrence in western Oregon and concern about the representativeness of the available data motivated a synthesis of eight dendrochronological studies from the region. Time-series images of past patterns were used to explore the spatial and temporal variability of fire occurrence for the period A.D. 1200 to present. Fires were most widespread in the 1800s, particularly between 1850 and 1875, and fires were widespread, but less numerous, in the 1500s. Many fires occurred during the 1600s and 1700s, but they were localized and asynchronous. Study sites spanned the range of western Oregon climate and vegetation conditions with the exception of areas of very high and low precipitation.

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# CHAPTER I

# INTRODUCTION

Knowing that natural disturbance is a vital process in any healthy ecosystem obligates us to investigate its role in present forests and understand how and why disturbance regimes have changed over time. Historically, the predominant agent of disturbance in the Pacific Northwest was wildfire (Agee 1993). Fire frequency and severity largely influenced the structure and composition of forests in the region. Since the early 1900s, however, fire suppression and elimination have been an objective of forest management policy across the U.S. (Pyne 1982). Suppression was less effective during the first half of this century, but improved dramatically after World War II due to equipment and aircraft enhancements and renewed collaboration between Federal agencies and the military. Despite current efforts to control fire, 7,000,000 acres of U.S. wildlands burned in the 2000 fire season, more than in any of the previous 13 years (National Interagency Fire Center 2000). Total acreage burned in recent years in the state of Oregon has also been alarming. In 1996, 591,053 acres of Federal land burned in Oregon (378% of the annual average for the decade), and in 1994, 270,500 acres burned (173% of the annual average for the 1990s) (Northwest Interagency Coordination Center 2000, Oregon Department of Forestry 2000). These statistics raise the question of whether or not the current incidence of fire has a precedent prior to Euro-American settlement.

Information on past fire events, including their size and frequency, is one way to address such questions. The primary source of pre-settlement fire history information comes from dendrochronology. Such fire history reconstructions are based on stand establishment dates and fire-scarred tree rings exposed on tree stumps, wedges, or cores. Fire-scarred tree rings provide information on non-lethal fire events. Stand-age analysis is used to date fires based on the assumption that an even-aged stand of trees develops following a moderate or high-severity fire event. Multiple trees are sampled and the oldest is used to estimate the fire date. Fire-scar and stand-age methods provide high resolution reconstructions of fire history for the last few centuries, but the reconstructions become less certain farther back in time as fewer living trees are of appropriate age to provide a record. Once the fire history is known for an area, researchers can evaluate how the fire regime has changed over time and can compare current patterns of fire occurrence to the historic record.

In the Pacific Northwest, Weisberg and Swanson (in review-a) have synthesized the dendrochronological fire-history data of the last 600 years in ten fire-history studies, eight in Oregon, and two in Washington. The area burned during particular time intervals was used to identify periods of widespread burning (Fig. 1). They reported two periods of extensive fires, from the A.D. 1400s to ca. 1650, and from ca. A.D. 1801 to ca. 1925. The first period ended at different times for different study areas, but a distinctive

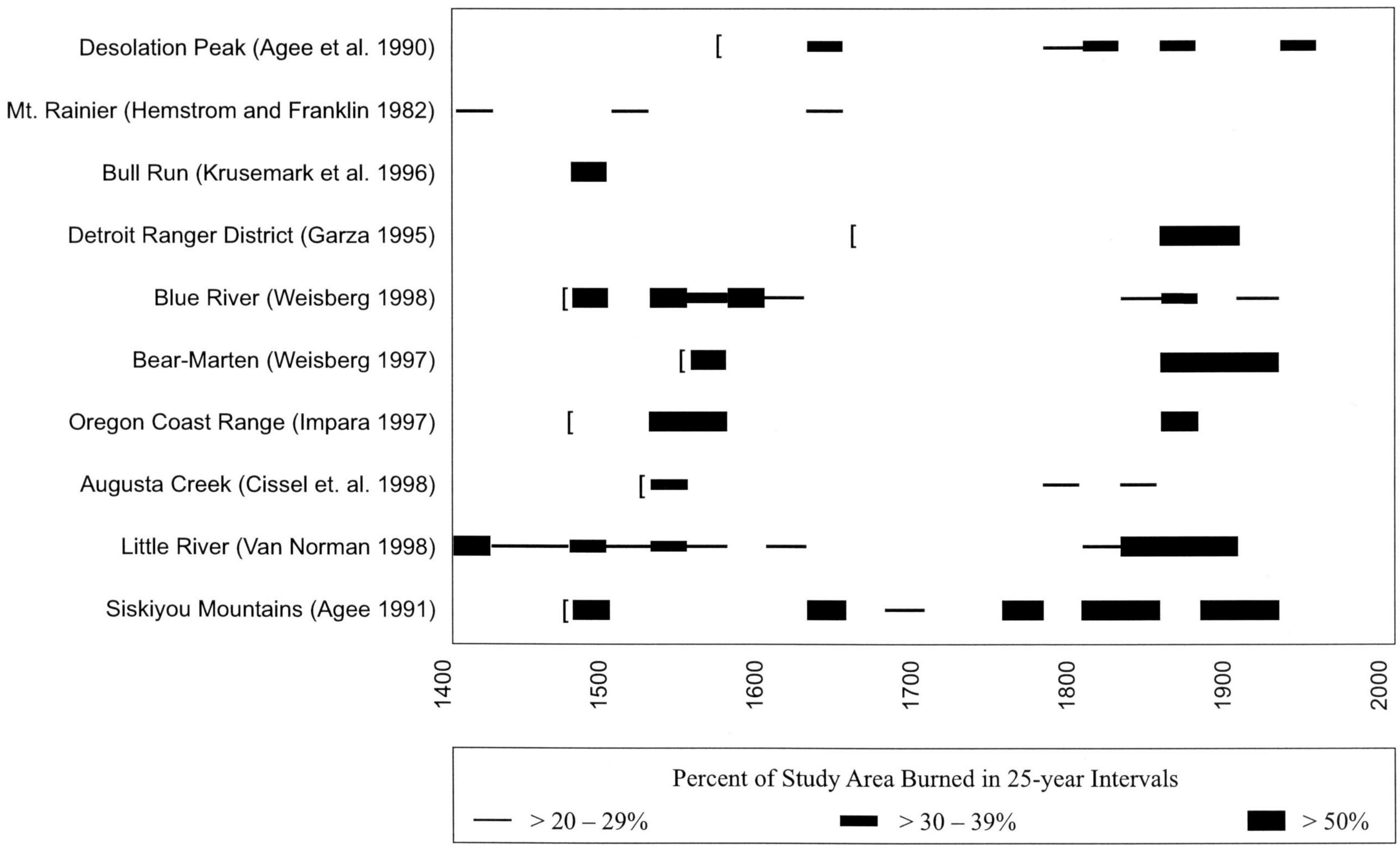



FIGURE 1. Fire regime patterns of western Oregon and Washington (from Weisberg and Swanson, in review-a). The beginning of each tree-ring series is designated by a bracket.

non-fire interval between the two periods existed for all study areas. The patterns suggest strong regional synchroneity in the occurrence of large fires in Oregon and Washington.

Some important issues concerning the data in Weisberg and Swanson's synthesis remain unaddressed. For example, it is unclear whether fires occurred at all sites within a study area or only at certain sites. It is unknown whether fires occurred in sites of similar or varying climate and vegetation. The geographic pattern of fire occurrence through time is not addressed. It is also unclear whether the studies chosen by Weisberg and Swanson (in review-a) were sufficiently representative of the environmental diversity of western Oregon to warrant a regional synthesis. These concerns form the two research questions of this thesis.

1. How well do fire-history study sites sample the range of climate conditions and vegetation types in the region?
2. How have the spatial and temporal patterns of fire occurrence changed through time in western Oregon?

In order to address these questions, fire-history data from eight dendrochronological studies, six of which were used in Weisberg and Swanson (in review-a), were compiled and merged with environmental data for the same locations. Although fire-history studies tend to cover only local areas (less than 100 $km^2$), the selected studies ranged from 66 to 1375 $km^2$ in area and thus were large enough to reveal patterns at a landscape-to-regional scale (Fig. 2). Reconstructions spanned the last 450 to 795 years. The earliest fire record was A.D. 1200 at a few study areas, but most records began in the 1500s. The sampling density of the studies ranged from 0.1 to 3.6 sites/$km^2$. The

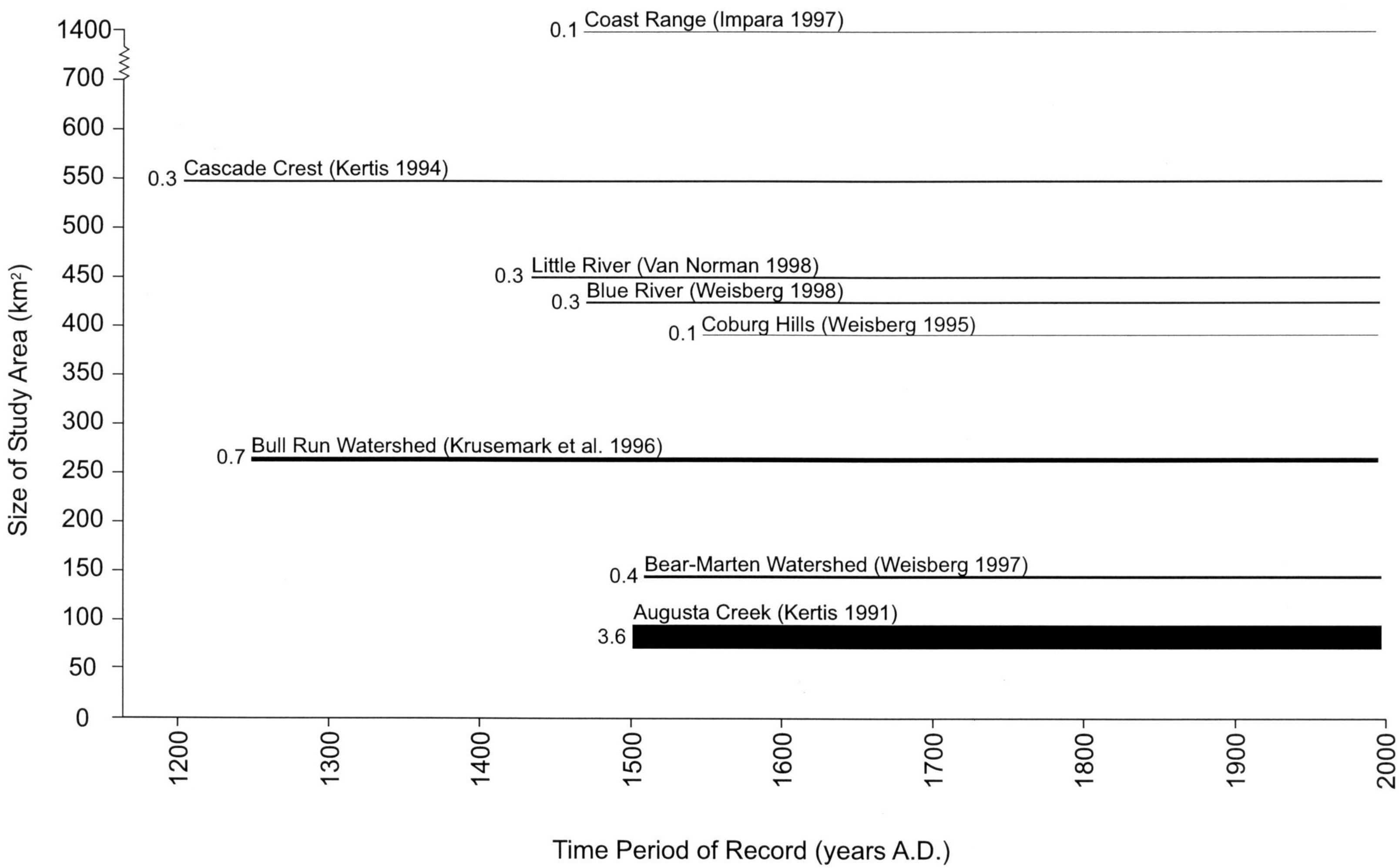



FIGURE 2. Area, time period, and sampling density of fire-history studies. Horizontal bars indicate the temporal extent of studies included in this synthesis. Studies are arranged vertically according to study area size. The width of the bar and the number to the left of each bar reflect the samping density of the study (number of sites/$km^2$).

combination of large spatial extent, long time period of record, and relatively high sampling density rendered these studies suitable for a regional synthesis. Visualization techniques, specifically an animated time series of images, were used to analyze the temporal and spatial patterns of fire occurrence within and among the study areas.

# CHAPTER II

# EXPLANATION OF DATA

Two types of data were used in this thesis. The first type is the fire-history data obtained from existing fire-history studies. Those studies are summarized in the following section. The second type is the corresponding climate and vegetation data for the sites within the study areas. The sources of these data are described in the second section of this chapter. Throughout this thesis, "study" or "study area" refers to the entire spatial extent of a fire-history study (e.g., Bull Run watershed). "Site" or "study site" refers to one of many plots within a study area where a fire chronology was reconstructed based on data collected from a number of trees within the plot.

## Fire-History Datasets

Five of the eight fire-history studies are located in the Cascade Range, which, when combined with one located west of the southern Cascades, form a north-south transect through the state (Fig. 3). Studies in the central Coast Range, the western Cascade foothills, and the central Cascade Range form a west-east transect across western Oregon. Most of the data used in the fire-history reconstructions were collected from stumps in

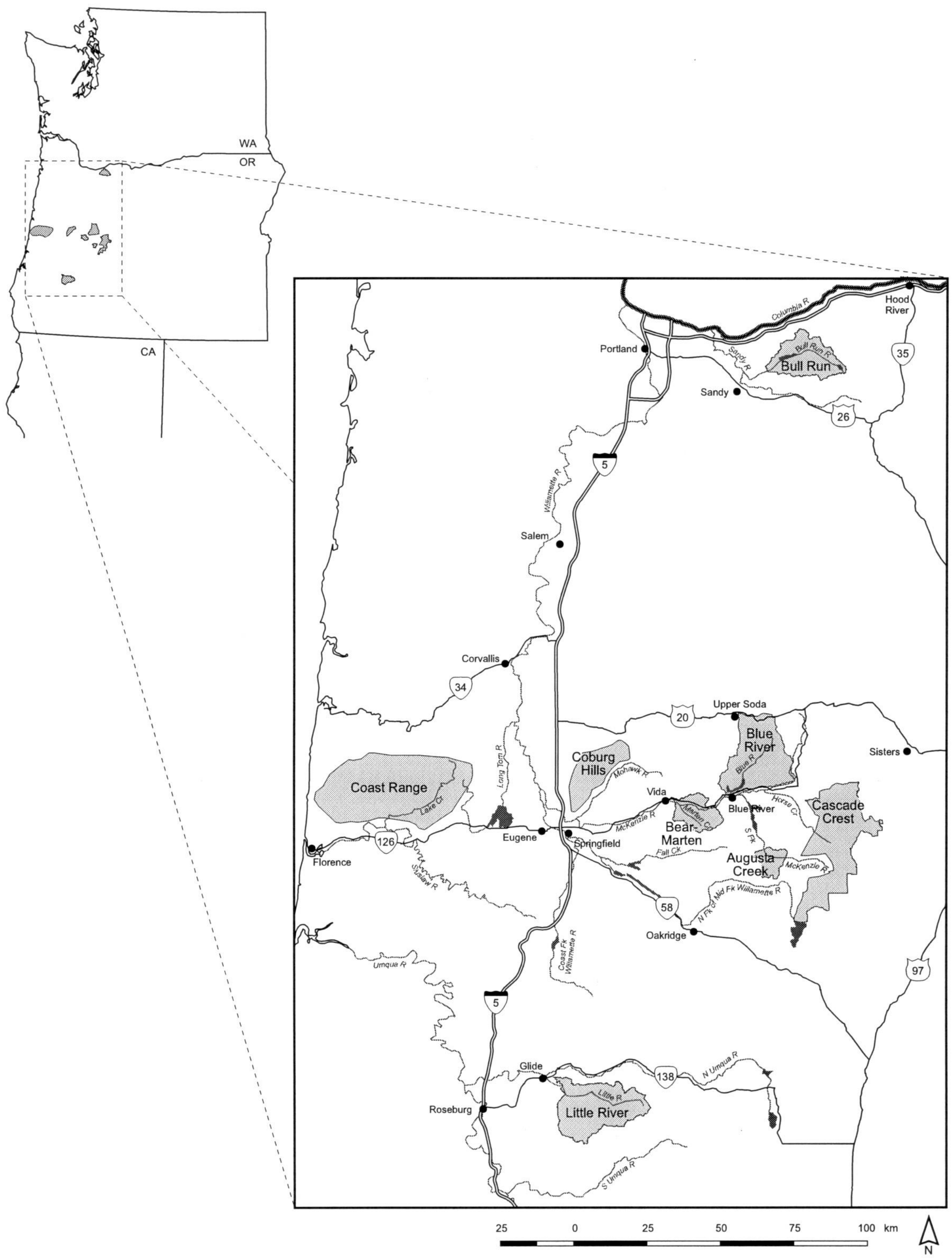



FIGURE 3. Location of study areas.

clearcuts, where intensive sampling of large areas was possible. Few stumps were cross-dated because the objectives of the studies emphasized large spatial coverage and high sampling density rather than temporal precision (Weisberg and Swanson in review-b). A brief description of the physical environment of each study area, as well as a few remarks about sampling design, follows. A summary of these study characteristics is presented in Table 1. Vegetation zones mentioned in the following study area descriptions are from Franklin and Dyrness (1973). The name of the vegetation zone refers to the dominant late-successional tree species of the area.

## Bull Run Watershed

The northernmost study area is the Bull Run watershed, the primary source of water for the Portland metropolitan area (Krusemark et al. 1996). Mean annual precipitation in Bull Run is 143 cm, with some areas receiving up to 180 cm/yr. Mean annual temperature is 7.3 °C, and the elevation ranges from 300 to 1300 m. Most of the watershed lies within the *Tsuga heterophylla* Zone, and western hemlock (*Tsuga heterophylla*) and Douglas-fir (*Pseudotsuga menziesii*) are the dominant species. Higher elevation sites are in the *Abies amabilis* Zone, which is populated by species such as western hemlock and Pacific silver fir (*Abies amabilis*) in undisturbed areas.

The Bull Run fire-history study area covers 264 $km^2$ and has a sampling density of 0.7 sites/$km^2$ (Krusemark et al. 1996). To reconstruct past fires, aerial photos were first used to identify distinct cohorts of trees, which were presumed to have established

TABLE 1. Summary of Study Sampling Designs and Environmental Characteristics of Study Areas

| Study Area | Time Period of Record (years A.D.) | Study Area Size (km$^2$) | Sampling Density (# sites/km$^2$) | Elevation (m) | Mean Annual Temp. (°C) | Mean Annual Precip. (cm) | Vegetation Zone(s) (Franklin and Dyrness 1973) |
|---|---|---|---|---|---|---|---|
| Bull Run Watershed | 1243 – 1995 | 264 | 0.7 | 300 – 1300 | 7.3 | 143 | *Tsuga heterophylla*<br>*Abies amabilis* |
| Coast Range | 1478 – 1994 | 1,375 | 0.1 | Sea level – 1000 | 9.8 | 170 | *Picea sitchensis*<br>*Tsuga heterophylla* |
| Coburg Hills | 1545 – 1995 | 400 | 0.1 | 100 – 930 | 9.7 | 112 | *Tsuga heterophylla* |
| Bear-Marten Watershed | 1511 – 1997 | 145 | 0.4 | 230 – 1270 | 7.1 | 106 | *Tsuga heterophylla* |
| Blue River | 1475 – 1996 | 440 | 0.3 | 320 – 1650 | 7.3 | 120 | *Tsuga heterophylla*<br>*Abies amabilis* |
| Augusta Creek | 1500 – 1991 | 81 | 3.6 | 700 – 1740 | 7.3 | 126 | *Tsuga heterophylla*<br>*Abies amabilis*<br>*Tsuga mertensiana* |
| Cascade Crest | 1200 – 1994 | 546 | 0.3 | 1100 – 2000 | 4.5 | 161 | *Abies amabilis*<br>*Tsuga mertensiana* |
| Little River | 1430 – 1996 | 450 | 0.3 | 250 – 1600 | 8.5 | 112 | *Tsuga heterophylla*<br>*Mixed Conifer* |

following fire. Representative ages for each cohort were then estimated by counting rings on wedges or increment cores in the field. In logged areas, cohort ages were estimated by counting rings on stumps.

## Coast Range

The central Coast Range study has the largest spatial extent of all the studies, 1375 $km^2$ (Impara 1997). Mean annual precipitation is high along the coast (232 cm/yr) and in the interior of the study area (220 cm/yr), and relatively low in the Willamette Valley (154 cm/yr). Mean annual temperature is 9.8 °C, and elevation in the study area ranges from sea level to 1000 m. Most of the vegetation is in the *Tsuga heterophylla* Zone, and Douglas-fir is typically the dominant species, except along the coast where Sitka spruce (*Picea sitchensis*) is dominant.

Dendrochronological data were collected throughout the study area using a scale-hierarchical design that allowed sampling by precipitation zone, land-type association, aspect, and hillslope position (Impara 1997). The sampling density is 0.1 sites/$km^2$.

## Coburg Hills

The Coburg Hills are located in the foothills of the Cascade Range at the eastern edge of the Willamette Valley (Weisberg 1995). The 400-$km^2$ study area ranges from 100 to 930 m in elevation and consists of alternating square-mile sections of public and private property. The study area is in the *Tsuga heterophylla* Zone, and Douglas-fir is the dominant tree species, although western hemlock, western redcedar (*Thuja plicata*), and incense cedar (*Calocedrus decurrens*) are also common. Big leaf maple (*Acer macrophyllum*), giant chinkapin (*Chrysolepsis chrysophylla*), red alder (*Alnus rubra*), and Oregon white oak (*Quercus garryana*) are common hardwoods. Precipitation averages 112 cm per year, and mean annual temperature is 9.7 °C.

Sampling was conducted in clearcuts on U.S.D.I. Bureau of Land Management property (Weisberg 1995). Sites were stratified over three elevation zones, with a sampling density of 0.1 sites/$km^2$. Within each site, transects were established at different hillslope positions, and fire-scar ages and tree-origin dates for early-successional tree species were obtained. In addition, old tree stumps with plentiful fire-scar evidence were sampled opportunistically.

### Bear-Marten Watershed

The Bear-Marten watershed is located in the central western Cascades and surrounds a segment of the McKenzie River (Weisberg 1997). Elevations range from 230 to 1270 m, and there is a mix of private and public land ownership in the study area. Mean annual precipitation is 106 cm, and mean annual temperature in the area is 7.1 °C. The Bear-Marten watershed is in the *Tsuga heterophylla* Zone.

The size of the study area is 145 $km^2$, and the sampling density is 0.4 sites/$km^2$ (Weisberg 1997). Fire-scar ages and tree-origin dates were determined by tree-ring counts in the field. Eleven of 63 sites—located in the northeastern, eastern, and southwestern sections of the watershed—were sampled intensively, and the remaining sites were sampled with a combination of systematic and opportunistic approaches. Twenty cross-sections at five sites were also removed and cross-dated.

## Blue River

The Blue River study area, just northeast of Bear-Marten watershed, encompasses several small watersheds that feed into the McKenzie River valley. Most of the study area is within the Willamette National Forest, with the H.J. Andrews Experimental Forest occupying about 14% of the total area (Weisberg 1998). The Blue River study area is characterized by steep and dissected topography, with elevation ranging from 320 to 1650 m. Mean annual precipitation is 120 cm, and mean annual temperature is 7.3 °C. Areas up to about 1000 m in elevation are in the *Tsuga heterophylla* Zone, and elevations over 1000 m are generally in the *Abies amabilis* Zone. Douglas-fir is the dominant species in the lower zone, whereas Pacific silver fir, noble fir (*Abies procera*), and western hemlock, in addition to Douglas-fir, are dominant in the upper zone. The highest elevations are in the *Tsuga mertensiana* Zone where mountain hemlock (*Tsuga mertensiana*) is common.

The Blue River study area encompasses 440 $km^2$, and the sampling density is 0.3 sites/$km^2$ (Weisberg 1998). A randomly selected clearcut from each legal section, averaging 2.79 $km^2$ in area, was chosen for sampling. Of 137 sampled clearcuts, 90 were sampled with a combination of systematic and opportunistic approaches, and 47 were sampled only opportunistically due to rough terrain.

## Augusta Creek

The Augusta Creek watershed is located just west of Chucksney Mountain and drains into the South Fork of the McKenzie River in the western Cascades. The study area is composed of several distinct landforms, including areas of highly dissected topography and cirque basins, as well as basalt slopes and valley floor (Kertis et al. 1995, Cissel et al. 1998). Elevation ranges from 700 to 1740 m. Annual precipitation averages 126 cm, and annual temperature averages 7.3 °C. About three-quarters of the sites were in the *Tsuga heterophylla* Zone, and the remainder were in the *Abies amabilis* and *Tsuga mertensiana* zones.

At 81 $km^2$, Augusta Creek is the smallest study area and also has the highest sampling density (3.6 sites/$km^2$) (Kertis et al. 1995). About 78% of the sites are in clearcuts, where stumps were prepared and counted. The other sites are forested and required increment cores to be taken from live trees. Sampling frequency was increased in areas of varied topography and where scar histories appeared complex.

## Cascade Crest

The Cascade Crest study area is located in the high elevations (1100 – 2000 m) of the central Cascade Range (Kertis and Huff 1997). Most sites are within the Three Sisters Wilderness Area, although some extend into the northern portion of Waldo Lake Wilderness Area. Precipitation along this segment of the crest of the Cascade Range averages 161 cm/yr, and annual temperature averages 4.5 °C. The study area includes portions of both the *Abies amabilis* and *Tsuga mertensiana* zones.

The study area is 546 $km^2$, which is the second largest of all the studies. Site locations were chosen based on a nested sampling scheme that targeted different landblocks (areas of similar vegetation characteristics and topography) (Kertis and Huff 1997). The sampling density is 0.3 sites/$km^2$. Fire history was reconstructed using stand-age analysis based on aerial photos, as well as using fire evidence such as charred wood or soil.

## Little River

Little River is the southernmost study area and occupies most of the Little River watershed, a tributary watershed of the North Umqua River (Van Norman 1998). The terrain consists of mostly steep slopes and narrow valleys, with elevation ranging from 250 to 1600 m. About 70% of the land is under federal management, and the remainder is mostly private industrial forest. Mean annual precipitation in the area is 112 cm, and mean annual temperature is 8.5 °C. Little River is located in an ecotone between the Mixed Conifer and *Tsuga heterophylla* zones. Douglas-fir dominates at low to mid-elevations, whereas western hemlock is common at mid- to high elevations. Several other conifer and hardwood species are found at low to mid-elevations, depending on the amount of moisture available. At dry low to mid-elevations are incense cedar, sugar pine (*Pinus lambertiana*), and grand fir (*Abies grandis*). At moist low to mid-elevations, western redcedar and Pacific yew (*Taxus brevifolia*) occur.

The study area is 450 $km^2$ in size, and the sampling density is 0.3 sites/$km^2$ (Van Norman 1998). One or more clearcuts from each cell within a 2-$km^2$ grid covering the study area was sampled. Where terrain was fairly homogeneous, a transect was randomly placed at each site. All stumps at the beginning of each transect were sampled, and additional stumps were sampled further along and outside the transect to verify fire dates.

## Climate and Vegetation Datasets

The first objective of this synthesis was to determine how well the existing fire-history site locations sample the present range of climate and vegetation conditions that exist in western Oregon. In order to address this question, modern climate and vegetation data were needed for each site within the study areas, as well as for all of western Oregon. The second objective was to determine how the pattern of fire occurrence has changed through time. This second objective involved comparing the number of fire events during different time periods and comparing the climate and vegetation conditions of the particular sites that burned during different time periods.

In an ideal study design, one would approach the second objective by comparing the fire-history records to independent records of past climate for the same region. Because paleoclimate data are not available for the entire region (Graumlich 1987), it was necessary to use modern climate as a basis of assessment. Although climate has changed over the last 800 years, relative differences between study areas have probably remained constant (Mock 1996). Thus, it is reasonable to use modern data to investigate whether fire events tend to occur in areas with specific climate or vegetation characteristics. The variables used in the climate analysis are based on western Oregon weather station data for the period A.D. 1951 – 1980 (Bartlein 2000) (Fig. 4). Temperature, precipitation, and percent possible sunshine data were interpolated onto a 2.5-min grid of western Oregon using a procedure that considers the influence of elevation (Thompson et al. 1999). These values were also interpolated for the fire-history sites. Bioclimatic variables that influence the distribution of plants (Prentice et al. 1992, Sykes et al. 1996) were also derived from the climate data (Shafer 2000). The two variables used were soil moisture, indicated by actual evapotranspiration divided by potential evapotranspiration, and length of growing season, indicated by growing degree days above 5 °C.

Two different vegetation datasets were used in this study: current vegetation, as defined by the Gap Analysis 2 land cover map (GAP2), and potential natural vegetation, as determined by a U.S.D.A. Forest Service modeling effort. The GAP2 data (2000) were obtained from the Oregon Geospatial Data Clearinghouse, and documentation was

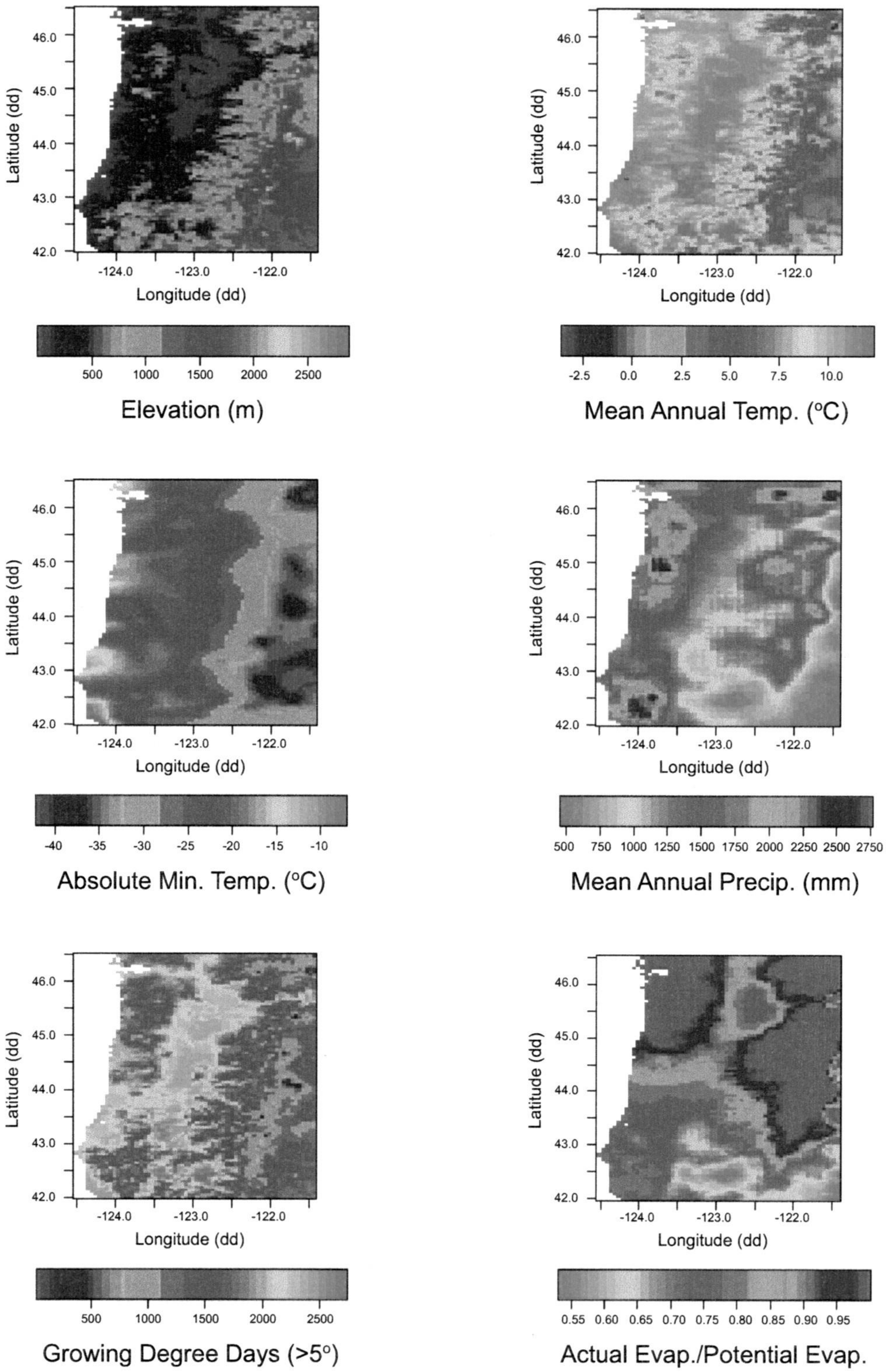



FIGURE 4. Modern climate conditions of western Oregon.

provided by the Oregon Natural Heritage Program (Kiilsgaard 1999). The primary goal of the Gap Analysis Program is to support the conservation of native vertebrates and natural land cover by producing land cover maps of the U.S. for assessment and management activities (U.S. Geological Survey Gap Analysis Program 2000). Data are derived mostly from satellite imagery, and the minimum mapping unit is estimated at 100 ha (Oregon GAP Analysis 2 Metadata 1998). Land cover is categorized according to dominant canopy vegetation, which is usually composed of multiple tree species (Fig. 5). One limitation of this dataset is that changes in project management and funding over the life of the project have probably led to some inconsistency in the resolution of the data.

Potential natural vegetation (PNV) data generated by the U.S.D.A. Forest Service (2000) represents the vegetation that would exist if current forests reached a climax community state in the absence of catastrophic disturbance (McCain 2000a). Although most stands in the Pacific Northwest would not reach such a state given the frequency of disturbance in the region, PNV is a useful concept because it represents the successional potential of a stand, not just its current condition. The vegetation is classified according to Plant Association Group, which is based on both canopy and subcanopy species. The PNV data were obtained in three separate ArcInfo grids from the Siuslaw National Forest Supervisor's Office (McCain 2000b). Each grid represented areas coinciding with the Siuslaw, Willamette, and Klamath national forests. The main limitation of this dataset is that it does not cover the entire region. As seen in Figure 6, the three combined grids provide coverage of the northern two-thirds of western Oregon, which include all of the fire-history study areas except Little River and a few Cascade Crest sites.

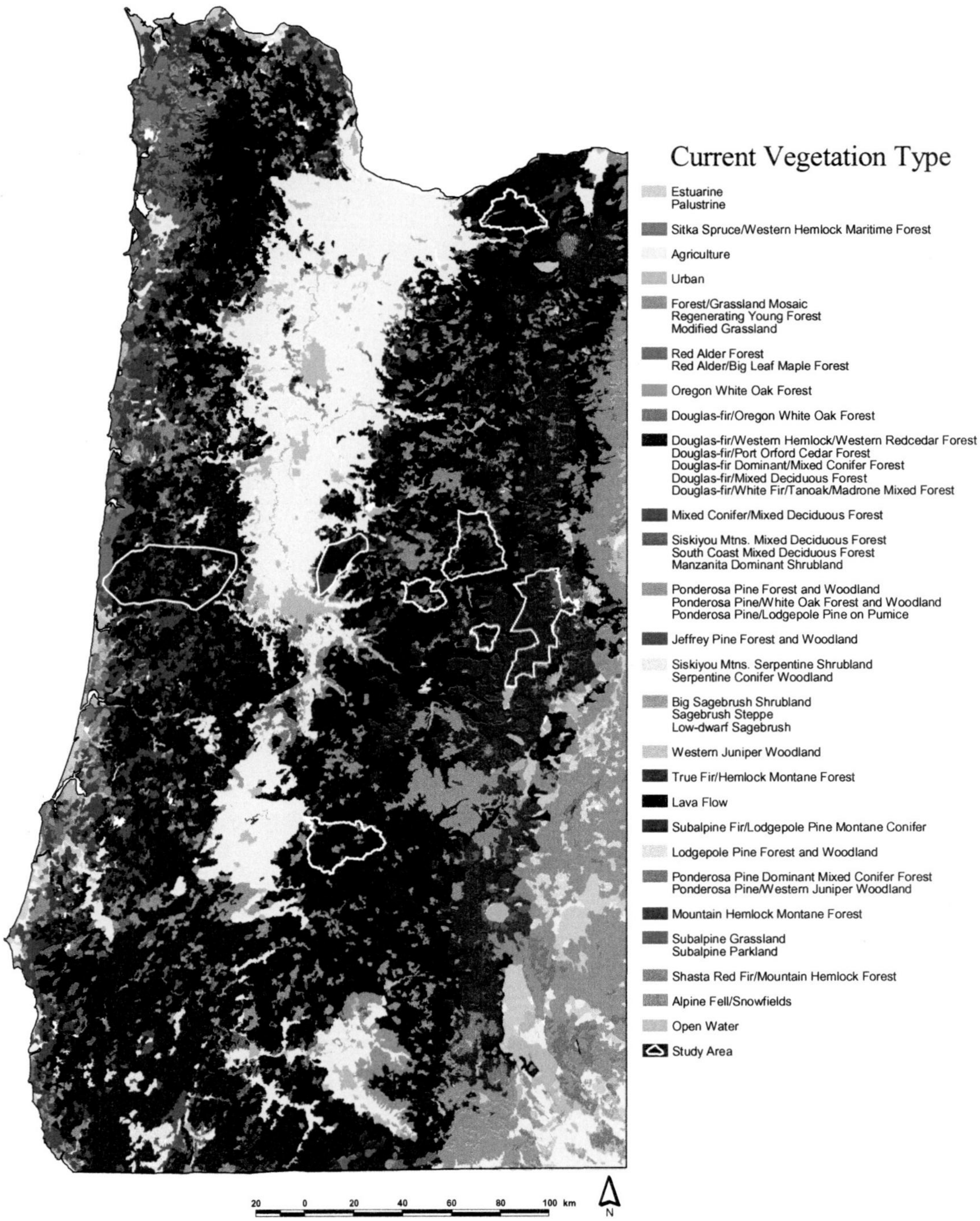



FIGURE 5. Current GAP2 vegetation of western Oregon. Vegetation types are based on dominant canopy vegetation.

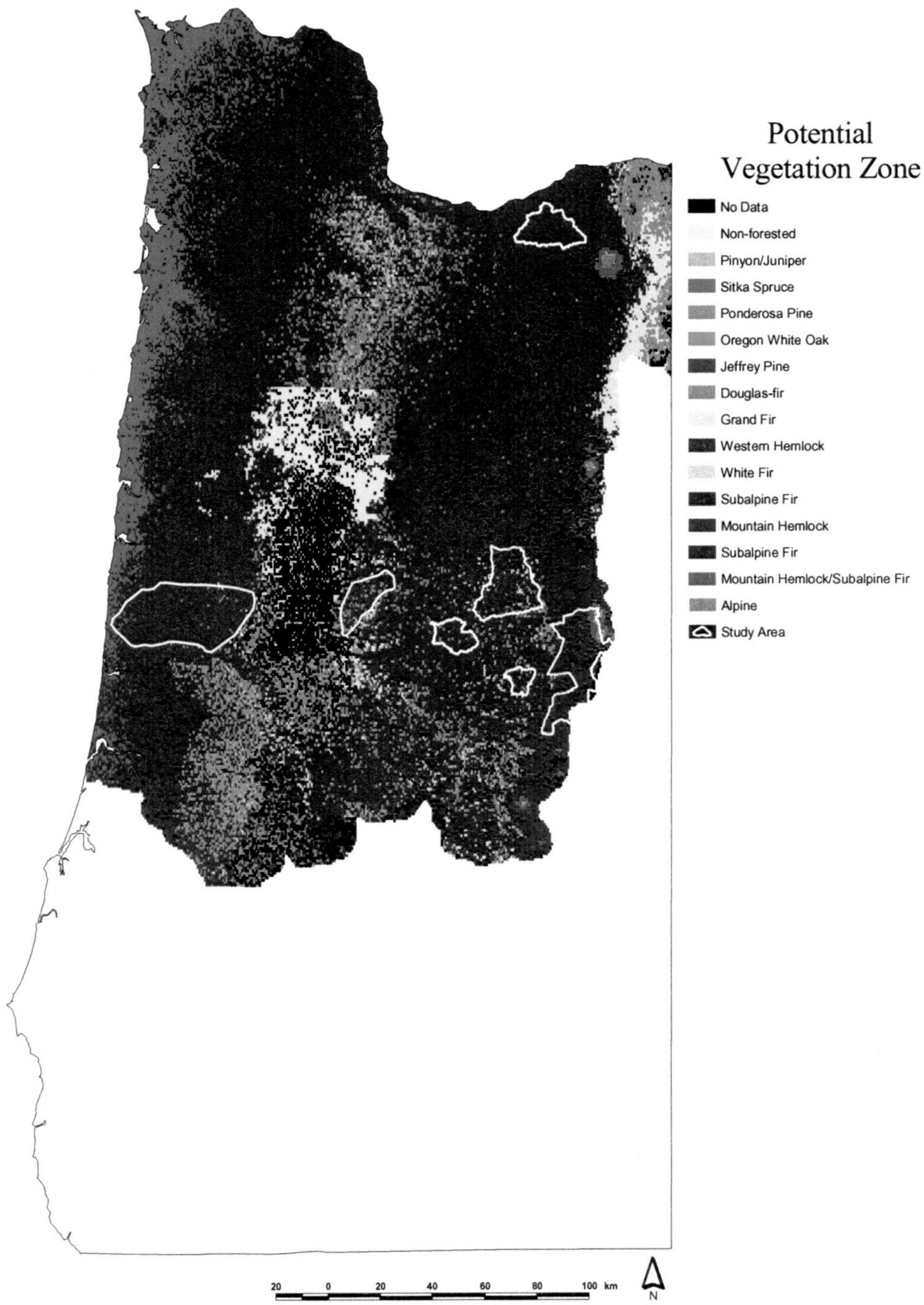



FIGURE 6. Potential natural vegetation of western Oregon. Vegetation zones are based on climax community vegetation.

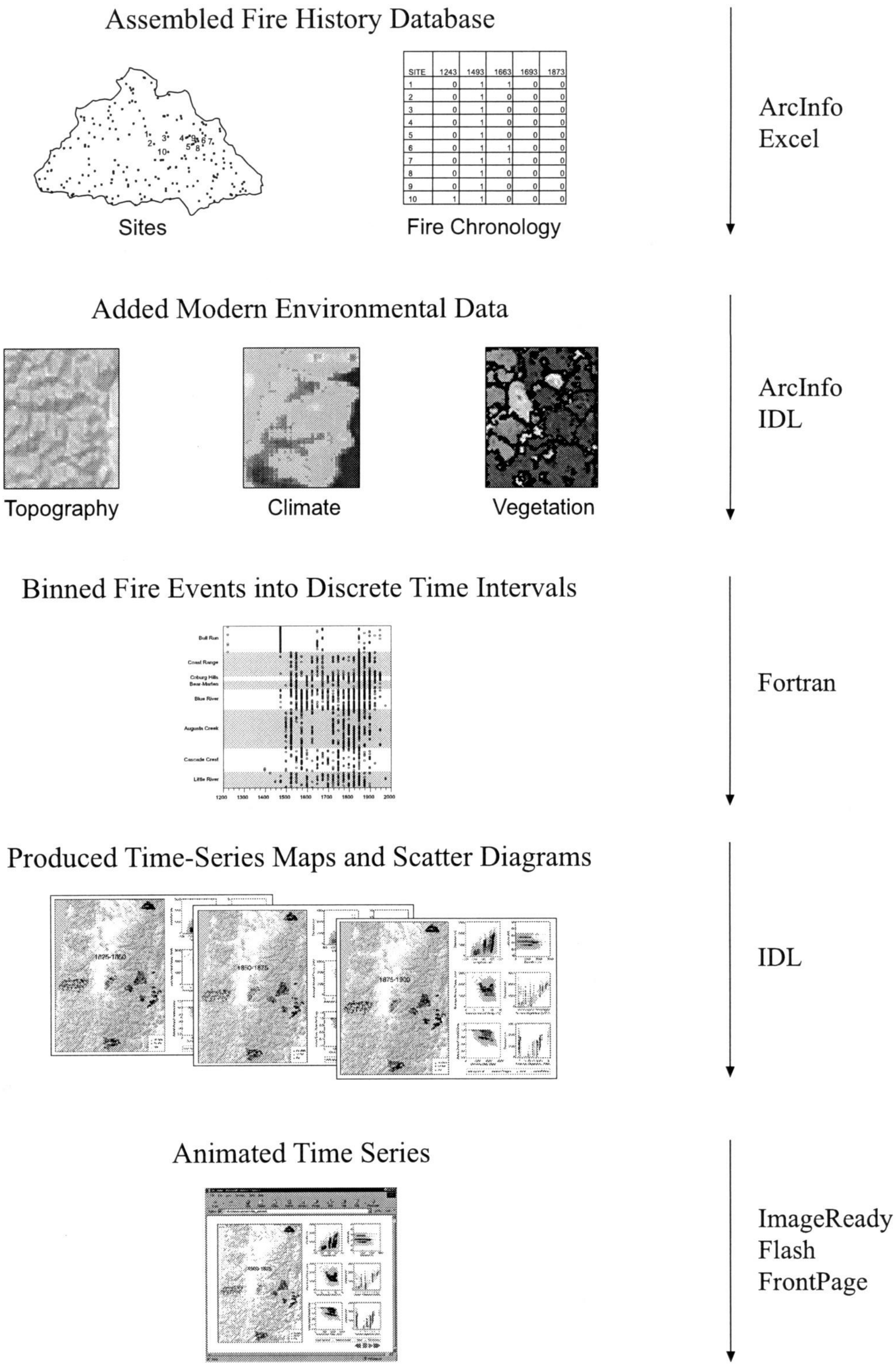
# CHAPTER III

# METHODS

The initial phase of this project involved compiling the fire-history data for all of the sites within each study area into a single fire-history database. The second phase consisted of adding information about the environment of each site to the database. Data were added for coordinate location, elevation, climate conditions, and vegetation type (current and potential). In the third phase, a variety of visualization and analysis techniques were used to explore the spatial and temporal patterns of fire occurrence in the region. Patterns were studied in geographic space (i.e., on a map of western Oregon), as well in the environmental space of western Oregon (i.e., on diagrams showing climate and vegetation gradients of western Oregon). A summary of procedures is presented in Figure 7.

## Compilation of Fire-History Data

The fire-history data were obtained from the researchers directly or from the Forest Science Data Bank (2000), a partnership between the Department of Forest Science, Oregon State University, and the U.S.D.A. Forest Service Pacific Northwest




| SITE | 1243 | 1493 | 1663 | 1693 | 1873 |
|---|---|---|---|---|---|
| 1 | 0 | 1 | 1 | 0 | 0 |
| 2 | 0 | 1 | 0 | 0 | 0 |
| 3 | 0 | 1 | 0 | 0 | 0 |
| 4 | 0 | 1 | 0 | 0 | 0 |
| 5 | 0 | 1 | 0 | 0 | 0 |
| 6 | 0 | 1 | 1 | 0 | 0 |
| 7 | 0 | 1 | 1 | 0 | 0 |
| 8 | 0 | 1 | 0 | 0 | 0 |
| 9 | 0 | 1 | 0 | 0 | 0 |
| 10 | 1 | 1 | 0 | 0 | 0 |

FIGURE 7. Flowchart of Procedures.

Research Station, Corvallis, Oregon. For each study area, an ArcInfo or ArcView file containing the point locations of the individual sites was obtained. The fire-event data for each study were available in spreadsheet form. In a few instances, the fire-event data had already been joined to the GIS point coverage of locations. When that was not the case, the fire-event data sometimes needed to be reformatted so that there was one row for each site and one column for each year in which there were one or more fire events. The resulting matrix contained data indicating "no fire event" or "fire event" for every site in every year included in the matrix. If no fire event occurred, the researcher had sometimes made a distinction between "no fire event" and "no evidence of a fire event because trees were not old enough to have recorded fire". Half of the studies also included fire-severity estimates.

The fire-event matrices were then joined to the corresponding GIS point coverages (ArcInfo version 8.0.2). This joining was feasible because each point in a GIS coverage had a label that matched a unique site number in the corresponding fire-event data table. The final result was a unique GIS coverage of sites for each study area, composed of a map of site locations and a corresponding point attribute table containing the years in which fire events occurred at each site. Because half of the studies did not include estimates of the fire severity of individual fire events, fire severity could not be used in the analysis. The original data were in the Universal Tranverse Mercator (UTM) projection and were converted to decimal degrees to be consistent with the climate data format.

## Addition of Environmental Data

To determine how well the sites represent the range of western Oregon environment types and to investigate how past fire patterns varied across different environmental conditions, information about the topography, climate, and vegetation of each site was incorporated into the fire-history database.

Topographic information was extracted from U.S. Geological Survey and U.S.D.A. Forest Service digital elevation models (DEMs) (1997) converted to ArcInfo Grid format. A public domain AML (a program written in Arc Macro Language) was used to extract the elevation, slope, and aspect for sites within each study area from the DEMs. The AML then added these values to the point attribute table in the corresponding GIS coverage. A shaded-relief map of western Oregon was also generated to provide a locational context for the fire-history data. The data for the shaded relief were obtained from GTOPO30 (1996), a global DEM with a resolution of approximately 1 km that is available from the U.S. Geological Survey, and converted to an index of gray shades.

Two climate subsets were prepared for use with the fire-history database. One contained the latitude and longitude values and climate conditions of the sites, and the other contained the latitude and longitude values and climate conditions for all of the points in a 2.5-min (~4.6-km) grid covering western Oregon.

The vegetation data were prepared in a similar manner as the climate data. The GAP2 vegetation data were exported from ArcInfo and used to generate two separate datasets, one containing current vegetation types for the sites and the other containing current vegetation types for all of western Oregon. In a few instances, classes were combined (e.g., different wetland types were merged into one class called "wetland").

After merging the potential natural vegetation grids, two subsets of data were also extracted. The first contained the PNV Plant Association Groups for the sites, and the second contained the PNV Plant Association Groups for points on the grid of western Oregon. Because there were no modeled data for southwestern Oregon, the sites and grid points that fell within that area received the value "no data". The PNV Plant Association Groups (e.g., Douglas-fir/vine maple/western fescue or Douglas-fir/common snowberry) were then aggregated according to potential dominant canopy vegetation (e.g., Douglas-fir zone) in order to facilitate the analysis. Thus, each PNV vegetation zone, which differs from the more generalized Franklin and Dyrness vegetation zones (1973), is characterized by one dominant tree species for which the zone is named, but within a zone, a variety of different understory combinations can exist. The potential and existing vegetation data were then combined with the two climate datasets.

## Data Visualization and Analysis

The temporal and spatial components of the data were studied simultaneously. An animated time series of images was constructed as a practical and effective means of analyzing the data. Four steps were involved to create the animated time series of images: the fire data were binned temporally, the location of burned sites were shown on a map of western Oregon for all time intervals, scatter diagrams were created to examine fire occurrence along climate and vegetation gradients, and the time series of maps and scatter diagrams was animated. Finally, density plots (smoothed histograms) were generated to summarize the time series data.

The first step in creating the animated time series of images was to choose an appropriate time interval for binning the fire data. Although the fire events in the fire-history database were associated with individual years, the temporal resolution reported by the researchers varied. Dating-error research in Douglas-fir forests of the central western Cascades has demonstrated that about 75% of fire dates established from scarred tree rings are likely to be within ten years of the actual date, and about 87% are likely to be within 20 years of the actual date (Weisberg and Swanson in review-b). Thus, 25 years, which was the lowest temporal resolution estimated in the studies, seemed an appropriate binning interval. The fire-history dataset was summarized by 25-year intervals at a 25-year step, beginning with the year A.D.1200 and ending with A.D. 1975. Trials were also done with other discrete and overlapping time intervals, ranging from one to 30 years, to verify the robustness of 25 years as a basis for analysis. The resulting scatterplots showed similar trends.

The second step was to create maps of fire occurrence in geographic space for each 25-year interval from A.D. 1200 to 1975. Interactive Data Language (IDL version 5.2) was chosen as the programming language and visualization environment in which to create the maps because it permits a high level of control over the output. The instructions for creating the map were written in IDL, which has built-in mapping functionality.

Each site on the time-series maps was designated by a dot. If one or more fire events occurred at a site in a particular year within the given 25-year time interval, the dot was shaded red. Otherwise, the dot was left hollow, indicating "no data" (i.e., sampled trees were not present during that particular 25-year period), or the dot was shaded black, indicating "no fire" (i.e., trees were present during the specified time period, but did not bear any evidence of a fire during that period).

Relatively few stands over 500 years old remain in most of the study areas resulting in only a partial fire record at most sites for the earliest centuries; therefore many symbols show "no data" (hollow dot) at the beginning of the time series of images. They become black or red later in the series when fire events could be reconstructed from trees that were alive during the given time interval. Unfortunately, half of the studies (Bull Run watershed, Augusta Creek, Cascade Crest, and Little River) did not distinguish between "no data" and "no fire". In other words, it was not clear whether a site (1) lacked evidence of a fire event because there were no trees of appropriate age, or (2) actually experienced no fire events during that time period. Thus, if all the non-burning sites for those areas were shown as black dots, the resulting map might under-represent the actual number of sites that burned. Although this problem is less critical in recent centuries when most sites had trees of appropriate age, it is a concern for earlier centuries. In order to minimize misrepresentation for the Bull Run watershed, Augusta Creek, Cascade Crest, and Little River, all sites were designated "no data" (hollow dot) until the first fire event was recorded anywhere within the study area. At this time interval, all of the hollow dots in the study area, except the one(s) that experienced fire (now red dots), change to black dots, indicating that data exist, but no fire occurred. Some under-representation of fire undoubtedly remains, but this technique at least reduces over-interpretation of the record when no data exist.

The maps of fire occurrence in geographic space are instrumental in identifying the spatial location of fire events and assessing the synchroneity of fires through time. However, it was also of interest to know how well the studies captured the environmental diversity of the entire region, which the geographic maps could not demonstrate. Climate conditions or vegetation types not represented by these eight studies might indicate appropriate locations for future studies.

To assess the representativeness of the studies, scatter diagrams were used to compare the climate and vegetation of the sites to the entire range of climate and vegetation conditions of western Oregon. Figure 8 shows how the sites within each study area relate to the rest of the region in terms of these environmental characteristics. The gray background symbols in the scatter diagrams correspond to the map of western Oregon. The colored foreground symbols in the scatter diagrams correspond to the study sites. In the time-series images of fire occurrence, burned sites were shaded red on the scatter diagrams just as they were on the maps.

The entire time series of images was made by creating a separate layout containing a geographic map and set of climate and vegetation scatter diagrams for each of the 32 time intervals. To animate the images, the 32 layouts were made into an

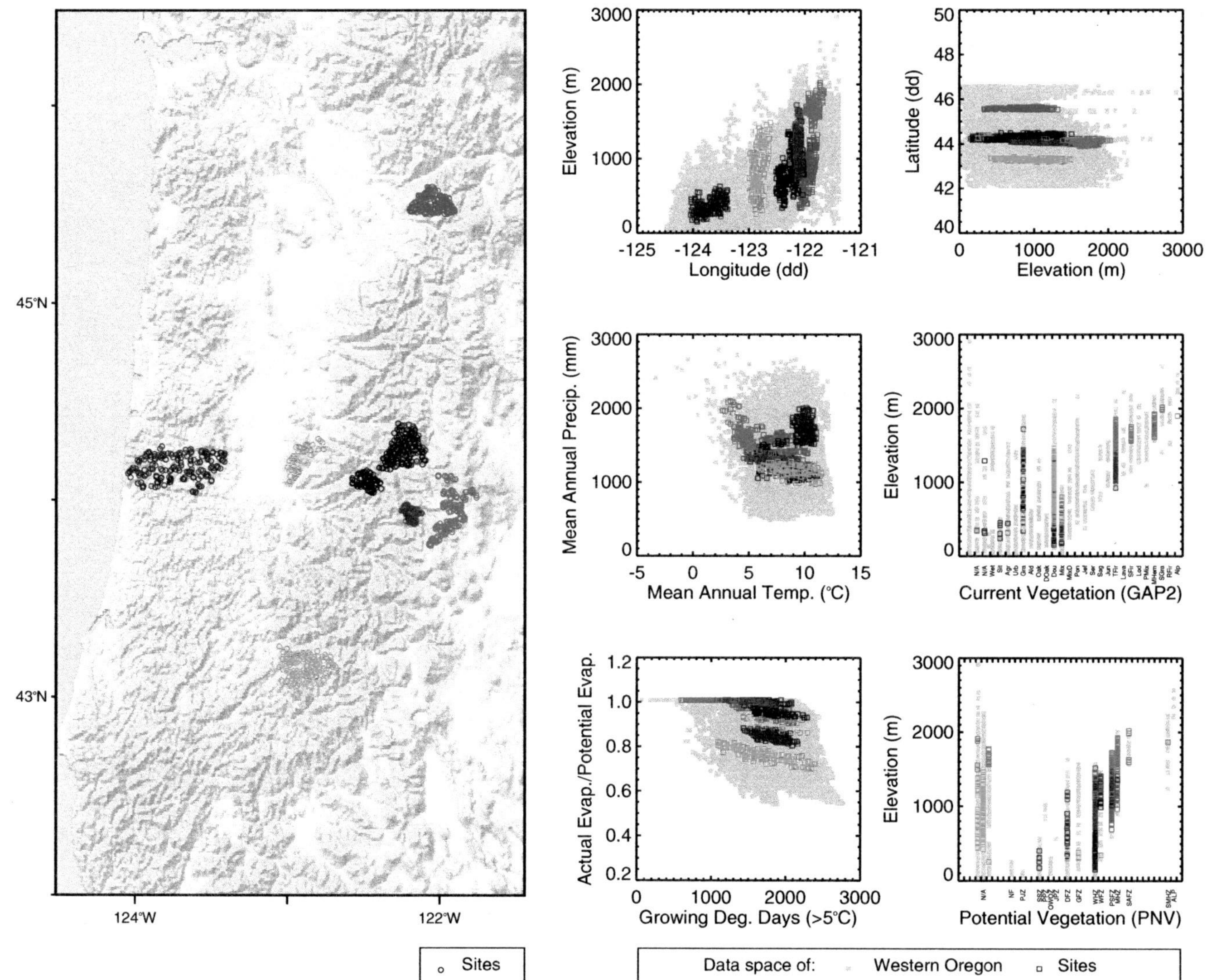



FIGURE 8. Correspondence between geographic space and data space of study sites and western Oregon. Some symbols are obscured in the scatterplots because they are overlapped by others.

animated GIF (ImageReady version 2.0). To give the user control over the animation, the animated GIF was then imported into Macromedia Flash, where stop, start, forward, and reverse buttons were added (Flash version 4). The new animation was exported as a Flash file embedded in an HTML-based webpage. The animation can be viewed using a web browser with the Flash plug-in.

Density plots of the fire data were generated to summarize the information presented in the time series of images (S-Plus 2000 Professional Release 2). A density plot is a form of smoothed histogram in which the height of the data curve is adjusted so that the total area beneath it is equal to one. The area under the curve for a particular time period represents the proportion of fire events that occurred in that period, relative to the total number of fire events that occurred over the entire record. Density plots were created for each study area to show the number of fire events in each 25-year period, smoothed over the record from A.D. 1500 to 2000. Only data for the period A.D. 1500 – 2000 were used because the record is very incomplete prior to A.D. 1500.

Finally, the tendency of study areas to have distinctive climate characteristics led to an examination of specific ranges of climate variables and of their corresponding geographic locations in western Oregon. For example, all locations in western Oregon with mean annual temperature between 5.1 and 11.7 ºC and mean annual precipitation between 918 and 1203 mm—slightly broader ranges than those of the Little River sites—were selected and displayed on the map and in the data space of the scatter diagrams.

# CHAPTER IV

# RESULTS

## Temporal and Spatial Coverage of Database

This section first describes the results of temporally binning the fire data and second addresses the spatial distribution of sites with respect to climate and vegetation conditions in western Oregon.

### Temporal Binning of Fire Data

The temporal distribution of the binned fire-event data is shown in Figure 9. The data symbols (black circles) in the first column correspond to A.D. 1225 and represent fire events in the bin beginning at A.D. 1225 and ending at A.D. 1250. Data for each subsequent 25-year time interval are also shown at the starting point of each interval. Each symbol represents a site that experienced one or more fire events at any time during the given time interval. Thus, vertically aligned symbols may suggest periods of widespread fire, but they represent events that occurred over the entire 25-year period, as opposed to a single fire event. Care should also be taken in interpreting fire events at

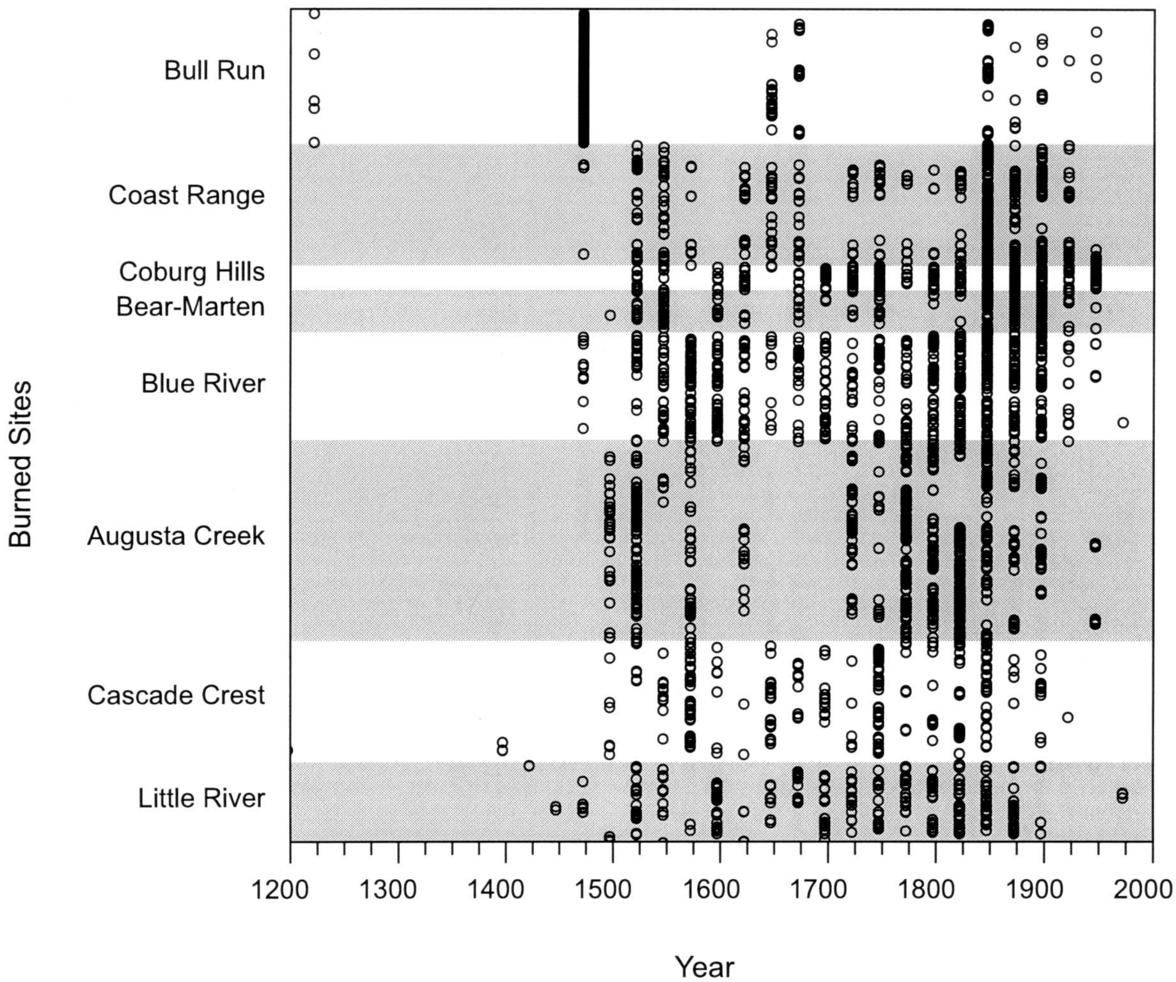


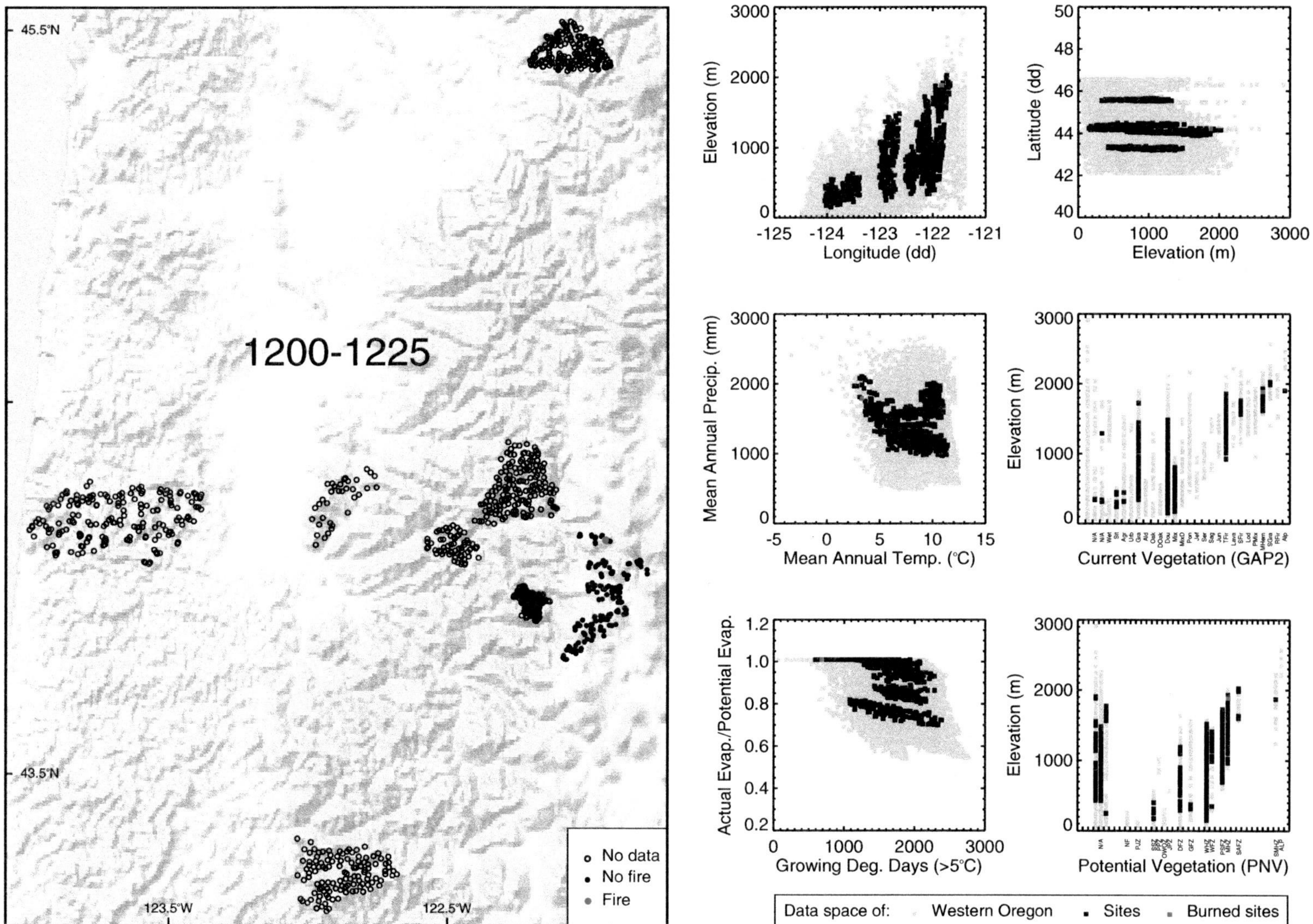

FIGURE 9. Fire-event data binned at 25-year intervals with a 25-year step. Black circles represent sites that had one or more fire events within each 25-year interval. These data were used in constructing the time-series maps and scatter diagrams in Figure 10.

different sites because, although vertical symbols may be close together in the figure, the corresponding sites are not necessarily close together geographically.

Two somewhat distinct clusters of vertically aligned symbols are evident in Figure 9. The largest cluster, indicating many sites burned in multiple study areas, occurs between ca. A.D. 1775 and 1900. The second largest cluster occurs between ca. A.D. 1500 and 1625. Fewer sites burned in the years between these two periods. Individual exceptions are sites in the Bull Run, Coast Range, Coburg Hills, Augusta Creek, and Crest study areas, all of which also experienced brief, asynchronous periods of fire occurrence between ca. A.D. 1625 and ca. 1800. In general, past fire occurrence appears less episodic than Figure 1 suggests.

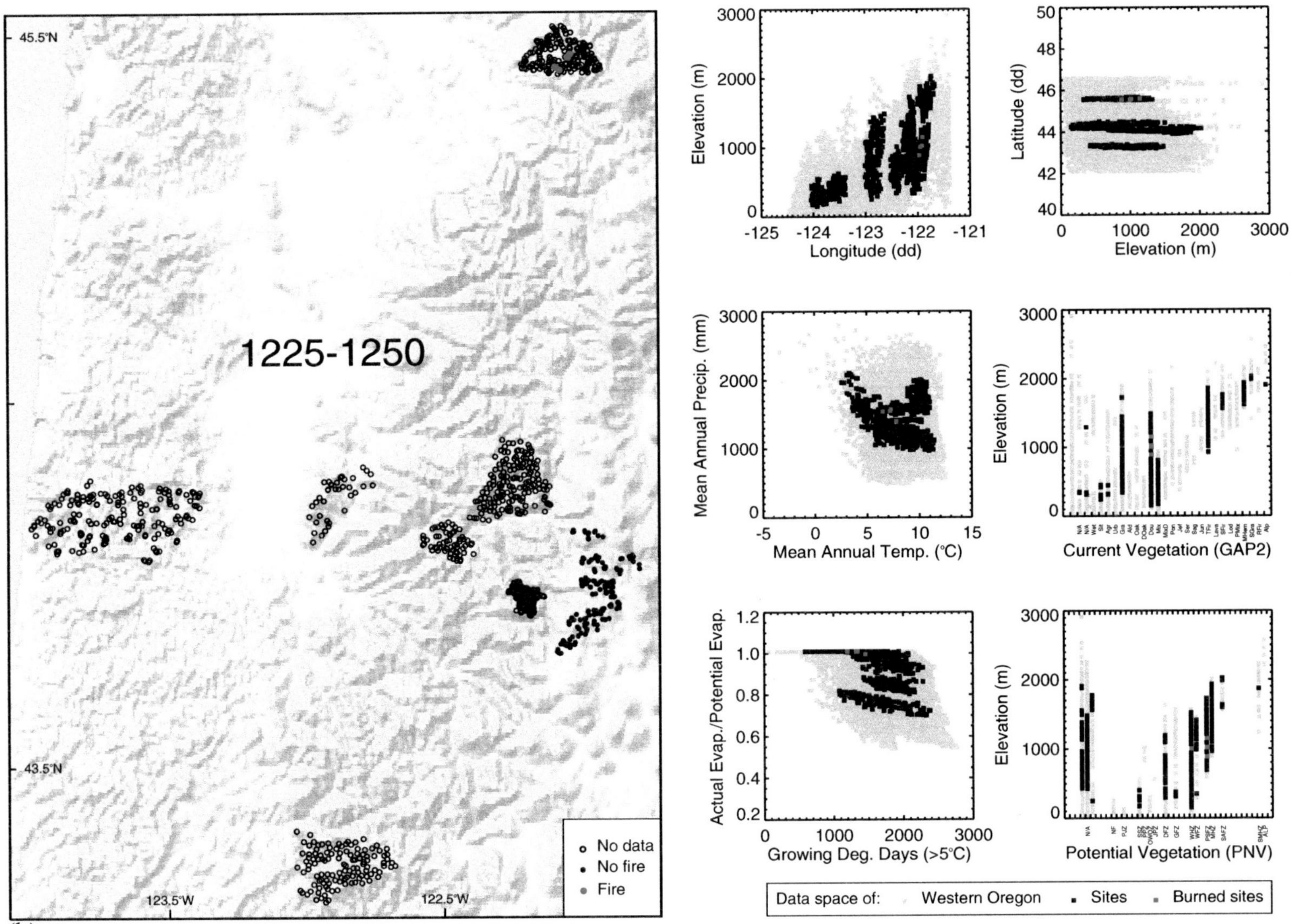
## Spatial Distribution of Sites by Climate and Vegetation Type

The climate conditions, current vegetation (GAP2), and potential vegetation (PNV) of the sites were evaluated in terms of the range of climate and vegetation conditions in western Oregon. As in Figure 8, the scatter diagrams in Figure 10 compare the climate space and vegetation space of the sites to the climate space and vegetation space of western Oregon. The vegetation key is presented in Table 2. The elevation, climate, and vegetation characteristics of each of the sites are all shown with black symbols. The Elevation vs. Longitude and Latitude vs. Elevation scatter diagrams (in the upper right of Figure 10) are the easiest to interpret initially because latitude and longitude correspond directly to the geographic coordinates on the map. The other four



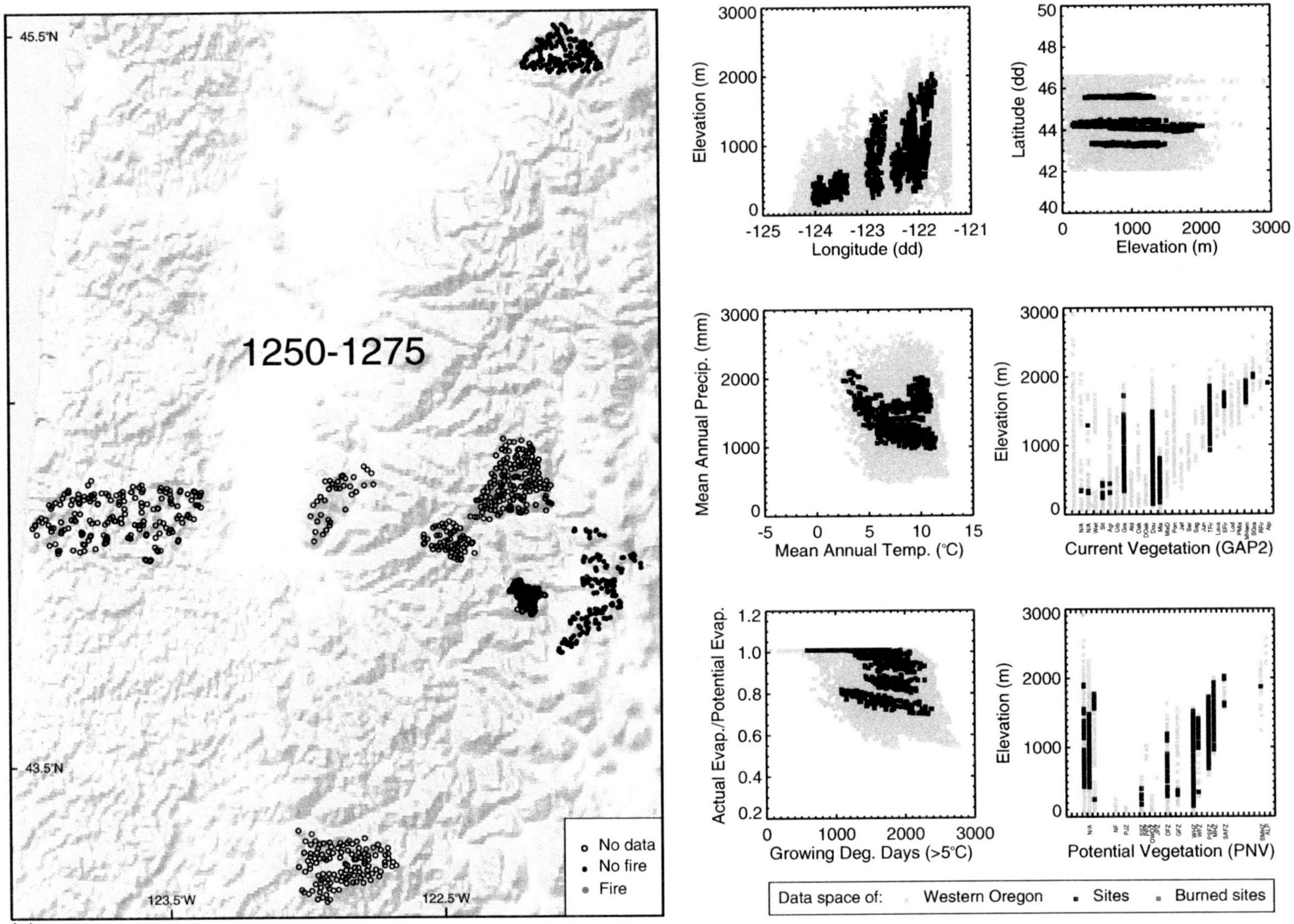

(a)

FIGURE 10. Time series of fire occurrence in geographic, climate, and vegetation space. See Table 2 for vegetation key.



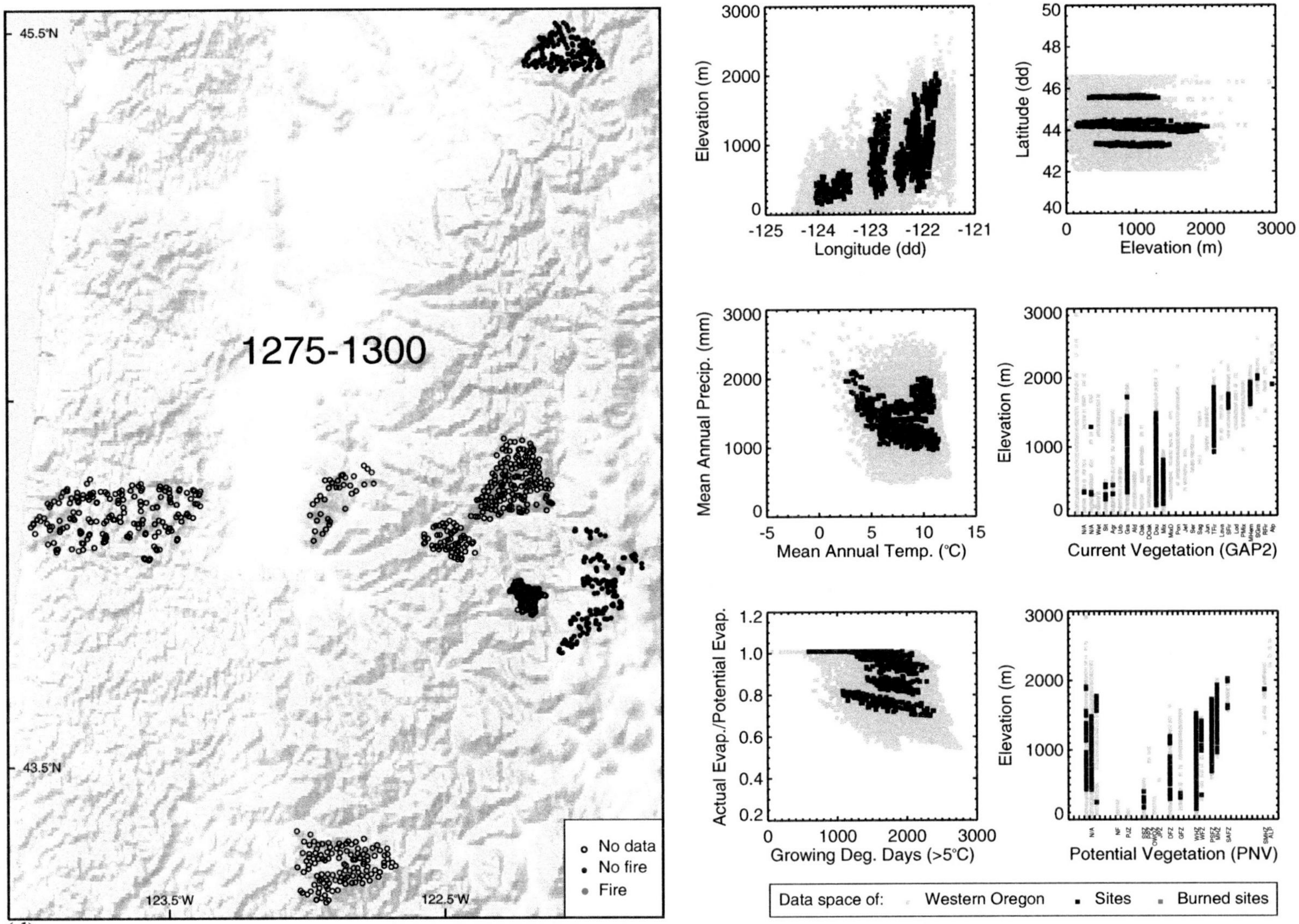

(b)

FIGURE 10. (Continued).



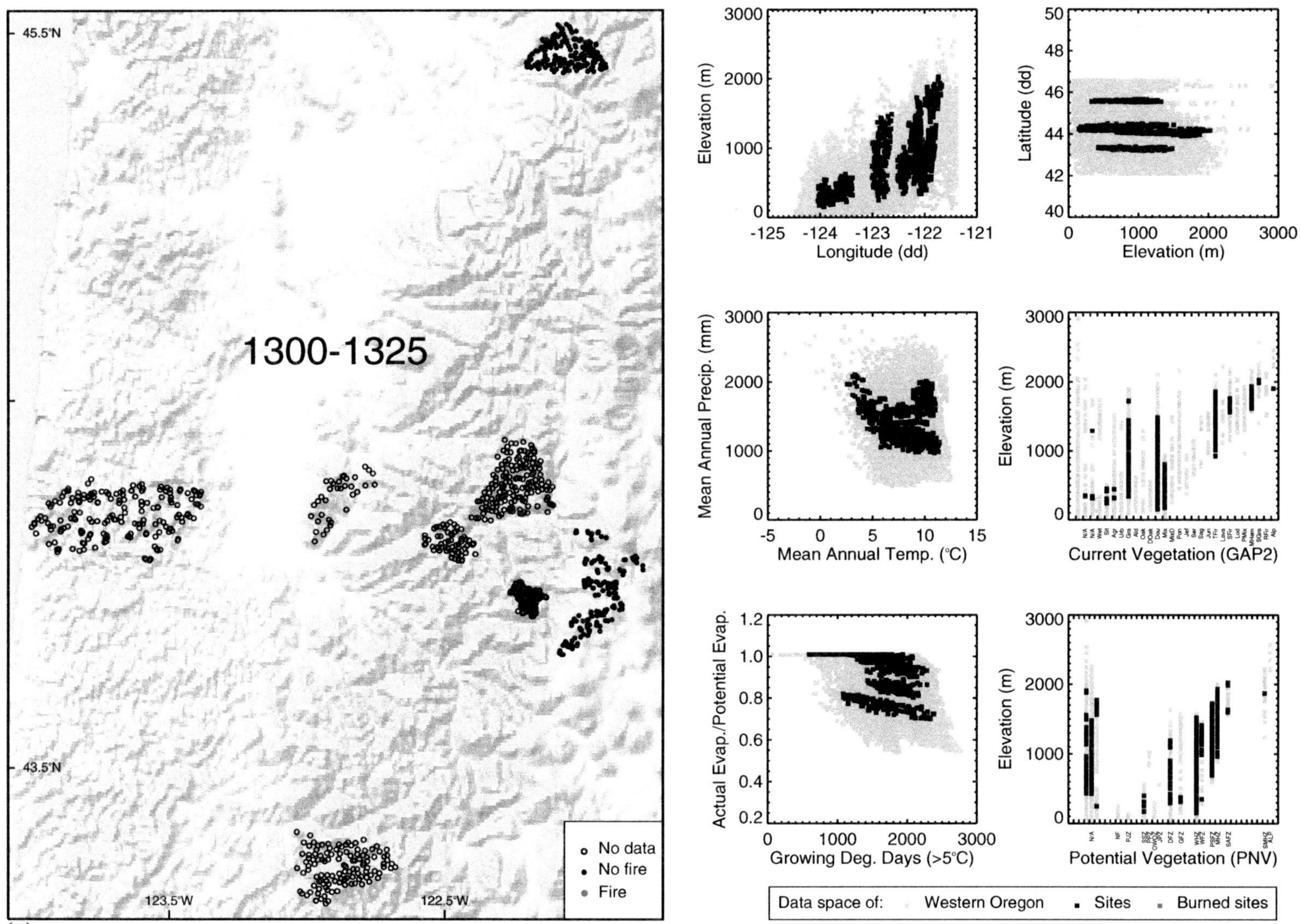

(c)

FIGURE 10. (Continued).



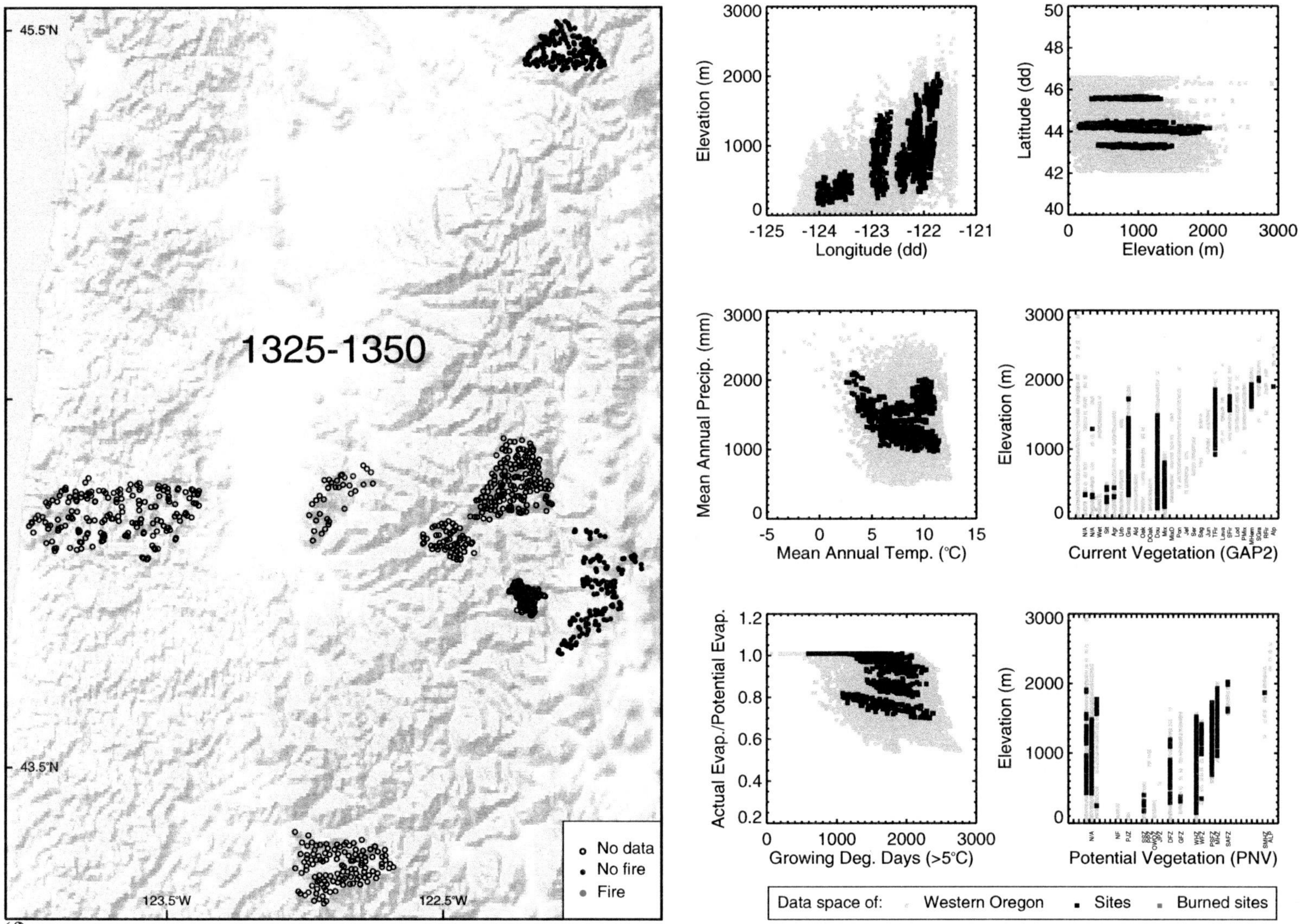

(d)

FIGURE 10. (Continued).



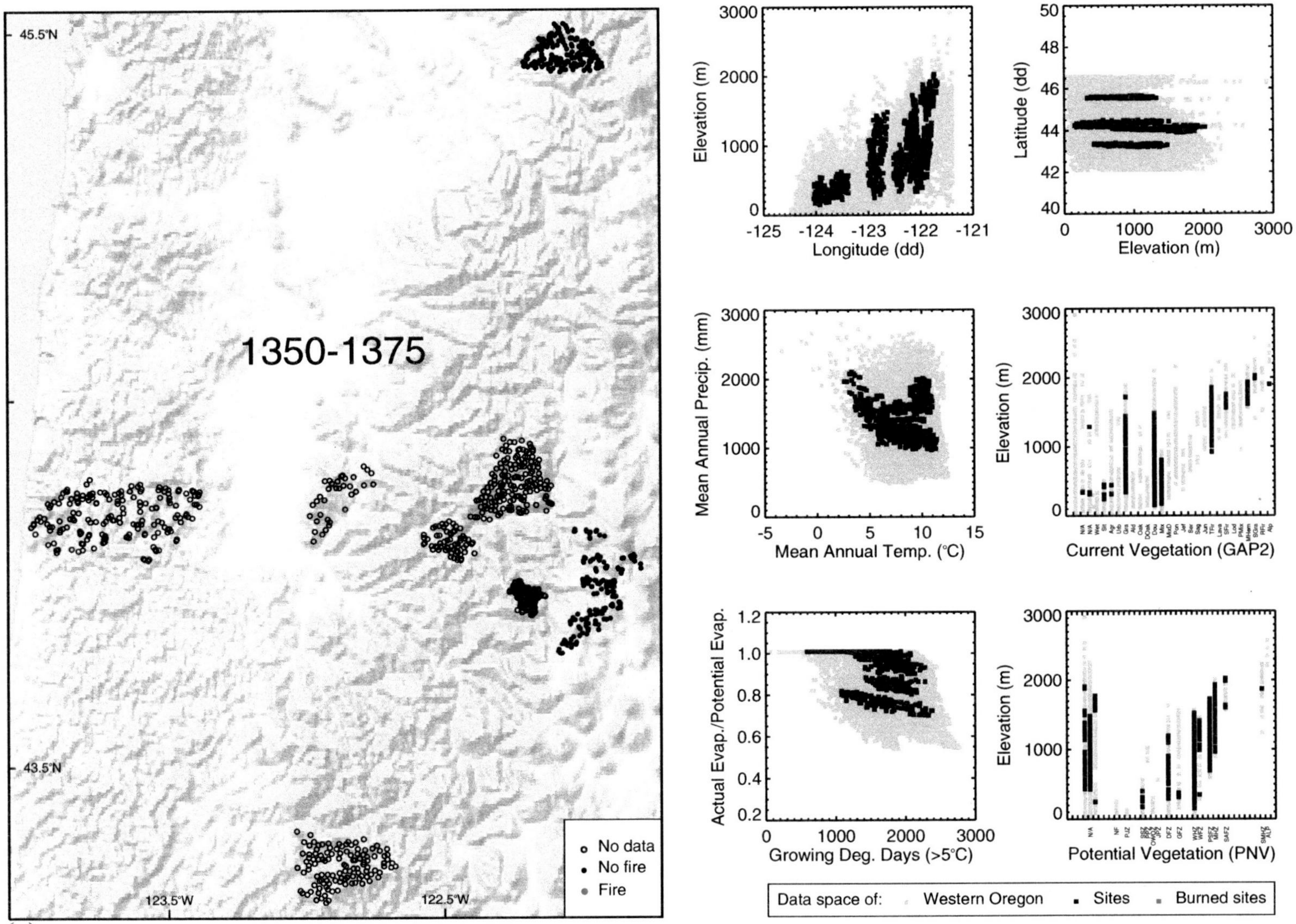

(e)

FIGURE 10. (Continued).



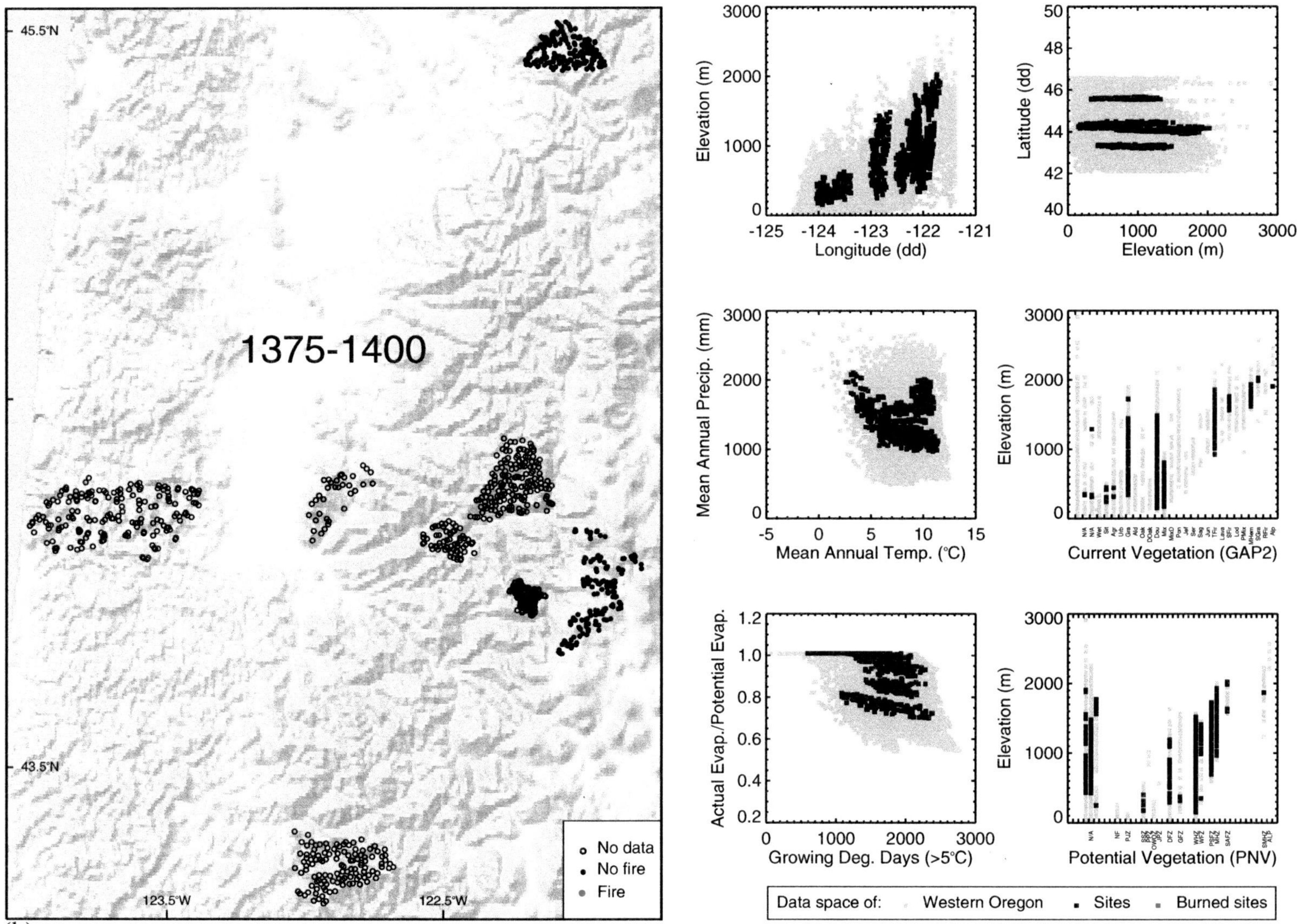

(f)

FIGURE 10. (Continued).



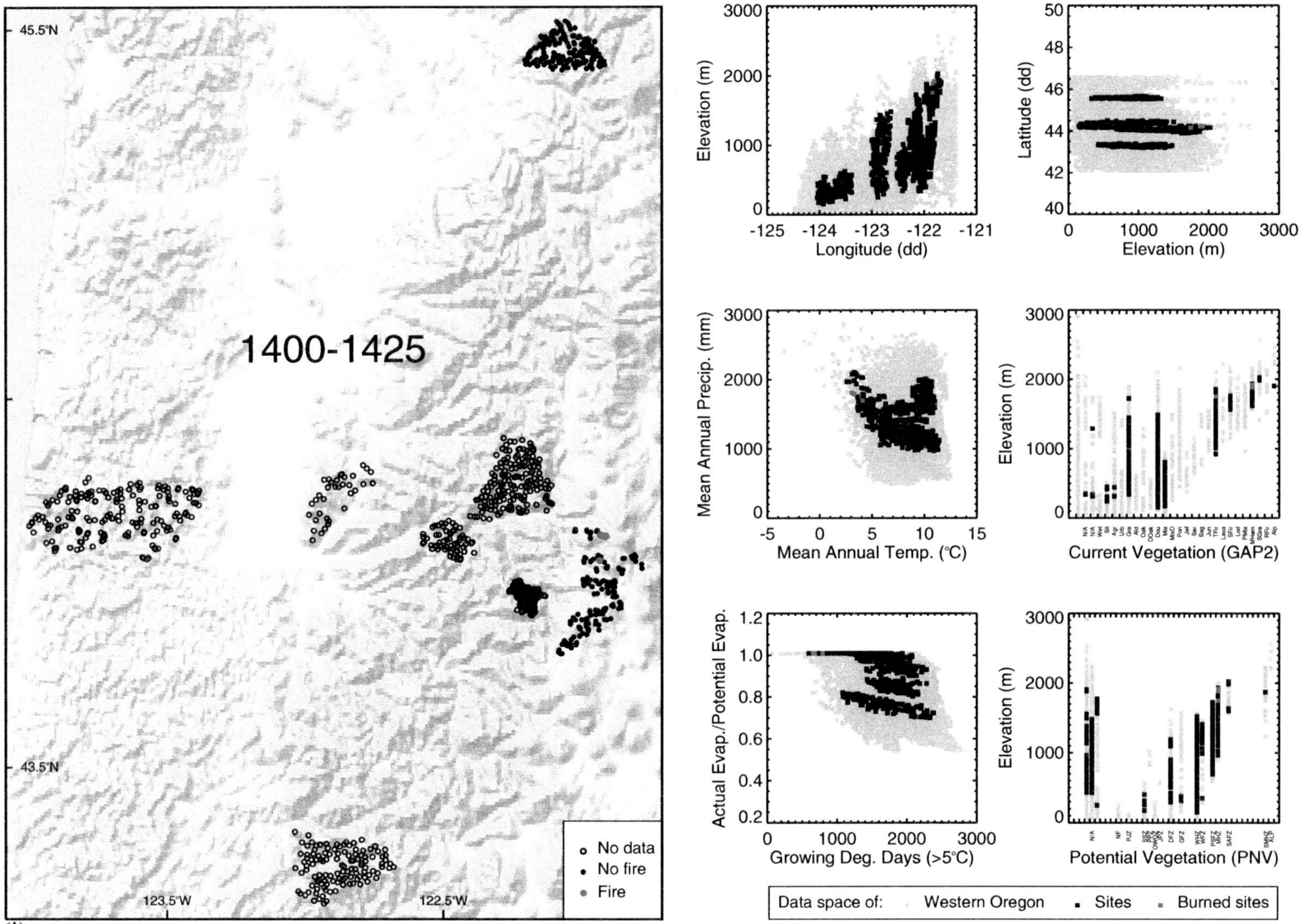

(g)

FIGURE 10. (Continued).



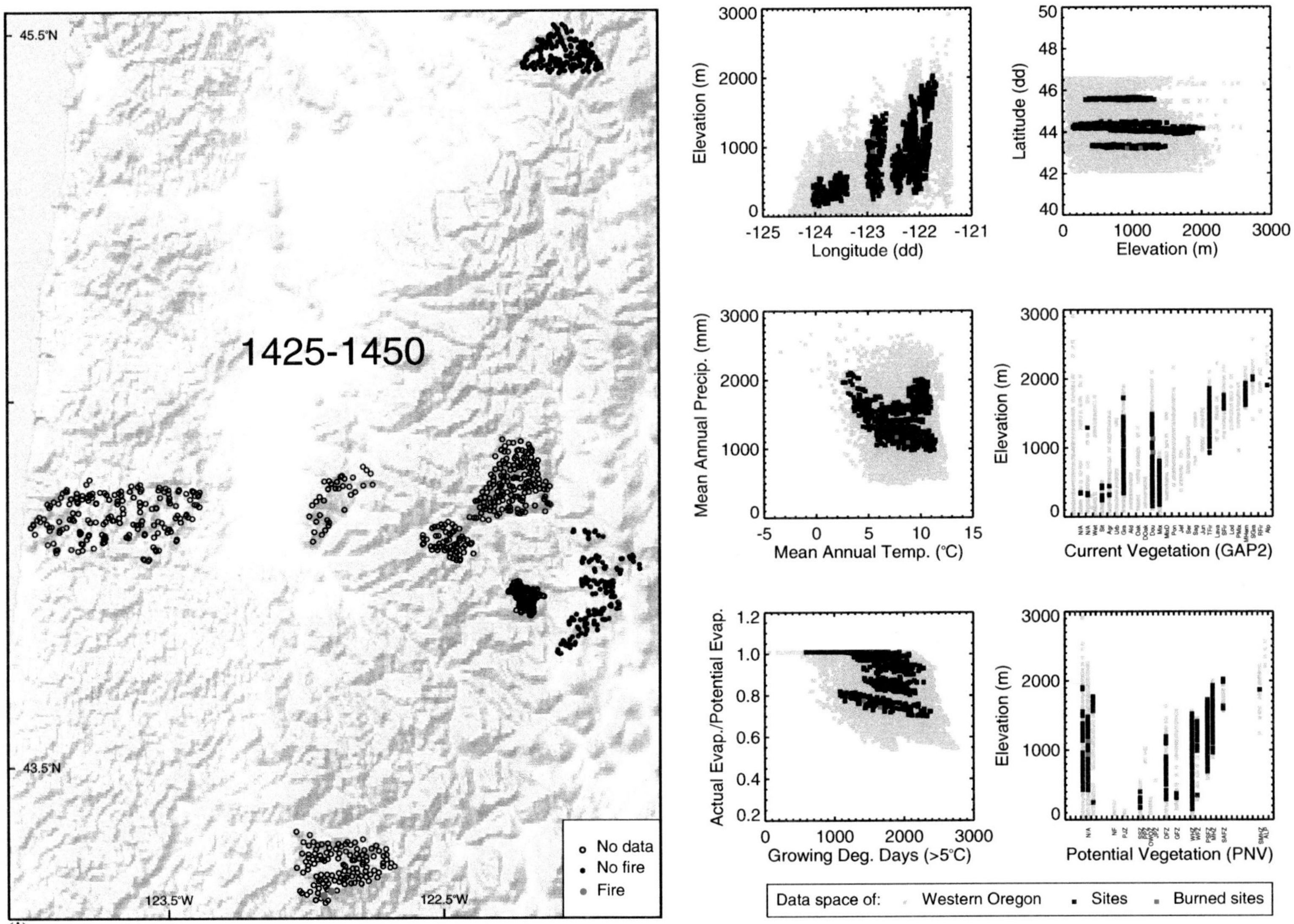

(h)

FIGURE 10. (Continued).



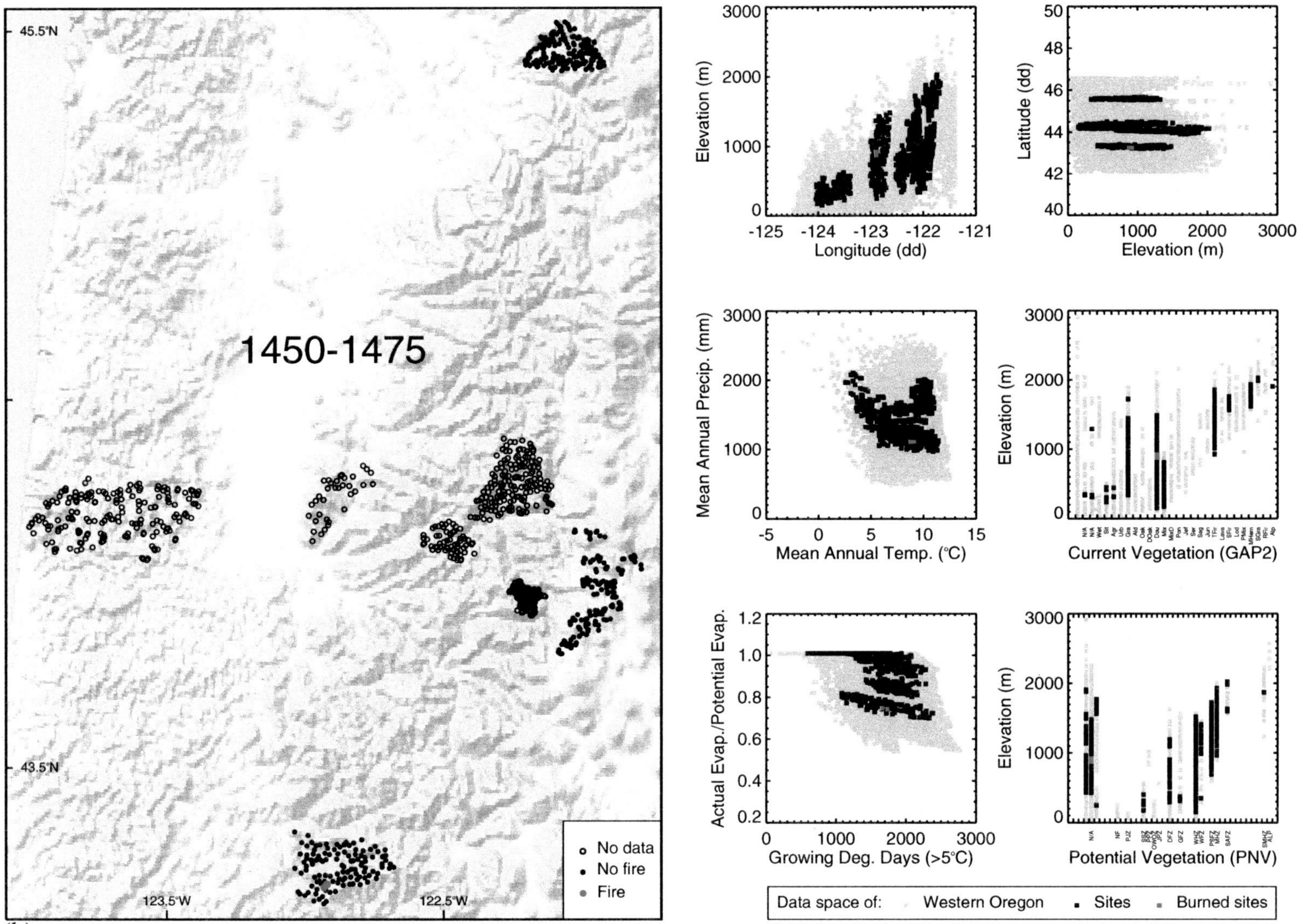

(i)

FIGURE 10. (Continued).



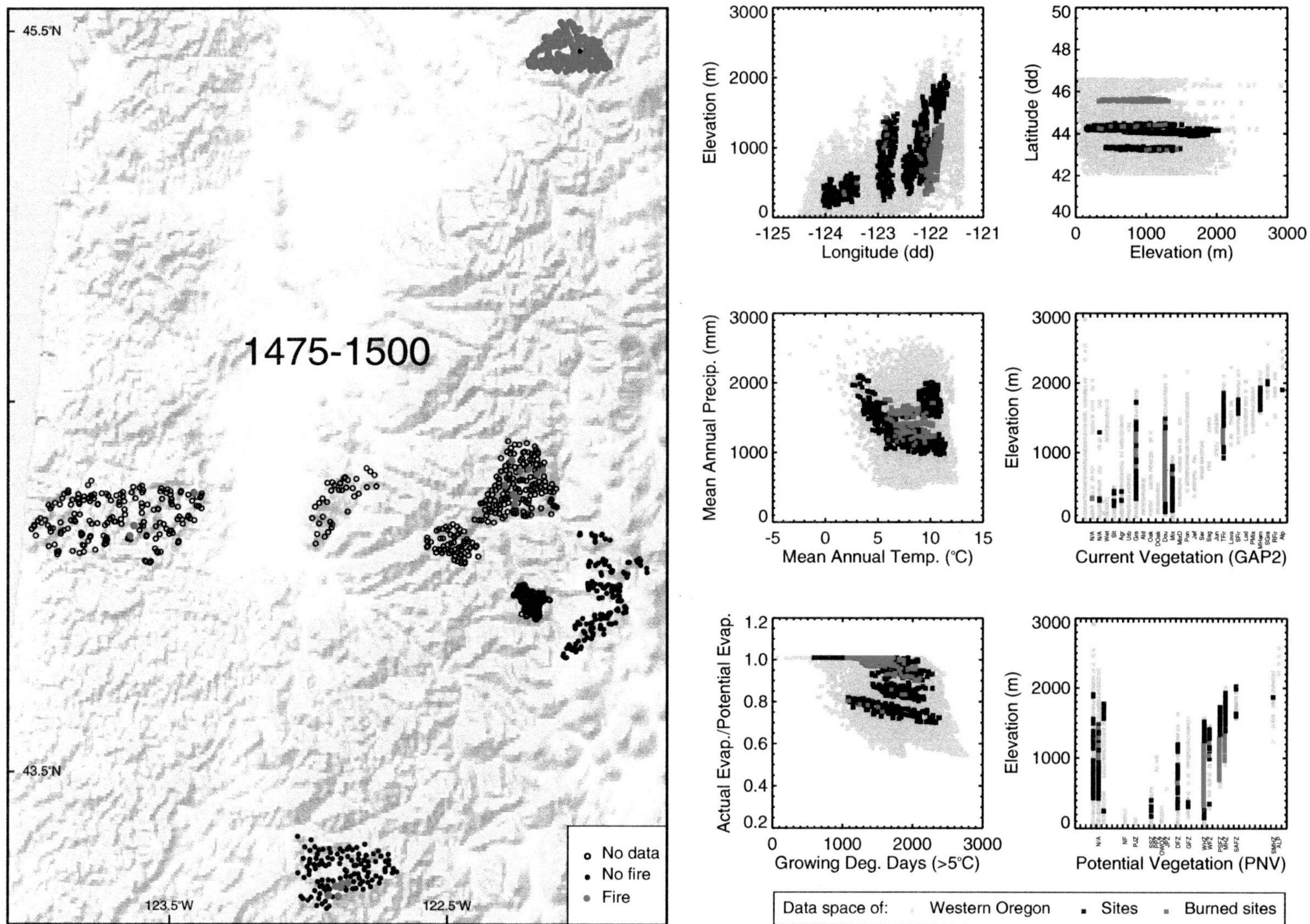

(j)

FIGURE 10. (Continued).



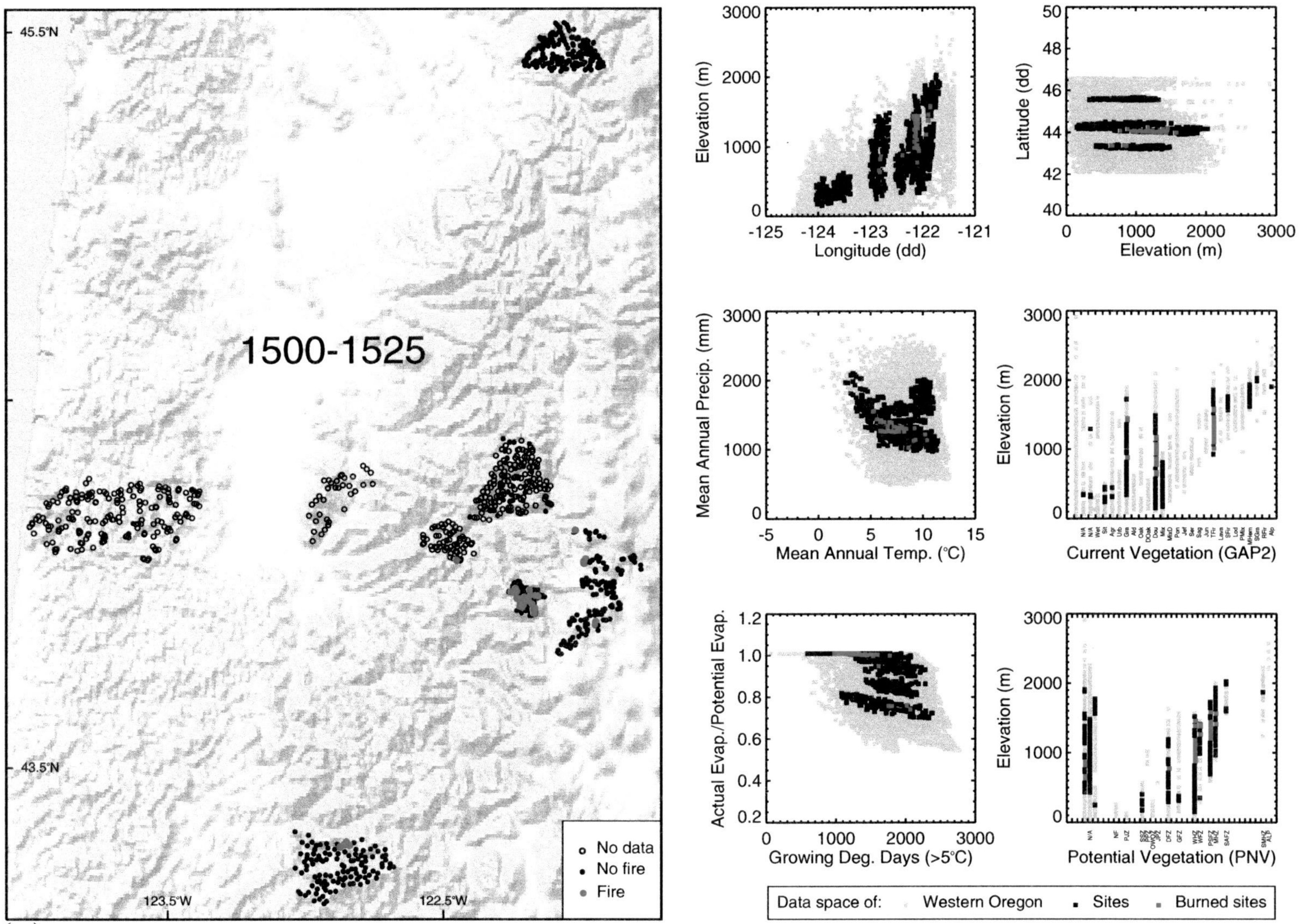

(k)

FIGURE 10. (Continued).



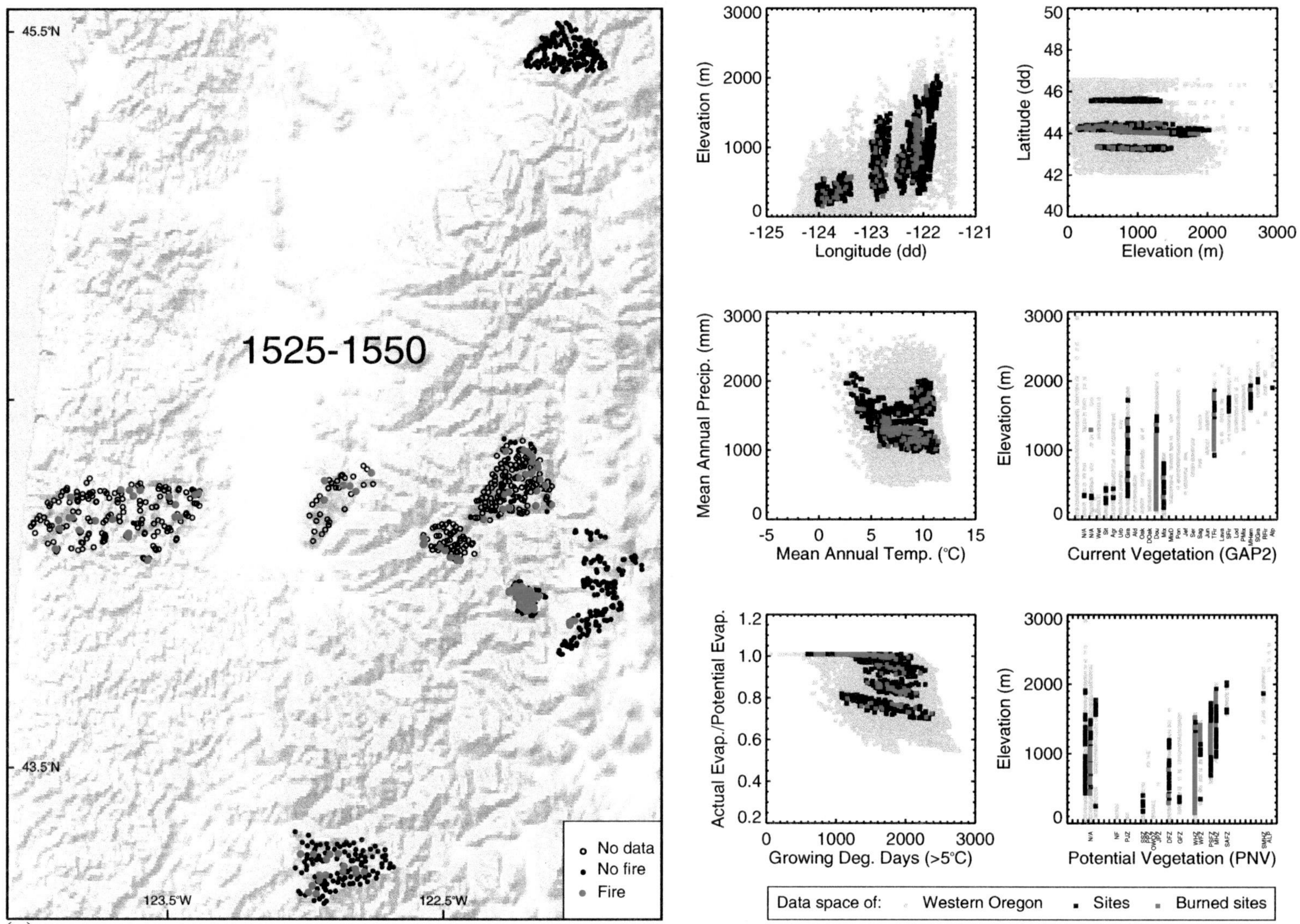

(l)

FIGURE 10. (Continued).



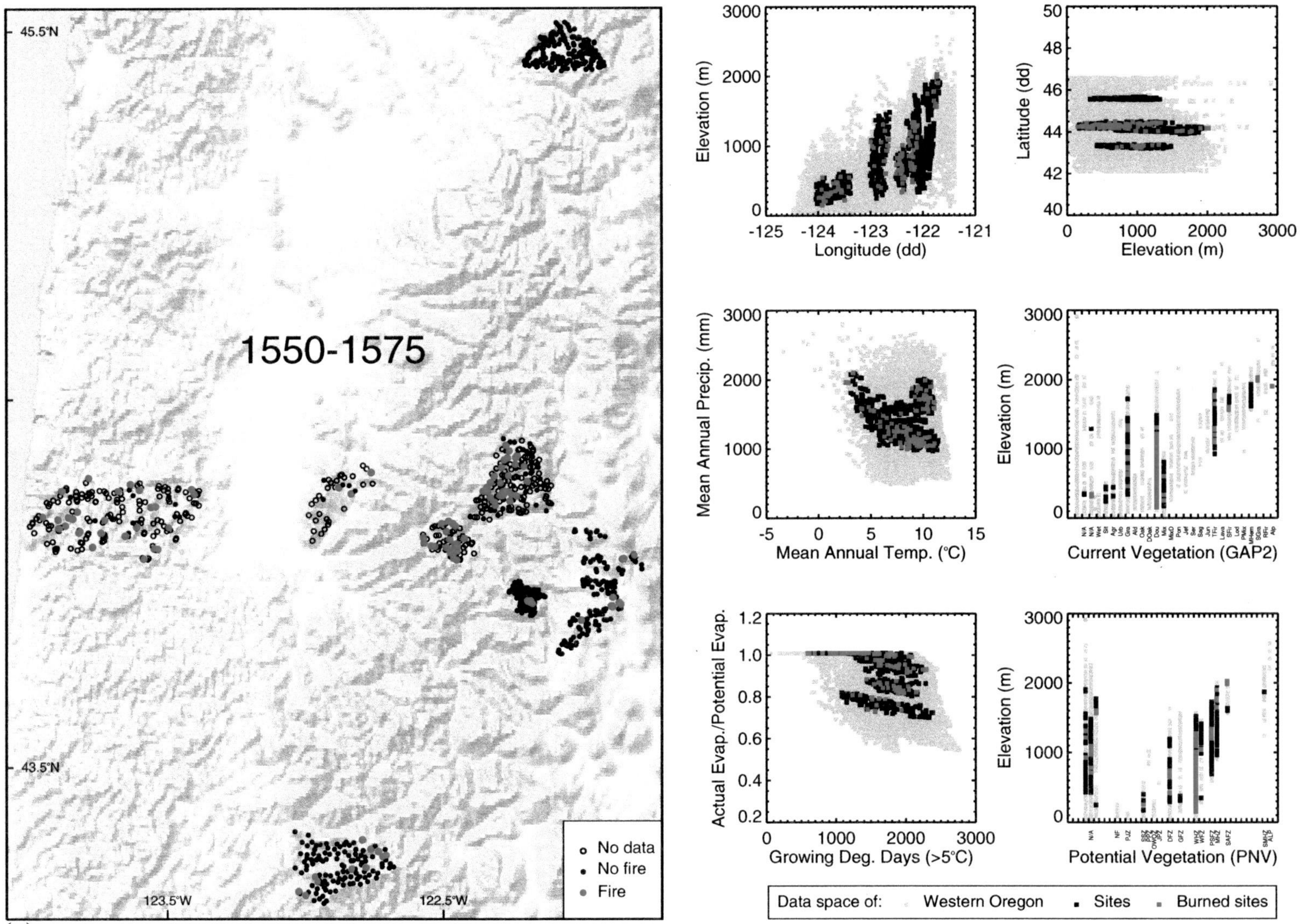

(m)

FIGURE 10. (Continued).



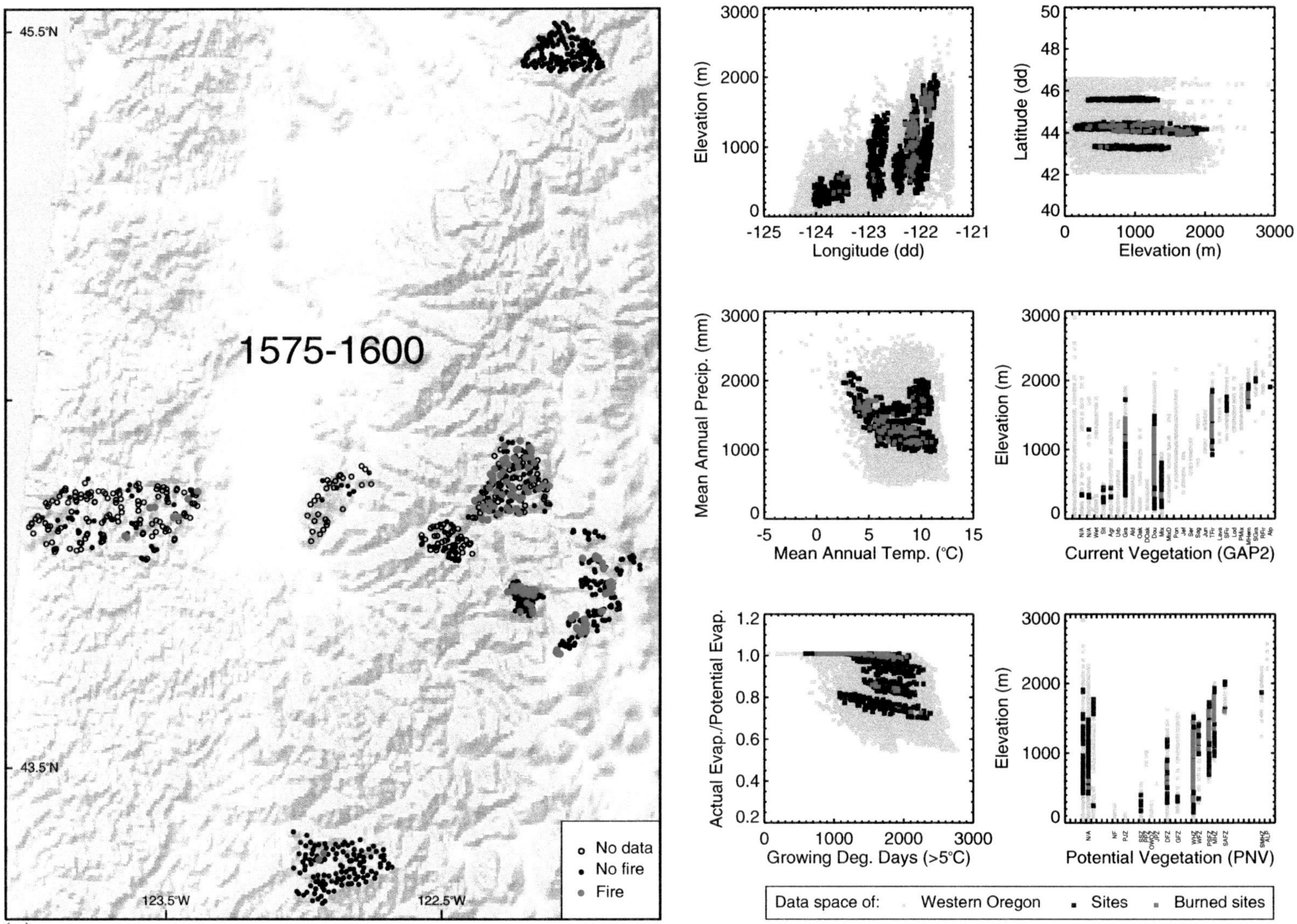

(n)

FIGURE 10. (Continued).



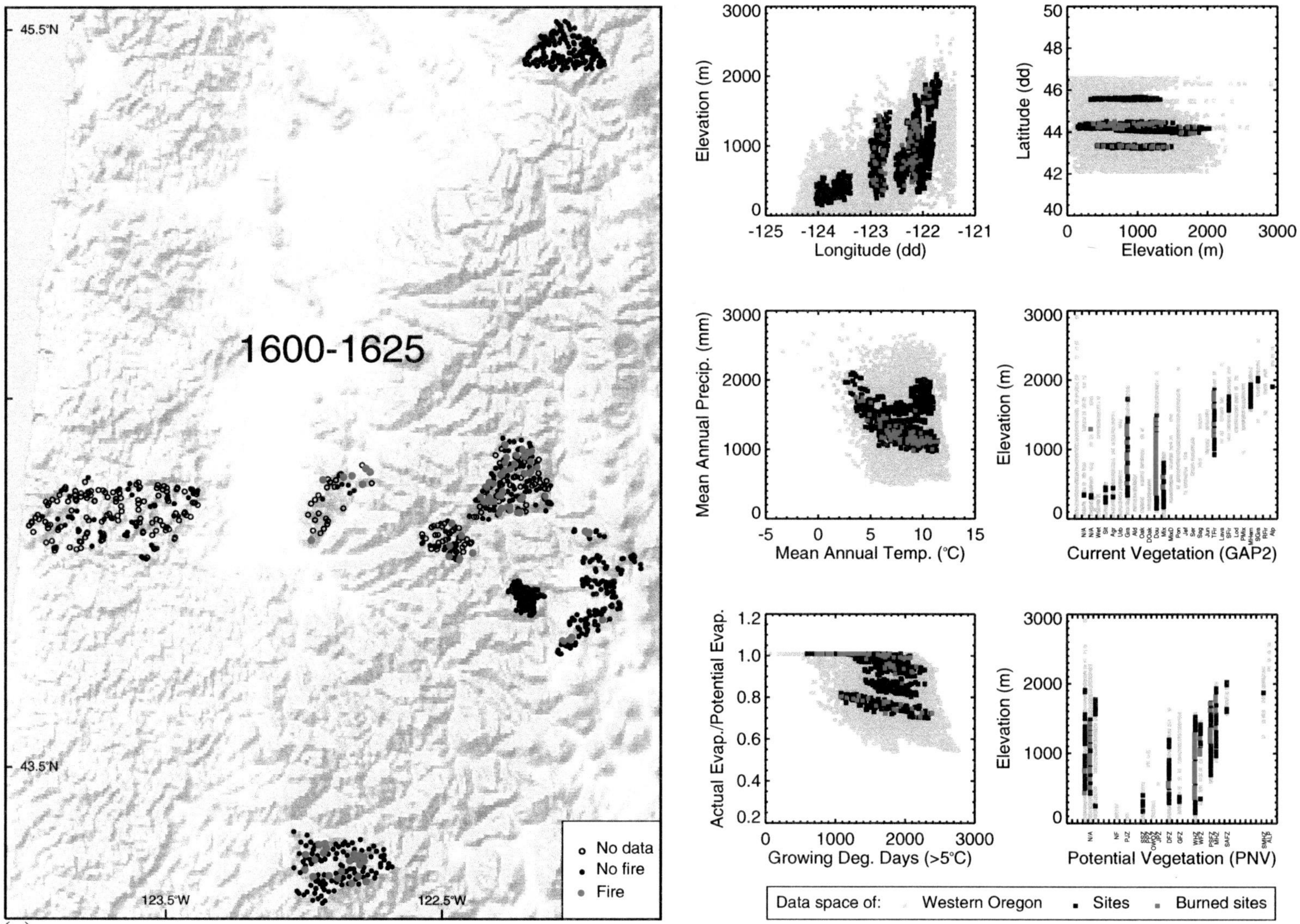

(o)

FIGURE 10. (Continued).



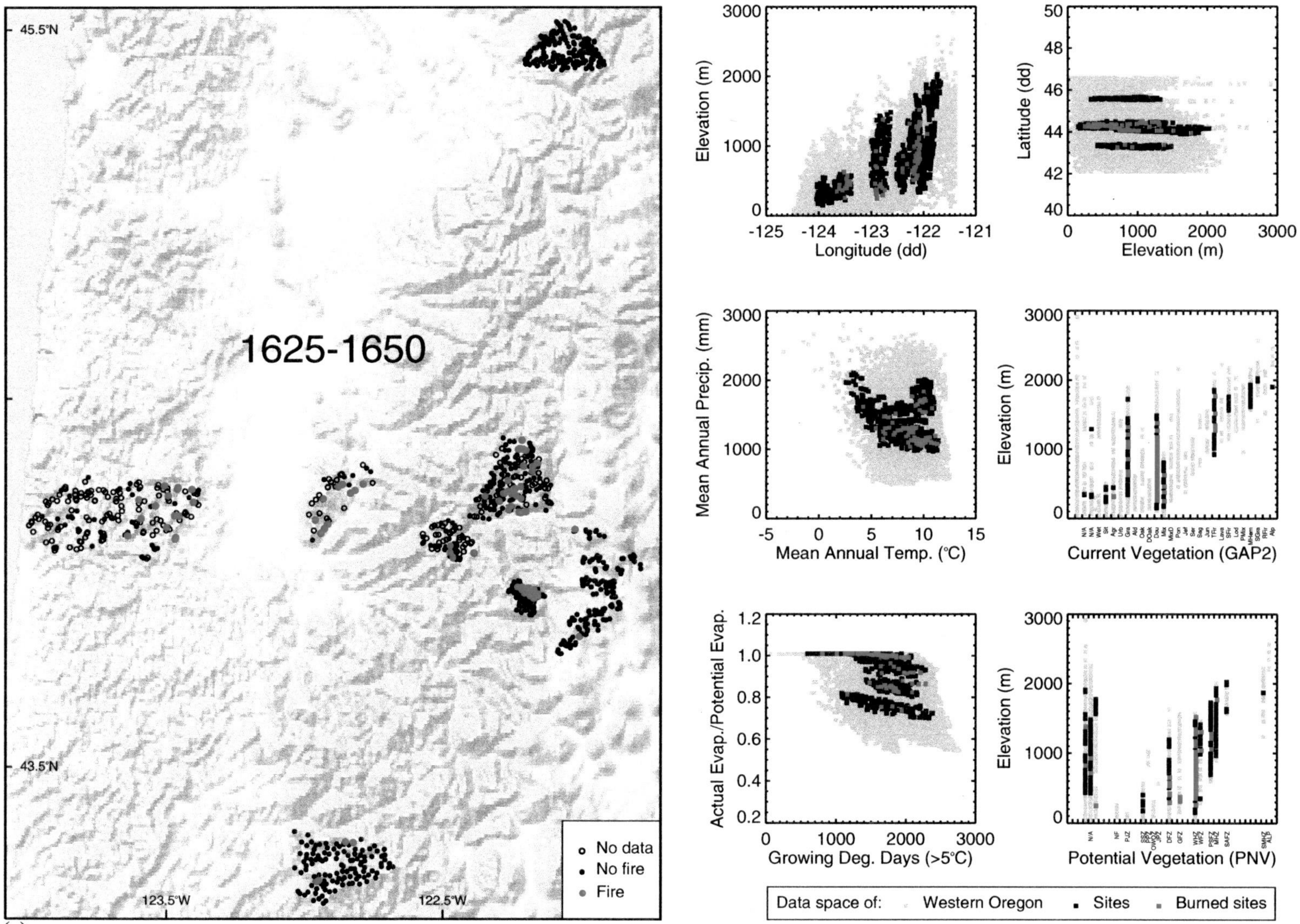

(p)

FIGURE 10. (Continued).



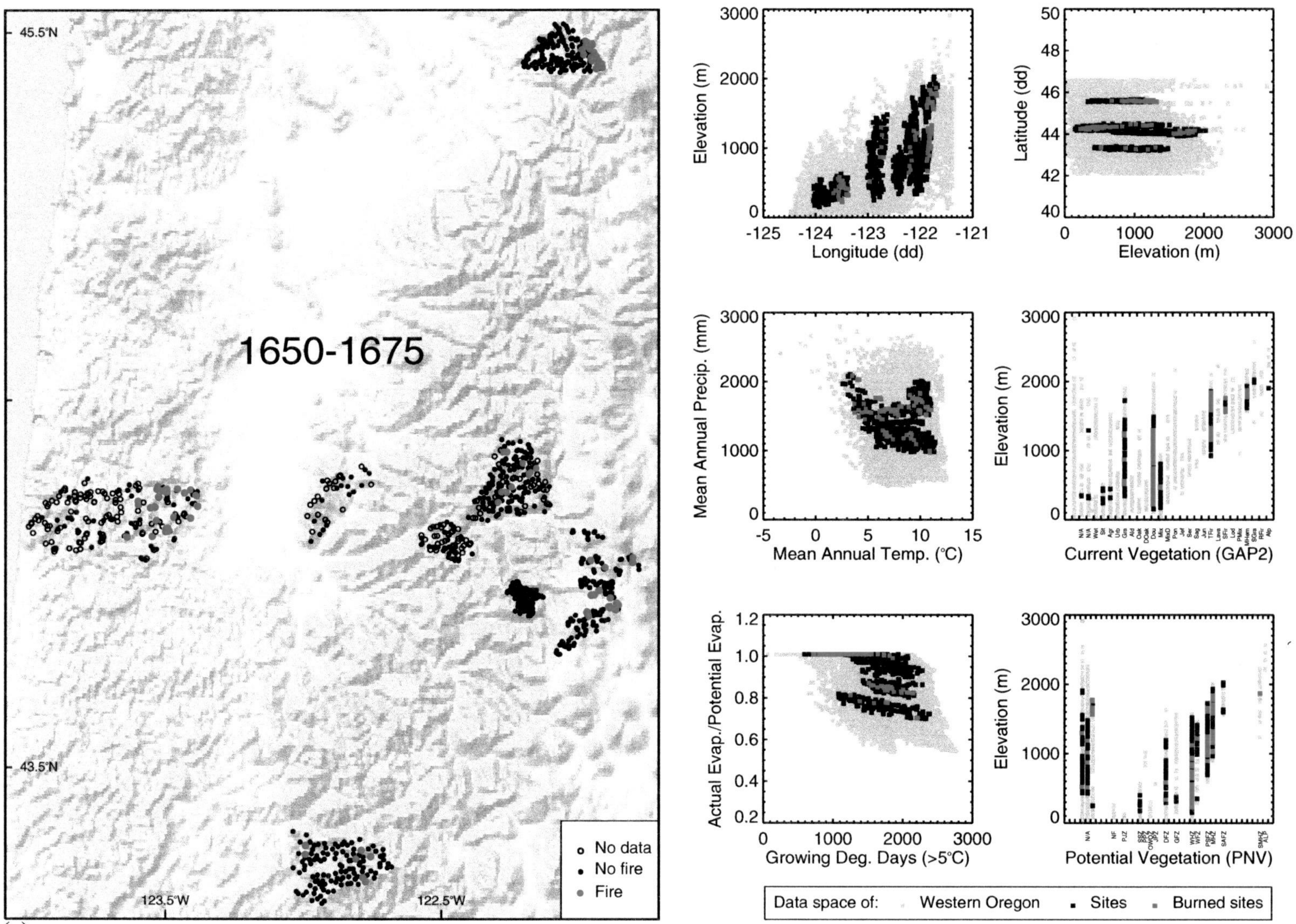

(q)

FIGURE 10. (Continued).



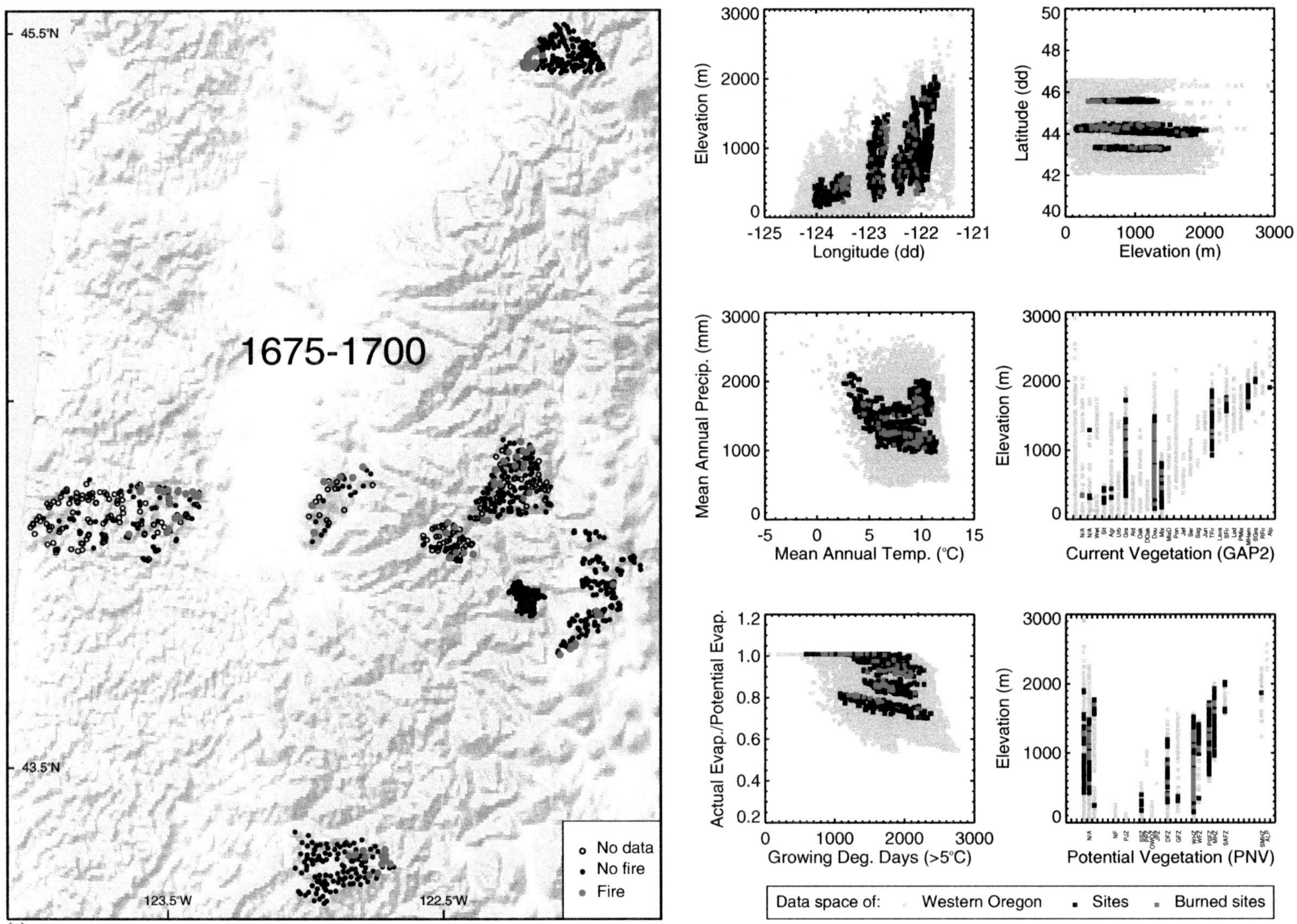

(r)

FIGURE 10. (Continued).



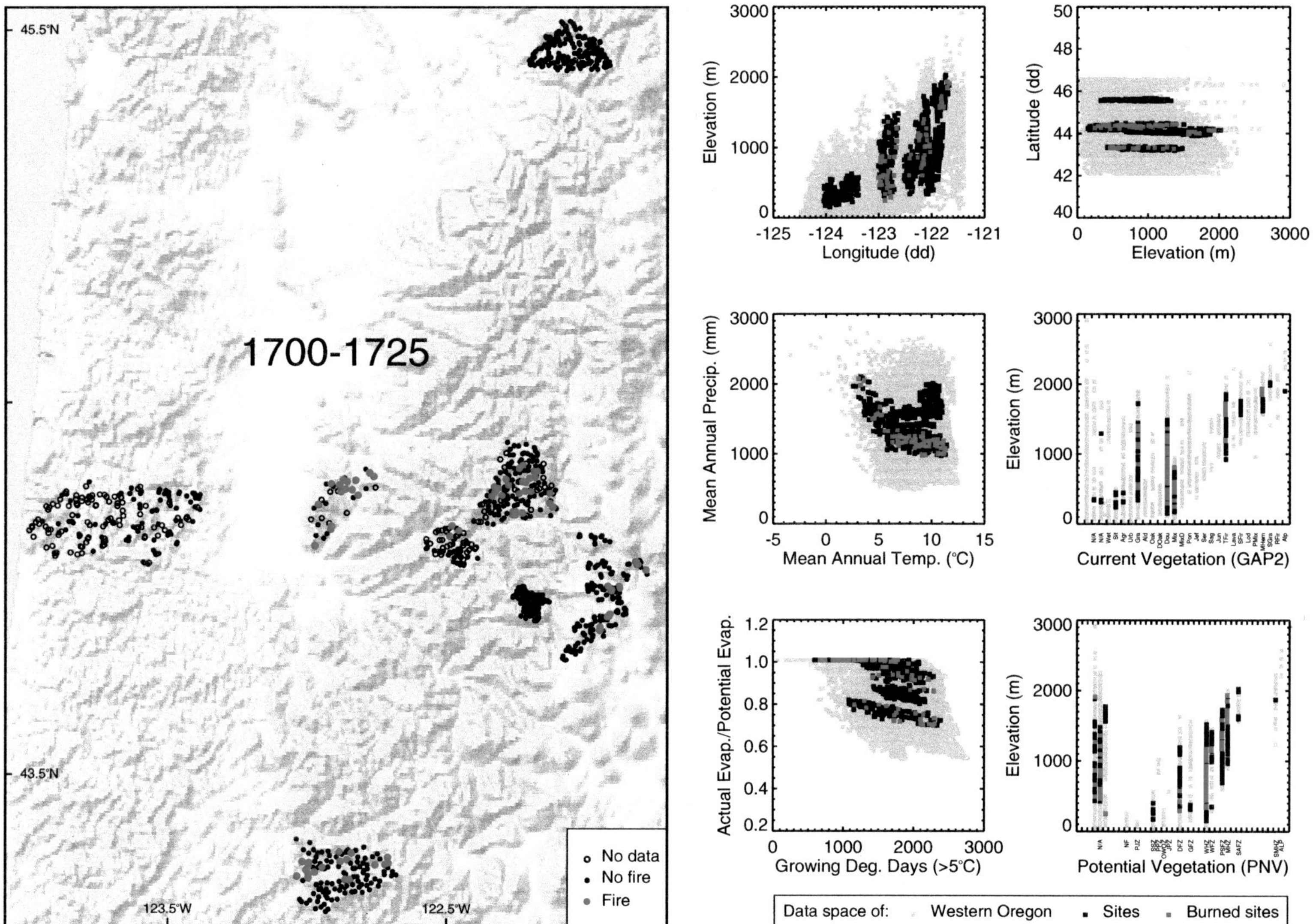

(s)

FIGURE 10. (Continued).



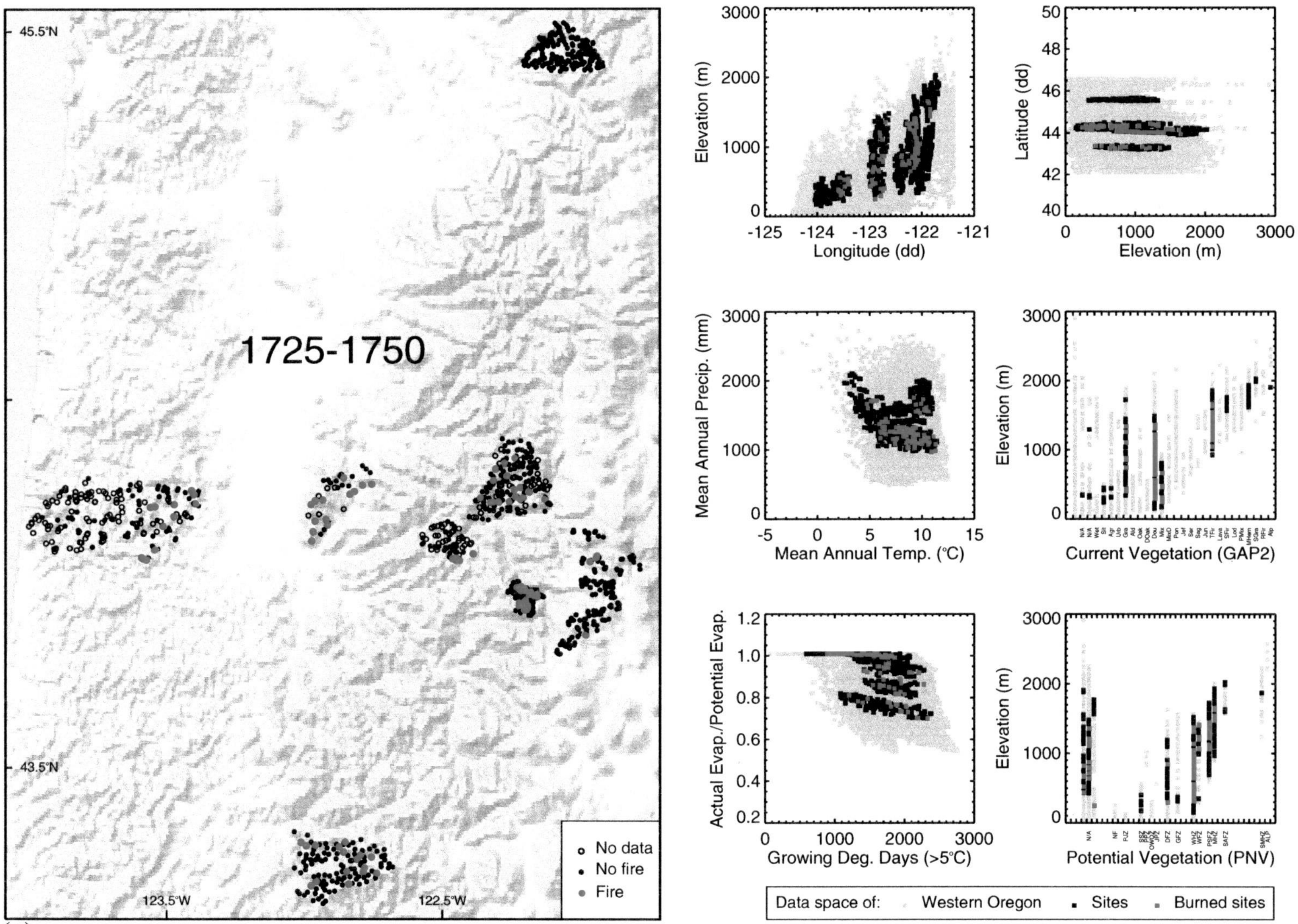

(t)

FIGURE 10. (Continued).



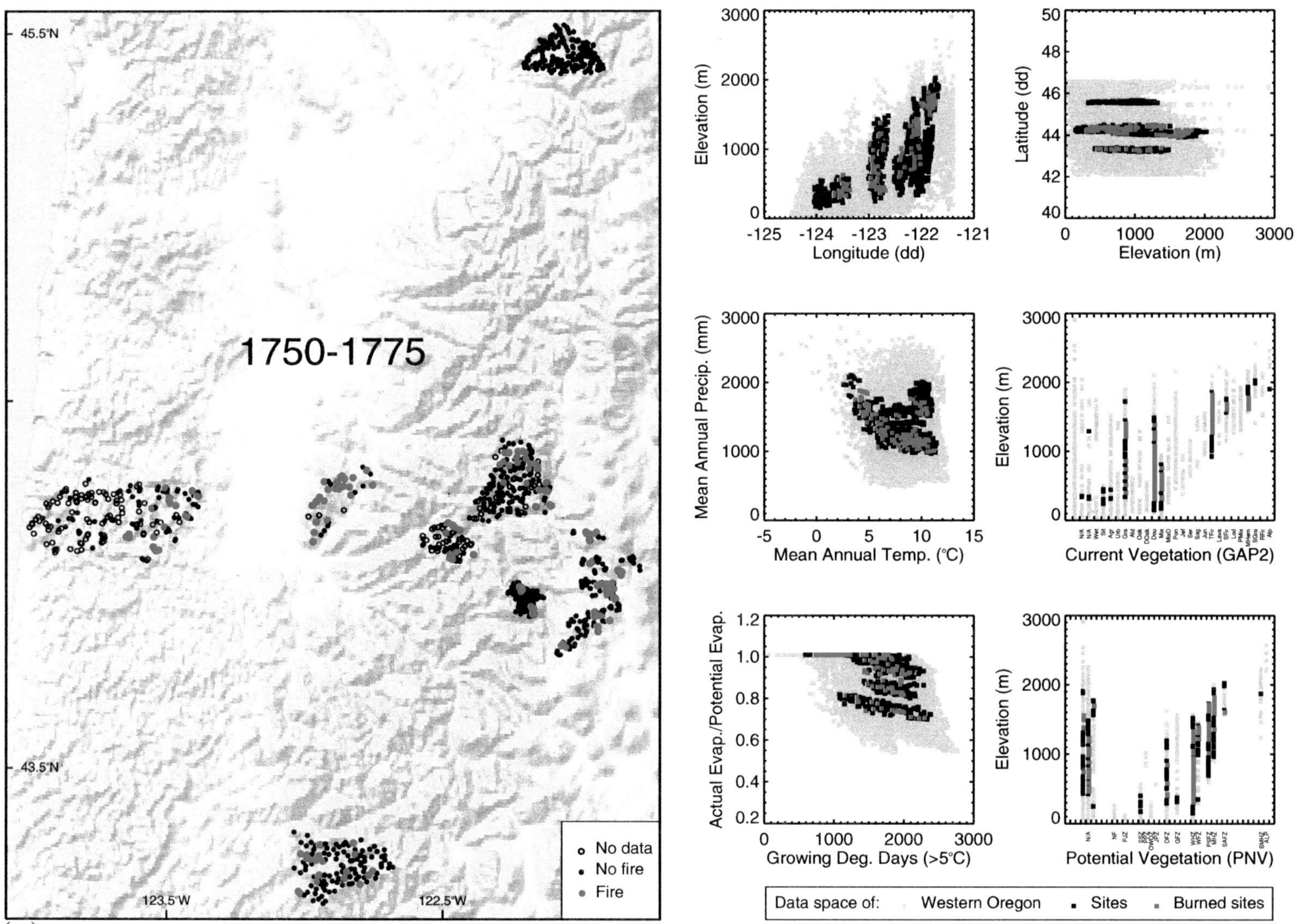

(u)

FIGURE 10. (Continued).



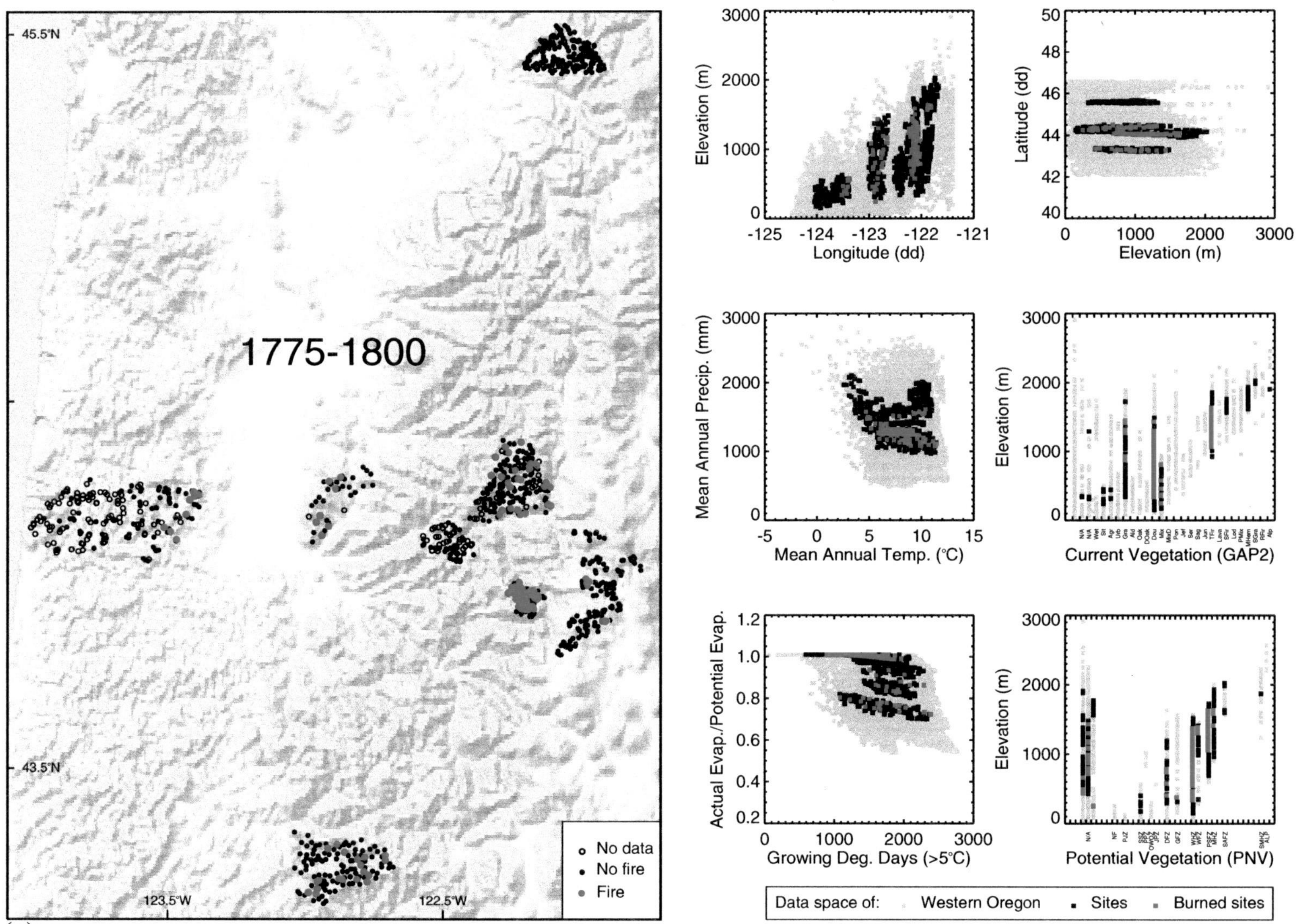

(v)

FIGURE 10. (Continued).



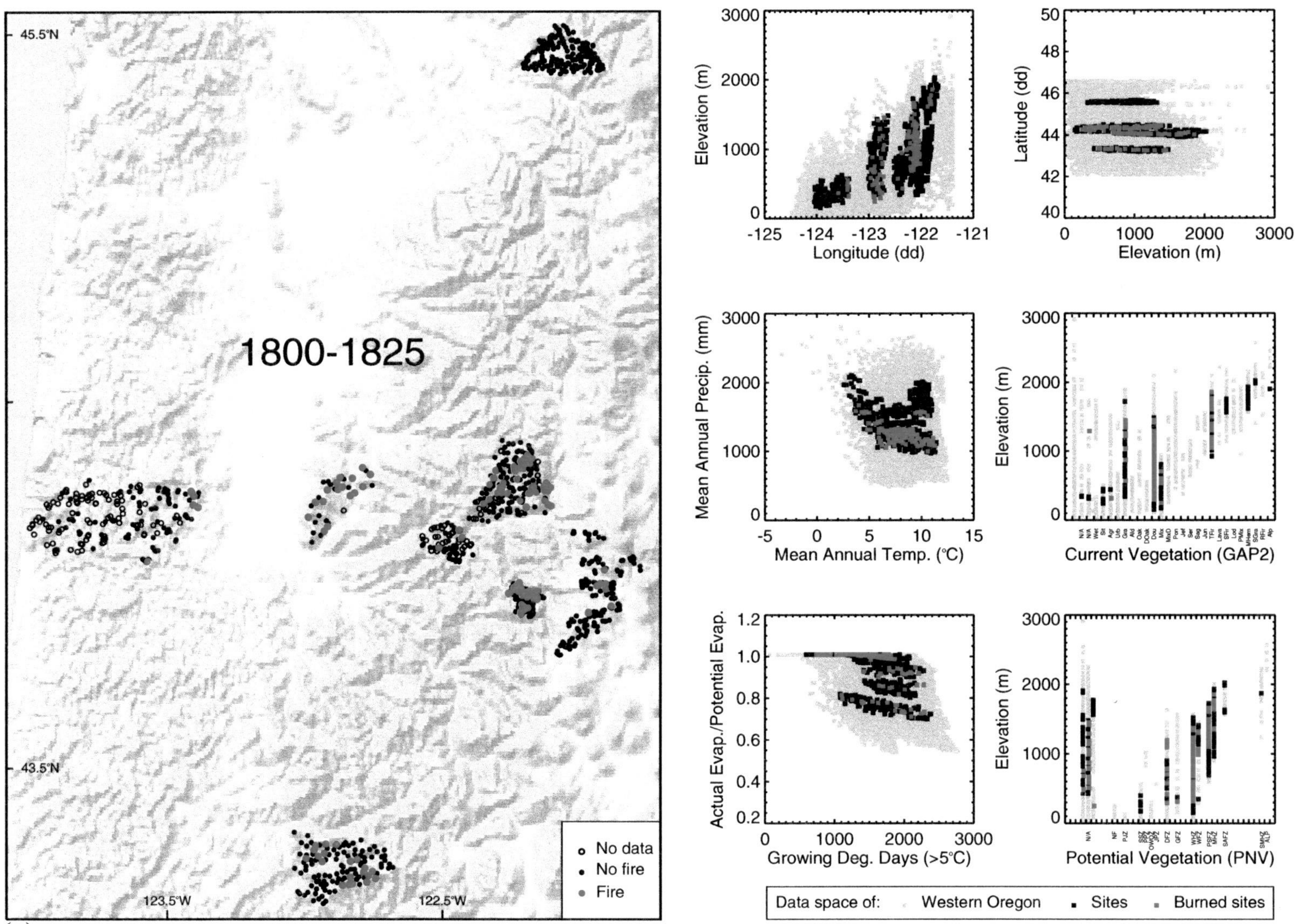

(w)

FIGURE 10. (Continued).



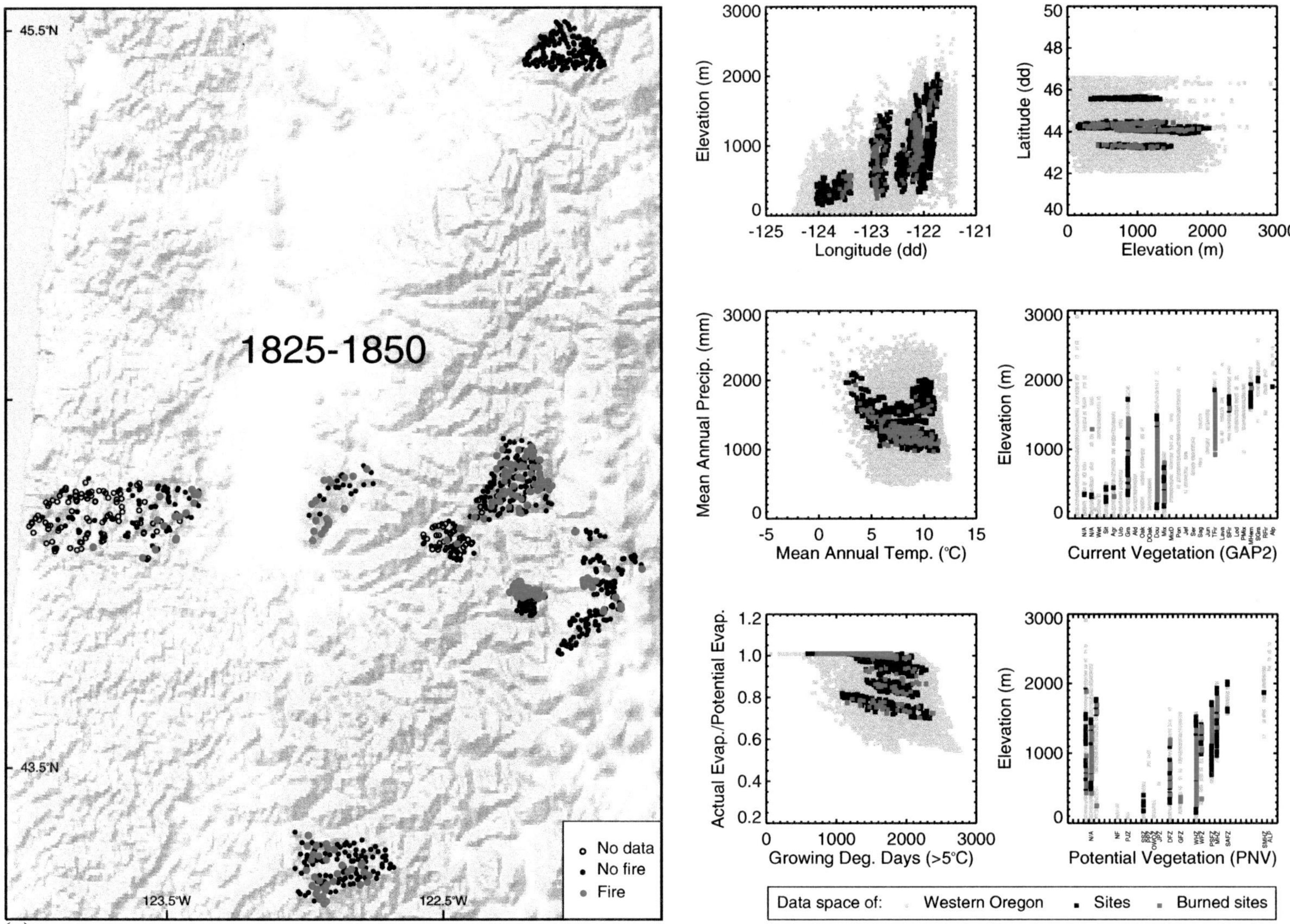

(x)

FIGURE 10. (Continued).



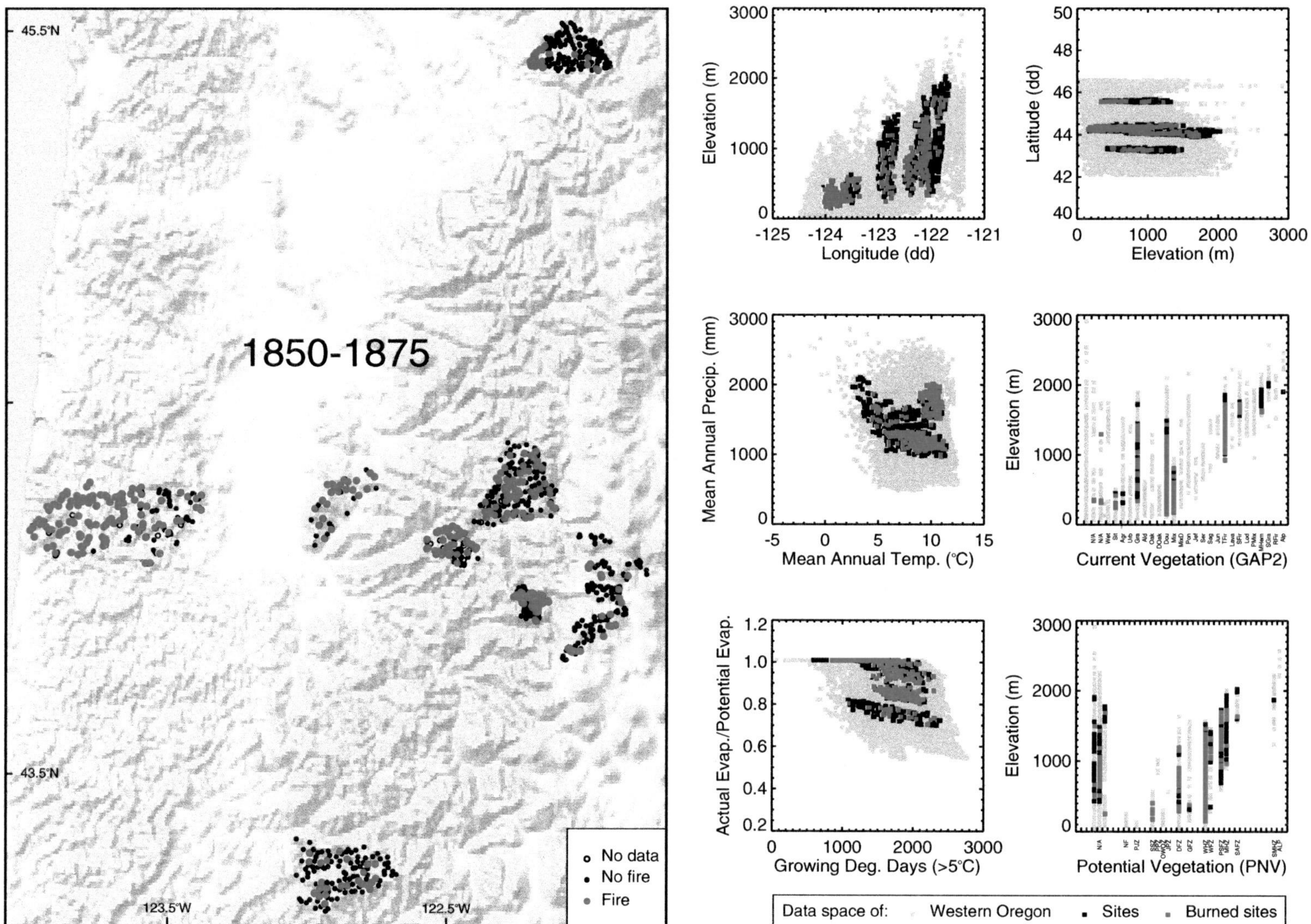

(y)

FIGURE 10. (Continued).



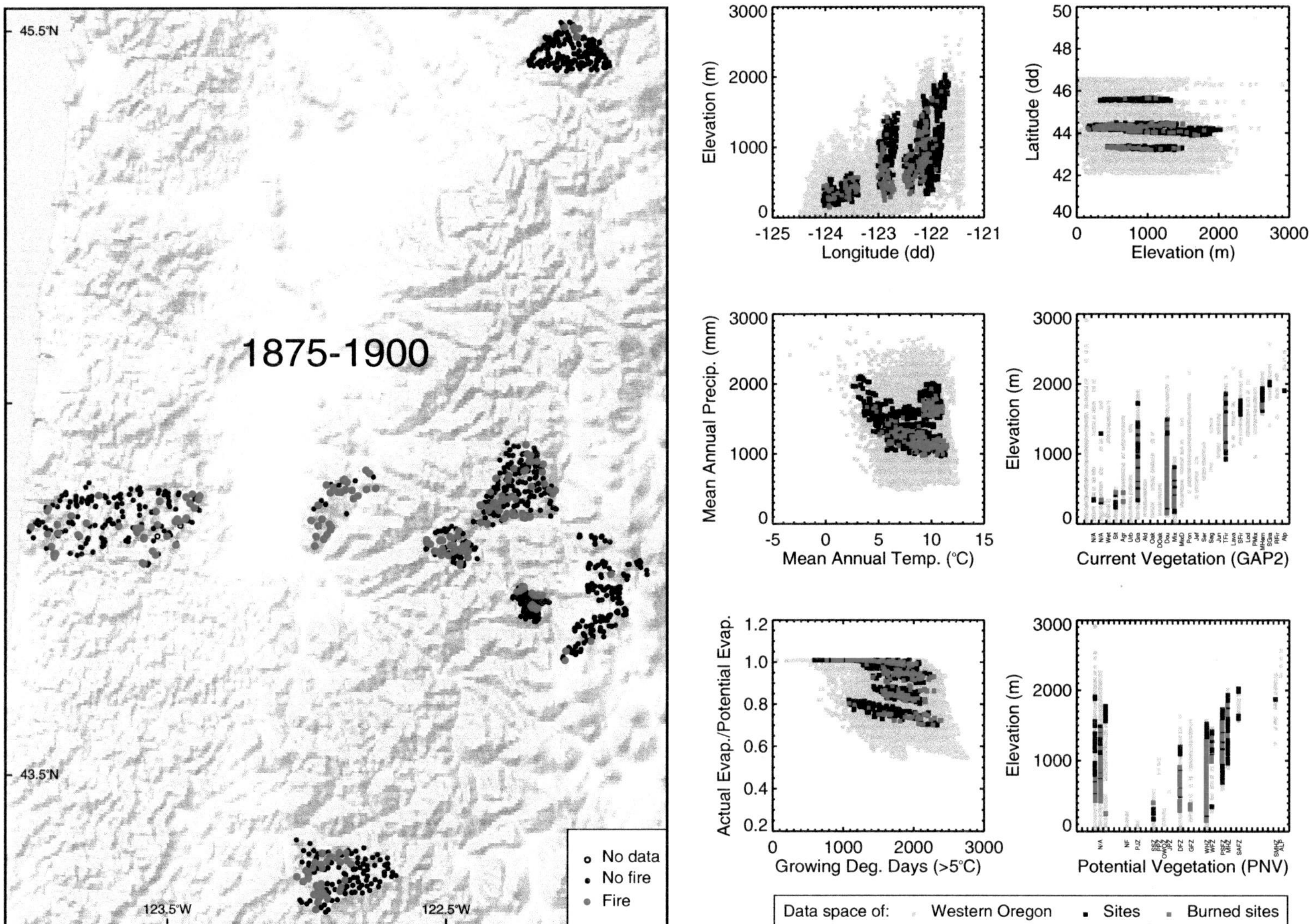

(z)

FIGURE 10. (Continued).



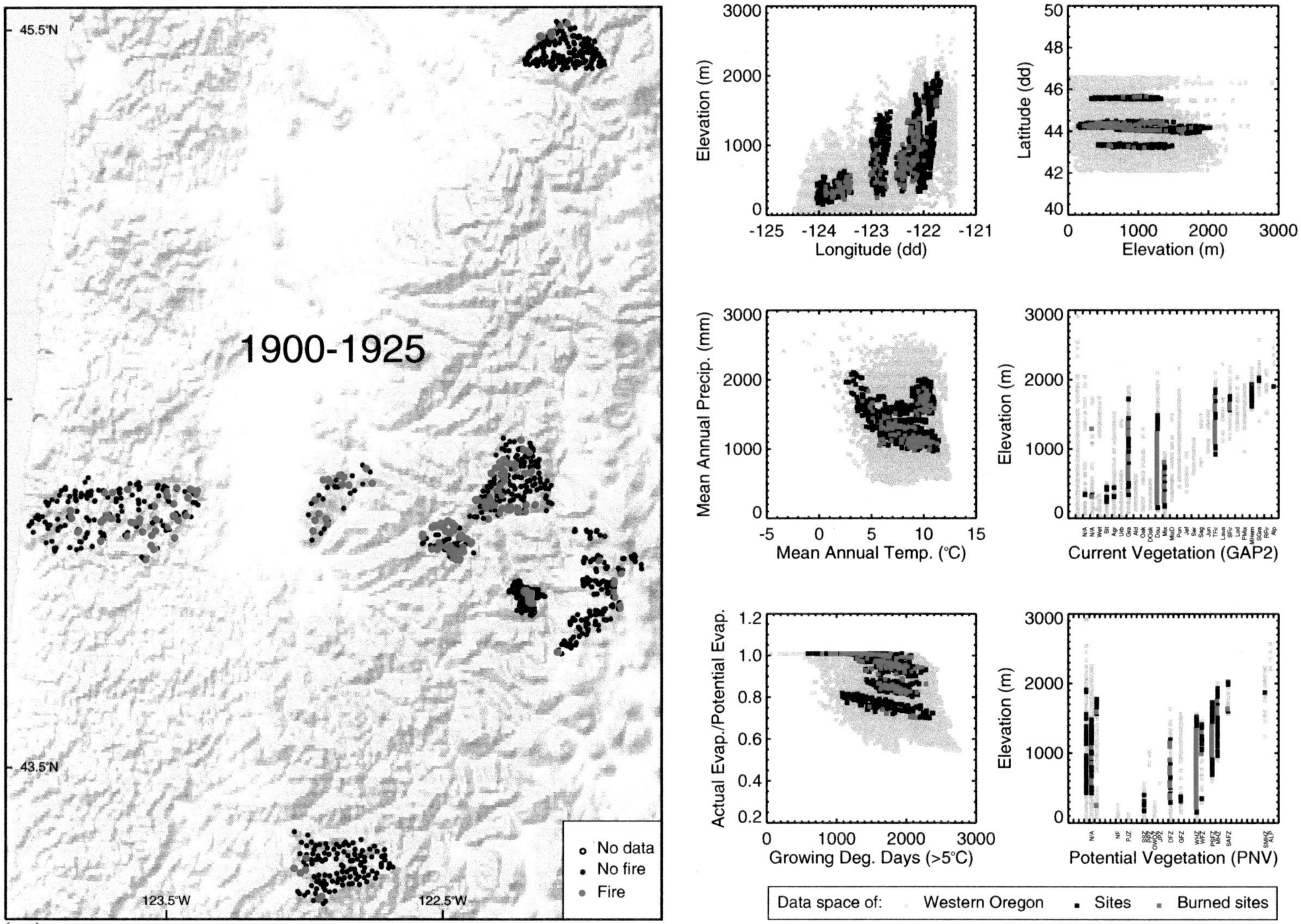

(aa)

FIGURE 10. (Continued).



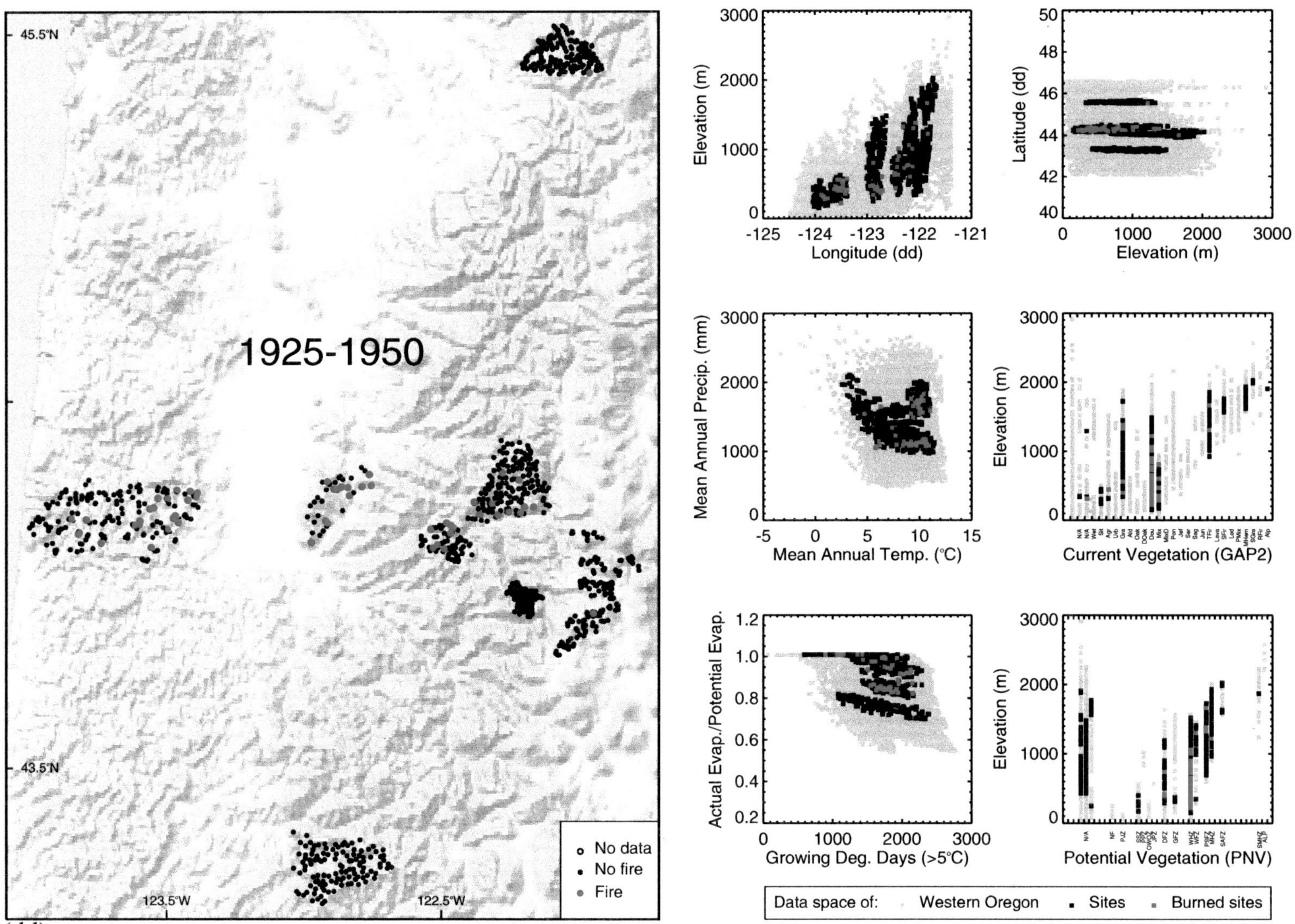

(bb)

FIGURE 10. (Continued).



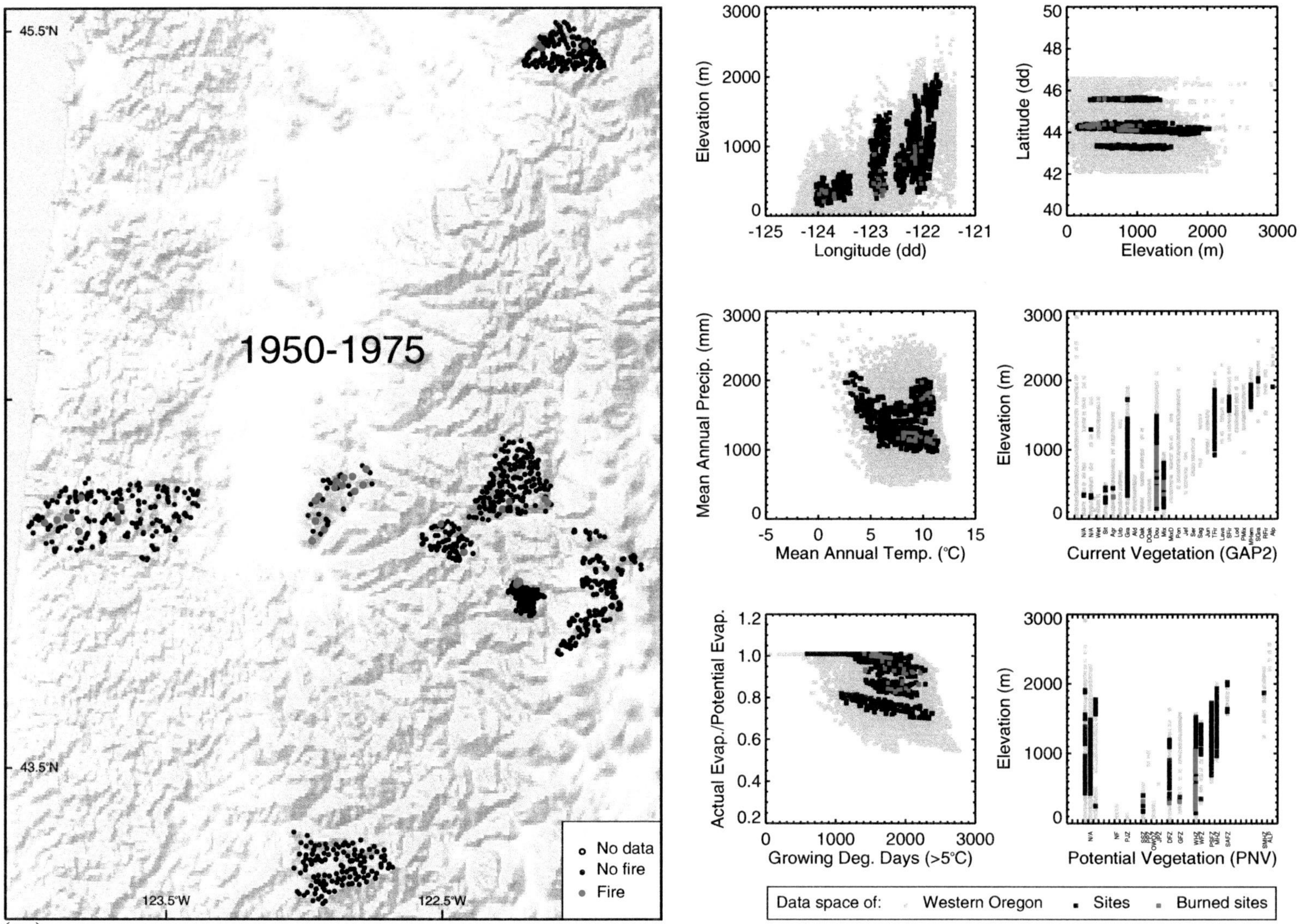

(cc)

FIGURE 10. (Continued).



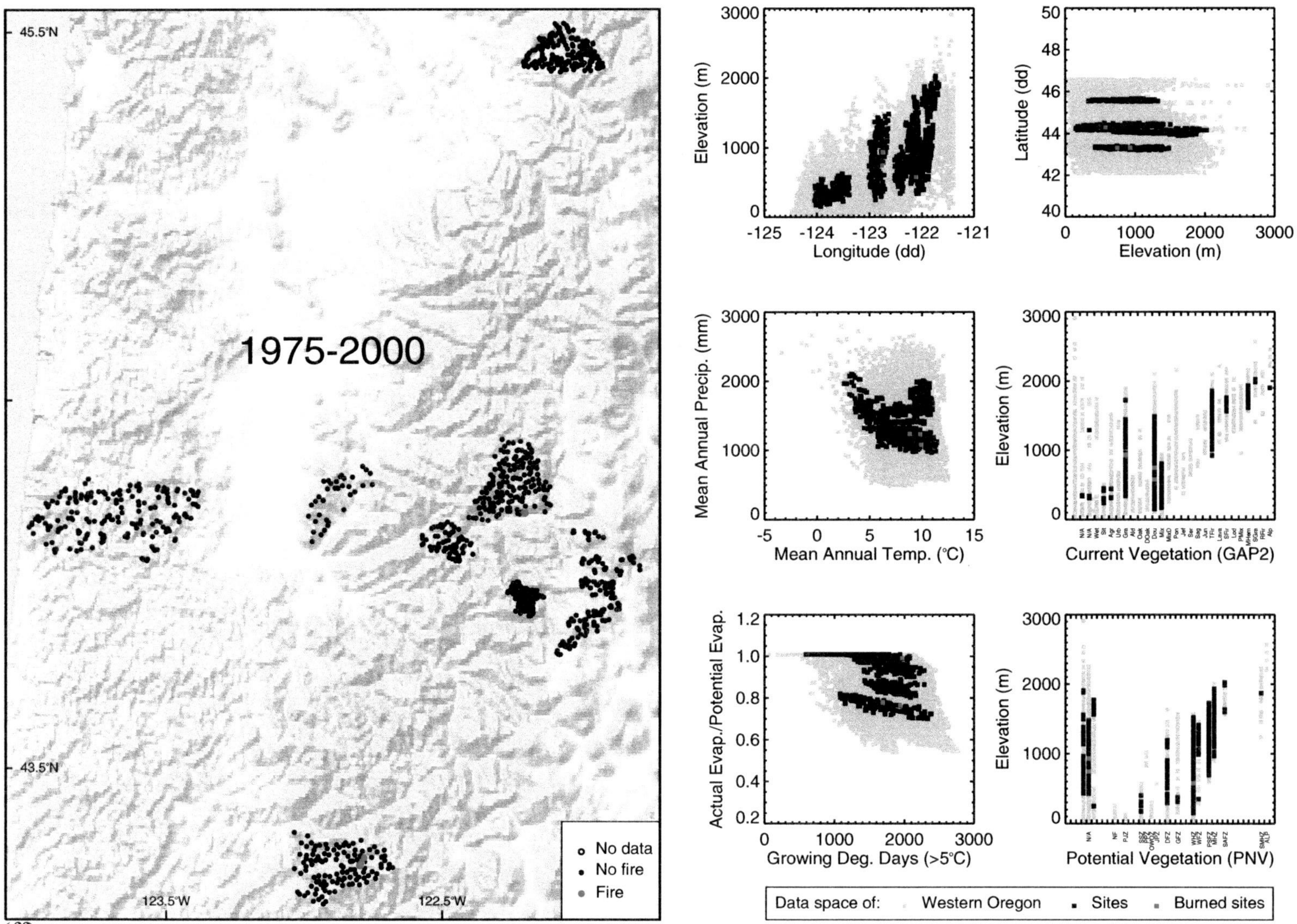

(dd)

FIGURE 10. (Continued).




(ee)

FIGURE 10. (Continued).




(ff)

FIGURE 10. (Continued).

Insert Figure 10:

Time Series of Fire Occurrence in Geographic, Climate, and Vegetation Space

Caption: FIGURE 10. Time series of fire occurrence in geographic, climate, and vegetation space. See Table 2 for vegetation key.

TABLE 2. Vegetation key. Explanation of GAP2 and potential natural vegetation codes used in Figure 10.

GAP2 Vegetation

| Code | Vegetation Type |
|---|---|
| N/A | unknown |
| Wet | estuarine or palustrine |
| Sit | Sitka spruce/western hemlock maritime forest |
| Agr | agriculture |
| Urb | urban |
| Gra | forest/grassland mosaic |
| | regenerating young forest |
| | modified grassland |
| Ald | red alder forest |
| | red alder/big leaf maple forest |
| Oak | Oregon white oak forest |
| DOak | Douglas-fir/Oregon white oak forest |
| Dou | Douglas-fir/western hemlock/western redcedar forest |
| | Douglas-fir/Port Orford cedar forest, |
| | Douglas-fir dominant/mixed conifer forest |
| | Douglas-fir/mixed deciduous forest |
| | Douglas-fir/white fir/tanoak/madrone mixed forest |
| Mix | mixed conifer/mixed deciduous forest |
| MixD | Siskiyou Mtns. mixed deciduous forest |
| | south coast mixed deciduous forest |
| | manzanita dominant shrubland |
| Pon | ponderosa pine forest and woodland |
| | ponderosa pine/white oak forest and woodland |
| | ponderosa pine/lodgepole pine on pumice |
| Jef | Jeffrey pine forest and woodland |
| Ser | Siskiyou Mtns. serpentine shrubland |
| | serpentine conifer woodland |
| Sag | big sagebrush shrubland |
| | sagebrush steppe |
| | low-dwarf sagebrush |
| Jun | western juniper woodland |
| TFir | true fir/hemlock montane forest |
| Lav | lava flow |
| SFir | subalpine fir/lodgepole pine montane conifer |
| Lod | lodgepole pine forest and woodland |
| PMix | ponderosa pine dominant mixed conifer forest |
| | ponderosa pine/western juniper woodland |
| MHem | mountain hemlock montane forest |
| SGra | subalpine grassland |
| | subalpine parkland |
| RFir | Shasta red fir/mountain hemlock forest |
| Alp | alpine fell/snowfields |

Potential Natural Vegetation

| Code | Vegetation Zone |
|---|---|
| N/A | unknown |
| NF | non-forested |
| PJZ | pinyon/juniper zone |
| SSZ | Sitka spruce zone |
| PPZ | ponderosa pine zone |
| OWOZ | Oregon white oak zone |
| JPZ | Jeffrey pine zone |
| DFZ | Douglas-fir zone |
| GFZ | grand fir zone |
| WHZ | western hemlock zone |
| WFZ | white fir zone |
| PSFZ | Pacific silver fir zone |
| MHZ | mountain hemlock zone |
| SAFZ | subalpine fir zone |
| SMHZ | mtn. hemlock-subalpine fir zone |
| ALP | alpine zone |

scatter diagrams (Mean Annual Temp. vs. Mean Annual Precip., GAP2 Vegetation vs. Elevation, Growing Degree Days vs. Actual Evap./Potential Evap., and Potential Vegetation vs. Elevation) show the sites only in data space.

Elevation in western Oregon ranges from sea level to approximately 2300 m, with a few peaks reaching over 3000 m. The sites represent this range well. The distribution of black symbols in the two climate diagrams covers most of the climate space that exists in western Oregon. The climate spaces that are not sampled by the sites are the extremely wet and extremely dry sites in western Oregon. This deficiency can be seen most clearly in the lack of overlap between black and gray symbols at the top and bottom of the Mean Annual Temp. vs. Mean Annual Precip. diagram.

The vegetation data are discrete variables, rather than continuous variables like the climate data, and therefore form separate columns instead of a cloud of points. The data in the two vegetation diagrams use different vegetation classification systems, but both diagrams present the vegetation classes roughly in order of increasing elevation. As in the climate diagrams, the gray symbols indicate the vegetation types that exist in western Oregon, and the black symbols indicate the vegetation types of the sites.

The current vegetation diagrams (GAP2 Vegetation vs. Elevation) indicate that 25 land cover classes are present in western Oregon. The most common types, in order of decreasing prominence, are dominated by Douglas-fir (Douglas-fir/western hemlock/western redcedar forest, Douglas-fir/Port Orford cedar forest, Douglas-fir dominant/mixed conifer forest, Douglas-fir/mixed deciduous forest, and Douglas-fir/white fir/tanoak/madrone mixed forest); ponderosa pine (ponderosa pine forest and woodland, ponderosa pine/Oregon white oak forest and woodland, and ponderosa pine/lodgepole pine on pumice); grassland (forest/grassland mosaic, regenerating young forest, and modified grassland); agriculture; true fir/mountain hemlock montane forest; subalpine fir/lodgepole pine/montane conifer; mixed deciduous forest (Siskiyou Mtns. mixed deciduous forest, south coast mixed deciduous forest, and manzanita dominant shrubland); mixed conifer/mixed deciduous forest; Oregon white oak forest; and wetland (estuarine or palustrine lands).

Of these vegetation types, those that are most extensively sampled by the sites are Douglas-fir/western hemlock/western redcedar forest, forest/grassland mosaic, mixed conifer/mixed deciduous forest, true fir/hemlock montane forest, and subalpine fir/lodgepole pine montane conifer. Sitka spruce/western hemlock maritime forest and mountain hemlock montane forest, although less common in western Oregon than the other GAP2 types, are also well sampled by the sites. Current vegetation types that are most under-sampled are wetland, agriculture, Oregon white oak forest, mixed deciduous forest, ponderosa pine/white oak forest and woodland, lodgepole pine forest and woodland, and ponderosa pine dominant mixed conifer forest. Areas of western Oregon for which there were no GAP data are designated by "N/A".

The potential vegetation diagrams (Potential Vegetation vs. Elevation) reveal 15 PNV zones in western Oregon. The western Oregon PNV data (gray symbols) correspond to a slightly smaller region of western Oregon than the data for western Oregon in other diagrams because the PNV dataset only extends to the north edge of the Little River study area and to the crest of the Cascade Range. Areas with no data, including all sites in Little River and a few in the Cascade Crest study area, are labeled "N/A". For the areas within the extent of the dataset, the most common PNV zones (in order of decreasing prominence) are Douglas-fir, western hemlock, grand fir, Pacific silver fir, white fir, mountain hemlock, Sitka spruce, mountain hemlock/subalpine fir, subalpine fir, Oregon white oak, ponderosa pine, alpine, non-forest, Jeffrey pine, and pinyon-juniper.

The sites extensively sample four of the PNV zones in western Oregon: western hemlock, Pacific silver fir, Douglas-fir, and mountain hemlock. The Sitka spruce zone is also relatively well sampled. Poorly sampled PNV zones are the grand fir, mountain hemlock-subalpine fir, and lower-elevation white fir zones. Mountain hemlock-subalpine fir, a mixed zone, is different from the distinct mountain hemlock and subalpine fir zones, and occupies the highest elevations of all of the PNV zones except the Alpine zone.

## Spatial and Temporal Patterns of Fire Occurrence

In this section, patterns of fire occurrence within and among studies are described geographically and in terms of the climate and vegetation of western Oregon. The results are presented by century based on a visual interpretation of the time-series images (Fig. 10) and on the percentage of sites recording fire within each study area (Fig. 11). Because the fire data presented in the time series are binned, Figure 10 shows which sites burned during a particular time interval but does not indicate the actual number of fire events that occurred at each site.

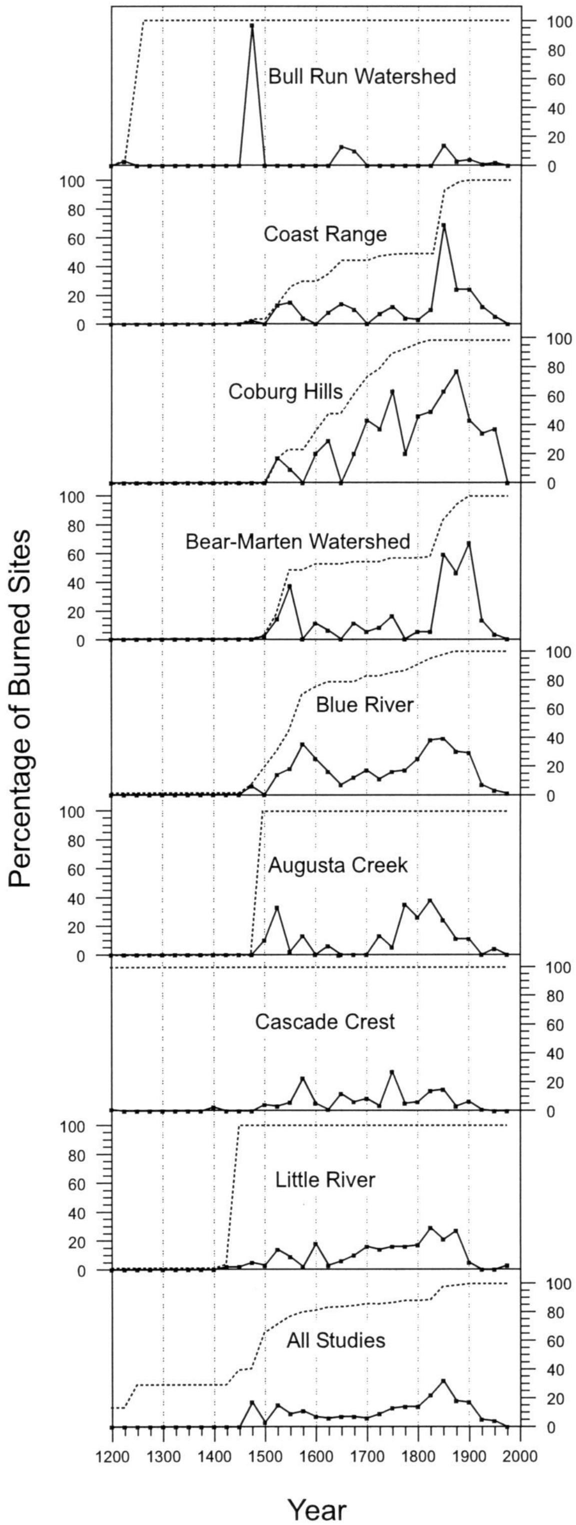



FIGURE 11. Percentage of burned sites in each study area at 25-year intervals from A.D. 1200 to 2000 (solid line and symbols). The dotted line shows the percentage of sites with fire data at each interval.

A.D. 1200 – 1300

The data are sparse in the early part of the record (Fig. 10a – 10d). One known site burned in the Cascade Crest study area between A.D. 1200 and 1225, and five burned in the Bull Run watershed in the northern portion of the Cascades between A.D. 1225 and 1250. The other studies did not contain trees of sufficient longevity, and thus are shown with the "no data" symbol (hollow dot).

A.D. 1300 – 1400

There was no evidence of fire in any study area from A.D. 1300 to 1400 (Fig. 10e – 10h). Again, most sites did not have trees old enough to record fire during this time.

A.D. 1400 – 1500

The most striking pattern during the A.D. 1400s (Fig. 10i – 10l) is that 97% of the sites in the Bull Run watershed burned between A.D. 1475 and 1500, a phenomenon that was attributed to a single fire event that swept the area in A.D. 1493 (Krusemark et al. 1996). Also between A.D. 1475 and 1500, the first recorded fire events occurred in the Blue River study area and the Coast Range. The burned Blue River sites were at relatively high elevations and spanned across the Blue River valley, and the burned Coast Range sites were scattered in the eastern half of the study area. A small cluster of sites in the southern part of the Little River study area in southwestern Oregon experienced fire events at different times throughout the last three-quarters of this century.

## A.D. 1500 – 1600

The A.D. 1500s (Fig. 10m – 10p) are marked by a sharp increase in the number of sites burned, reaching a maximum of 15% for all sites combined, followed by a decline to 9% and then 11% by the end of the century. The first recorded fire events in the Augusta Creek study area occurred between A.D. 1500 and 1525 and were well distributed spatially. Although data are still unavailable for the beginning of this century in the Coast Range, the Coburg Hills, and the Bear-Marten watershed, all of the studies have at least some data for the period A.D. 1525 – 1550 and onward. During these years, several sites in the western Coast Range burned as well as some in the eastern part. The spatial distribution of fire events in the Coburg Hills and portions of the central Cascade Range (Bear-Marten watershed and Blue River) appears asymmetrical, but there is no fire record for most of the sites that appear unburned within these three study areas.

Between A.D. 1550 and 1575, fire events in the Blue River study area shifted from mostly high-elevation eastern sites to low-elevation western sites. Sites burned in the highest elevations of the Cascade Crest study area, and, for the first time in the record, sites in the eastern portion of the Little River study area burned. Between A.D. 1575 and 1600, the spatial distribution of burned sites was very different compared to the rest of the 16th century. In part of the central Cascade Range (Blue River and Augusta

Creek) and the Cascade Crest study area, most of the sites experienced fire events during this period. Within these areas, burned sites were well distributed. Only a few sites burned in the Coast Range and those were limited to the east side. Two sites burned in the northern part of the Little River study area, and no sites burned in the Bull Run watershed, the Coburg Hills, nor the Bear-Marten watershed. For study areas that did burn, there was a general shift of fire events to higher-elevation wetter sites during this last quarter-century.

## A.D. 1600 – 1700

A general shift of fire occurrence to lower-elevation dry sites occurred at the beginning of the A.D. 1600s (Fig. 10q – 10t). The total percentage of sites burned was consistently about 7% for each 25-year interval within this century. No sites burned in the Coast Range from A.D. 1600 to 1625, but all sites that burned during the last three-quarters of the 17th century and in the 150 years thereafter were limited to the eastern margin of the study area. About 25% of sites in the Blue River study area burned from A.D. 1600 to 1625, but this percentage dropped during the rest of the century. More sites burned (18%) in the Little River study area than during any previous period. A few sites burned in the Bull Run watershed, the eastern part of the Bear-Marten watershed, and the northern and southern sections of the Cascade Crest study area.

The period from A.D. 1625 to 1650 featured many fire events in the Coburg Hills, as well as clusters of fires in the central Cascade Range, including the southeastern part of Bear-Marten watershed, the Blue River valley, and the northern part of Augusta Creek. During the period A.D. 1650 – 1675, fires did not register in the Coburg Hills nor in most of the central Cascade Range study areas, but fires increased in the Cascade Crest study area and in the southeastern section of the Bull Run watershed. Some of the Cascade Crest fire events occurred at the wettest sites of the study area, which had not burned in prior centuries. The percentage of total sites that burned from A.D. 1675 – 1700 is similar to that from A.D. 1625 – 1650, yet the distribution is different. Fires in the Coburg Hills during this last quarter-century occurred along the western margin of the study area and those in the Blue River study area were mostly in the northern portion. Sites that burned in the Bull Run watershed were confined to the southwestern corner, and fires in the Cascade Crest study area were located to the south and tended to be at lower-elevation dry sites. Sites that burned in the Little River study area were all on the east side.

## A.D. 1700 – 1800

The A.D. 1700s (Fig. 10u – 10x) resembled the A.D. 1500s in terms of percentage of total sites burned, however, the spatial distribution across all studies was more uneven. As in the A.D. 1600s, the only sites that burned in the Coast Range were limited to the eastern portion. From A.D. 1700 to 1725, no sites burned in the Augusta Creek study area. A few sites in the Coburg Hills and the northern part of the Bear-Marten watershed, several sites in the Cascade Crest study area (including a few high-elevation, wet sites), and many in the Blue River and Little River study areas burned. From A.D. 1725 to 1750, some sites in the Coast Range burned, although fires were still confined to the east. Fire events shifted to the southwest in the Coburg Hills and parts of the central Cascade Range (Bear-Marten and Blue River study areas). Several sites burned in the Augusta Creek and Little River study areas and a few lower-elevation sites burned in the Cascade Crest study area. The period A.D. 1750 – 1775 was much like the previous 25 years, with a slight increase in the number of sites burned in most study areas. Fire events in the Blue River study area shifted from central and southwestern sites to northeastern sites. The percentage of sites burned in the Coburg Hills (63%) was higher than in any study area during any previous period. From A.D. 1775 to 1800, the number of fire events in all study areas decreased or stayed nearly the same except in the Augusta Creek area, where the percentage of burned sites increased to 35. The Bull Run watershed did not experience any fire events in the A.D. 1700s.

### A.D. 1800 – 1900

Many changes in fire patterns occurred across the region during the A.D. 1800s (Fig. 10y – 10bb). Between A.D. 1800 and 1825, little changed since the previous period, but from A.D. 1825 to 1850, the total percentage of sites that burned increased from 14 to 22%. The most dramatic increase in fire activity came between A.D. 1850 and 1875 when 32% of the total sites burned. For the first time in the record, the spatial distribution of fires was relatively even in all study areas during the same 25-year period.

Even the wettest, Sitka spruce-dominated sites near the coast burned. Between A.D. 1875 and 1900, the number of burned sites decreased to 18%, although it was still high relative to other periods. The decrease was most pronounced in the Coast Range where the number of burned sites dropped from 69 to 24%.

## A.D. 1900 – 2000

A dramatic decline in the number of fire events occurred in the A.D. 1900s (Fig. 10cc – 10ff). During the first quarter-century, western sites in the Coast Range recorded no fires and those in the Blue River study area were confined to the west and south. Fire events continued to occur in marginal sites in the Bull Run, Augusta Creek, Cascade Crest, and Little River study areas. The percentage of burned sites actually increased from the previous period by 20% in the Bear-Marten watershed. The most striking decline began in the period A.D. 1925 – 1950, when the percentage of total burned sites dropped from 17 to 5%. Sites that experienced fire events during this time tended to be at low elevations. Some sites burned in the Coast Range, the Coburg Hills, and the central Cascade Range (the Bear-Marten watershed and southern sites in the Blue River study area). Single sites burned in the Bull Run watershed and in the Cascade Crest study area. The decline continued from A.D. 1950 to 1975, when two sites burned in the eastern and western portions of the Bull Run watershed, a few sites burned in the western half of the Coast Range, a few burned in the study areas in the central Cascade Range, and several scattered sites burned in the Coburg Hills. By the period A.D. 1975 – 2000, the only sites that experienced fire events were three in the eastern part of the Little River study area and one in the southern portion of the Blue River study area.

## Summary Evaluation of Fire Patterns

Although the time-series maps and scatter diagrams contain a great deal of information at multiple spatial and temporal scales, the general patterns are difficult to describe. Density plots of the unbinned fire event data from A.D. 1500 to 2000 present a summary view of western Oregon fire history (Fig. 12). A peak in Figure 12 reflects a high density of fire events in the given 25-year time interval relative to the rest of the record for the study area. However, the absolute height of a peak in one study area should not be compared with the absolute height of a peak in another study area. For example, a peak of height 0.01 in one study area might represent 5 fire events, whereas a similar peak in another study area might represent 50 fire events. The curves are the same height because the fire events in that time period account for the same percentage of the total number of fire events in each study area. Thus, the utility of this figure lies in comparing the relative heights of curves within and among studies.

The temporal truncation of the record affected the data curve for the Bull Run watershed because A.D. 1475 – 1500 was a period when all sites burned in that area. If the density curve began at A.D. 1475, the highest peak for the Bull Run watershed would be from A.D. 1475 to 1500 and the other peaks would be much lower. Most of the major peaks in Figure 12 occurred between A.D. 1850 and 1900, with the highest density of fire

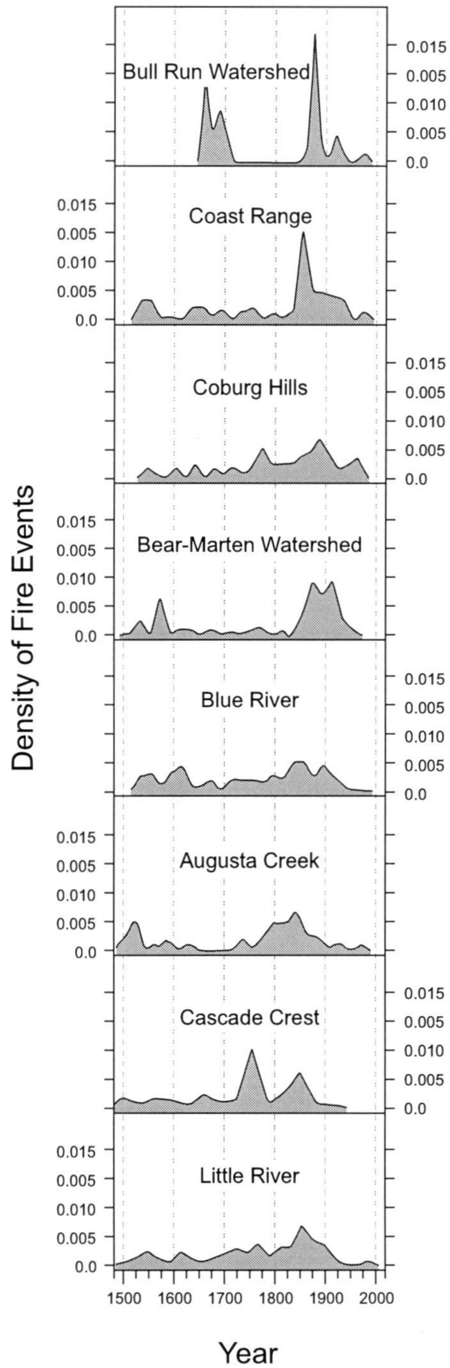



FIGURE 12. Smoothed histograms indicating the relative density of fire events in each study area at different time intervals. The area under a section of the curve reflects the local proportion, or density, of fire events during the given time interval relative to the total number of fire events recorded in the study area from A.D. 1500 to 2000. Data are smoothed using a 25-year window and 25-year step.

events occurring between A.D. 1850 and 1875. Half of the study areas (the Coast Range and the three study areas in the central Cascade Range) show pronounced peaks in fire events in the A.D. 1500s. Some study areas feature secondary peaks in fire events in the A.D. 1600s (the Bull Run watershed) or A.D. 1700s (the Coburg Hills, Cascade Crest, and Little River study areas).

Although the shapes of the density curves (Fig. 12) are similar to the shapes of the percentage graphs (Fig. 11), there are some differences. For example, compared to primary peaks, secondary peaks in fire occurrence in the Coburg Hills between A.D. 1600 and 1725 appear lower in amplitude in the density plot than secondary peaks in the percentage of sites burned for the same period. Similarly, peaks in fire occurrence in the Coast Range between A.D. 1625 and 1775 are also less pronounced in the density plot than peaks in the percentage of sites burned in Figure 11. In contrast, all peaks in fire occurrence in the Bull Run watershed are more prominent in the density plot than in the percentage graph, but this is expected because the density plot data do not include the large fire event in A.D. 1493 that occurred in the area.

## Geographic Ranges of Selected Climate Variables

Climate ranges associated with particular study areas were expanded slightly to encompass other areas in western Oregon with similar climate conditions. Figure 13 shows the clusters of data points that were selected for buffering. The ranges of selected points in the Mean Annual Temp. vs. Mean Annual Precip. scatter diagram were expanded by +/- 0.5 °C of temperature and by +/- 25 mm of precipitation. The ranges of selected points in the Growing Degree Days vs. Actual Evap./Potential Evap. scatter diagram were expanded by +/- 25 growing degree days and by +/- 0.01 on the AE/PE scale. Geographic locations corresponding to these buffered ranges were then mapped in Figures 14 – 24, as were their locations in climate and vegetation space.

Geographic locations with low temperature and high precipitation ranges similar to those of the Cascade Crest study area are mostly found in the crest of the Cascade Range, as would be expected from looking at the Mean Annual Temp. and Mean Annual Precip. images of western Oregon (Fig. 14, Fig. 4). Locations with temperature and precipitation ranges similar to those of the Bull Run watershed are limited to small, discontinuous areas of the Cascade Range and a few sites in the southern part of the Coast Range (Fig. 15). Temperature and precipitation conditions similar to those in Augusta Creek are common in parts of the Willamette and Umqua national forests between Augusta Creek and Little River, as well as in a narrow band of locations surrounding the Cascade Range (Fig. 16). Areas similar in temperature and precipitation to Little River study sites include large contiguous sections of the eastern half of the Willamette Valley, sections of the northern and central part of the Cascade Range and southern Oregon, a narrow band of sites east of the Cascade Range, and a few sites on the Coast (Fig. 17). The geographic extent of locations similar to the wettest Coast Range study sites (mean annual precipitation of 1821 – 2004 mm) is restricted to a band

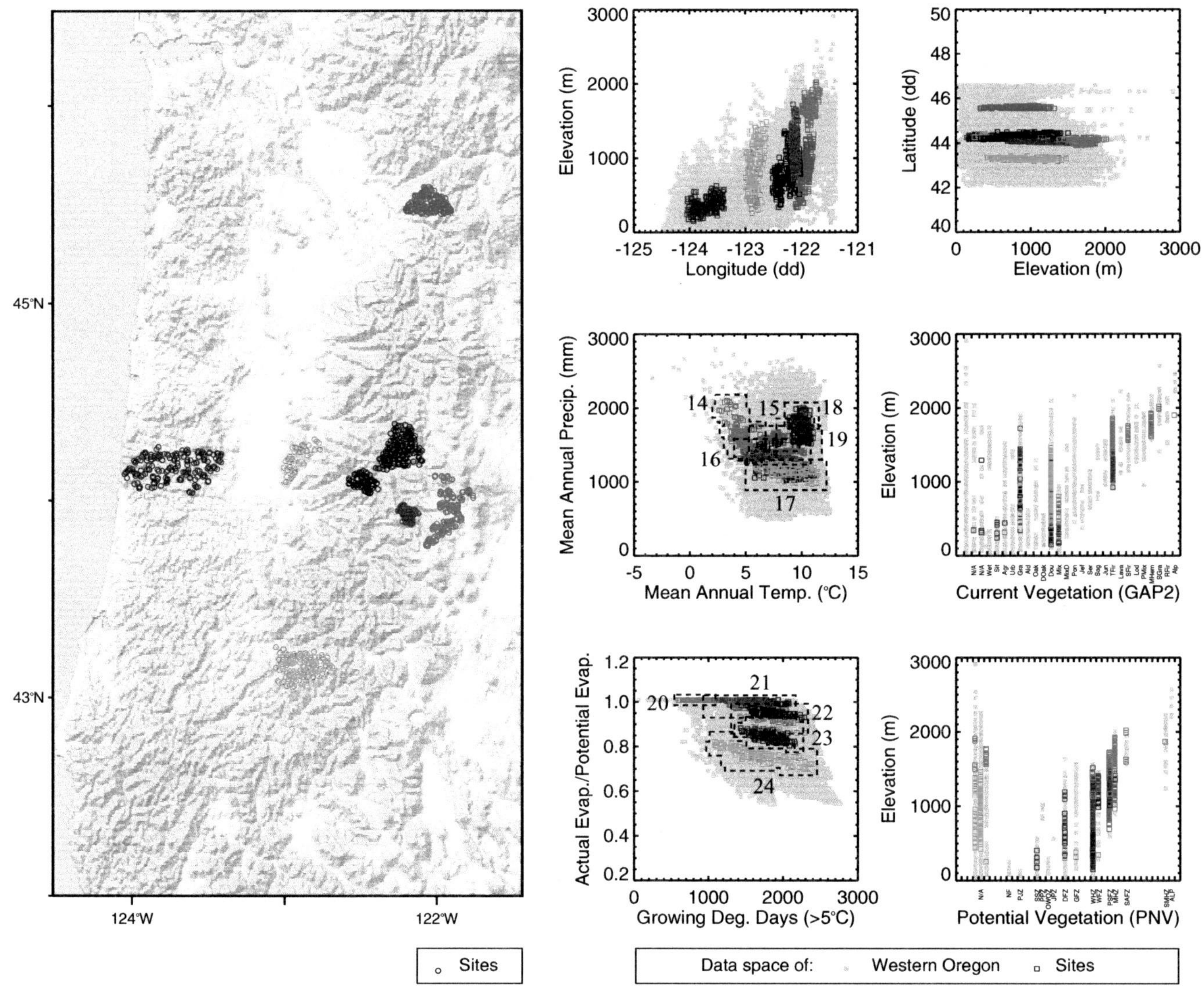



FIGURE 13. Ranges of climate variables used in Figures 14 – 24. Numbers correspond to figure numbers.

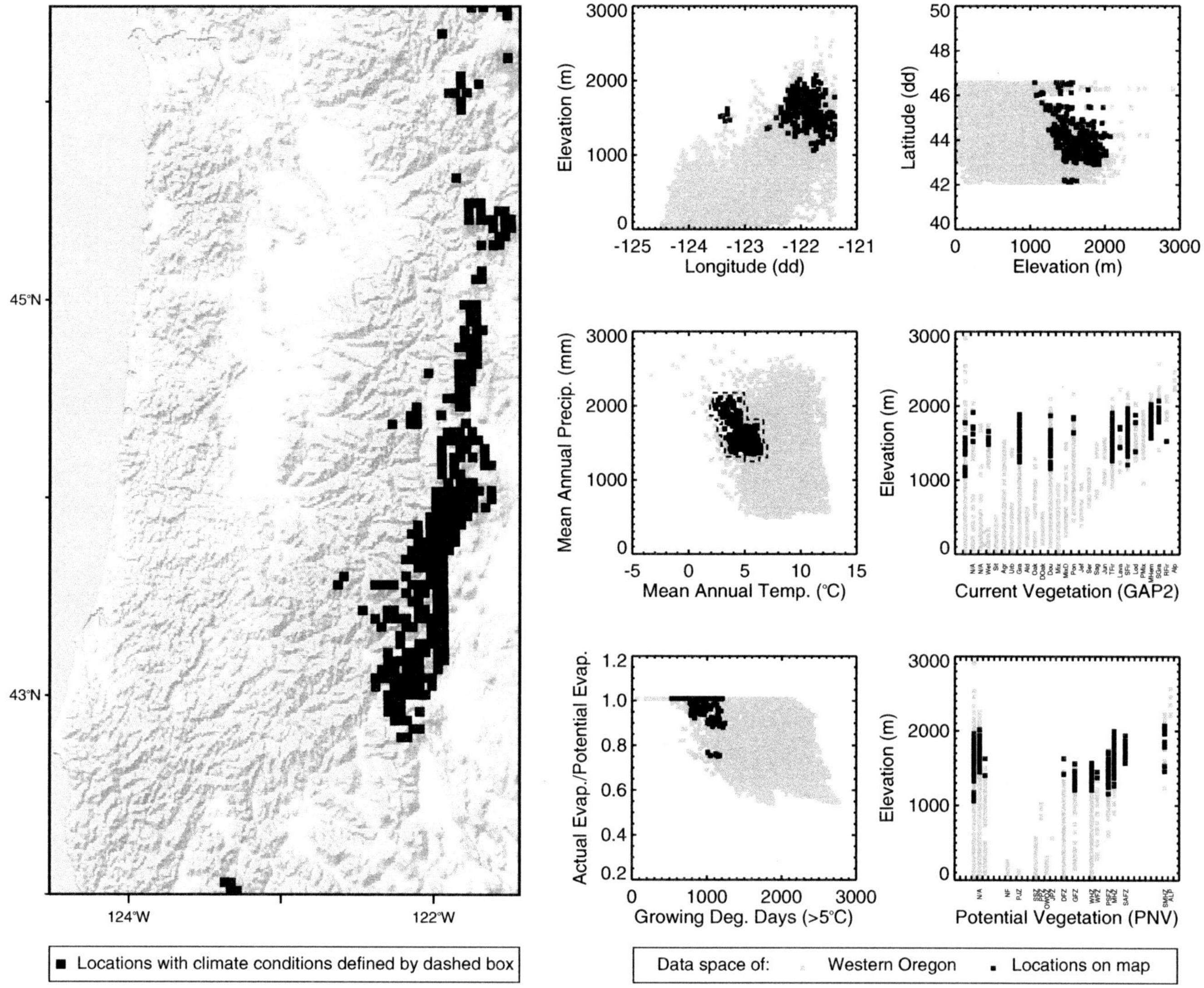



FIGURE 14. Areas with temperature and precipitation ranges similar to those of the Cascade Crest.

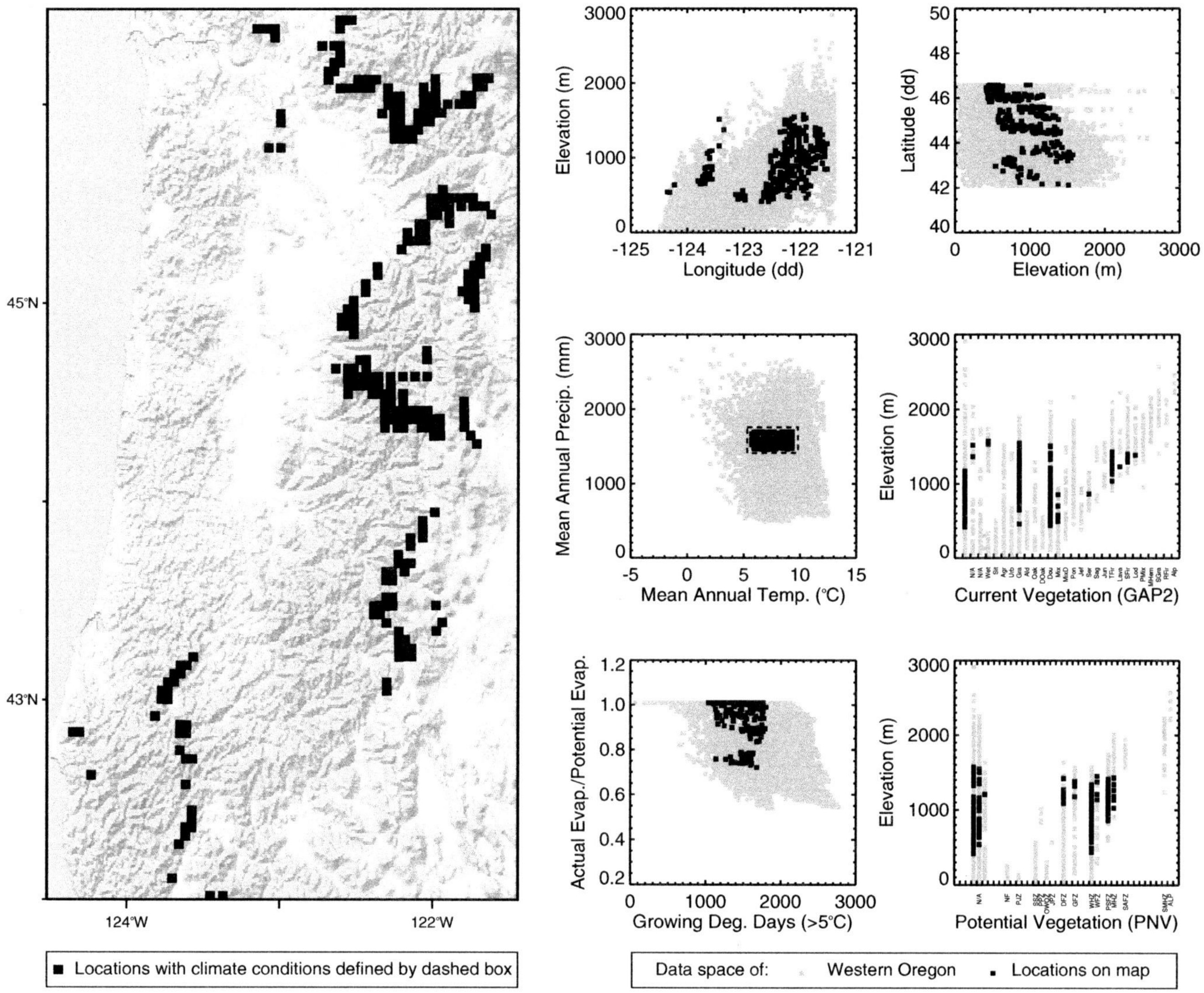



FIGURE 15. Areas with temperature and precipitation ranges similar to those of the Bull Run watershed.

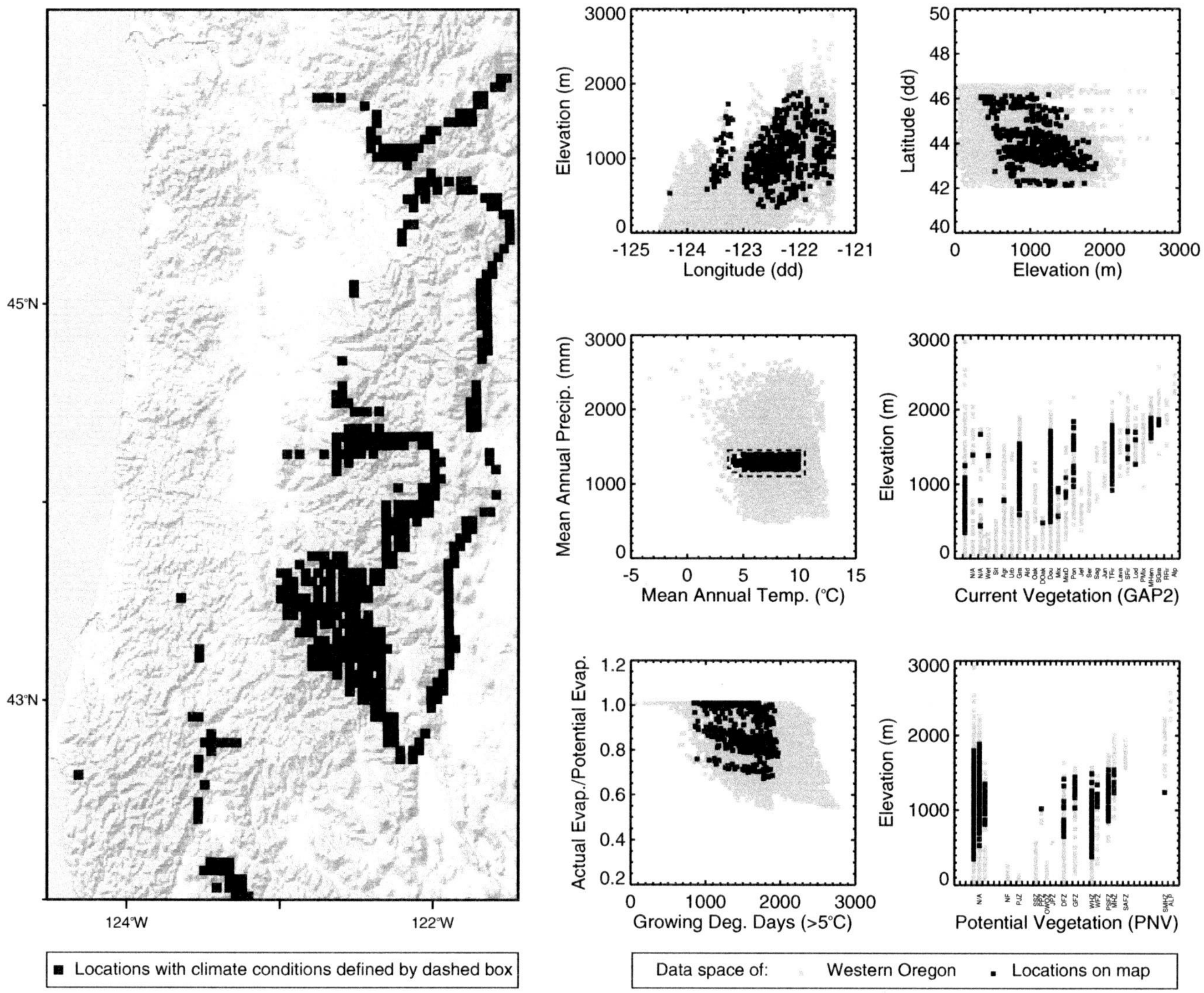



FIGURE 16. Areas with temperature and precipitation ranges similar to those of Augusta Creek.

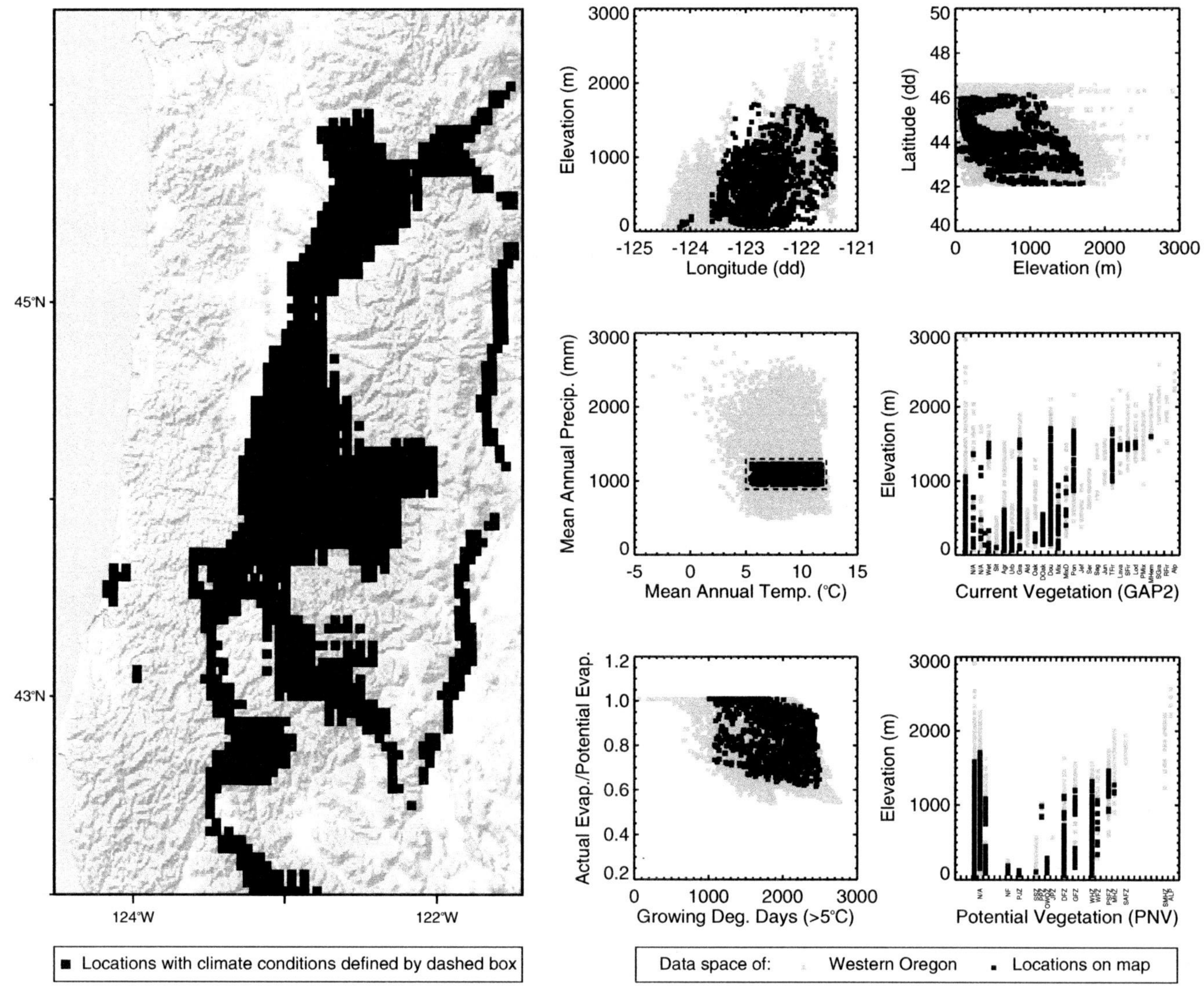



FIGURE 17. Areas with temperature and precipitation ranges similar to those of Little River.

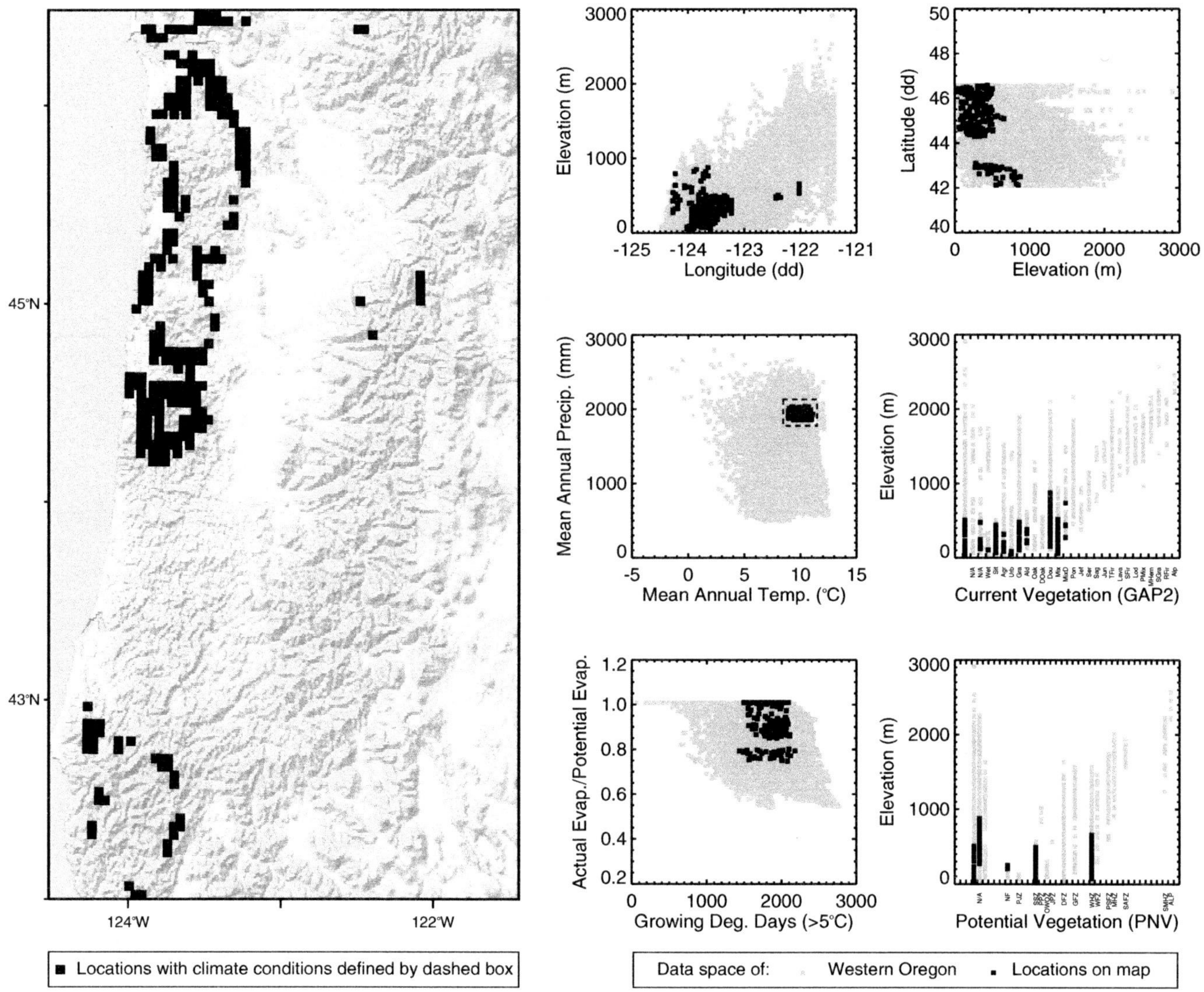



FIGURE 18. Areas with temperature and precipitation ranges similar to those of wet Coast Range sites.

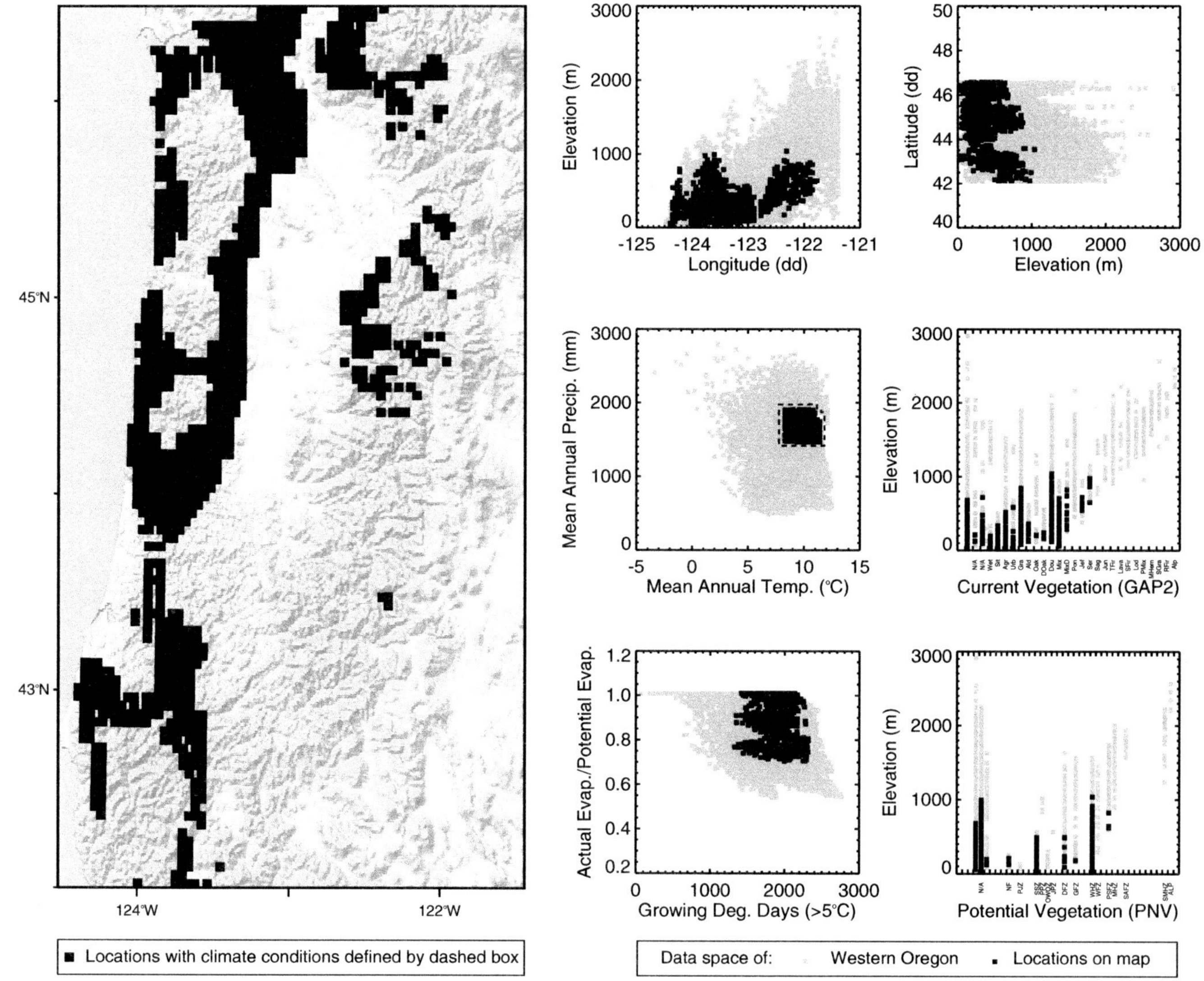



FIGURE 19. Areas with temperature and precipitation ranges similar to those of dry Coast Range sites.

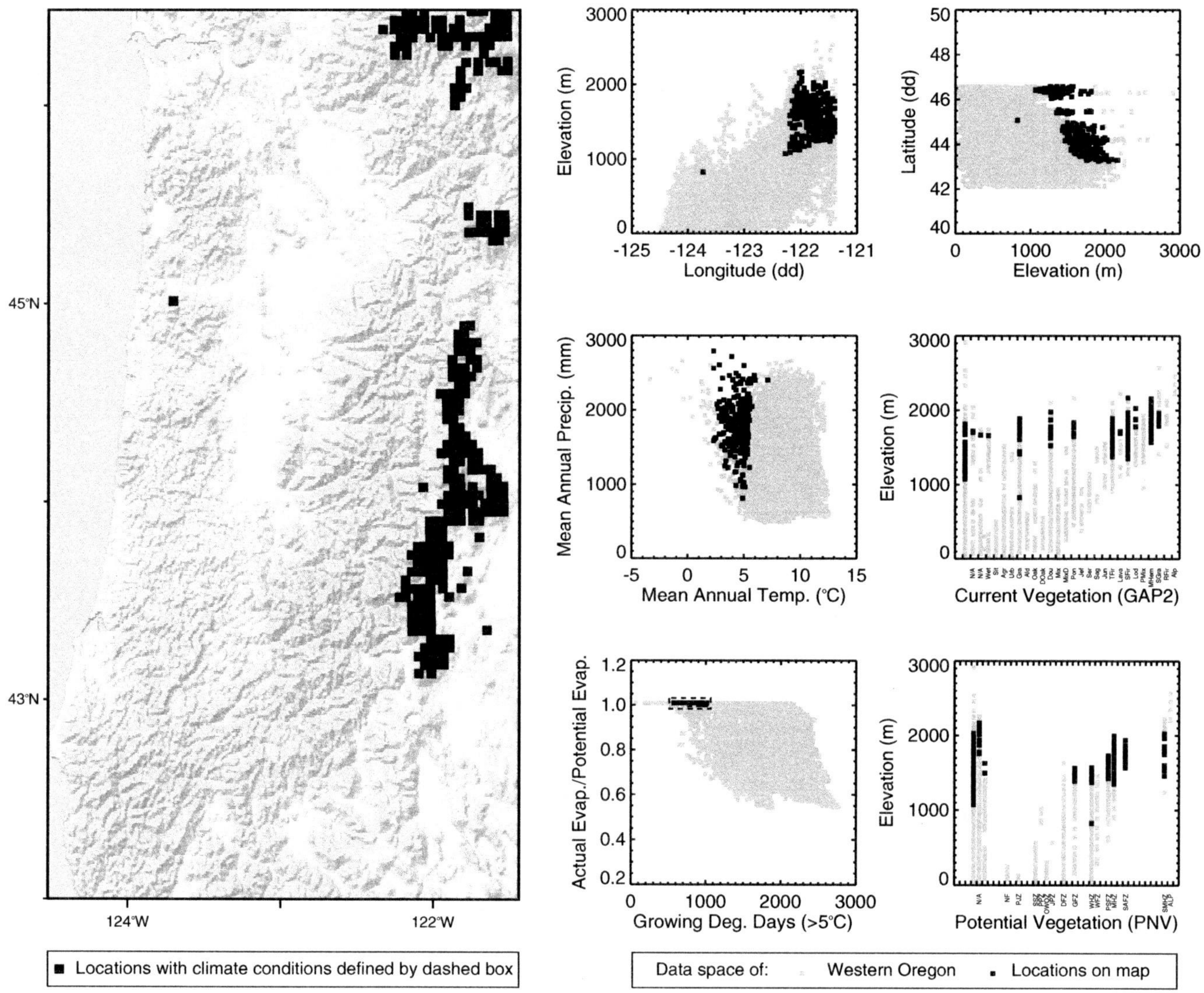



FIGURE 20. Areas with AE/PE and GDD ranges similar to those of the Cascade Crest.

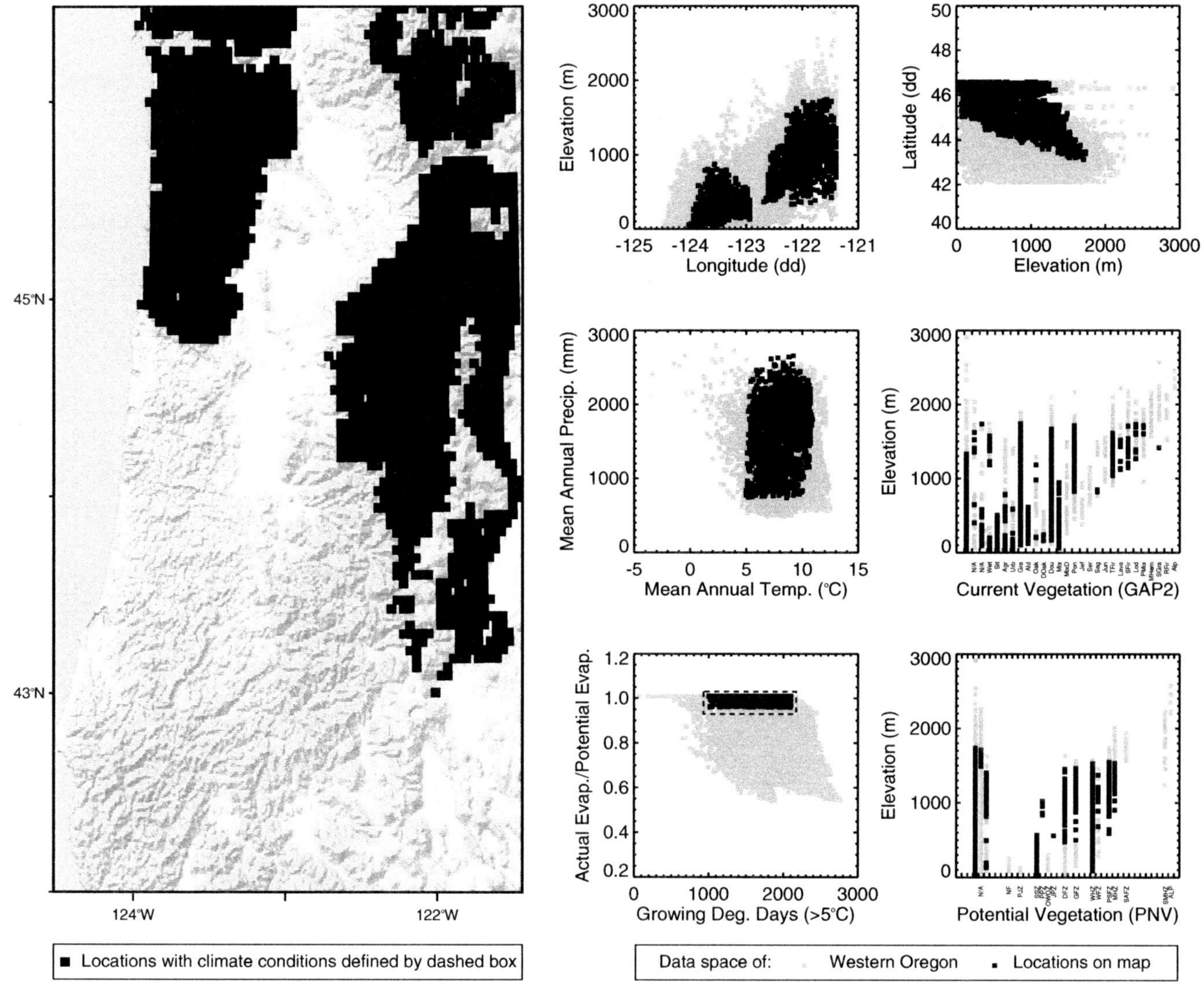



FIGURE 21. Areas with AE/PE and GDD ranges similar to sites with high soil moisture in the Cascades.

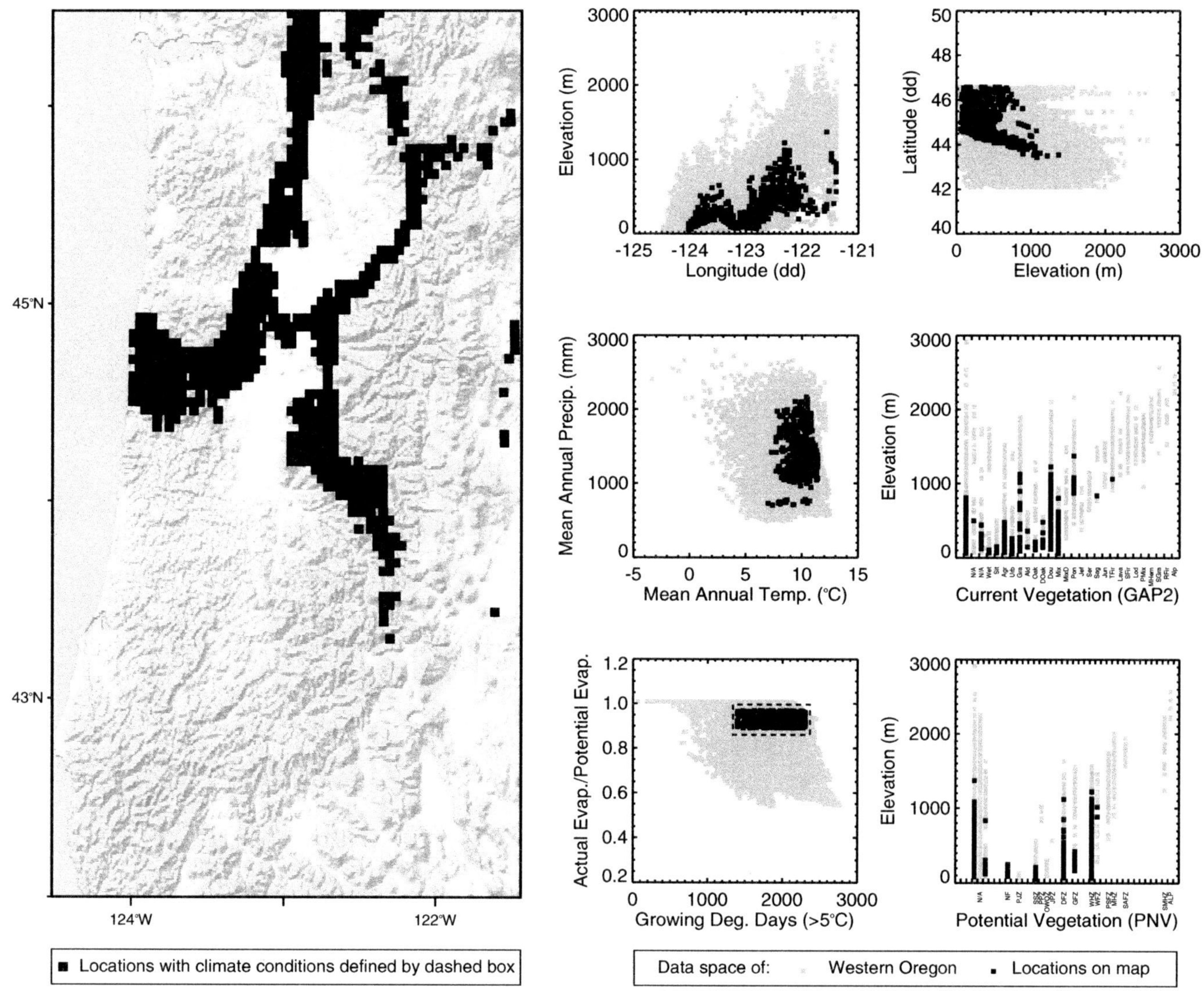



FIGURE 22. Areas with AE/PE and GDD ranges similar to sites with mod. soil moisture in the Cascades.

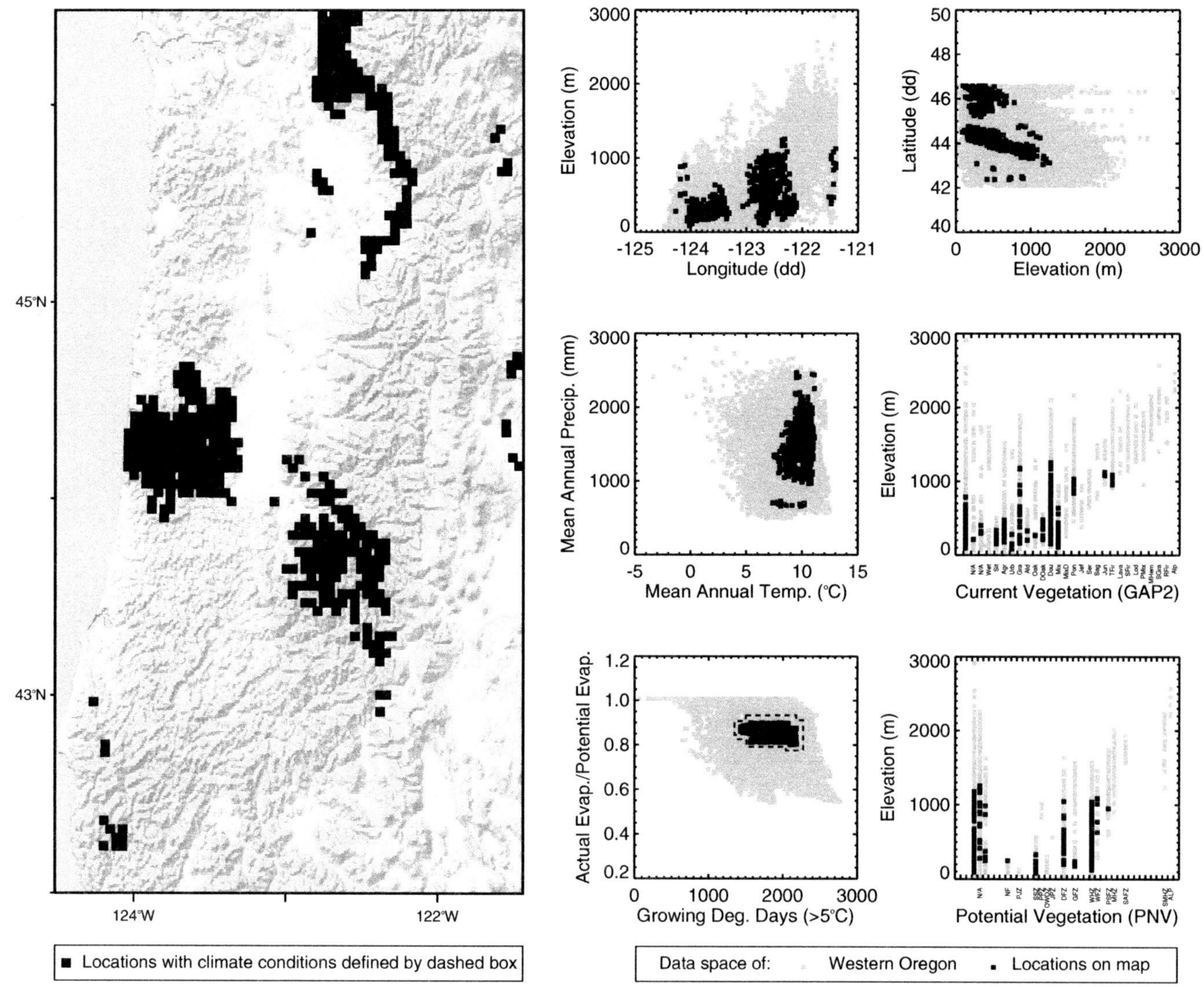



FIGURE 23. Areas with AE/PE and GDD ranges similar to those of the Coast Range.

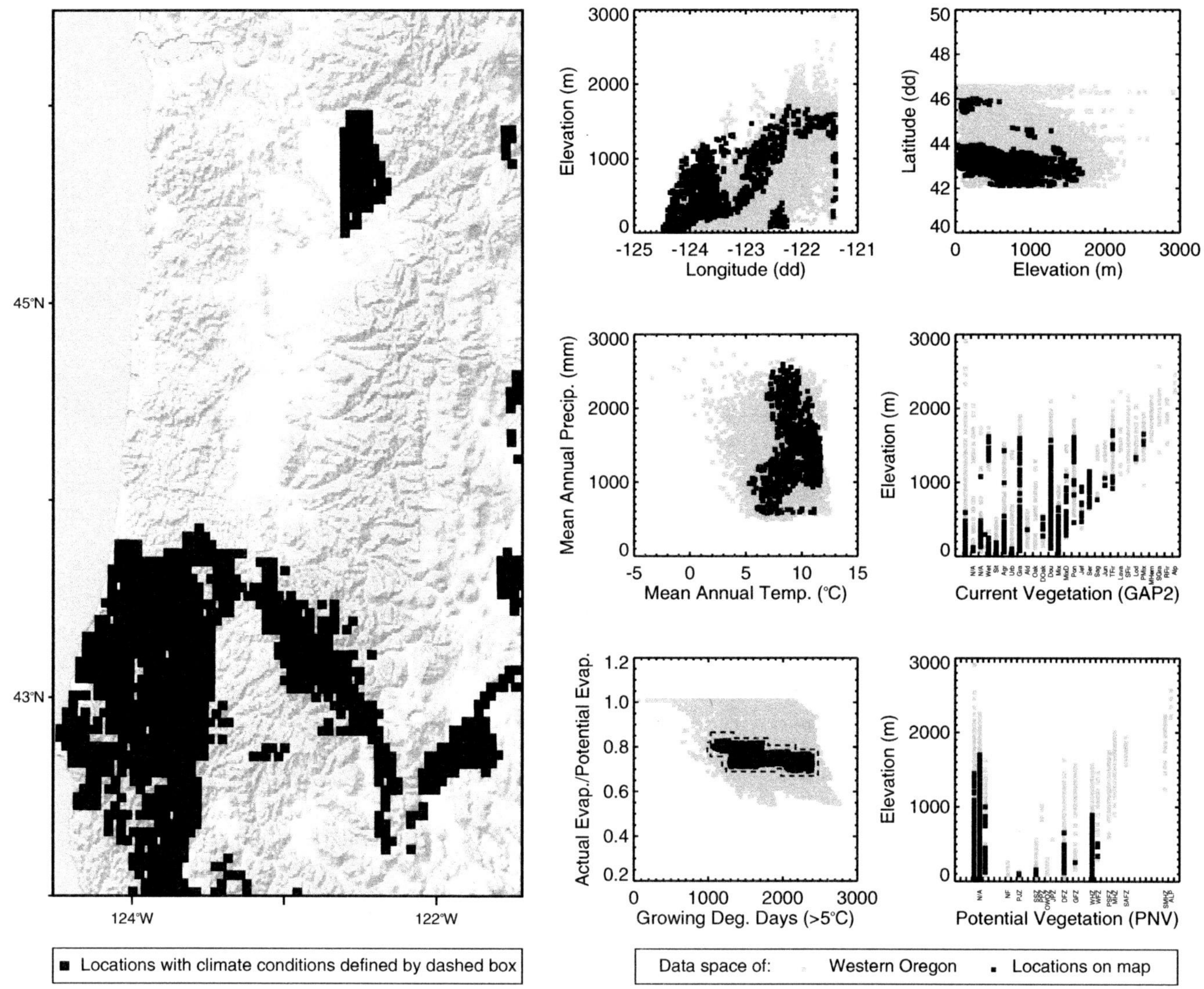



FIGURE 24. Areas with AE/PE and GDD ranges similar to those of Little River.

of high, but not the highest, elevations in the northern part of the Coast Range, as well as a few locations in the southern part of the Coast Range (Fig. 18). Temperature and precipitation ranges similar to drier Coast Range study sites (mean annual precipitation of 1434 – 1877 mm) exist in a wide band of lower elevation Coast Range locations, as well as some sites in the northern part of the Cascade Range (Fig. 19).

Areas with a range of soil moisture (AE/PE) and a range of growing degree days (GDD) similar to Cascade Crest study sites are limited to high elevations of the Cascade Crest and some locations in the northern part of the Cascade Range (Fig. 20). Areas in which the ranges of these climate variables approximate those of high-soil-moisture Cascade Range sites (e.g., Bull Run watershed, Augusta Creek, and some Blue River sites) are found in the northern part of the Coast Range and also the northern and central parts of the Cascade Range except along the crest (Fig. 21). Locations where ranges of soil moisture and growing degree days resemble those of moderate-soil-moisture Cascade Range sites (e.g., Coburg Hills and Bear-Marten watershed) are limited to a band on the western margin of the Willamette Valley, a section of the Coast Range just north of the Coast Range study area, a band along the western margin of the Cascade Range, and a section of the central part of the Cascade Range (Fig. 22). Locations where ranges of these climate variables are similar to those of the Coast Range study sites are restricted to the vicinity of the Coast Range study area, a band on the northeastern margin of the Willamette Valley, a section surrounding the Middle Fork of the Willamette River, and a few isolated sites in the region (Fig. 23). Locations with ranges of soil moisture and growing degree days similar to those of Little River span a large section in the southern part of the Coast Range, areas to the northwest and southeast of Little River, and scattered patches east of the Cascade Range and in the northern part of the Willamette Valley (Fig. 24).

# CHAPTER V

# DISCUSSION

## Representativeness of Study Sites

The range of climate and vegetation in western Oregon is better sampled by the eight studies in this synthesis than their geographic locations might suggest. The types of areas that are poorly sampled are those that are exceptionally wet or exceptionally dry. The wettest areas in western Oregon are in the northern part of the Coast Range, high elevations of the Cascade Range, the Bull Run area, and the Siskiyou National Forest in the southwestern corner of Oregon (Fig. 4). The driest areas are in the southwestern part of the region and the Willamette Valley. Of the potential natural vegetation types, mid- to high elevations in the grand fir zone, low elevations in the white fir zone, and the less common mountain hemlock-subalpine fir zone are the only ones that appear proportionally under-sampled compared to the range of potential vegetation modeled for western Oregon. The first two types exist in numerous small, scattered locations in the central part of the region, whereas the mountain hemlock-subalpine fir zone corresponds only to the parkland areas surrounding high peaks in the Cascade Range (Fig. 6). It is possible that some of the under-sampled potential vegetation types were indeed examined in the Little River study, but those sites are beyond the coverage of the PNV dataset. Oregon white oak forest, mixed deciduous forest, and ponderosa pine/Oregon white oak forest and woodland are the current vegetation types that are under-sampled by the studies. This poor sampling is not surprising because these vegetation types tend to occur in dry areas, which have not been studied well. Oregon white oak forest is dispersed throughout the Willamette Valley, mixed deciduous forest exists in patches south of the Little River study area, and ponderosa pine/Oregon white oak forest and woodland is found mostly on the eastern side of the Cascade Range (Fig. 5). Additional studies are needed in areas of low precipitation, which support dry vegetation types such as oak and mixed deciduous forest, as well as areas of high precipitation, which support coastal and upper montane vegetation types. In general, however, the broad distribution of sites in most of western Oregon climate and vegetation space indicates that the study sites can be considered fairly representative of western Oregon.

The figures of locations in western Oregon with similar climate characteristics as the study areas showed both predictable and unpredictable patterns (Figs. 14-24). The limited geographic extent of climate conditions similar to those in the Cascade Crest study area (Figs. 14 and 20) is not surprising because the Cascade Crest is such a unique geographic feature in western Oregon. The Bull Run watershed appears to be unique as well in terms of temperature and precipitation (Fig. 15), but there are many areas in both the Coast Range and the Cascade Range with similar ranges in soil moisture and growing degree days (Fig. 21). Although temperature and precipitation ranges of the Augusta

Creek study area overlap those of Little River, Coburg Hills, Blue River, and even Bull Run watershed (Fig. 13), the buffered ranges of August Creek do not incorporate these areas nearly as well as the buffered ranges of Little River (Figs. 16 and 17). Augusta Creek appears to be in a transition zone where some sites have climate conditions like those in Blue River and Bear-Marten watershed (Fig. 21), whereas others are more similar to locations between Augusta Creek and Little River (Fig. 16). The Coast Range study sites also seem relatively unique in terms of soil moisture and growing degree days, however, analogs exist in a band of sites at the northeastern edge of the Willamette Valley and in an area along the Middle Fork of the Willamette River (Fig. 23). The latter follows an AE/PE transition zone similar to that occupied by the Coast Range study area (Fig. 4). Future research might explore whether locations with climate conditions similar to those of the study sites experienced similar patterns of fire occurrence and synchroneity as well.

## Patterns of Fire Occurrence

This investigation differs from that of Weisberg and Swanson (in review-a) in its emphasis on the spatial component of past fires—the location of events, not the area burned. In contrast, the previous study emphasizes the temporal component of fire regimes and draws attention to medium and large fire events (Fig. 1). Furthermore, this study focuses on western Oregon, whereas the other considers sites in western Oregon and Washington. Both approaches have unique advantages. By concentrating on fires that burned >20% of a study area, Weisberg and Swanson (in review-a) eliminated some of the "noise" in the record and focused on events that were probably influenced by regional-scale controls. This investigation looks at all fire events and assesses how representative the sites are of western Oregon environments.

The results of this analysis are consistent with Figure 1 in many respects. The period of increased fire activity in the late 1800s is clearly evident in Figures 9 – 12. However, the time-series maps in Figure 10 imply that the period of synchroneity was somewhat more focused than that depicted in Figure 1 (i.e., ca. A.D. 1825 – ca. 1900, rather than ca. A.D. 1800 – ca. 1925). The increase in fire activity in the A.D. 1500s followed by a period of decreased fire activity in the A.D. 1600s and A.D. 1700s is also similar to the patterns in Figure 1.

There are also notable differences in the strength of these patterns. For example, Figure 1 gives the impression that fires in the A.D. 1500s were almost as widespread as those in the A.D. 1800s, but Figure 11 shows that the actual number of sites burned was far less in the A.D. 1500s than in the A.D. 1800s. It is interesting, though not entirely surprising, that western sites in the Coast Range only burned in the A.D. 1500s and 1800s. Fire-return intervals in Sitka spruce forests along the Pacific coast may be on the order of hundreds of years (Agee 1993). Thus, these forests are likely to burn only under extreme fire conditions. These wet sites are valuable in fire history reconstructions because they are likely to show changes in fire frequency and severity in response to extreme drought.

There are only five time intervals in which two or more of the wettest sites from either the Bull Run watershed, the Coast Range, or the Cascade Crest burned: A.D. 1475 – 1500 (Bull Run), A.D. 1550 – 1575 (Coast Range and Cascade Crest), A.D. 1650 – 1675 (Cascade Crest and Bull Run), A.D. 1700 – 1725 (Cascade Crest), and A.D. 1850 – 1875 (Coast Range). A.D. 1475 – 1500 is the only period in which all sites in a study area burned, possibly a consequence of a drought event in conjunction with high fuel loads. Without data from other sites during that time it is difficult to speculate on other scenarios. The second period, A.D. 1550 – 1575, may have been characterized by a dry climate that was associated with widespread fires, whereas the third and fourth periods, A.D. 1650 – 1675 and A.D. 1700 – 1725, may have been characterized by a wetter climate with localized drought conditions. Such drought conditions may have triggered fire events in wet sites of the Bull Run watershed and the Cascade Crest. The increase in fire activity in the Bull Run and Cascade Crest areas between A.D. 1650 and 1675 coincides with dendrochronological reconstructions of a brief warming period from A.D. 1650 to 1690 in Longmire, WA (Graumlich and Brubaker 1986). If there was a warming of the entire region, however, its impact was fairly insignificant in western Oregon compared with other periods of increased fire occurrence in the record. This may be because its short duration did not allow enough time for fuel to accumulate in areas that had burned in the A.D. 1500s. Finally, the fifth period, A.D. 1850 – 1875, is marked by widespread fires like the first period, but the only super wet sites that burn are in the Coast Range. Perhaps the absence of fire in the wettest Cascade Crest or Bull Run sites during this period suggests that either fuel load was low (although the wettest Cascade

Crest sites hadn't burned for 100 – 200 years) or that burning was largely a result of human-caused fires, rather than dry climate. Another possible explanation for burning in the wet sites along the Oregon Coast at different times in the record is strong east winds that may have spread fire from drier sites in the Willamette Valley (Impara 1997).

This investigation also highlights exceptions to the wholesale decrease in fire activity in the A.D. 1600s and 1700s depicted in Weisberg and Swanson (in review-a). During the mid-1600s, the number of burned sites increased in both the Bull Run watershed and in the Cascade Crest study area. The fire activity in the Bull Run watershed is not shown in Figure 1 because the events burned < 20% of the study area, but the extent burned was probably very close to that number. The fact that several sites in the Cascade Crest study area also burned during this period, including some of the wettest in the study area, suggests that regional climate patterns may have played a role. Upper montane forests in the Cascade Range are usually dominated by Pacific silver fir, a species that is particularly vulnerable to fire because of its thin bark. Consequently, these forests are associated with infrequent high-severity events, often brought on by summer drought and/or strong east winds (Agee 1993).

A steady increase occurred throughout the A.D. 1700s in the percentage of sites that burned in the Coburg Hills, Augusta Creek, and Little River. The Cascade Crest study area and the Coburg Hills experienced a distinct, coincident peak in fire occurrence between ca. A.D. 1750 and ca. 1775 (Figs. 11 and 12). These increases occurred well in advance of European settlement, leaving Native American practices, climate, and/or local weather conditions as possible contributing factors. The Molala are known to have inhabited the lowlands of the western Cascade Range, and archaeological evidence also indicates that they occupied higher elevations during summer (Aikens 1993). As Weisberg and Swanson (in review-a) suggest, higher resolution fire-history reconstructions would be helpful in discerning climate and human impacts during the late A.D. 1700s and early A.D. 1800s.

Although the time series of images (Fig. 10) and percentages of sites burned (Fig. 11) effectively communicate the spatial distribution of all fire events from A.D. 1200 to present, the density plots in Figure 12 best summarize the regional scale patterns over space and time. Because peaks in Figure 12 are scaled to show the number of fire events for each interval as a proportion of the total events for the entire 500 year period in each study area, they emphasize periods of unusually high fire occurrence and de-emphasize periods of background fire occurrence. Coincident peaks suggest periods of increased fire occurrence on a regional scale. In comparing the peaks among studies, it is evident that there was regional synchroneity in the mid- to late A.D. 1800s and in the A.D. 1500s, although the total number of fire events was much lower in the earlier period. At smaller spatial scales and shorter timescales, there was also synchroneity between some studies in the intervening years (e.g., the Bull Run watershed and the Cascade Crest study area from A.D. 1650 to 1675, and the Coburg Hills and the Cascade Crest study area from A.D. 1750 to 1775).

The visualization techniques used in this project were valuable in revealing spatial and temporal patterns in the data. The animated time series of fire occurrence was a more useful analytical tool than the static time-series maps because user controls enabled more efficient navigation. Change detection was also easier because the data remained in exactly the same place, and page turning, which distracts the eye, was avoided. It was difficult to assess periods in which similar numbers of sites burned, and sometimes it was difficult to discern temporal patterns in fire occurrence on long timescales, but the density plots made these assessments possible.

# CHAPTER VI

# CONCLUSION

The fire history sites included in this synthesis are generally representative of the range of climate conditions in western Oregon, with the exception of extreme wet and extreme dry conditions. Consequently, the current vegetation types that are most under-represented were Oregon white oak and ponderosa pine, which occur in areas with low annual precipitation. The potential vegetation types that were most under-studied were grand fir and white fir, which also occur in dry areas, and western hemlock/subalpine fir forest, which occurs at high elevations in wet environments. Other climate and vegetation types present in western Oregon were well sampled by the array of sites.

Fires occurred at all elevations sampled, from sea level to 2000 m in elevation, throughout the period of record. Fires also occurred in all sampled climate conditions and vegetation types during all time periods. Nonetheless, very wet sites along the Pacific coast and in high elevations of the Cascade Crest study area only burned when an unusually large proportion of all study sites burned.

Fire events were synchronous across the region in the mid to late A.D. 1800s. The largest number of fire events occurred during the interval A.D. 1850 – 1875. Fire events were also synchronous in the A.D. 1500s, but far fewer were recorded than in the

A.D. 1800s. Because of the lack of trees at the sites dating to the early A.D. 1500s, it is uncertain whether evidence of more fires during the A.D. 1500s once existed but has since been erased. Some peaks in the number of fire events occurred during the A.D. 1600s and A.D. 1700s, but they were not synchronous across the entire region. It is possible that sites in the Bull Run watershed and the Cascade Crest study area experienced more fires in response to a brief warming episode between A.D. 1650 and 1675 (Graumlich and Brubaker 1986). A gradual increase in the number of fire events occurred in nearly all of the study areas, beginning in the mid-A.D. 1700s and leading up to the large peak in fire occurrence in the mid-1800s.

These data support the notion of regional synchroneity in fires during the A.D. 1500s and A.D. 1800s, yet additional periods of increased fire occurrence took place at smaller spatial scales and shorter temporal scales. Specifically, small peaks in fire occurrence were evident in some study areas during the A.D. 1600s and A.D. 1700s, but, because they were not temporally coincident, they may not indicate regional climate change.

The record reveals that fire has been a part of the landscape in western Oregon throughout the past 800 years. Periods of both widespread and localized fires, as well as variation in the severity of fire events, must have maintained a mosaic of age classes in western Oregon forests. The spatial patterns of burned sites and the density of fire events for particular time periods support the idea that existing old-growth stands in the Bull Run watershed and in the western section of the Coast Range were produced by infrequent, high-severity fire events in the A.D. 1400s and 1500s (Krusemark et al. 1996, Impara 1997). The data also support the claim by Morrison and Swanson (1990) that old-growth stands in the central Cascade Range, as well as those in the Little River study area and dry sites in the Coast Range, are a consequence of mixed-severity fire regimes, which left some stands untouched by fire. Whether fire regimes were synchronized to produce widespread fires in western Oregon prior to A.D. 1500 is unknown. The dendrochronological record can serve as a benchmark for assessing current fire regimes, but to comprehend the variability of forest dynamics and fire regimes on longer timescales, paleoecological evidence is needed. Recent research on Holocene fire and vegetation history in the Coast Range suggests that current fire regimes may only be a phenomenon of the last 1000 years (Long et al. 1998). If this is true of the region, perhaps human-induced climate change in our lifetime could shift fire regimes beyond the range of variability that occurred in the historic record.

Knowledge about the range of past fire regimes not only informs current efforts to restore natural disturbance to the landscape, but also enables more accurate projections of fire regimes under future climate scenarios. To better understand the fire history of western Oregon, research efforts might focus on areas of climatic extremes in western Oregon, where fire regimes are most sensitive to climate change. Dendrochronological studies that target the late A.D. 1700s and early A.D. 1800s could also reveal more about the dynamic between human and climate impacts leading up to Euro-American settlement. Further paleoecological research is also needed to better understand how fire regimes have changed on longer timescales and whether regional synchroneity occurred in western Oregon during periods prior to A.D. 1500.

# REFERENCES


Agee, J. K. 1993. Fire ecology of Pacific Northwest forests. Island Press, Washington D.C.

Aikens, M. 1993. Archaeology of Oregon. U.S. Department of Interior, Bureau of Land Management. BLM/OR/WA/ST-93/16+8100.

ArcInfo version 8.0.2. 2000. Computer software. Environmental Systems Research Institute. Windows NT.

Bartlein, P.J., 2000. Personal communication.

Cissel, J.H., Swanson, F.J., Grant, G.E., Olson, D.H., Gregory, S.V., Garman, S.L., Ashkenas, L.R., Hunter, M.G., Kertis, J.A., Mayo, J.H., McSwain, M.D., Swetland, S.G., Swindle, K.A., and Wallin, D.O. 1998. A landscape plan based on historical fire regimes for a managed forest ecosystem: the Augusta Creek study. U.S.D.A. Forest Service General Technical Report PNW-GTR-422. Pacific Northwest Research Station, Portland, OR.

Digital Elevation Models. 1997. Dataset. Oregon Geospatial Data Clearinghouse. ftp://ftp.sscgis.state.or.us/pub/data/baseline97/raws.

Flash version 4.0. 2000. Computer software. Macromedia. Windows NT.

Forest Science Data Bank. 2000. H.J. Andrews Long-Term Ecological Research Program. http://www.fsl.orst.edu/lter/datafr.htm.

Franklin, J. F., and Dyrness, C. T. 1973. Natural vegetation of Oregon and Washington. U.S.D.A. Forest Service General Technical Report PNW-8.

GAP2 Vegetation Data. 2000. Dataset. Oregon Geospatial Data Clearinghouse. ftp://ftp.sscgis.state.or.us/pub/data/statewide/k100/orgapveg.zip.

Graumlich, L.J. 1987. Precipitation variation in the Pacific Northwest (1675 – 1975) as reconstructed from tree rings. Annals of the Association of American Geographers 77: 19–29.

Graumlich, L. J., and Brubaker, L. B. 1986. Reconstruction of annual temperature (1590 – 1979) for Longmire, Washington, derived from tree rings. Quaternary Research 25: 223–234.

ImageReady version 2.0. 2000. Computer software. Adobe. Windows NT.

Impara, P. C. 1997. Spatial and temporal patterns of fire in the forests of the central Oregon Coast Range. Ph.D. dissertation, Oregon State University, Corvallis, Oregon.

Interactive Data Language version 5.2. 2000. Computer software. Research Systems, Inc. Windows NT.

Kertis, J., and Huff, M. 1997. Unpublished data on fire history in the crest of the Cascade Range.

Kertis, J., Heyerdahl, E., and Pendergrass, K. 1995. Unpublished data on fire history in the Augusta Creek watershed.

Kiilsgaard. 1999. Land cover type descriptions: Oregon gap analysis 1998 land cover for Oregon. Documentation of GAP2 vegetation dataset.

Krusemark, F., Agee, J. K., and Berry, D. 1996. The history of fire in the Bull Run watershed, Oregon. U.S.D.A. Forest Service Mt. Hood National Forest final report PNW-92-0225.

Long, C. J., Whitlock, C., Bartlein, P.J., and Millspaugh, S.H. 1998. A 9000-year fire history from the Oregon Coast Range, based on a high-resolution charcoal study. Canadian Journal of Forestry Research 28:774–787.

McCain, C. 2000a. Personal communication.

McCain, C. 2000b. Potential natural vegetation dataset and documentation.

Mock, C. J. 1996. Climatic controls and spatial variations of precipitation in the western United States. Journal of Climate 9: 1111–1125.

Morrison, P.H., and Swanson, F. J. 1990. Fire history and pattern in a Cascade Range landscape. U.S.D.A. Forest Service General Technical Report PNW-254.

National Interagency Fire Center. 2000. Total number of wildland fires and acreage burned from January 1 to October 16, 2000 by state. http://www.nifc.gov/fireinfo/nfnmap.html.

Northwest Interagency Coordination Center. 2000. Unpublished data on annual acreage burned on lands of the U.S. Forest Service, Bureau of Land Management, Oregon Department of Forestry, Bureau of Indian Affairs, Fish and Wildlife Service, and National Park Service, 1990 – 1999.

Oregon Department of Forestry. 2000. Unpublished data on annual acreage burned on lands of the Oregon Department of Forestry, 1985 – 2000.

Oregon GAP Analysis 2 Metadata. 1998. Dataset documentation. ftp.sscgis.state.or.us/pub/data/statewide/k100/orgapvegt.txt.

Prentice, I. C., Cramer, W., Harrison, S. P., Leemans, R., Monserud, R. A., and Solomon, A. M. 1992. A global biome model based on plant physiology and dominance, soil properties and climate. Journal of Biogeography 19: 117–134.

Pyne, S. J. 1982. Fire in America: a cultural history of wildland and rural fire. Princeton University Press, New Jersey.

S-Plus 2000 Professional Edition Release 2. 2000. Computer software. Mathsoft. Windows NT.

Shafer, S. 2000. Personal communication.

Sykes, M. T., Prentice, I. C., and Cramer, W. 1996. A bioclimatic model for the potential distributions of north European tree species under present and future climates. Journal of Biogeography 23: 203–233.

Thompson, R. S., Anderson, K. H., and Bartlein, P. J. 1999. Atlas of relations between climatic parameters and distributions of important trees and shrubs in North America. U.S. Geological Survey Professional Paper 1650 A&B.

Weisberg, P. 1998. Fire history, fire regimes, and development of forest structure in the central western Oregon Cascades. Ph.D. dissertation, Department of Forest Science, Oregon State University, Corvallis, Oregon.

Weisberg, P. 1997. Fire history of the Bear-Marten watershed. Final report to the U.S.D.I. Bureau of Land Management, Eugene District.

Weisberg, P. 1995. Unpublished manuscript. Fire history in the foothills of the central western Oregon Cascades, U.S.A.

Weisberg, P., and Swanson, F. In review-a. Regional synchronicity in changing fire regime patterns of the western Cascades, U.S.A.

Weisberg, P., and Swanson, F. In review-b. Fire dating from tree rings in western Cascade Douglas-fir forests: an error analysis.

GTOPO30. 1996. Global digital elevation dataset. U.S. Geological Survey Eros Data Center. http://edcdaac.usgs.gov/gtopo30/gtopo30.html.

U.S. Geological Survey Gap Analysis Program. 2000. Mission statement. http://www.gap.uidaho.edu/About/MissionStatement.htm.

Van Norman, K. J. 1998. Historical fire regime in the Little River watershed, southwestern Oregon. M.A. thesis, Department of Forest Science, Oregon State University, Corvallis, Oregon.