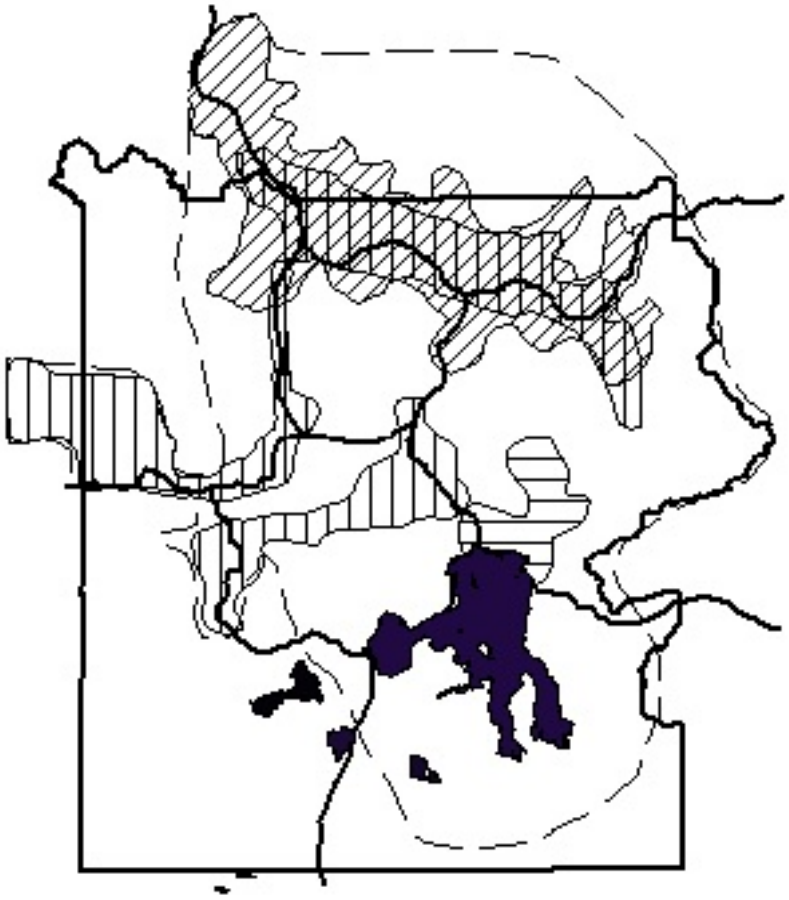


Figure 1. Study area boundary (dashed line), park boundary and main roads (thick solid lines), lakes (solid fill), northern elk winter range (diagonal hatching), northern bison winter range (vertical bars overlapping northern elk range), Pelican Valley bison winter range (horizontal hatching), Firehole/Hayden/West bison winter ranges (vertical hatching).

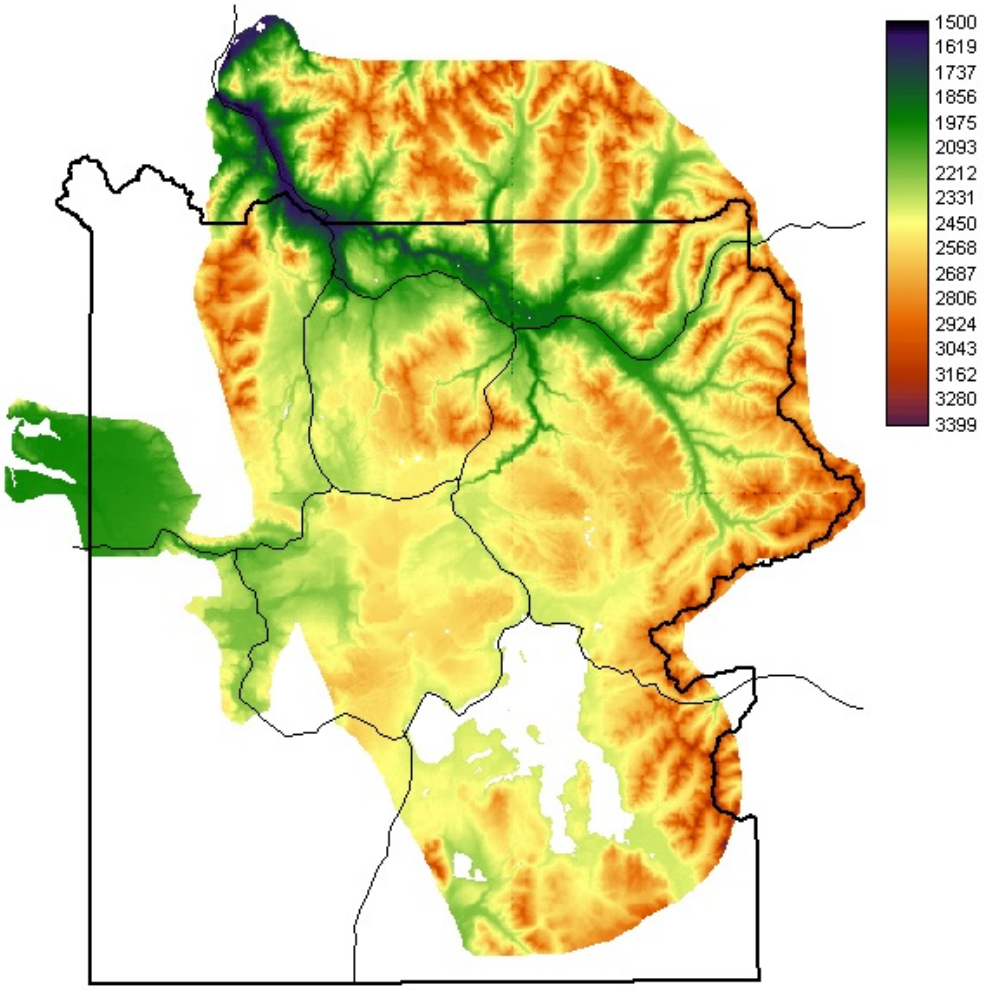


Figure 2. Elevation (m), boundary, and roads (black) of Yellowstone National Park and surrounding areas.

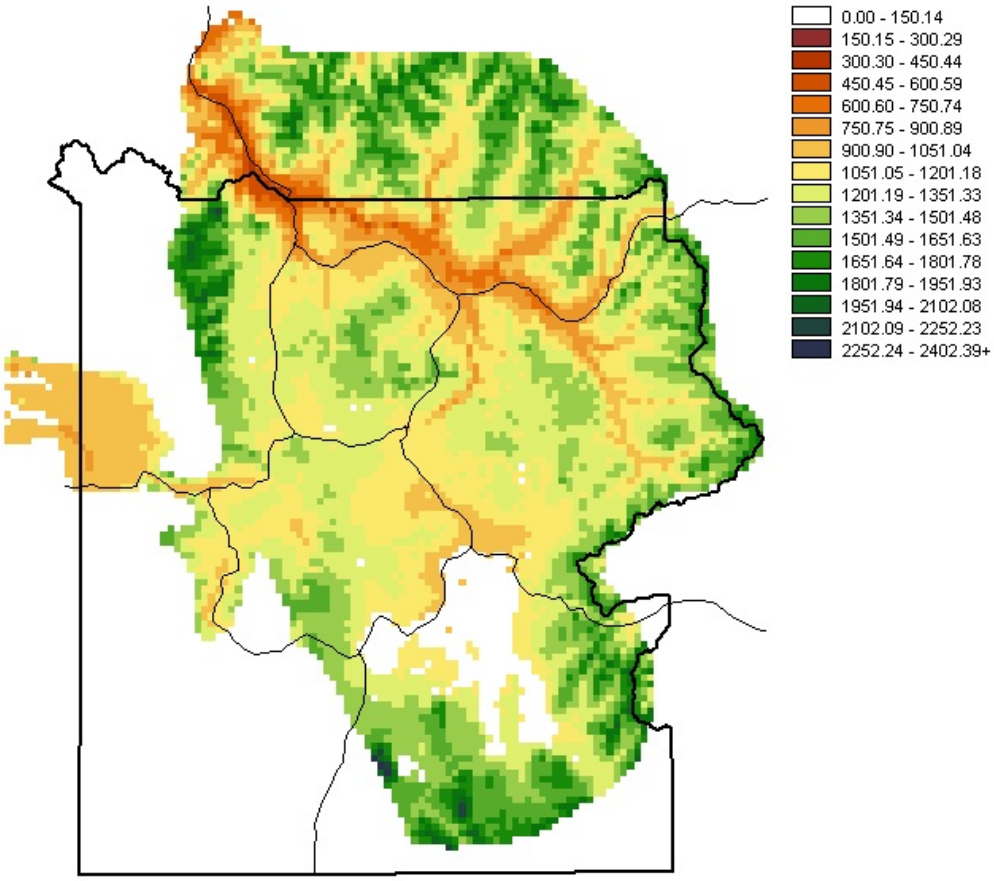
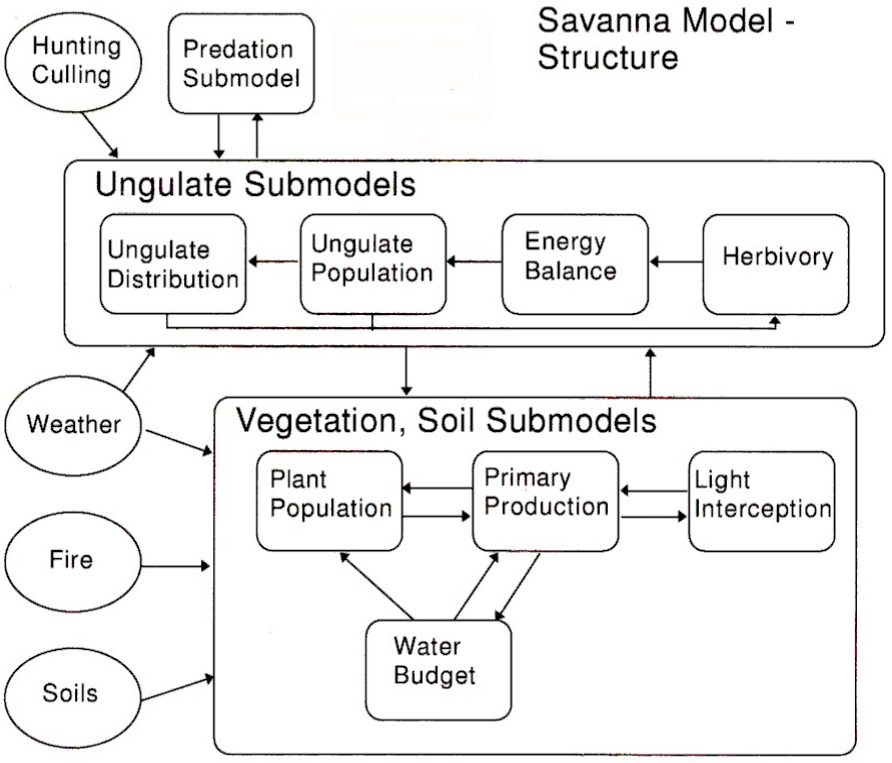


Figure 3. Average annual precipitation (cm) 1969-2004 with 1 km resolution. Also showing study area boundary, park boundary and roads.

A)



B)

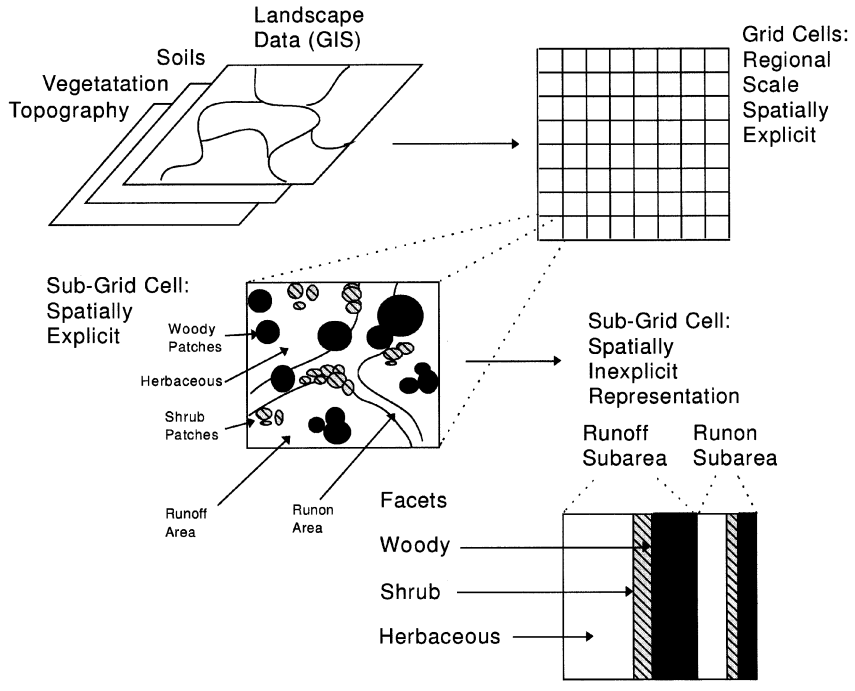


Figure 4. A) Primary components of the SAVANNA model. B) Spatial structure of the model.

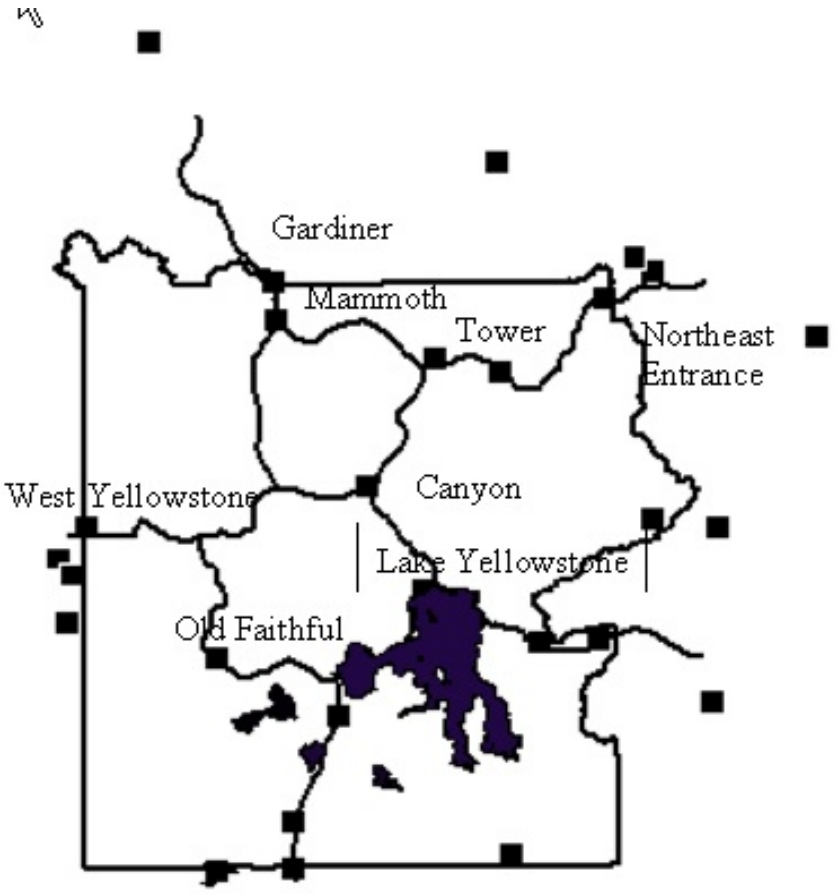


Figure 5. Locations of SNOTEL and climate stations.

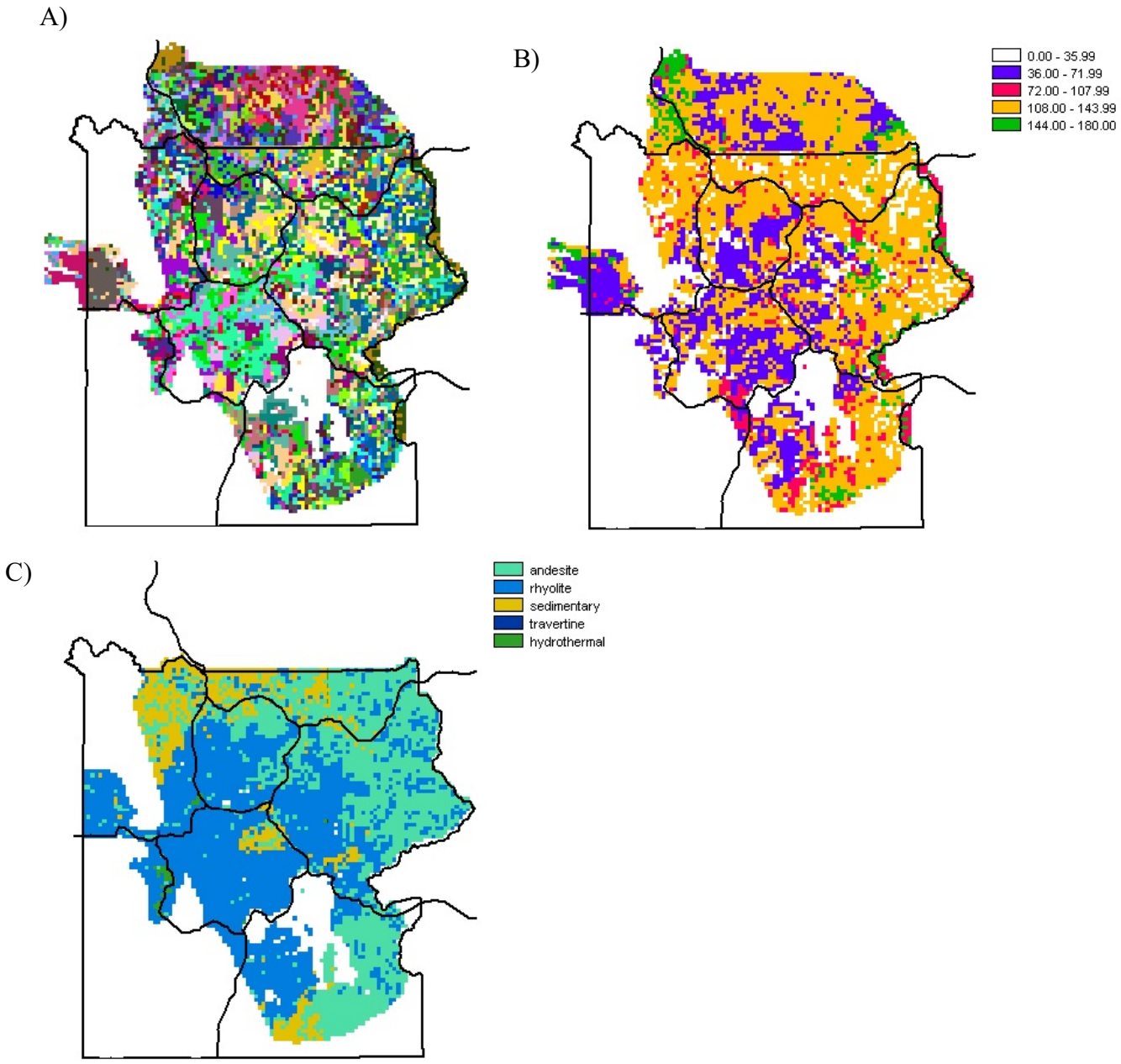


Figure 6. A) Soil map at 1 km resolution uniting data from three soil survey sources. There are 197 soil types, which more than can be displayed using color coded classes and a legend. B) Soil water holding capacity (mm) of the top meter of soil based upon soil textural classes and depths noted in the soil surveys, and typical field capacities and wilting points for the textural classes. . C) Soil substrate types in Yellowstone National Park.

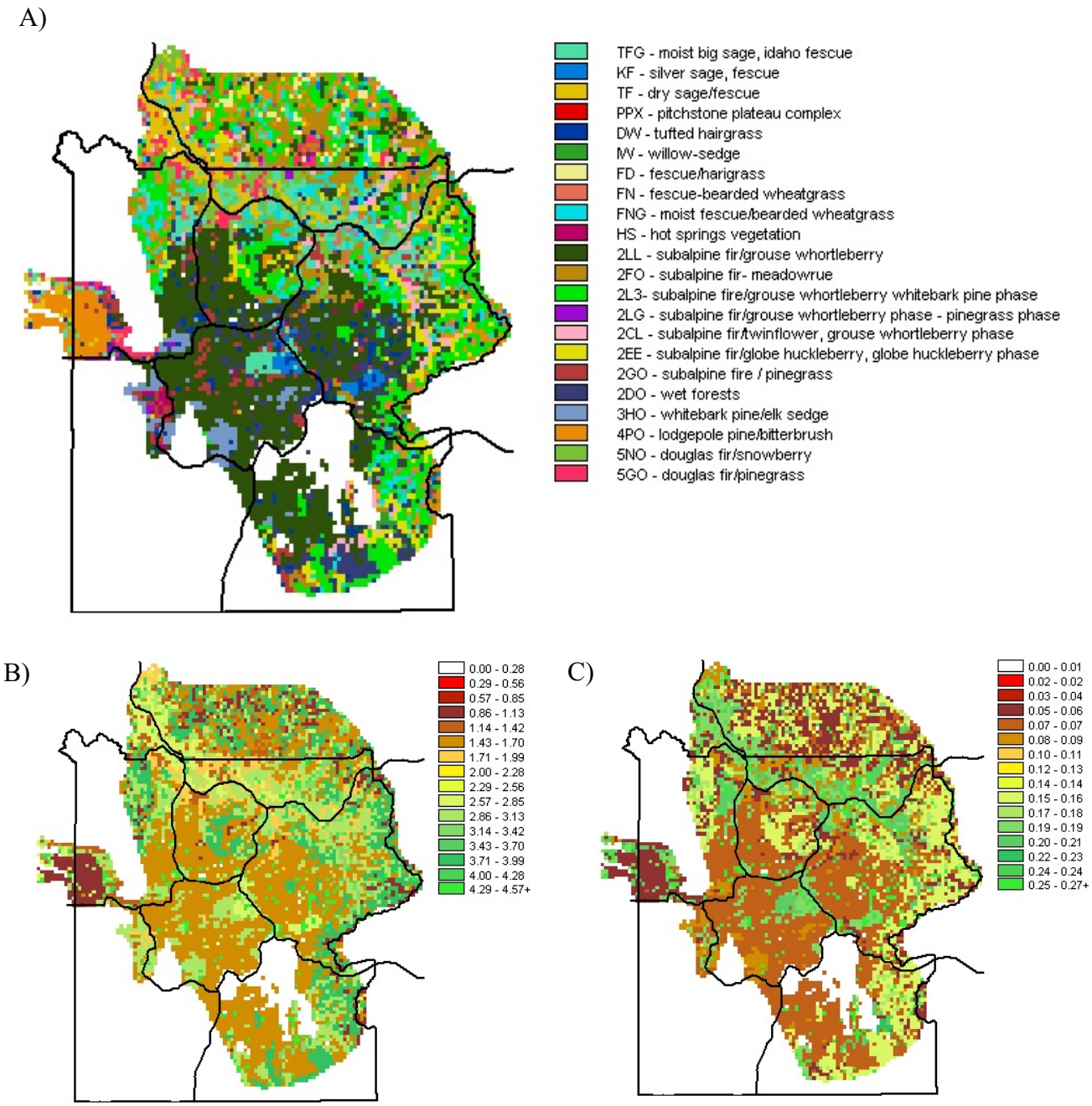


Figure 7. A) Simplified habitat map based upon an aggregation of habitat classes recognized on the habitat map of Despain (1990), to correspond to those habitat types sampled in Trettin's (1986) soil study. B) Soil carbon (%) and C) soil nitrogen (%) in the top 20 cm based on Trettin's soil data.

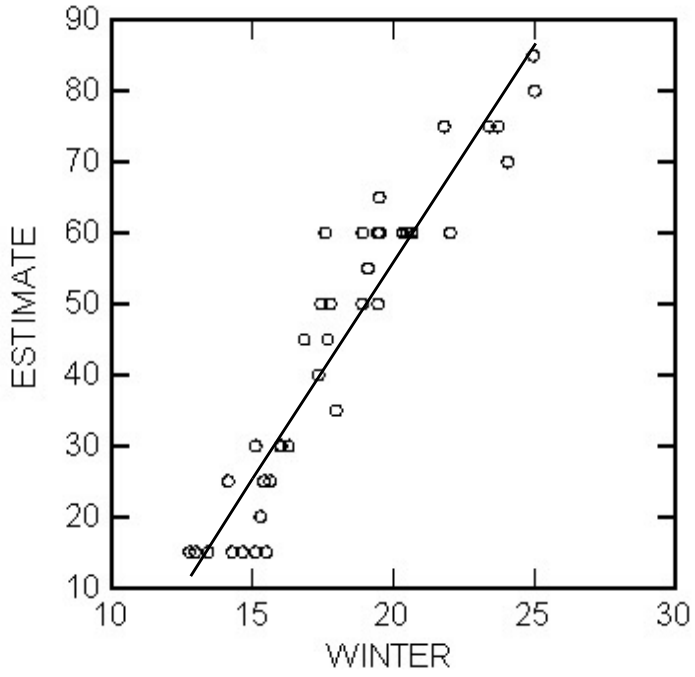


Figure 8. Estimated canopy cover plotted against the winter NDVI value. Y = -65.6 + 6.1*X; r^2=0.89; p<.001. Each point is the mean estimated tree cover for a tree cover class (eg. LP1, LP2, DF1, DF2).

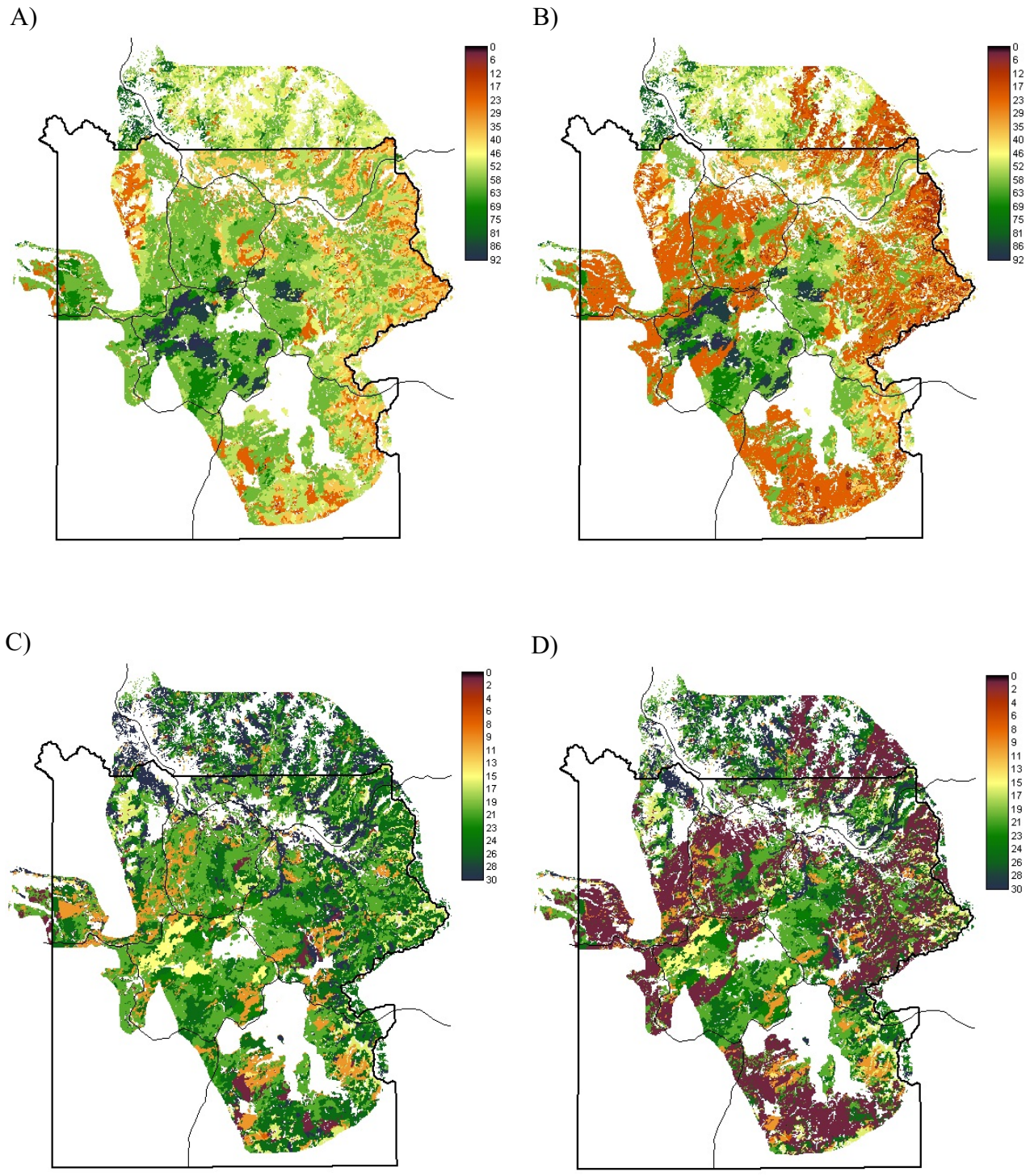


Figure 9. Estimated tree canopy cover (%) at 100 m resolution before (A) and after (B) the 1988 fires. Non-forested areas are white C) Tree diameter (mm) before 1988 fire. D) Tree diameter (mm) after the 1988 fires,

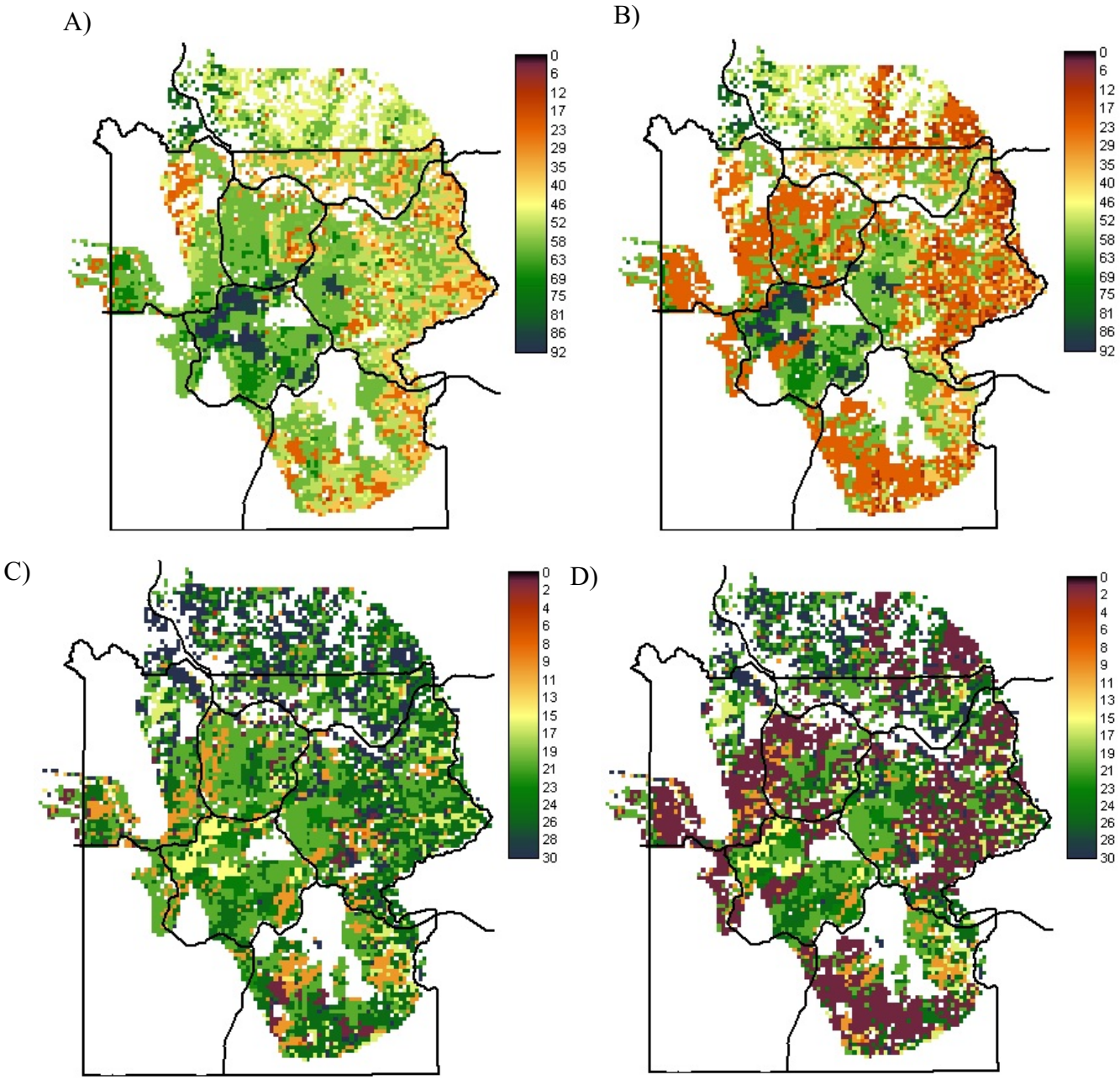


Figure 10. Estimated tree canopy cover (%) at 1 km resolution before A) and after (B) the 1988 fires and C) tree size (mm diameter) before and D) after the fires converted to 1 km resolution.

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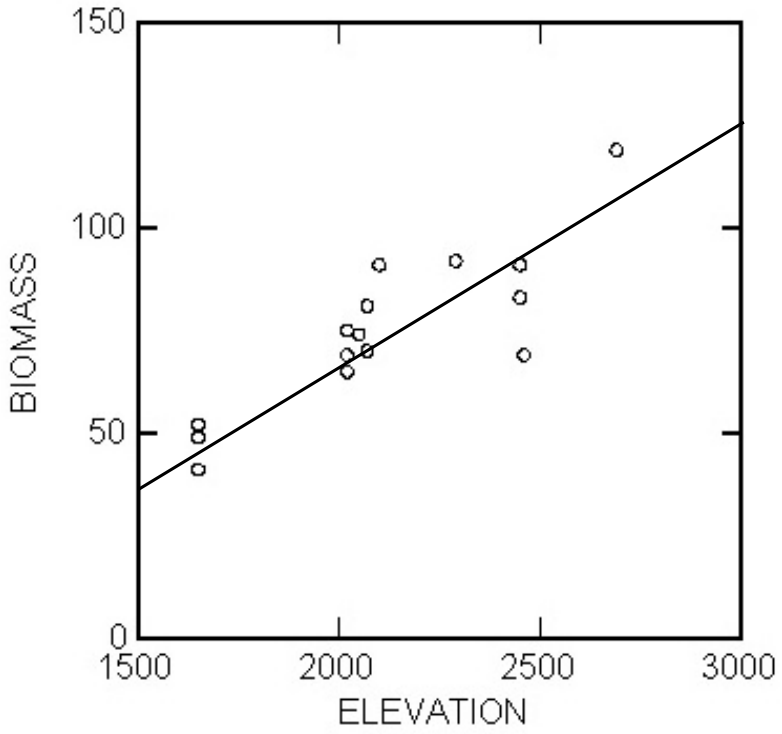


Figure 11. A) Total aboveground herbaceous biomass (g $m^{-2}2$) in dry grasslands vs. elevation (m), based upon a synthesis of data from various sources (Table 3). Y = -50.0 - 0.058*X, r^2=0.62, p<0.001. Each point represents a mean value for a study site (eg. Stevens Creek, Coughenour 1991).

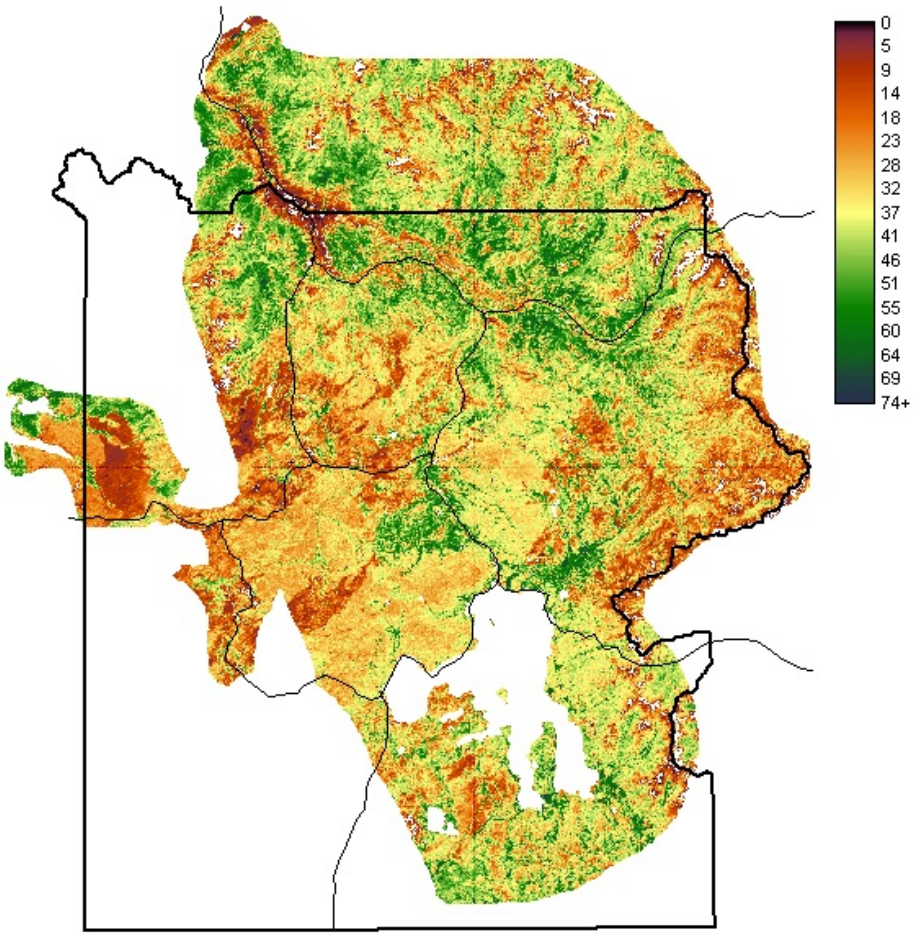


Figure 12. Normalized difference vegetation index (NDVI) over the entire extended study area.. This is a maximum value composite of three Landsat Thematic Mapper (TM) images for: July 7, 1998; July 19,1998; and July 31 2000.

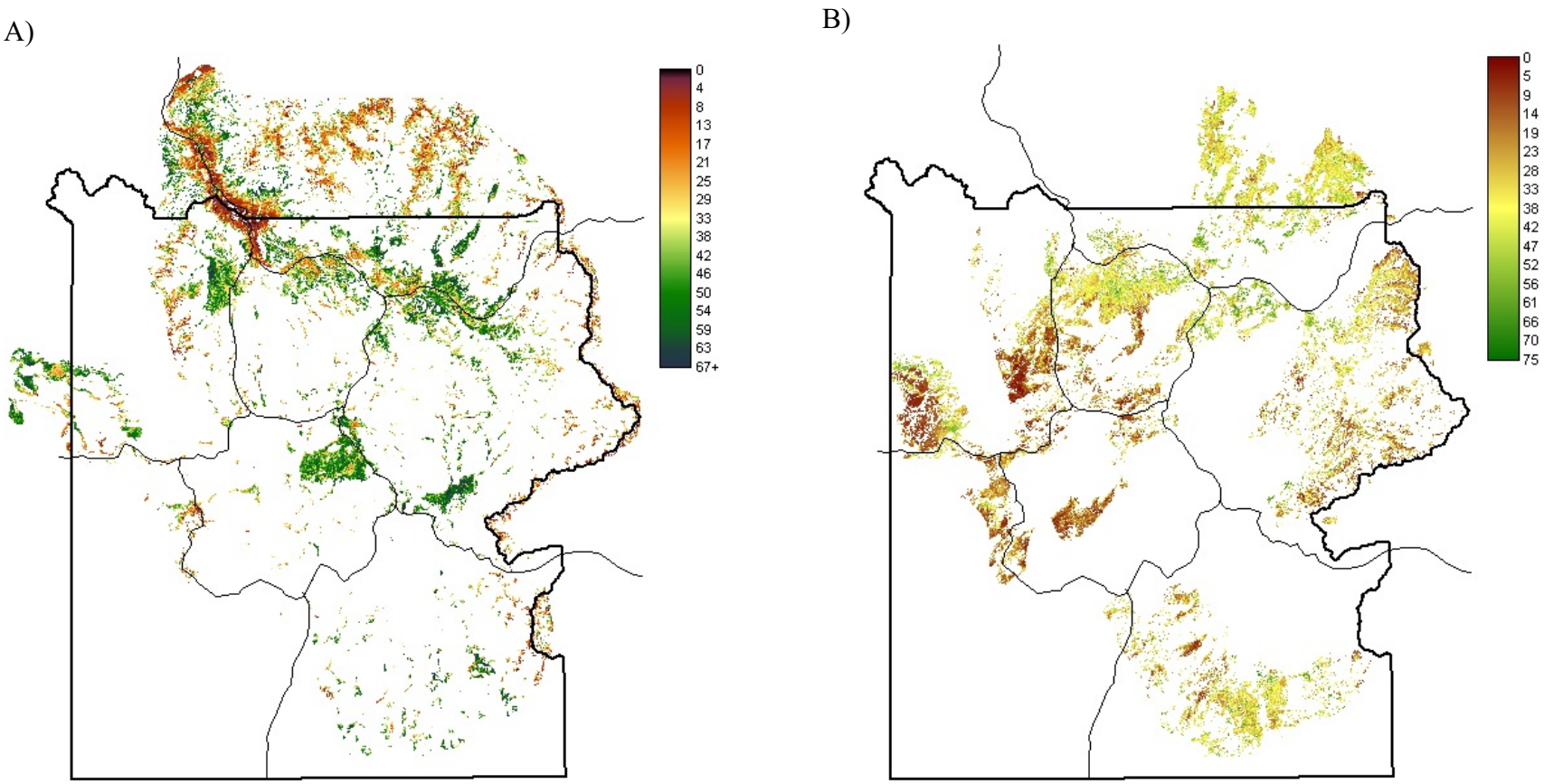


Figure 13. Normalized difference vegetation index (NDVI) in 1998-2000 in (A) non-forested cover types and (B) in areas that burned in the 1988 fires.

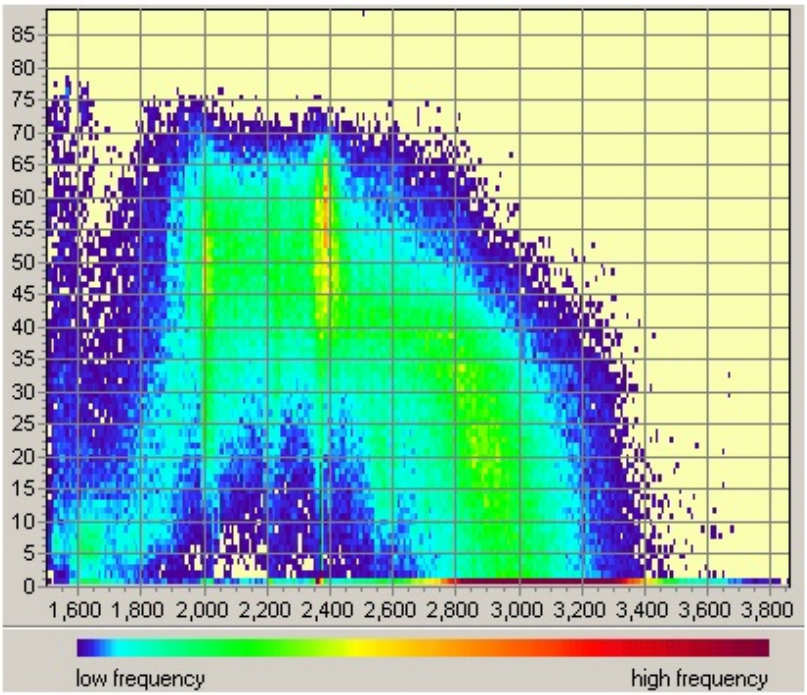


Figure 14. NDVI (X axis) versus elevation m (Y axis) in 100 m pixels in non-forested cover types. Colors show the frequency of pixels.

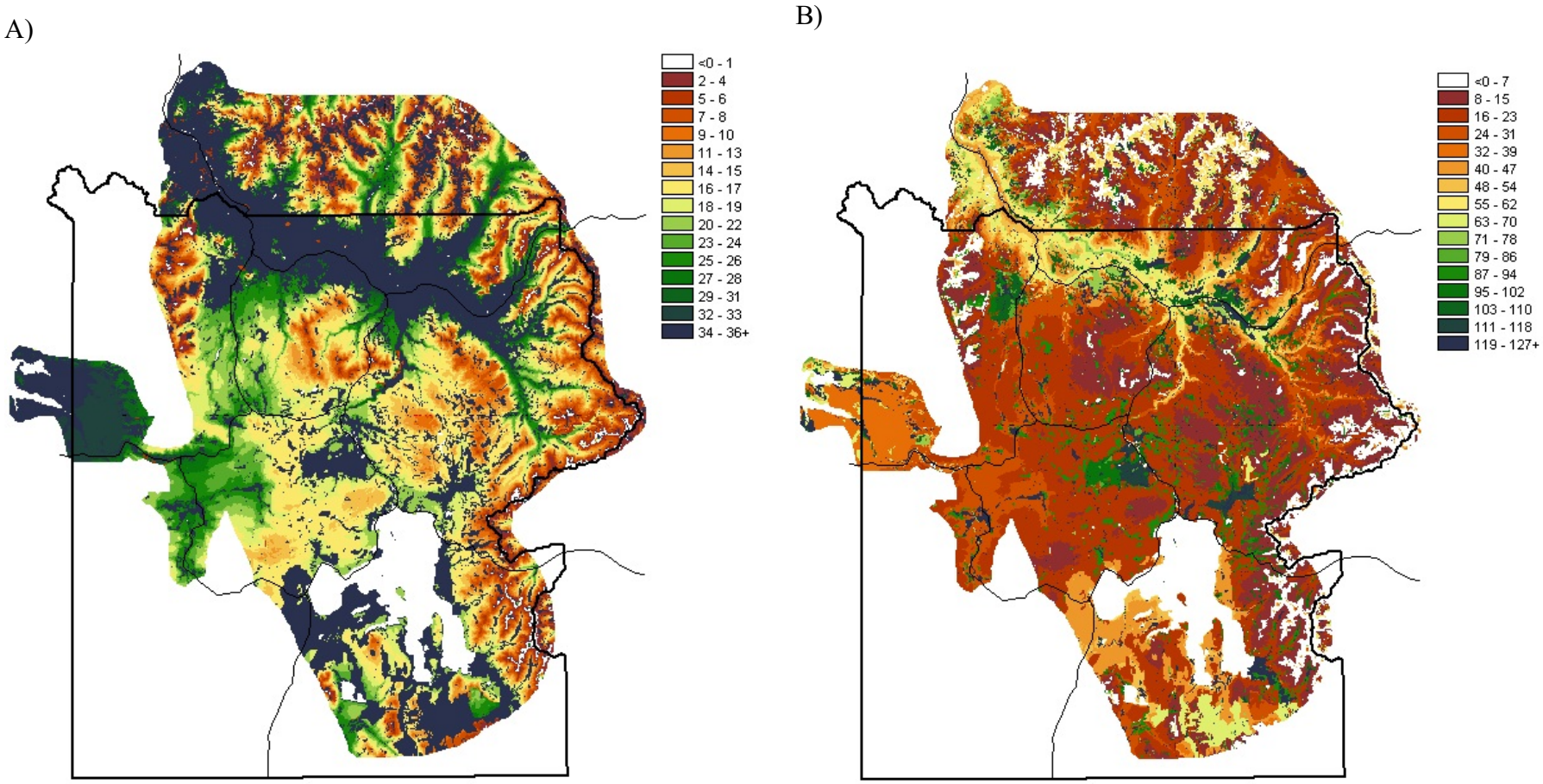


Figure 15. Herbaceous biomass (g m^{-2}) as estimated by the data model, at 100 m resolution. A) Scaled to show differences within low biomass areas, and B) scaled to show differences within high biomass areas.

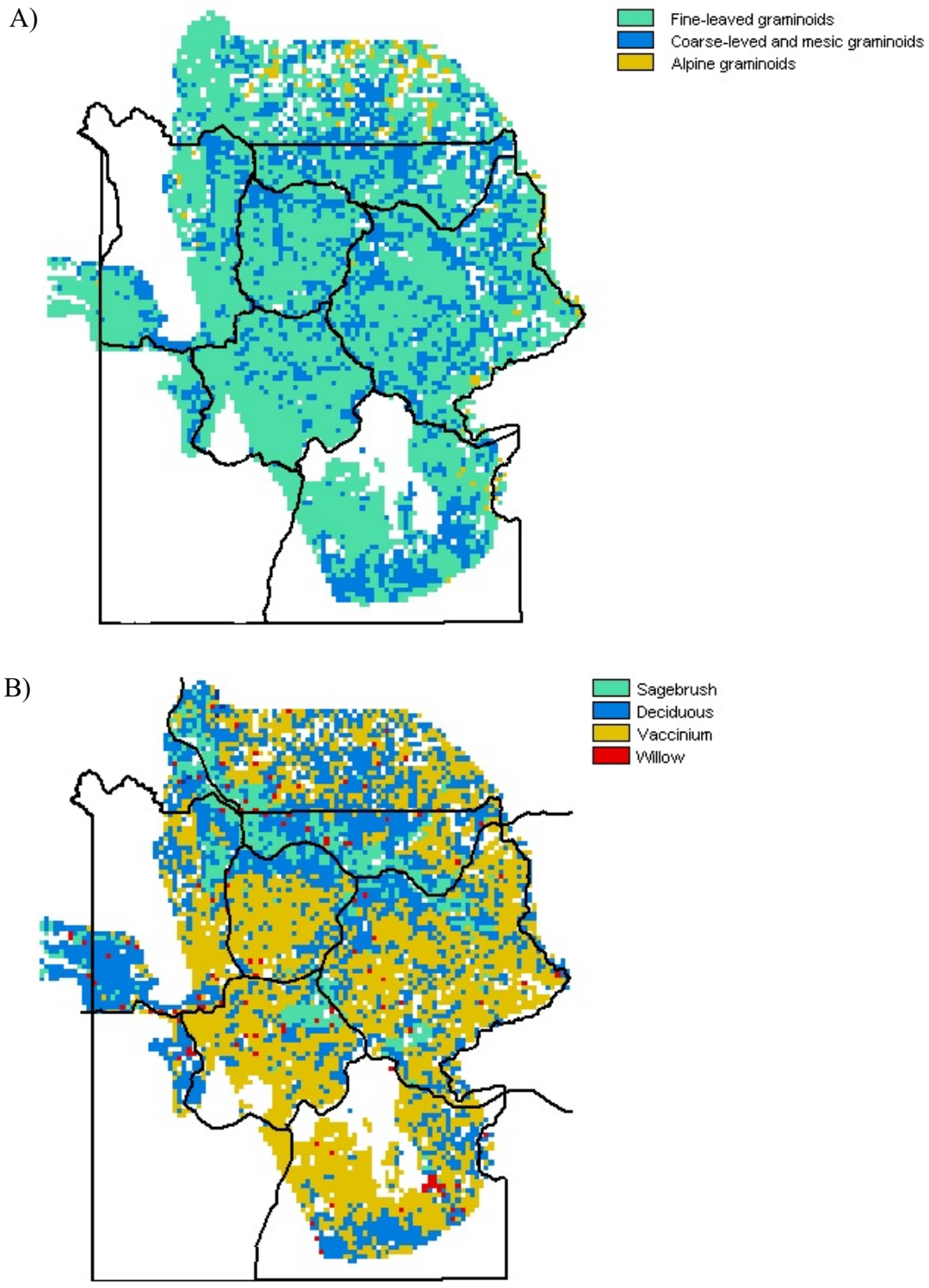
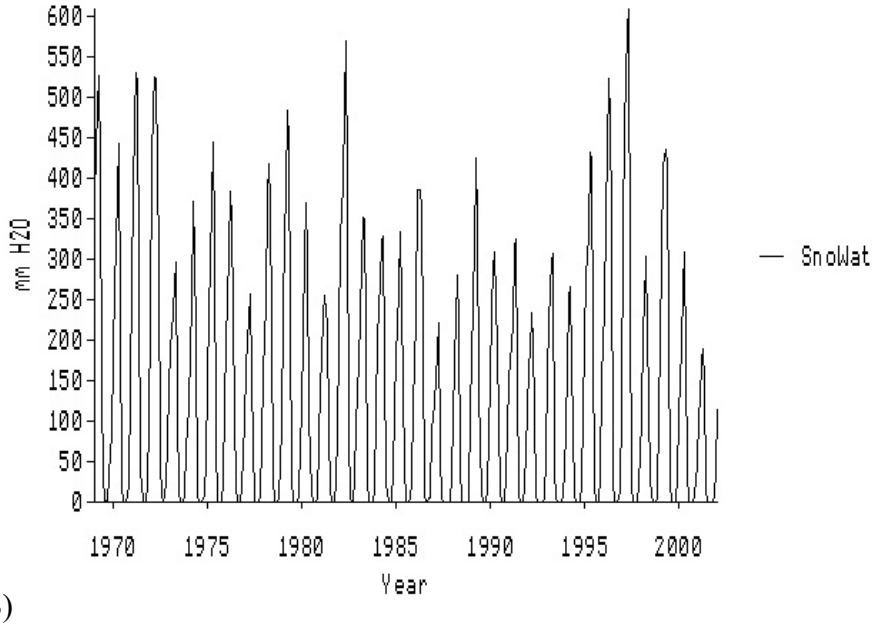


Figure 16. A) Distribution of the three major graminoid types and B) distribution of the four major shrub types simulated in the model.

A)



B)

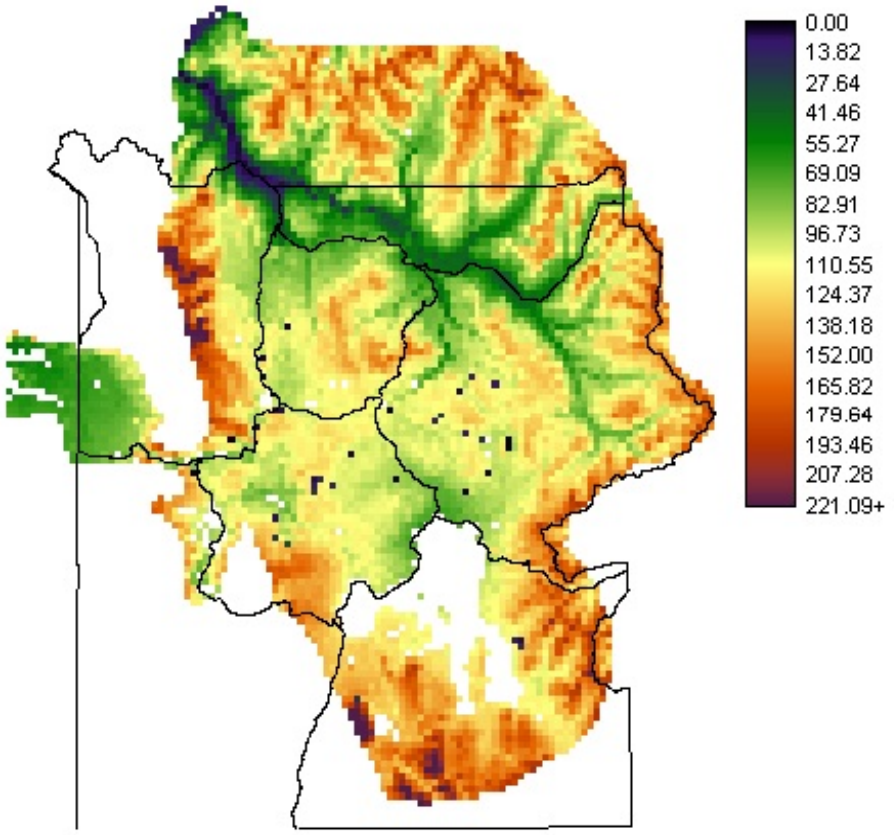
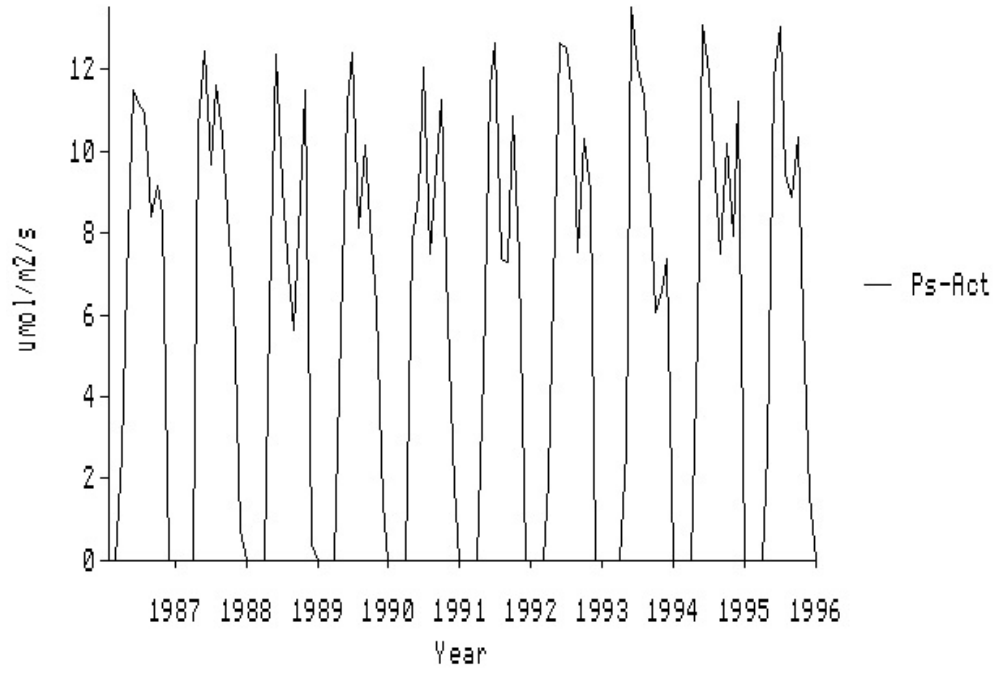


Figure 17. A) Predicted snow water content. B) Predicted mean snow depth(cm) at the end of February 1969-2001. Isolated white or blackened (low snow depth) grid-cells are thermal areas, with the exception of Heart Lake (southwest of Lake Yellowstone)..

A)



B)

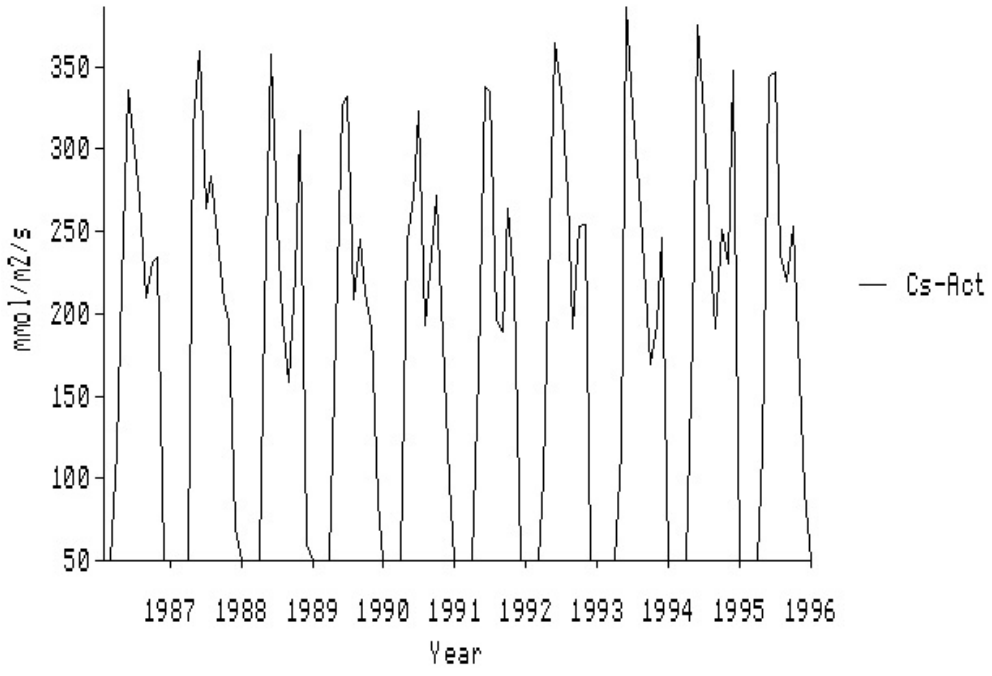
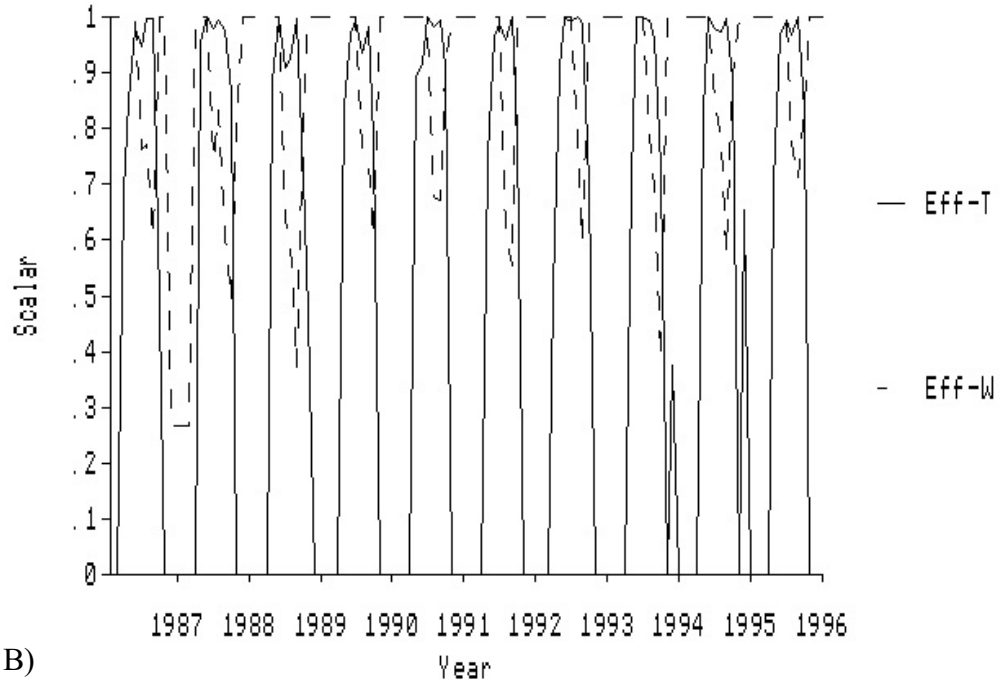


Figure 18. A) Daytime average photosynthetic rate and B) daytime average stomatal conductance of upland grasses on one grid-cell on the northern range.

A)



B)

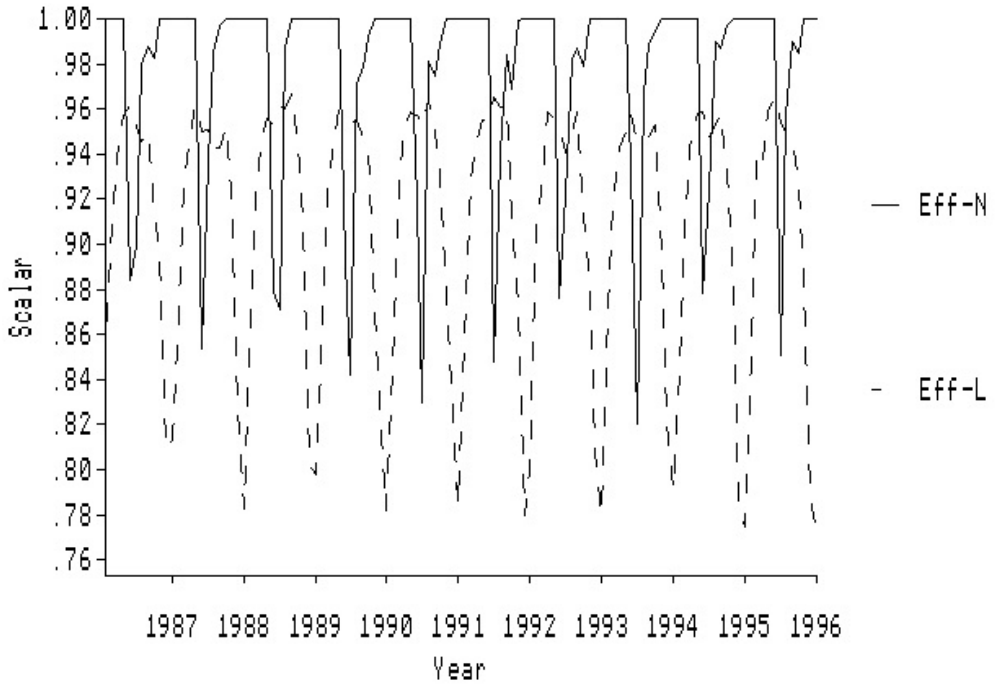
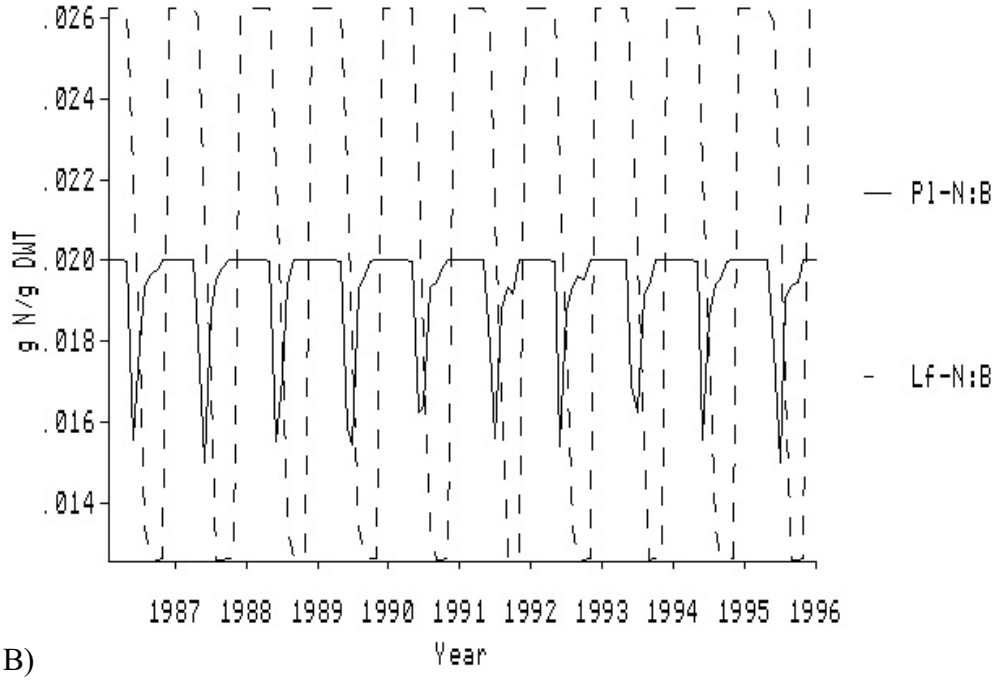


Figure 19. Scalar effects on grass photosynthetic rate on one sagebrush grassland grid-cell on the northern range. A) Effects of soil moisture (Eff-W) and temperature (Eff-T). B) Effects of nitrogen (Eff-N) and light (Eff-L).

A)



B)

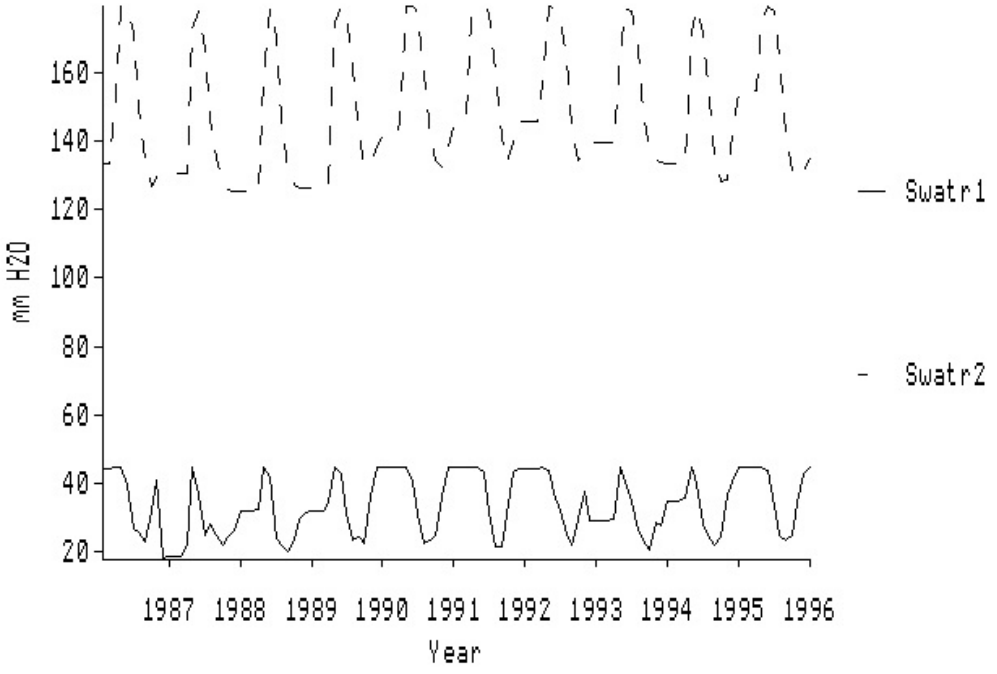
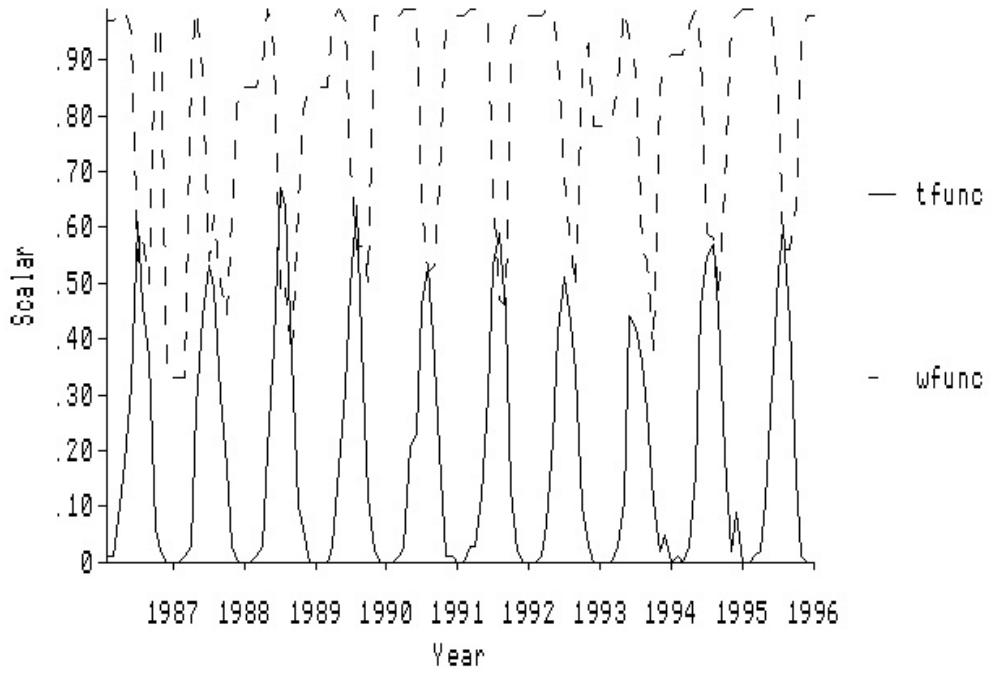


Figure 20. A) Plant (Pl-N:B) and live leaf (Lf-N:B) nitrogen concentrations. B) Soil water in top soil layer (Swatr1) and intermediate soil layer (Swatr2). Both on one grassland grid-cell on the northern range.

A)



B)

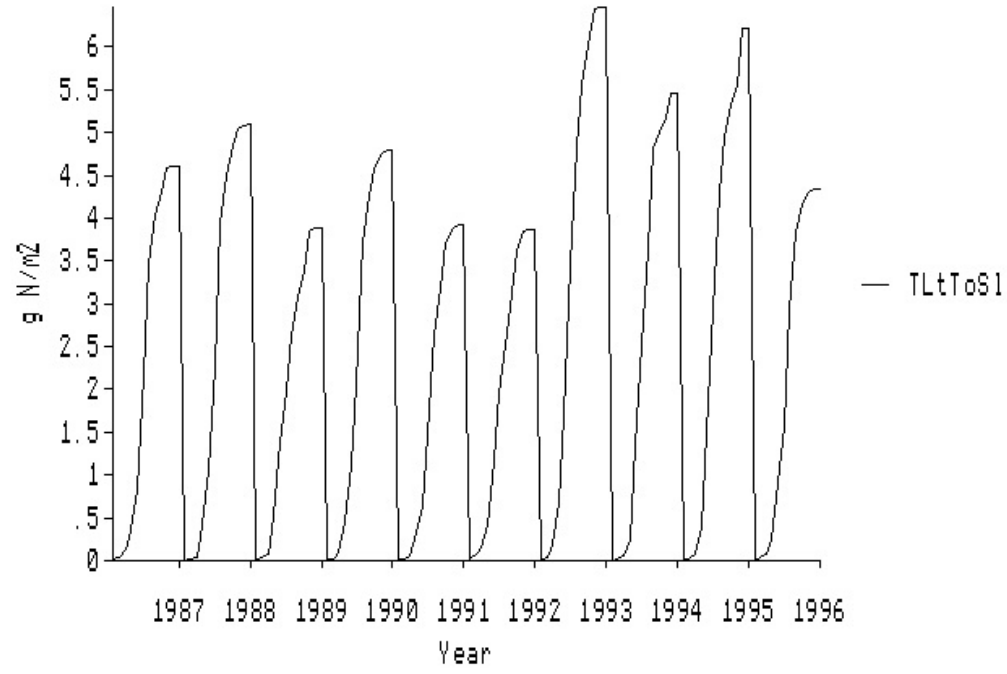
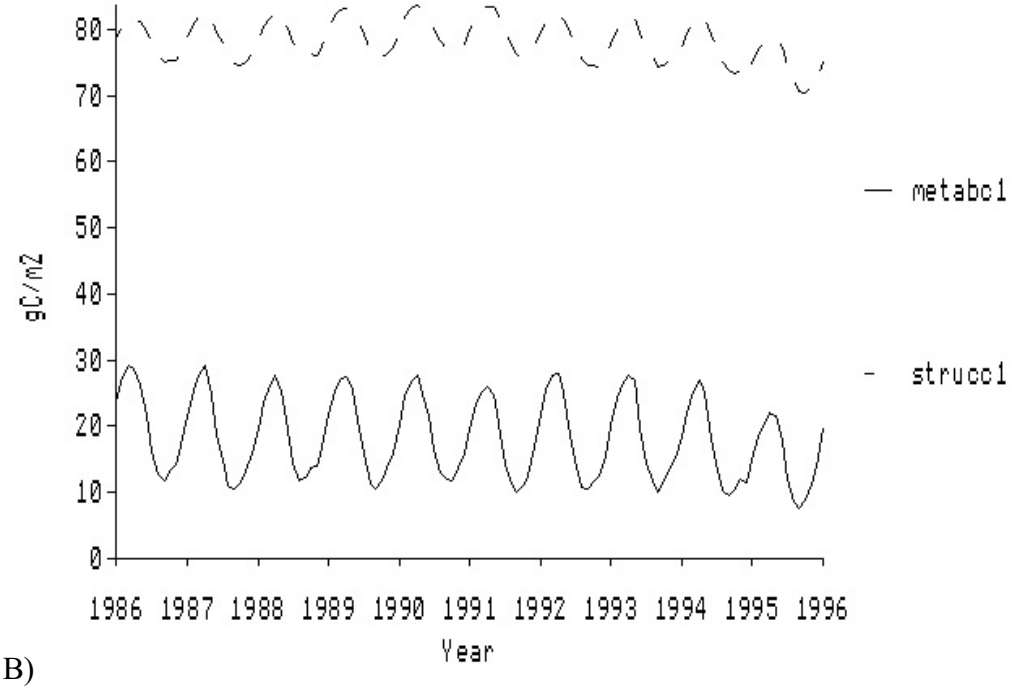


Figure 21. A) Effects of temperature (tfunc) and soil water (wfunc) on decomposition rate. B) Annual accumulative nitrogen mineralization from litter and soil organic matter.

A)



B)

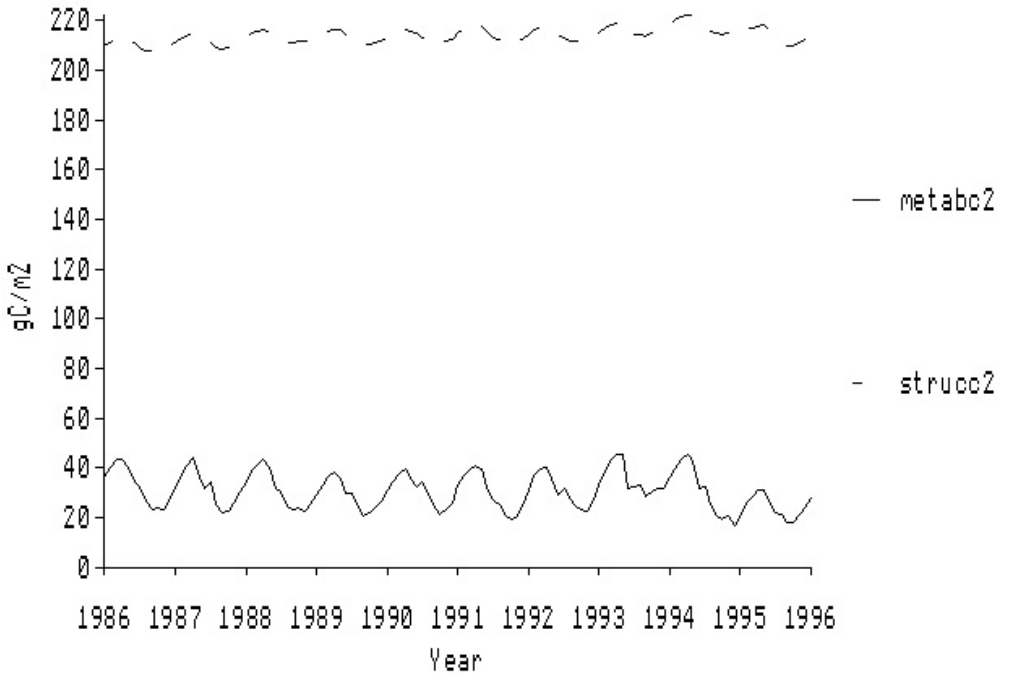


Figure 22. A) Metabolic (metabc1) and structural (strucc1) litter carbon on the soil surface. B) Metabolic (metabc2) and structural (strucc2) litter carbon belowground.

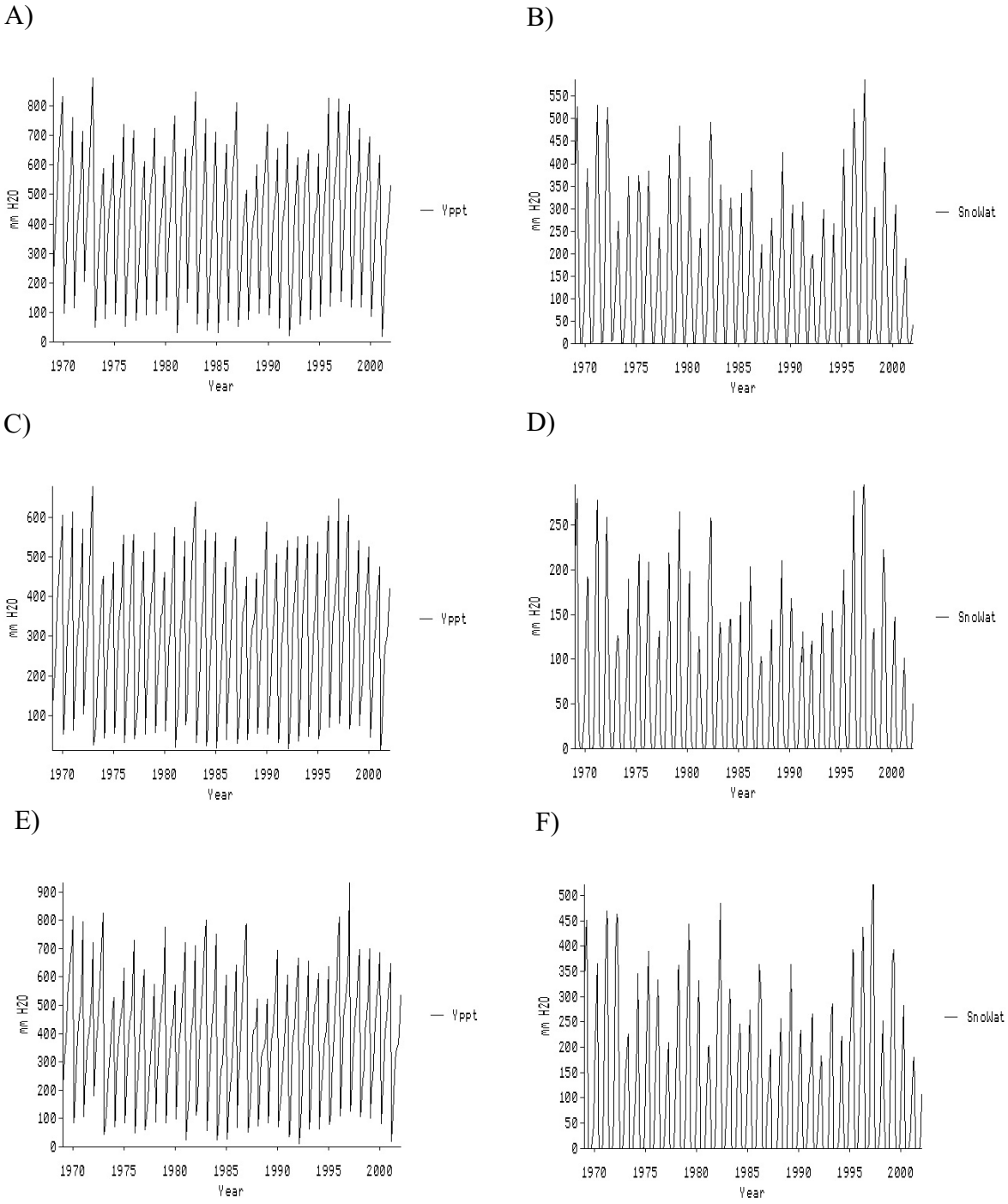


Figure 23. A) Cumulative annual precipitation over the entire study area (reset to zero each year), B) snow water over the entire study area, C) precipitation on the northern range non-forested area, D) snow water on the northern range, E) precipitation in Hayden Valley non-forested areas, F) snow water in Hayden Valley.

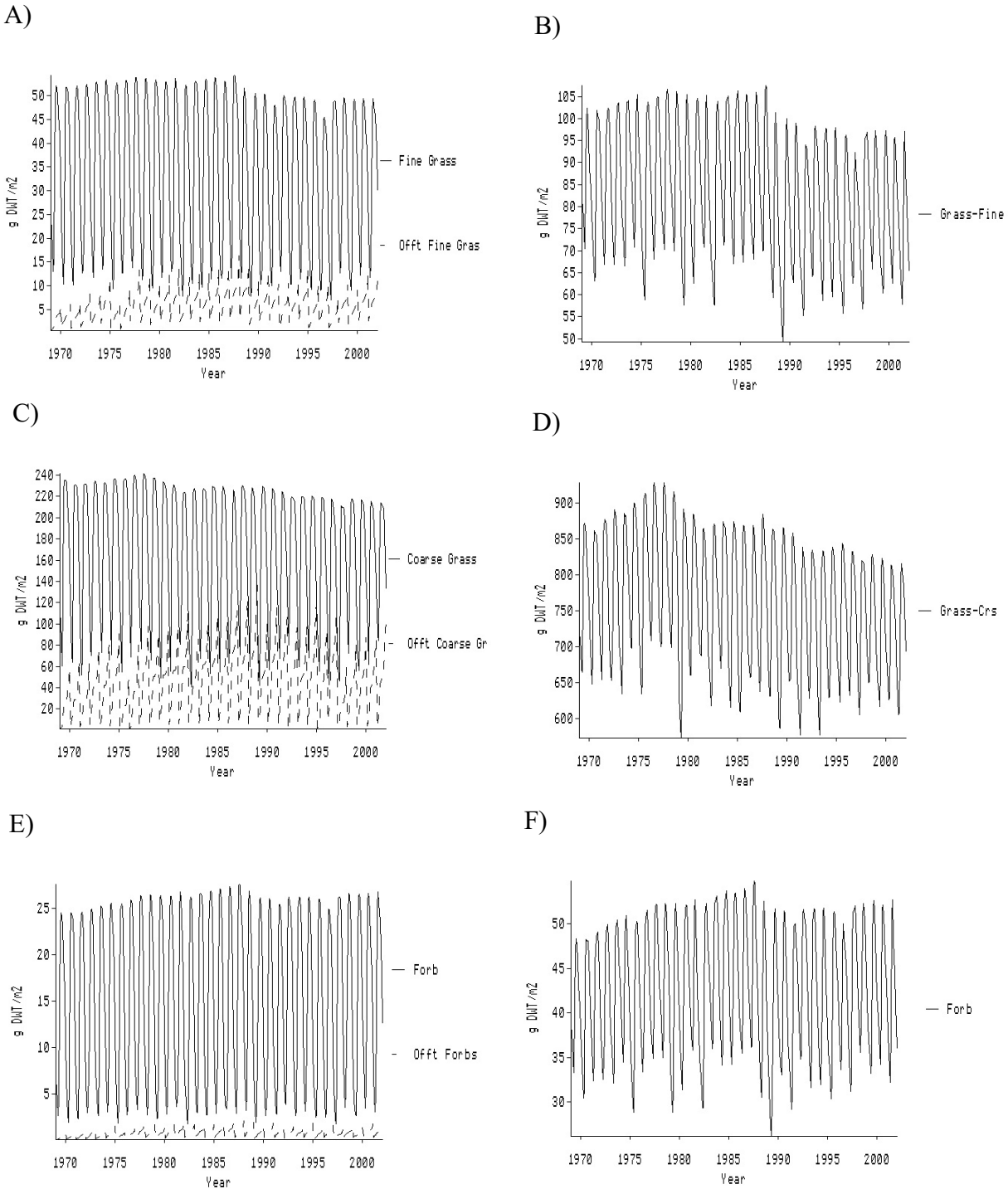


Figure 24. Herbaceous biomass dynamics on non-forested areas of the northern range. A) Fine grass aboveground biomass and offtake, B) fine grass roots, C) coarse (mesic) graminoid aboveground biomass and offtake, D) coarse grass roots, E) forb aboveground biomass and offtake, F) forb roots.

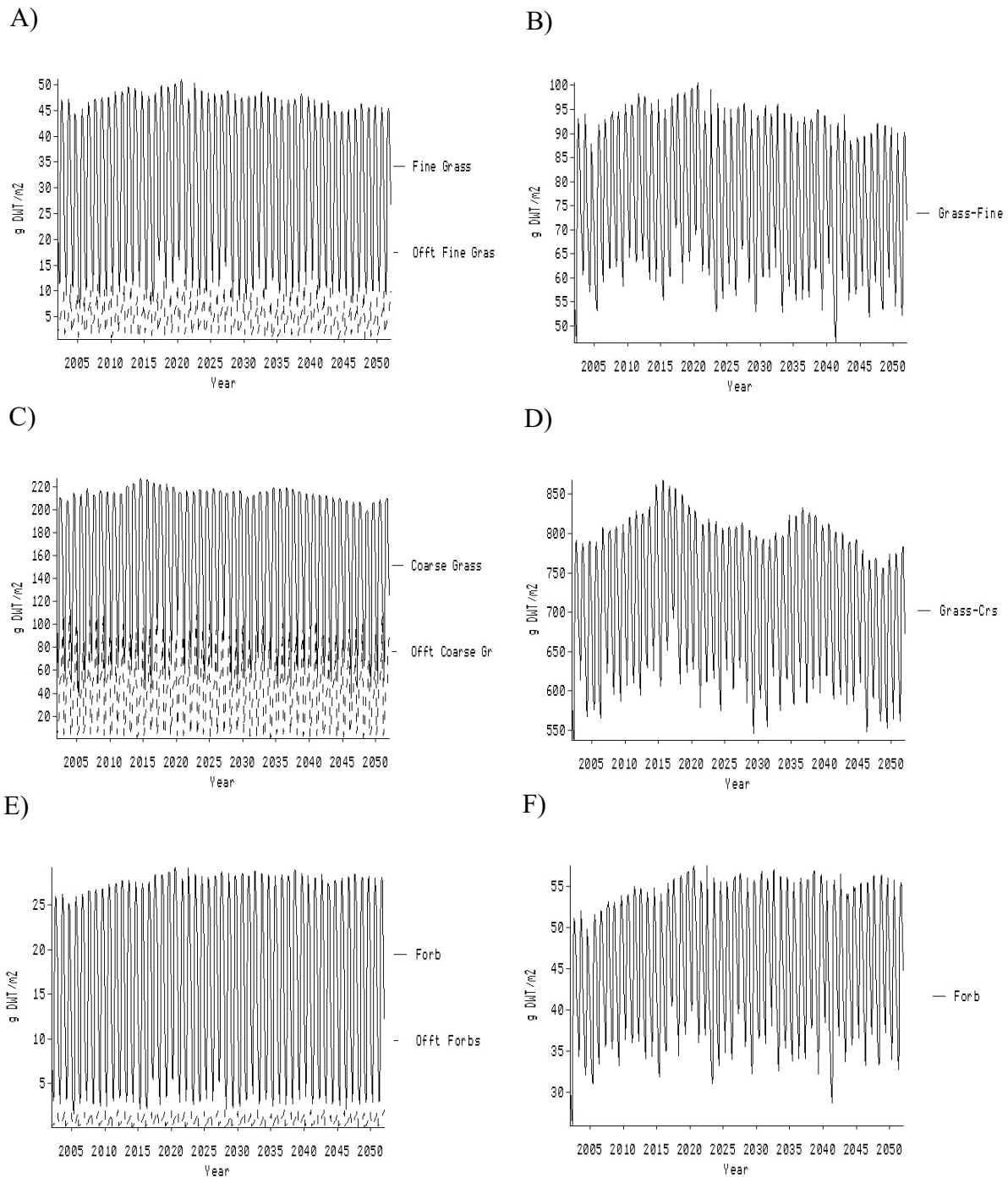


Figure 25. Herbaceous biomass dynamics on non-forested areas of the northern range in an extended 50-year run. A) Fine grass aboveground biomass and offtake, B) fine grass roots, C) coarse (mesic) graminoid aboveground biomass and offtake, D) coarse grass roots, E) forb aboveground biomass and offtake, F) forb roots.

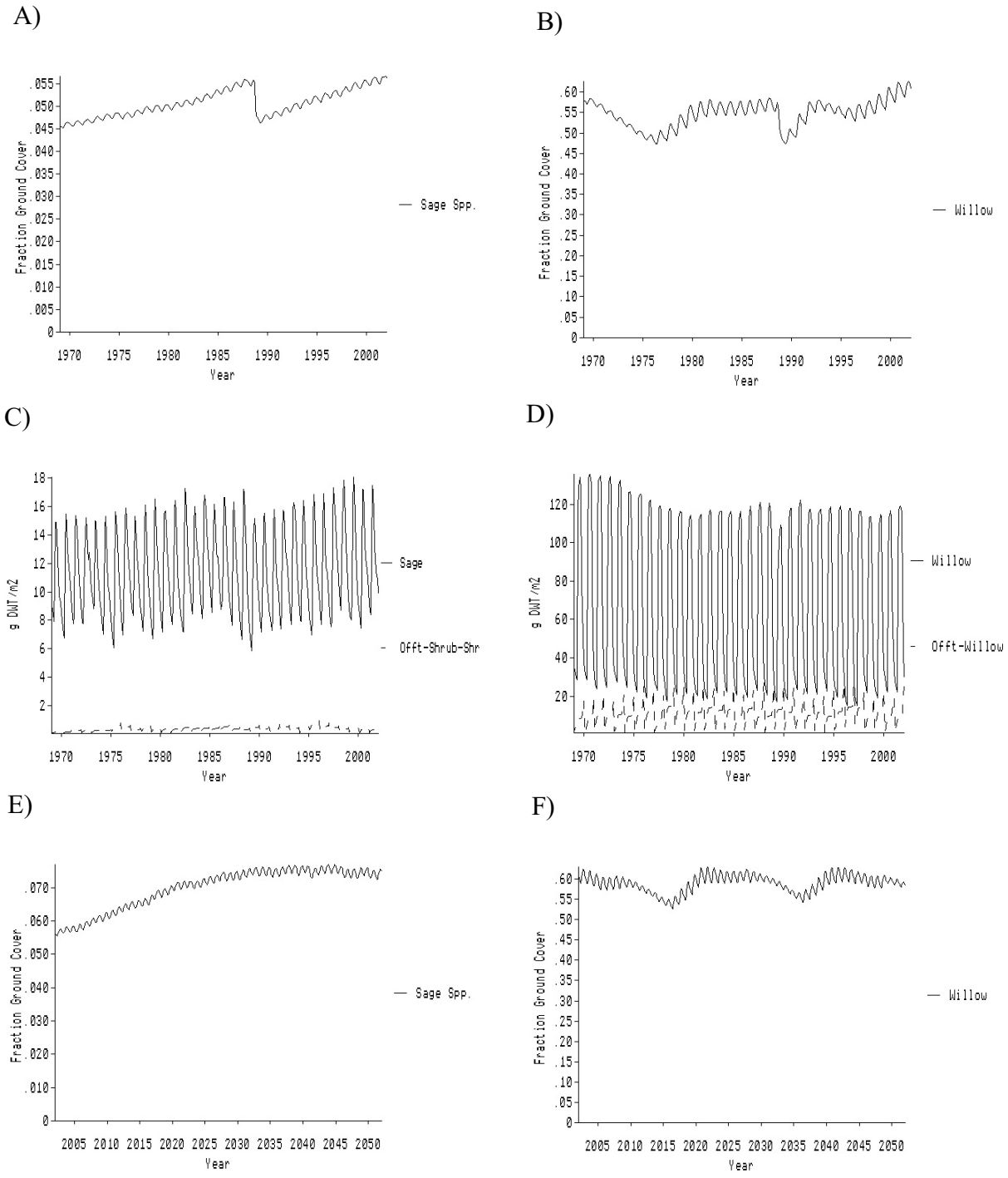


Figure 26. Northern range non-forested areas. A) Sagebrush cover (in sagebrush habitats), B) willow cover (in willow habitats), C) sagebrush leaf biomass and offtake, D) willow leaf biomass and offtake. E) Sagebrush cover and F) willow cover in an extended 50-year run

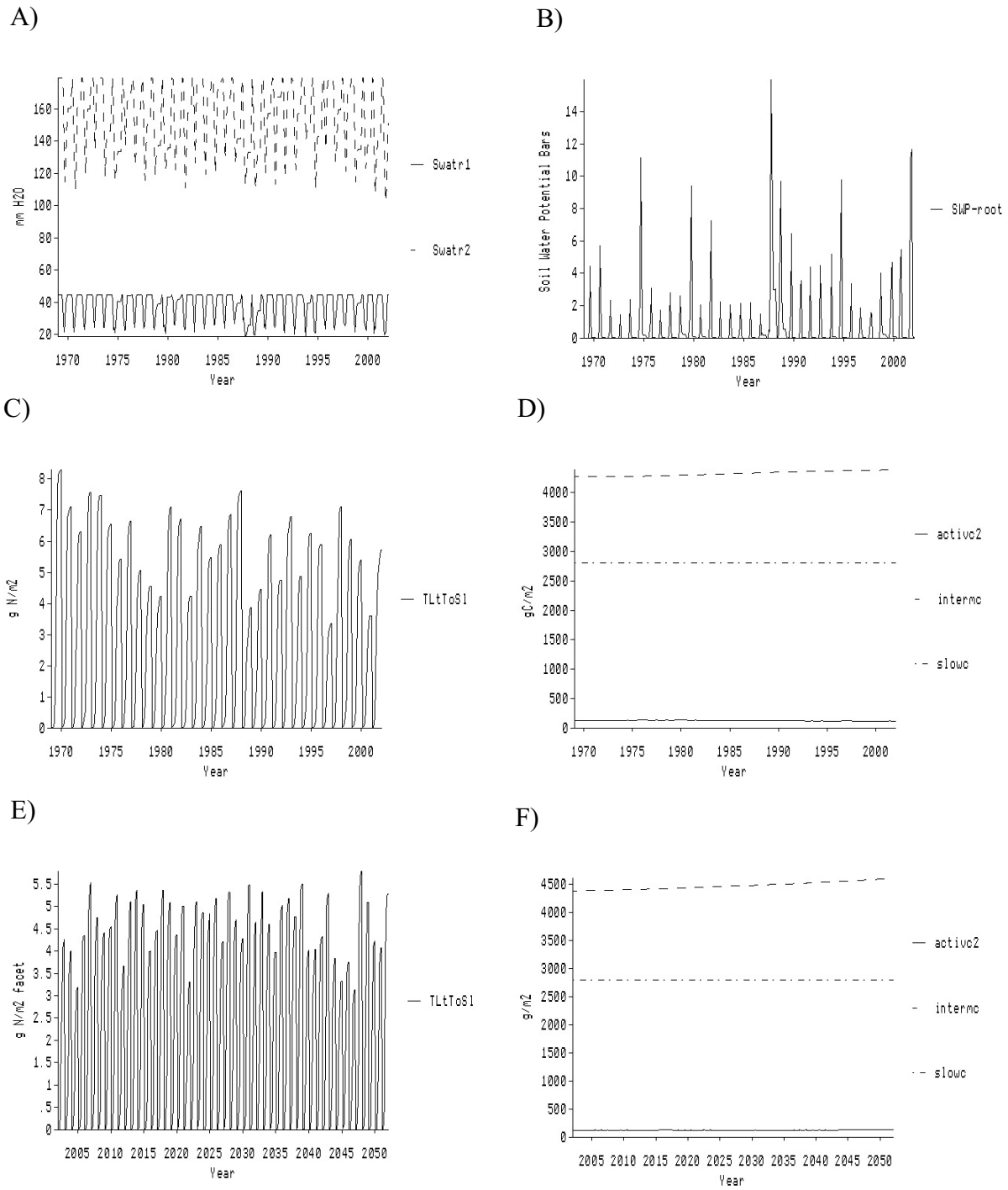


Figure 27. Northern range non-forested areas. A) Soil water in layer 1 (0-20cm) and layer 2 (20-100 cm), B) effective soil water potential experienced by herbaceous plants, C) nitrogen mineralization, cumulative each year, and D) soil organic matter carbon in the active, intermediate turnover time, and slow turnover pools. E) N mineralizatoin and F) SOM in the 50 yr extended run.

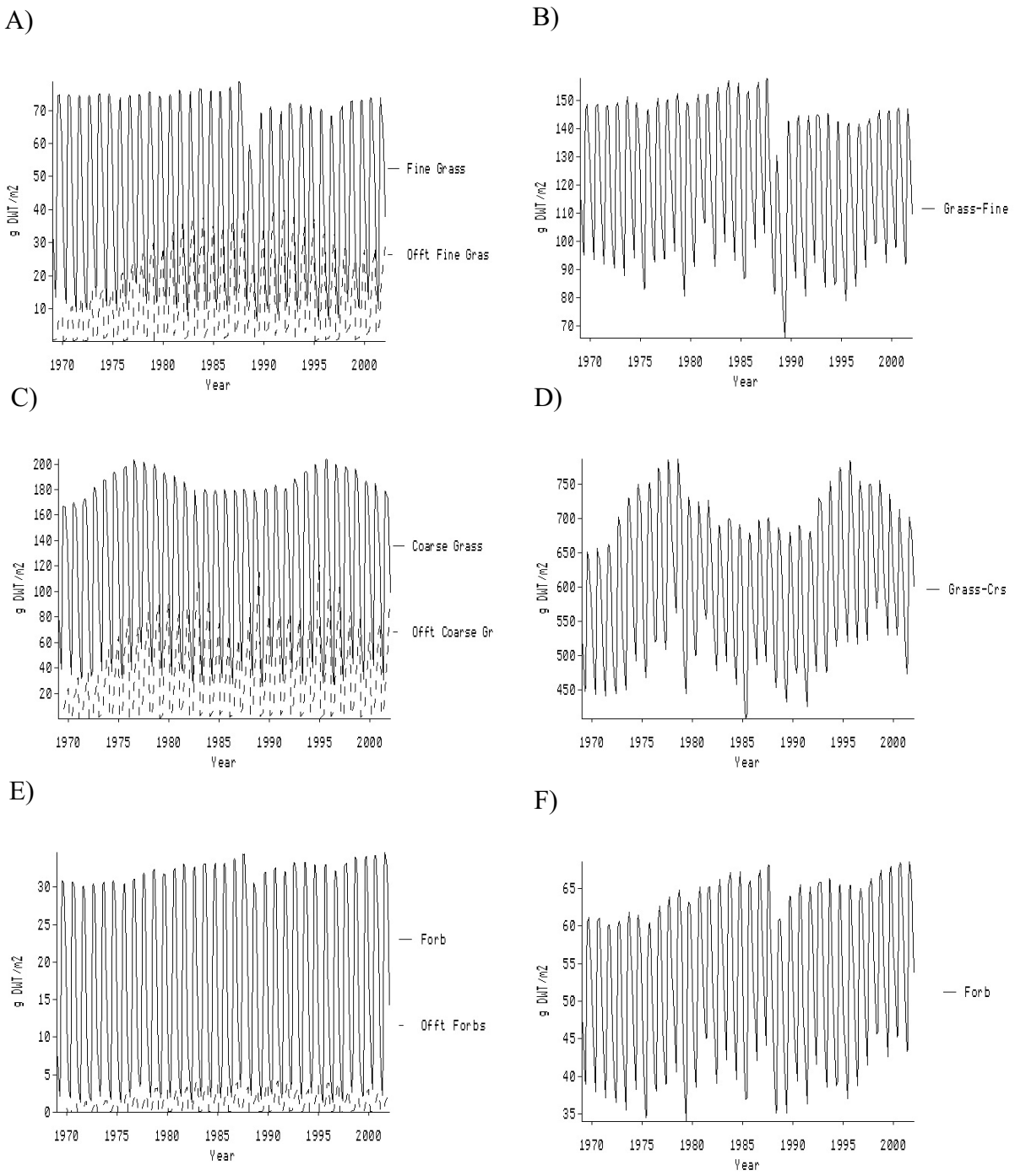


Figure 28. Herbaceous biomass dynamics on non-forested areas of the Hayden Valley. A) Fine grass aboveground biomass and offtake, B) fine grass roots, C) coarse (mesic) graminoid aboveground biomass and offtake, D) coarse grass roots. E) forb aboveground biomass offtake, F) forb roots.

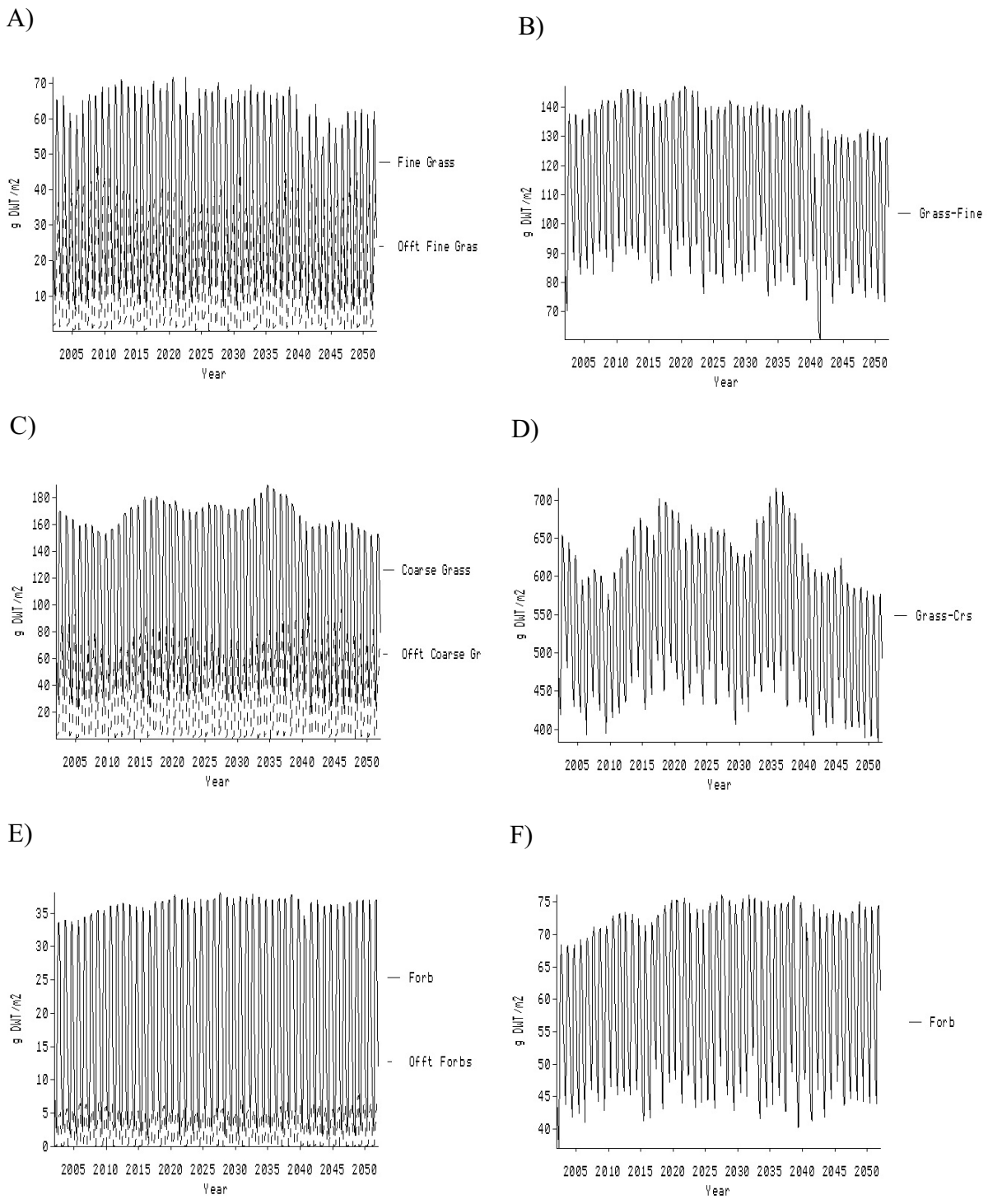


Figure 29. Herbaceous biomass dynamics on non-forested areas of the Hayden Valley in an extended 50-year run. A) Fine grass aboveground biomass and offtake, B) fine grass roots, C) coarse (mesic) graminoid aboveground biomass and offtake, D) coarse grass roots. E) forb aboveground biomass offtake, F) forb roots.

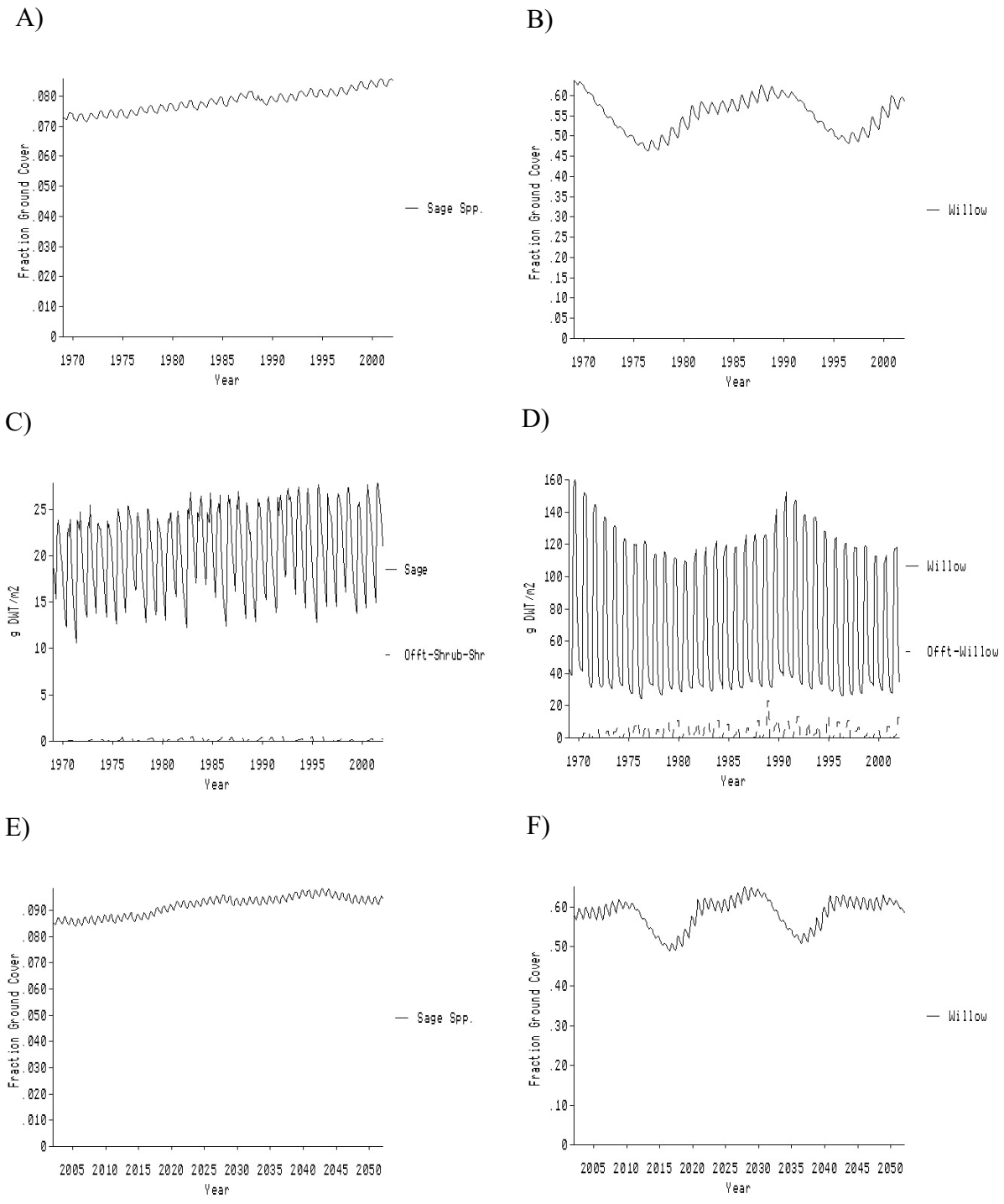


Figure 30. Hayden Valley non-forested areas. A) Sagebrush cover, B) willow cover (in willow habitats), C) sagebrush leaf biomass and offtake, D) willow leaf biomass and offtake (in willow habitats). E) Sagebrush cover and F) willow cover in the extended 50-year run.

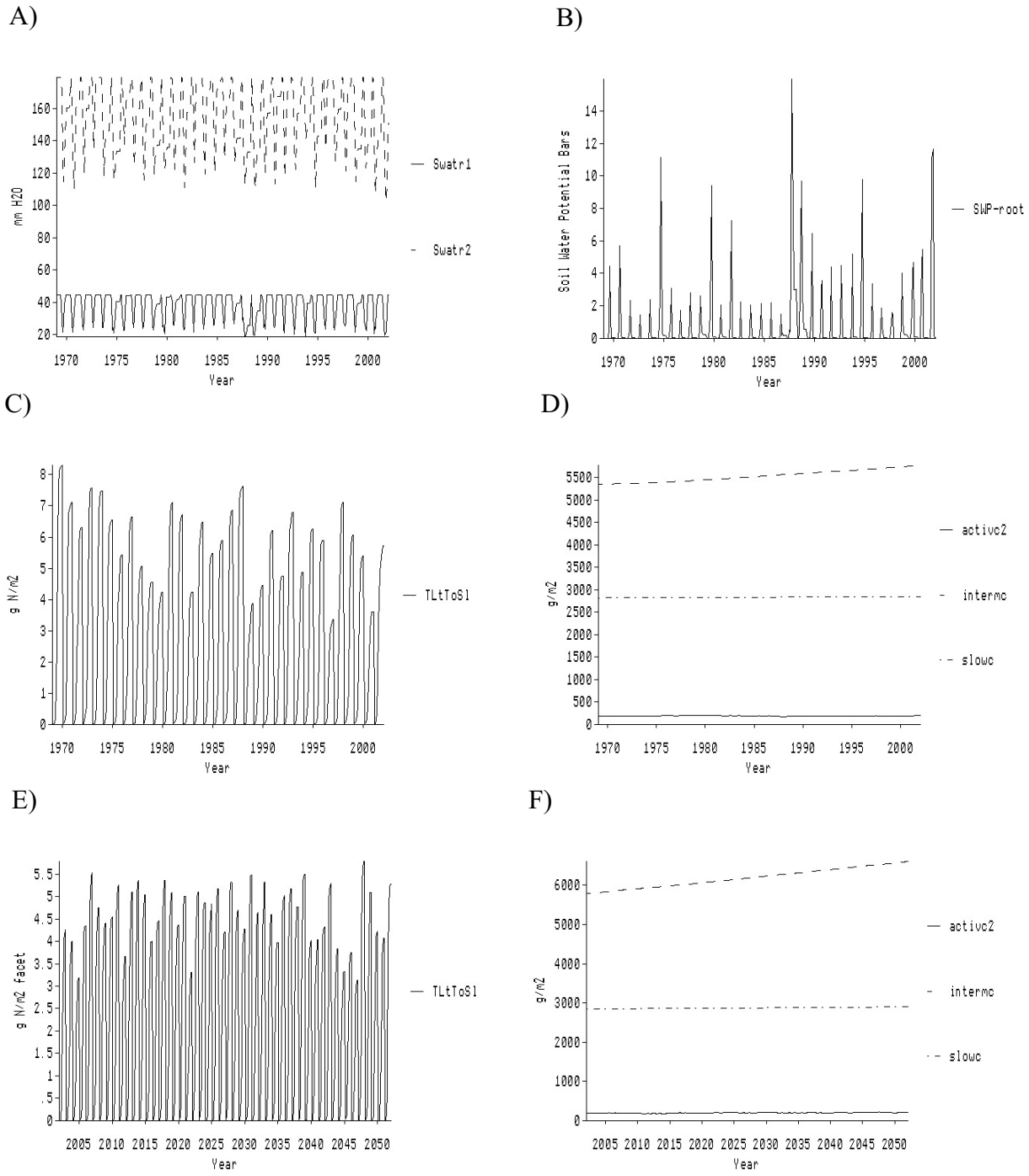


Figure 31. Hayden Valley non-forested areas. A) Soil water in layer 1 (0-20 cm) and layer 2 (20-100 cm). B) Effective soil water potential experienced by herbaceous plants. C) Nitrogen mineralization, cumulative each year, D) Soil organic matter carbon in the active, intermediate turnover time, and slow turnover time pools. E) N mineralization F) SOM in the extended 50 yr. run.

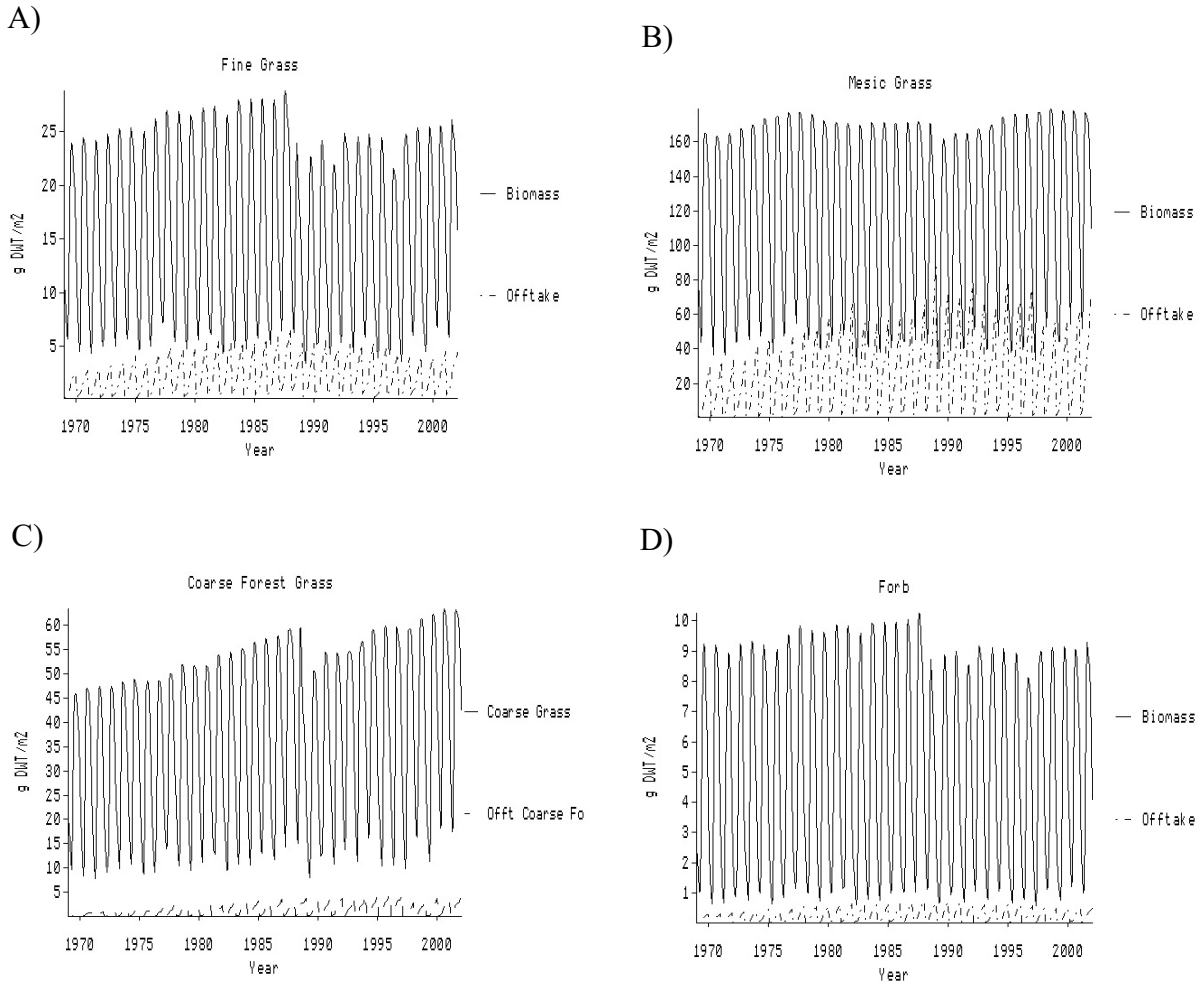


Figure 32. Biomass and offtake 1969-2001 for the entire study area. A) fine-leaved grasses, B) coarse wetland grasses, C) coarse forest grasses, D) forbs. Values are averages in areas where the species occurs.

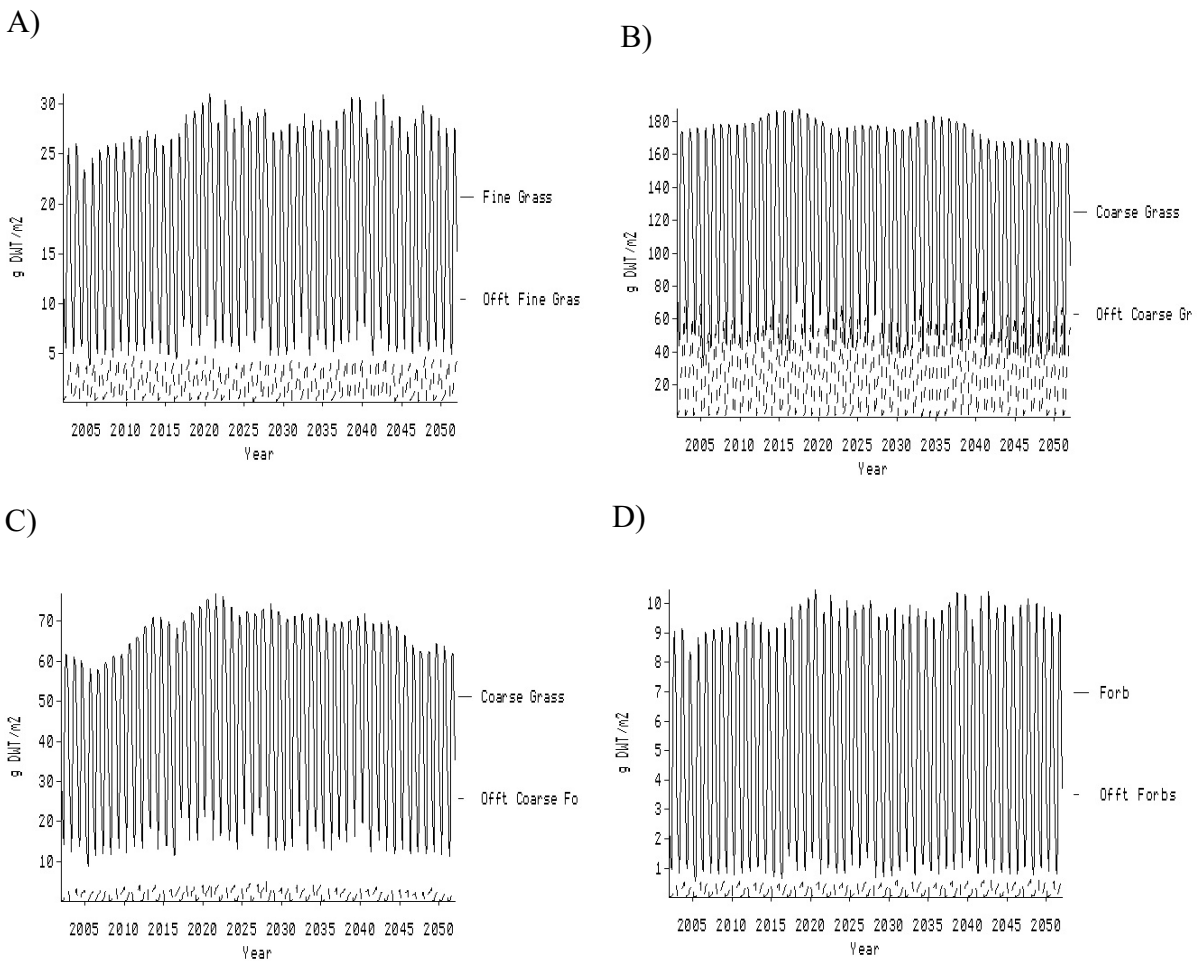


Figure 33. Biomass and offtake 1969-2001 for the entire study area in a 50-year extended simulation. A) fine-leaved grasses, B) coarse wetland grasses, C) coarse forest grasses, D) forbs. Values are averages in areas where the species occurs.

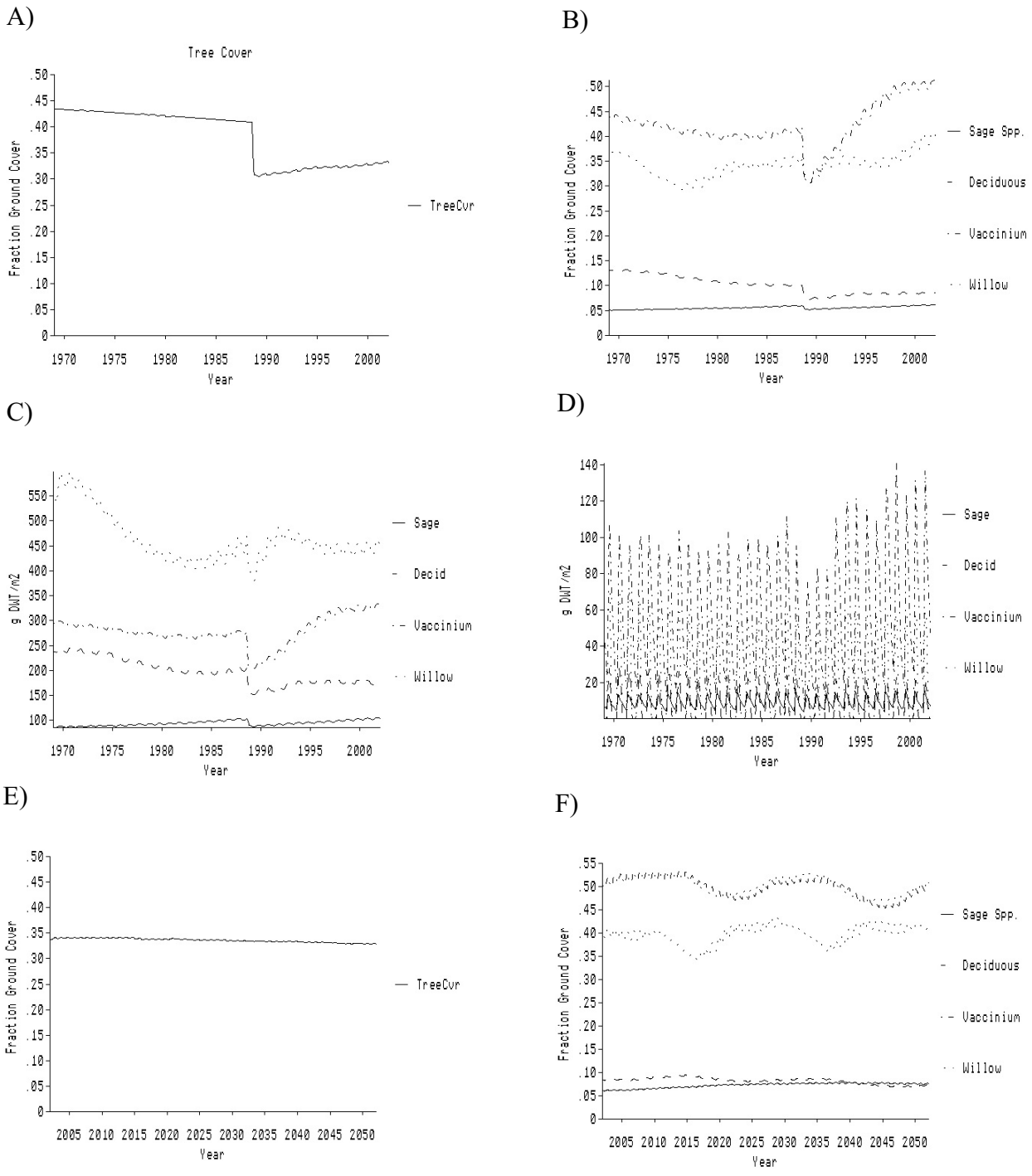


Figure 34. A) Tree canopy cover in vegetation types where it occurs. B) Shrub canopy cover in vegetation types where it occurs. Willow is most dense, followed by *Vaccinium*, deciduous, and sagebrush. C) Shrub stem biomass and D) shrub leaf biomass in areas where they occur. F) Tree cover and F) shrub cover in an extended 50-year simulation.

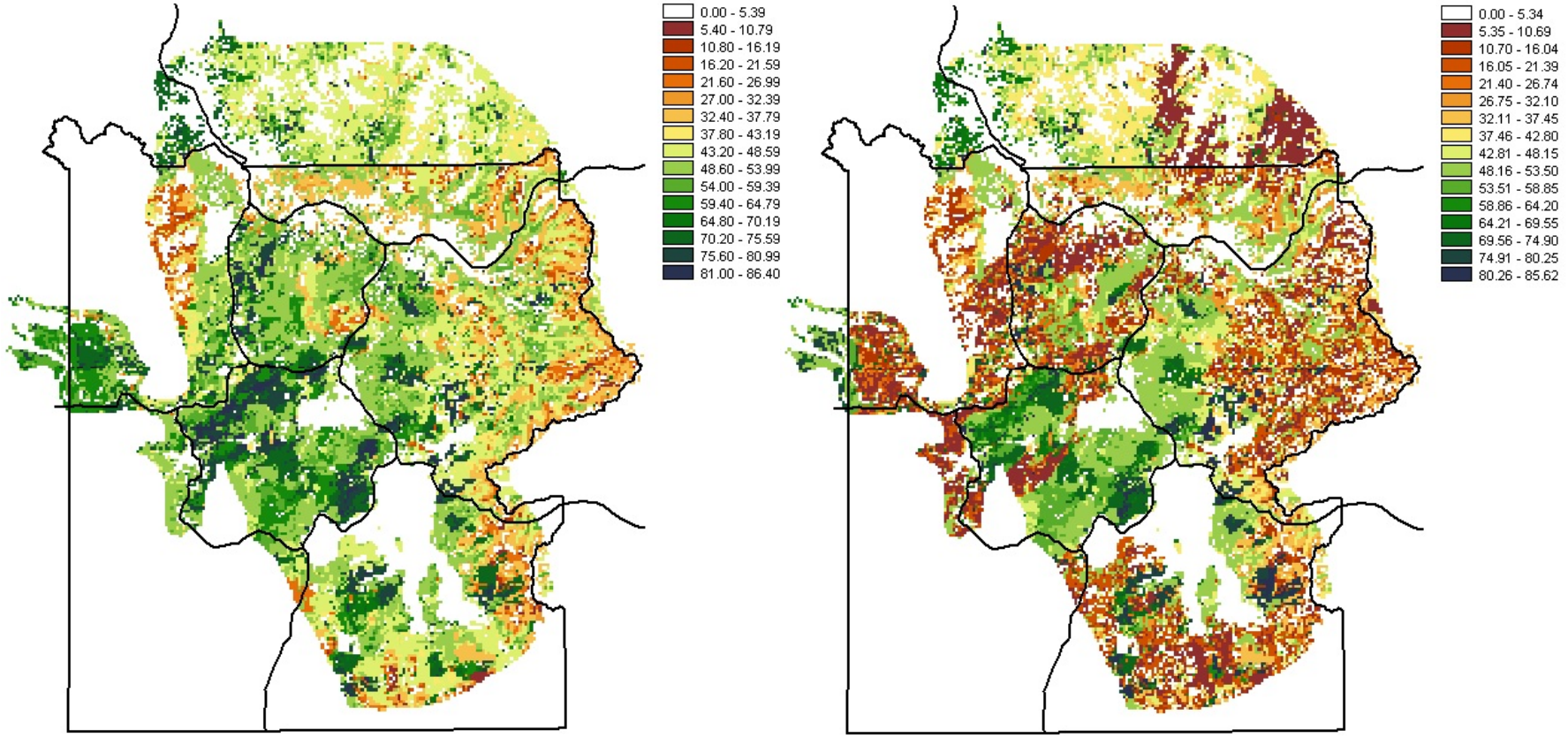


Figure 35. Tree canopy cover (percent) in Augusts 1969-1988 (left) and 1989-2001 (right).

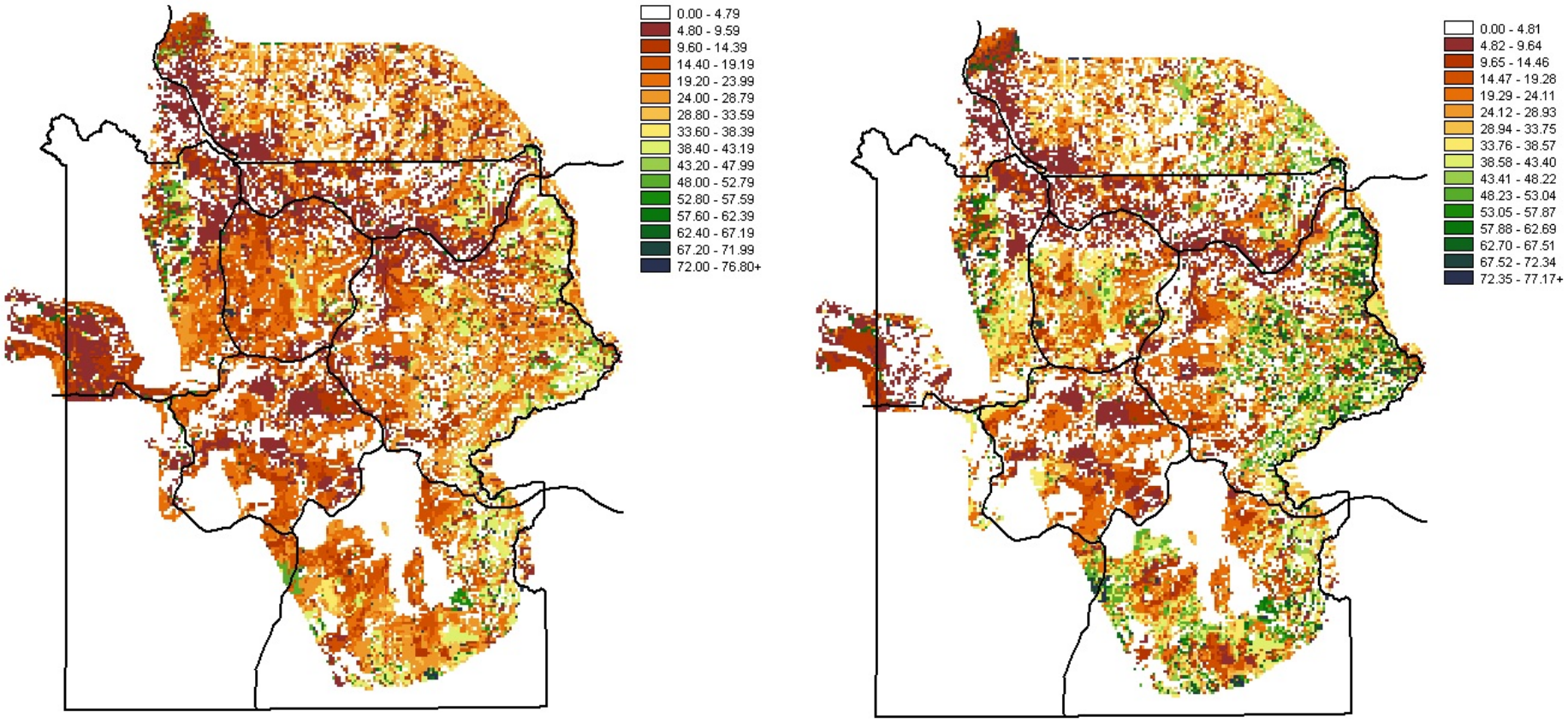


Figure 36. Overstory shrub canopy cover (percent) in Augusts 1969-1988 (left) and 1989-2001 (right).

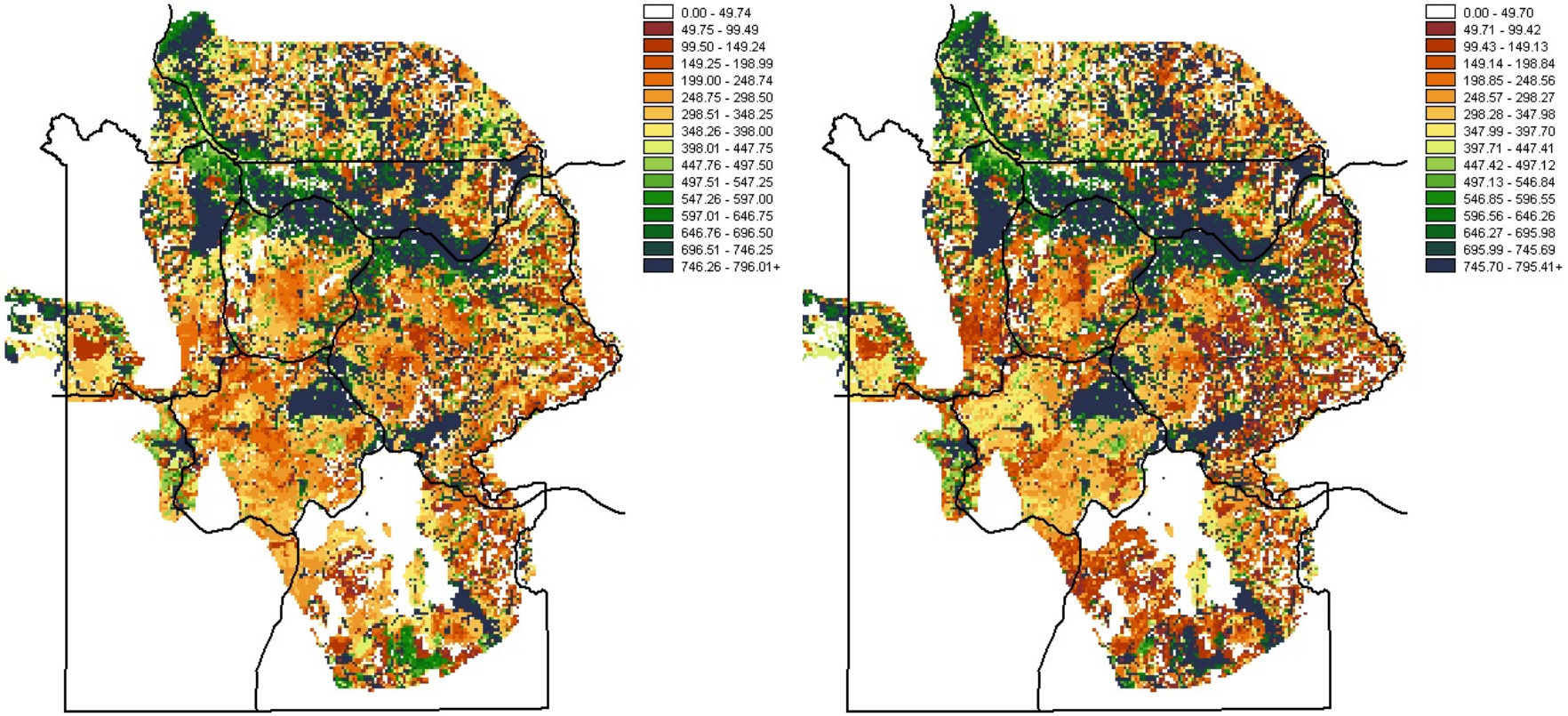


Figure 37. Herbaceous aboveground biomass (live plus dead shoots, kg/ha) in Augusts 1969-1988 (left) and 1989-2001 (right), scaled to show variations within areas with lower productivity.

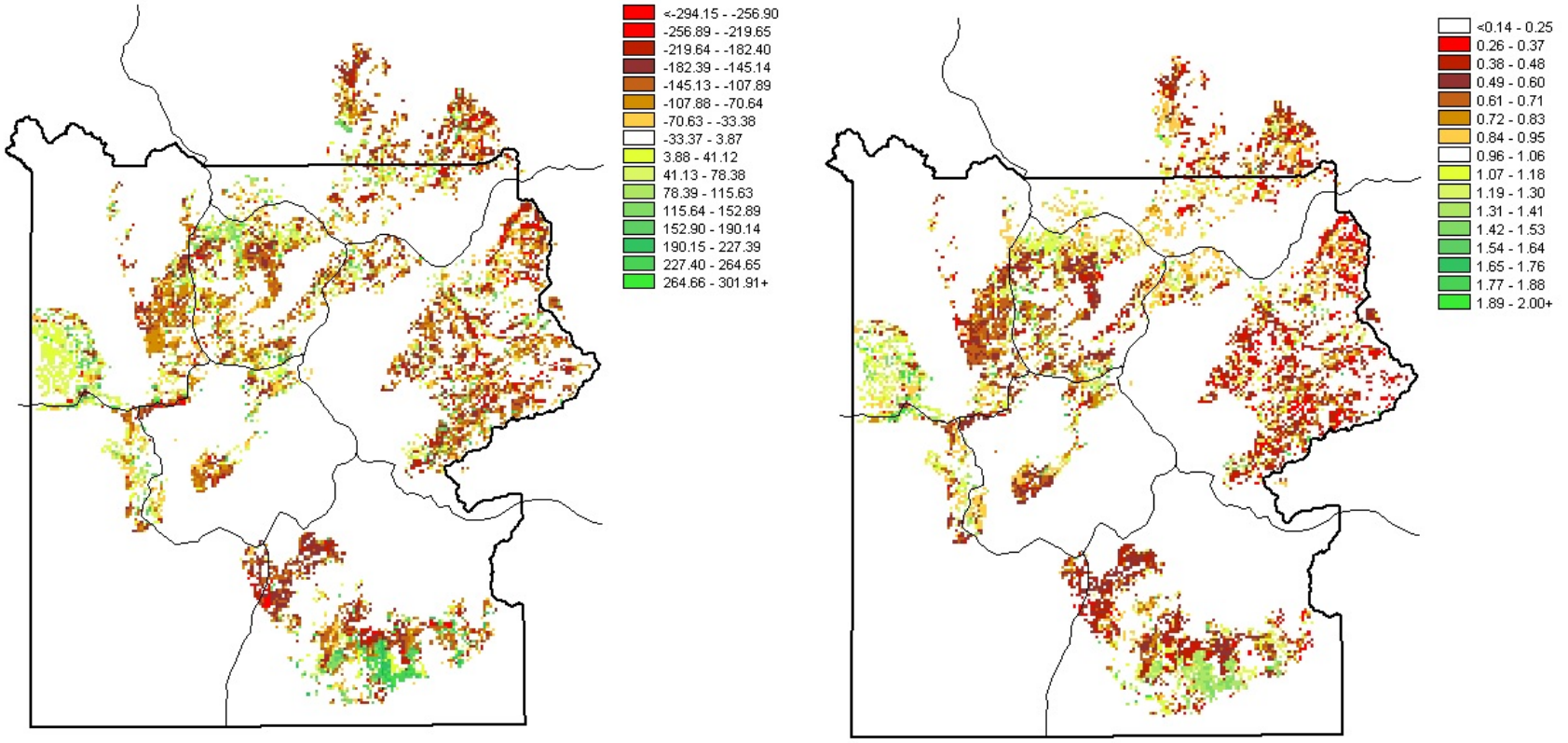


Figure 38. Difference in herbaceous aboveground biomass (live plus dead shoots, kg/ha) in Augusts between 1969-1988 and 1989-2001 in burned areas, with positive values indicating increases (left). The ratio of biomass in 1989-2001 to that in 1969-1988 (right).

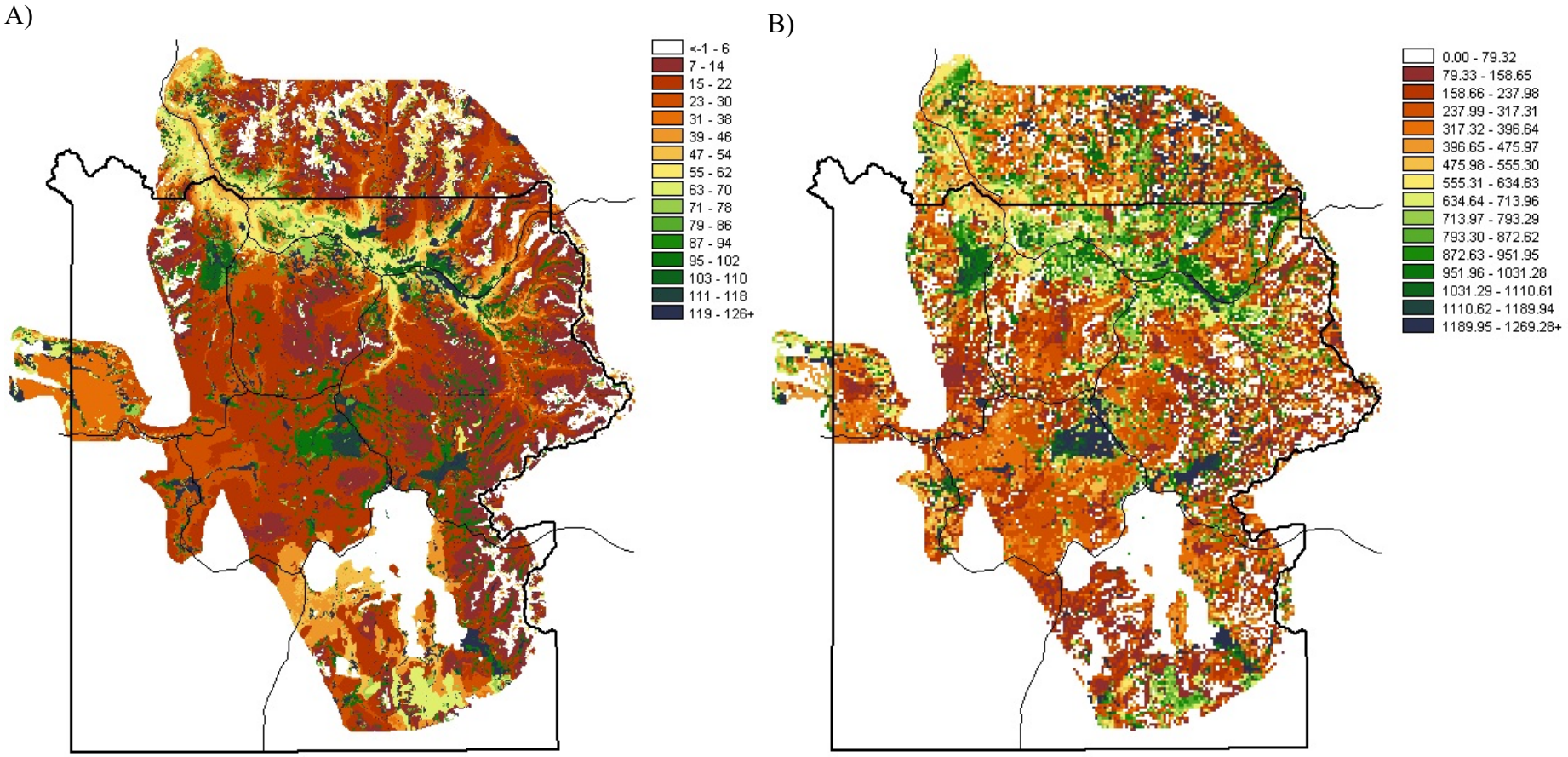


Figure 39. Comparison of total herbaceous total biomass 1989-2001 A) predicted by the biomass model (g m^{-2}) and B) predicted by the ecosystem model (kg/ha). kg/ha is 10x g m^{-2}.

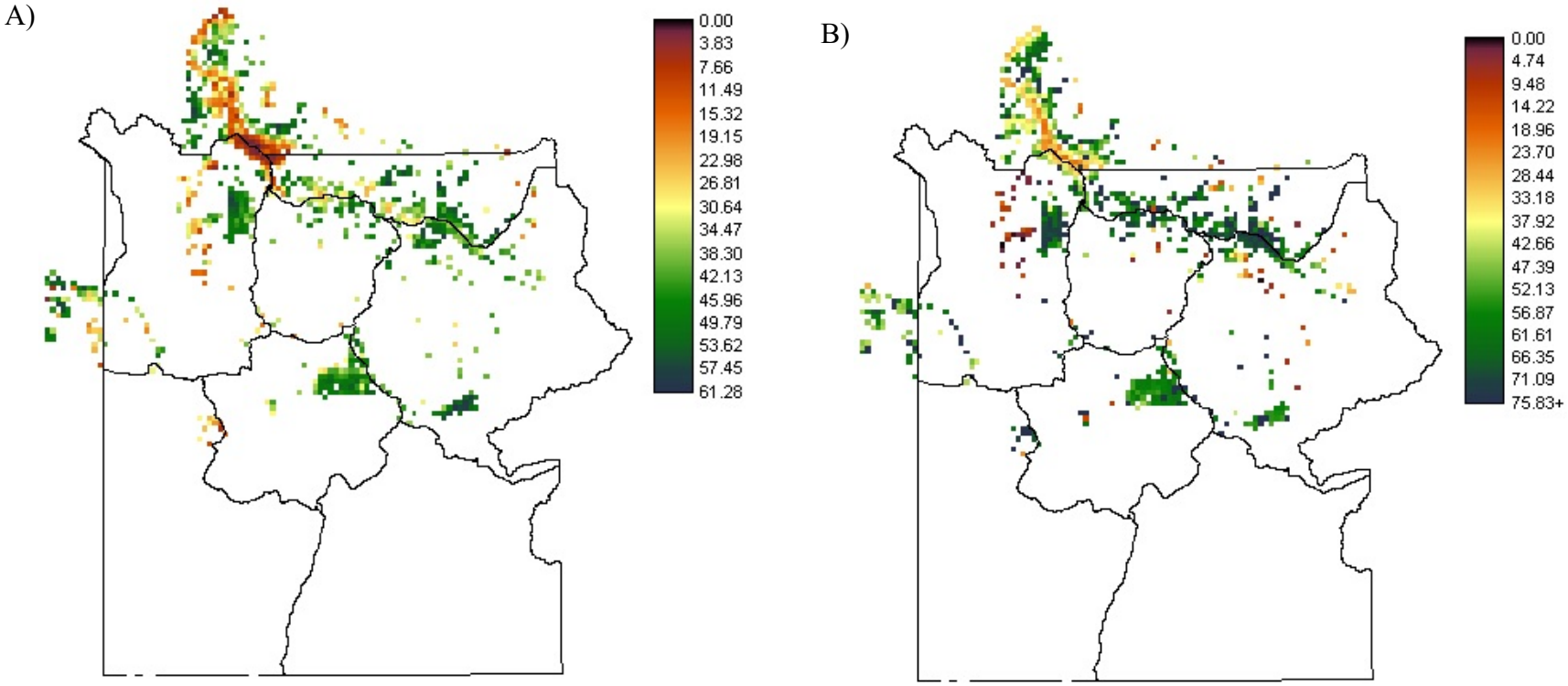


Figure 40. Comparison of A) Landsat-TM based normalized difference vegetation index (NDVI*100) from 1 scenes in July 1998 and two scenes in July 2001 with B) simulated herbaceous green leaf biomass at the end of June averaged over 1982-2001. Figures show non-forested areas of the northern winter range, Hayden Valley, Pelican Valley, Firehole, and the western side.

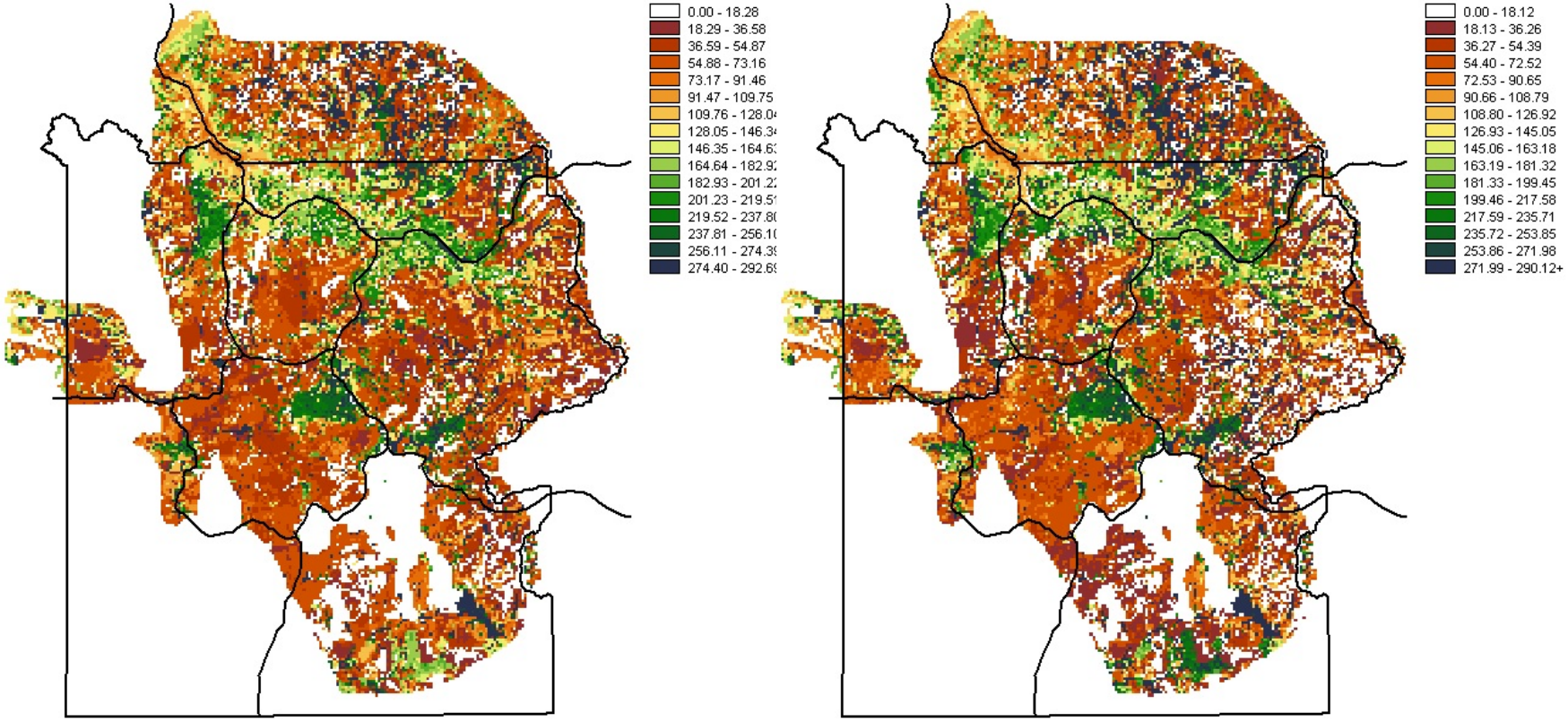


Figure 41. Herbaceous belowground biomass (live roots, g m^{-2}) in Augusts 1969-1988 (left) and 1989-2001 (right).

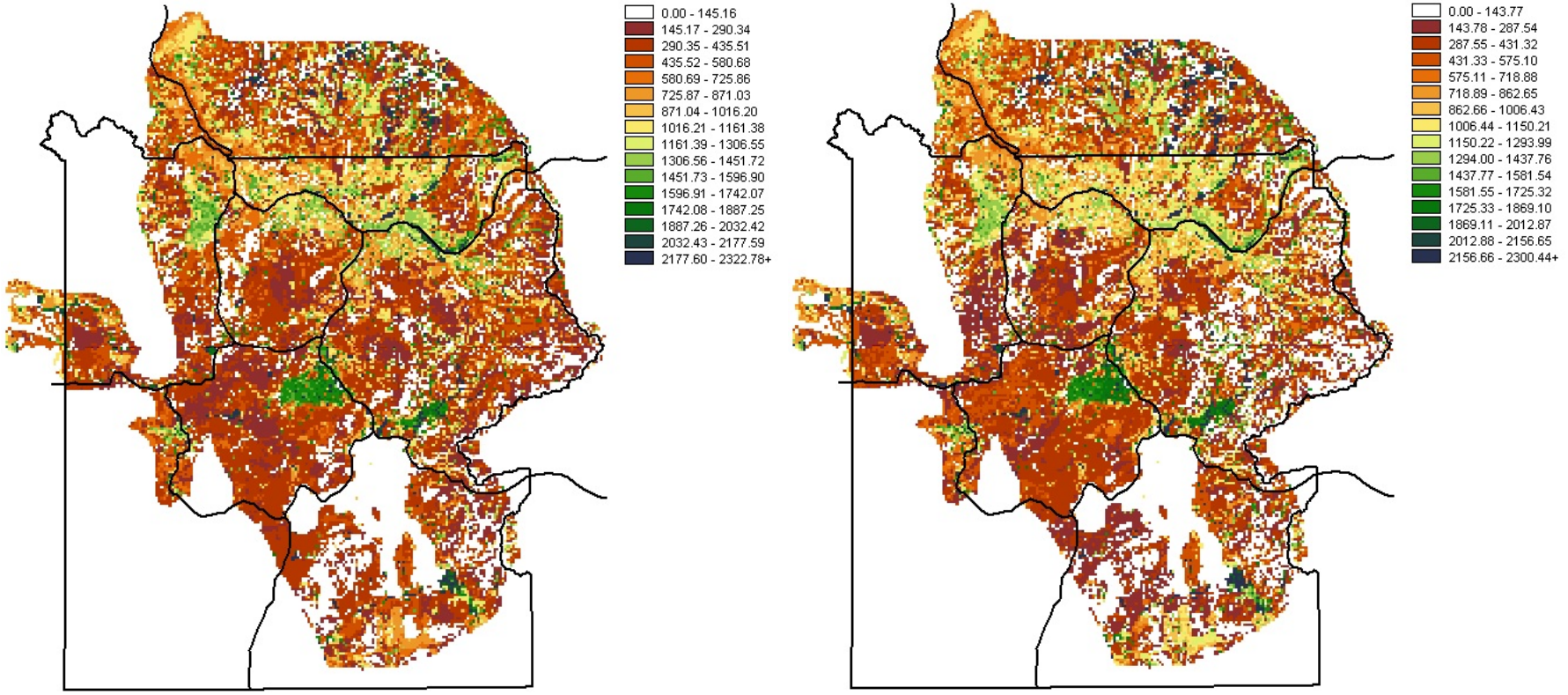


Figure 42 . Herbaceous aboveground net primary production (kg ha^{-1} yr^{-1}) in 1969-1988 (left) and 1989-2001 (right).

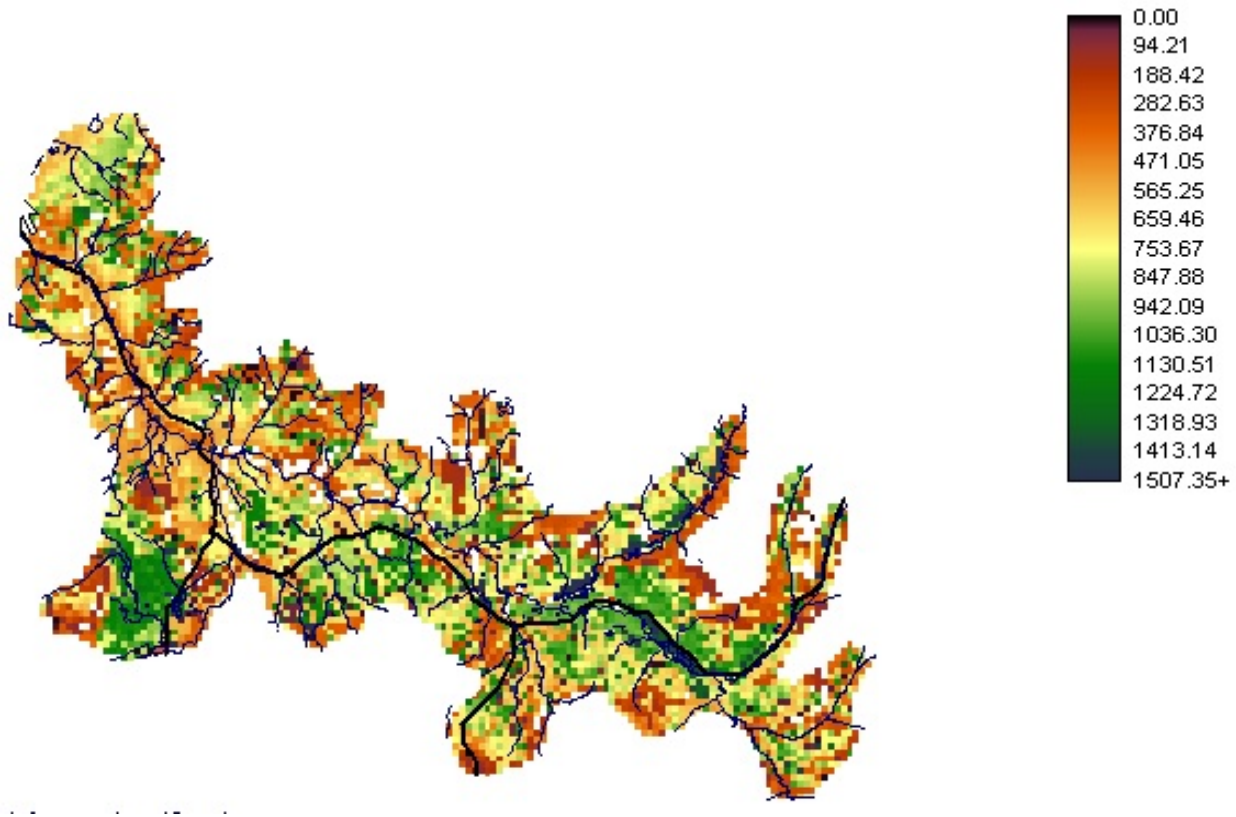


Figure 43. Simulated average aboveground herbaceous biomass (kg ha^{-1}) in Augusts 1969-2001 on the northern winter range, with 500 m grid-cells. Streams and roads are also shown.

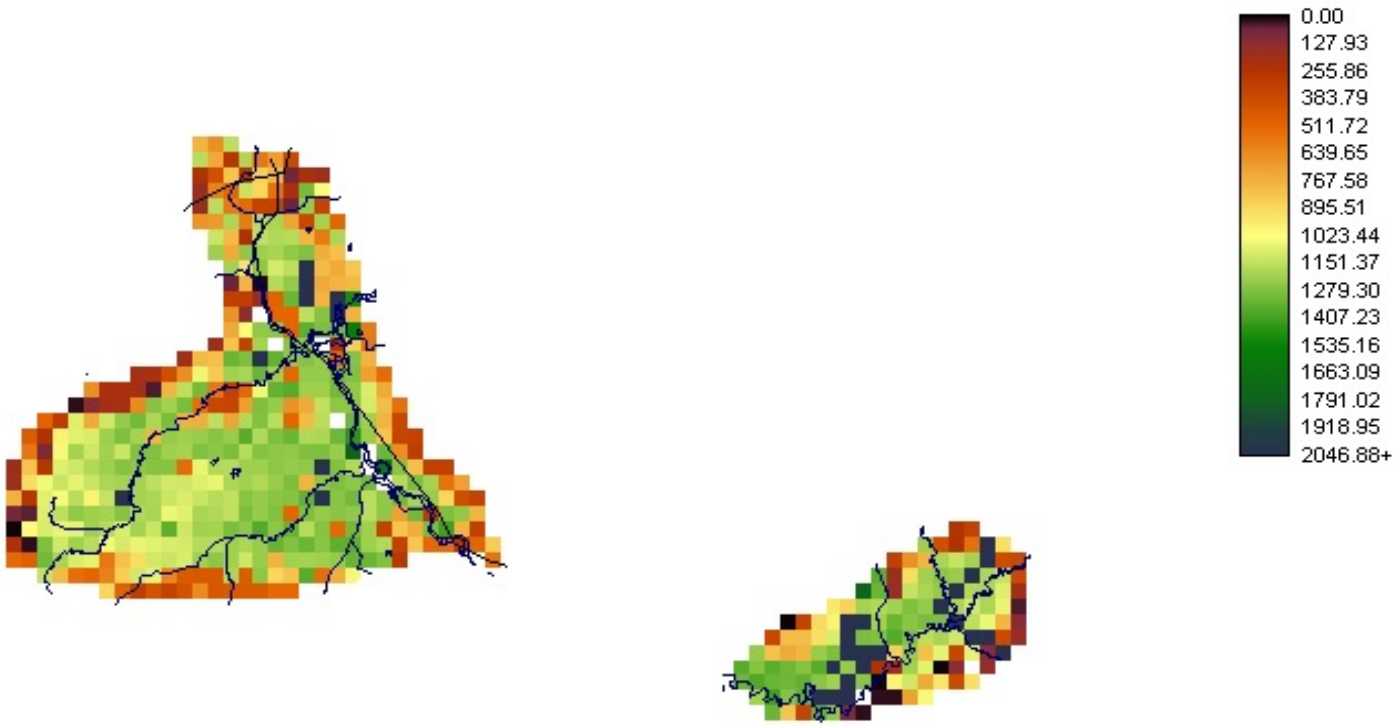


Figure 44. Simulated average aboveground herbaceous biomass (kg ha^{-1}) in Augusts 1969-2001 in Hayden Valley (left) and PelicanValley (right) with 500m grid-cells. Streams and roads are also shown.

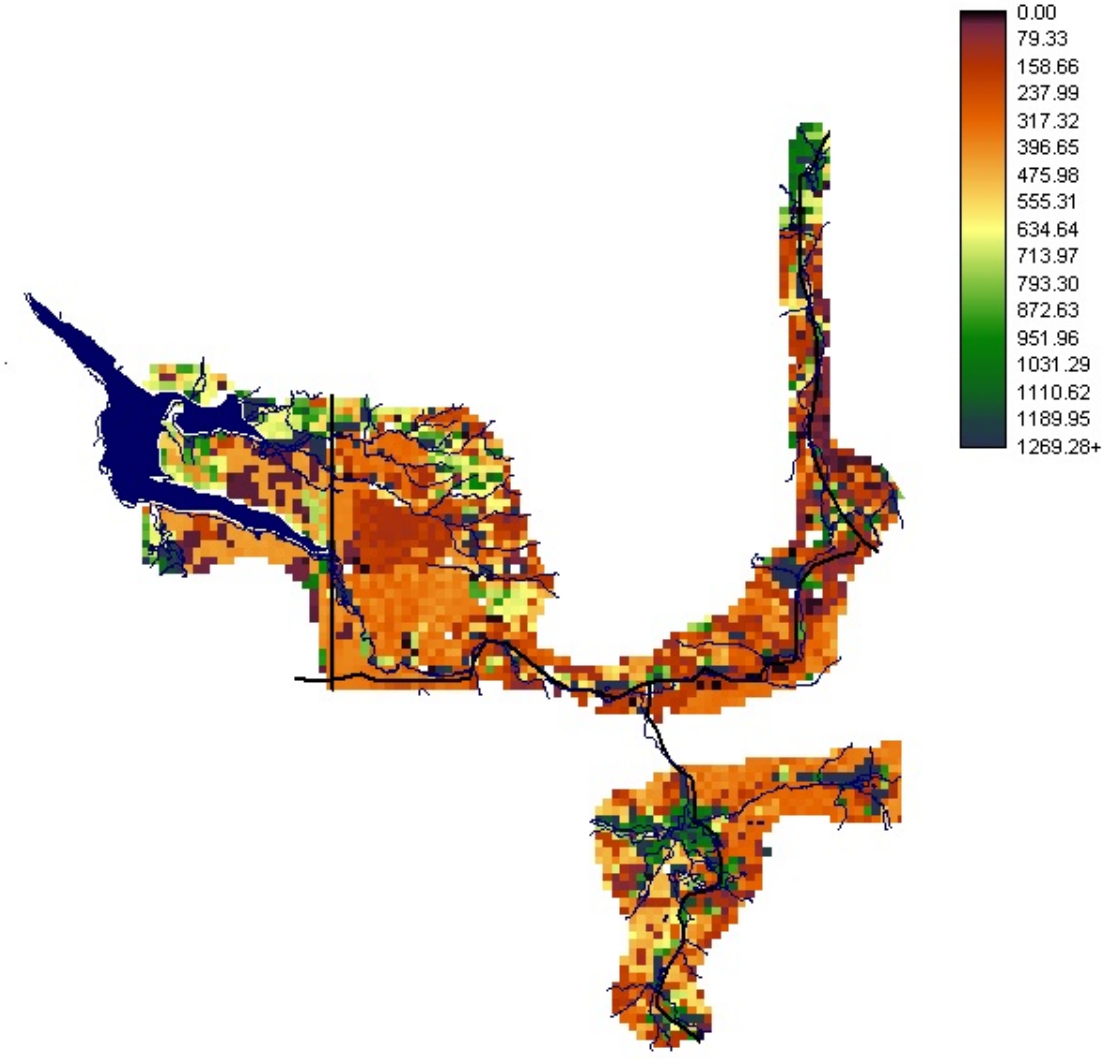


Figure 45. Simulated average aboveground herbaceous biomass (kg ha^{-1}) in Augusts 1969-2001 in Madison River/Cougar Creek area and Firehole River area (south) with 500m grid-cells. Streams and roads are also shown. The park boundary is shown as well as Hebgen Lake.

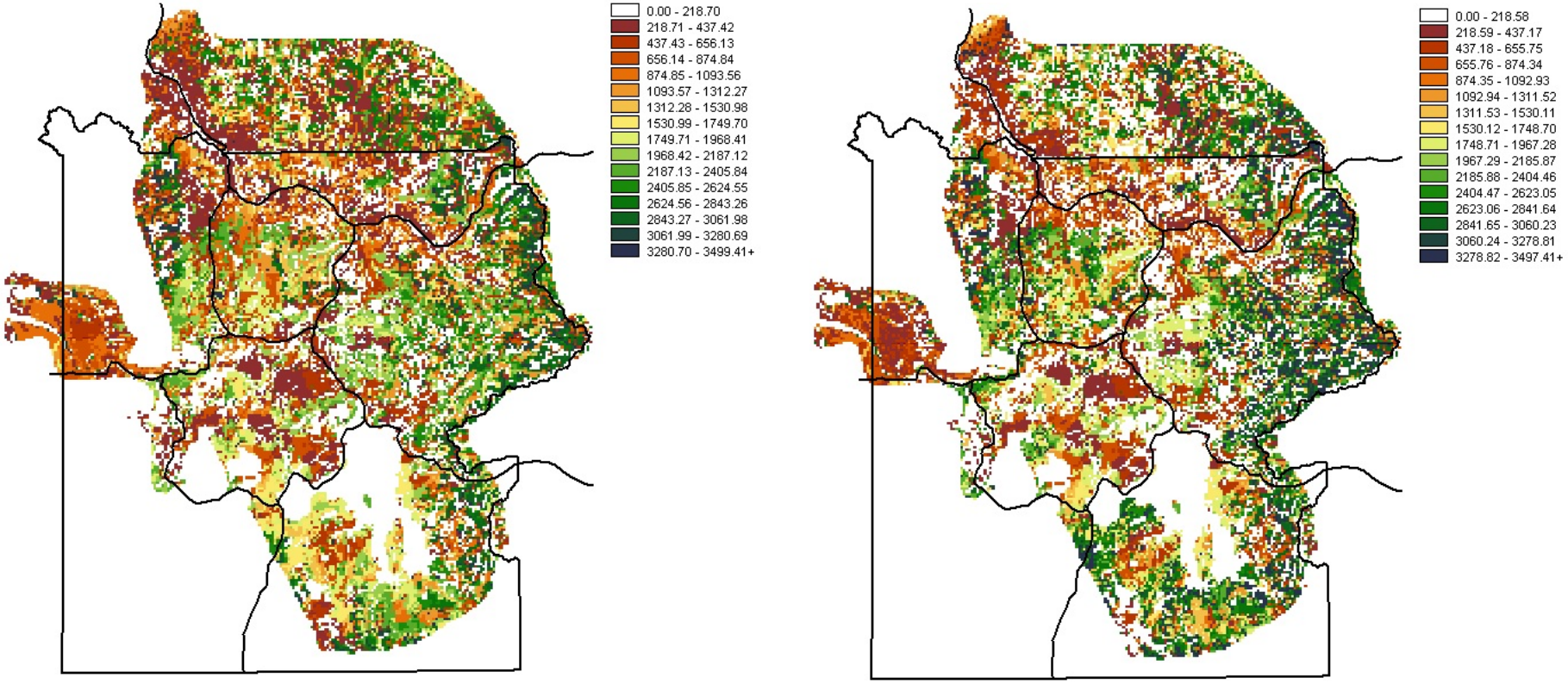


Figure 46. Total shrub (overstory and understory) aboveground net primary production (kg ha^{-1} yr^{-1}) in 1969-1988 (left) and 1989-2001(right).

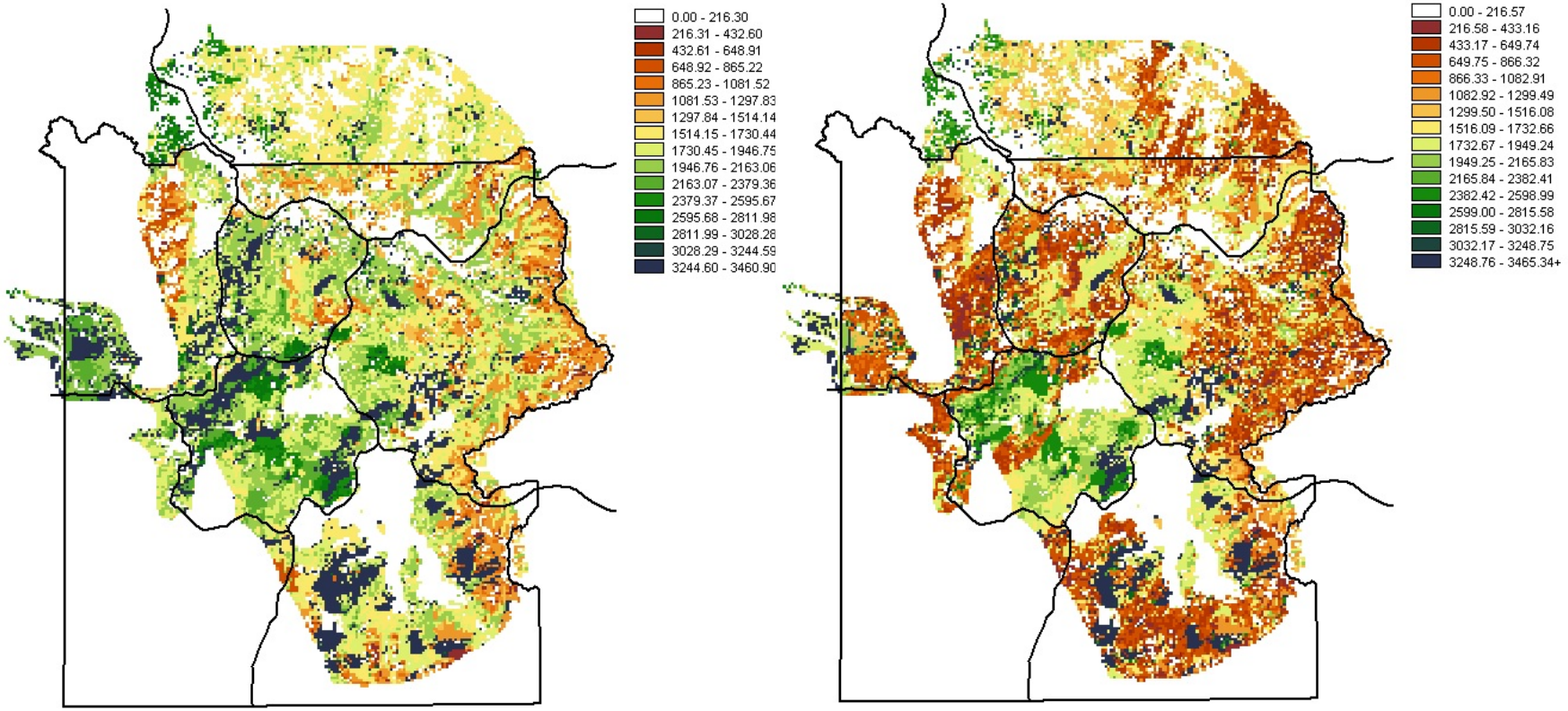


Figure 47. Tree aboveground net primary production (kg ha^{-1} yr^{-1}) in 1969-1988 (left) and 1989-2001 (right).

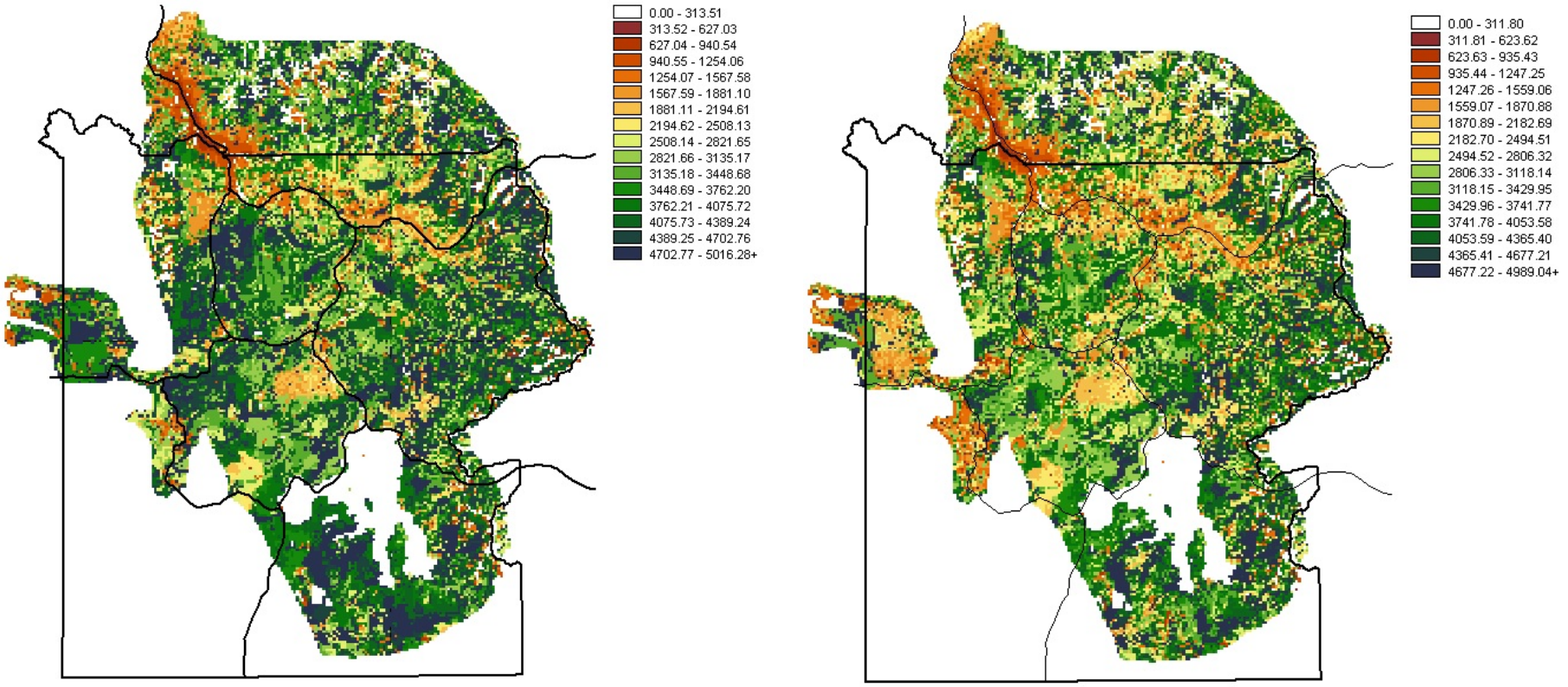


Figure 48. Total aboveground net primary production (kg ha^{-1} yr^{-1}) in 1969-1988 (left) and 1989-2001 (right).

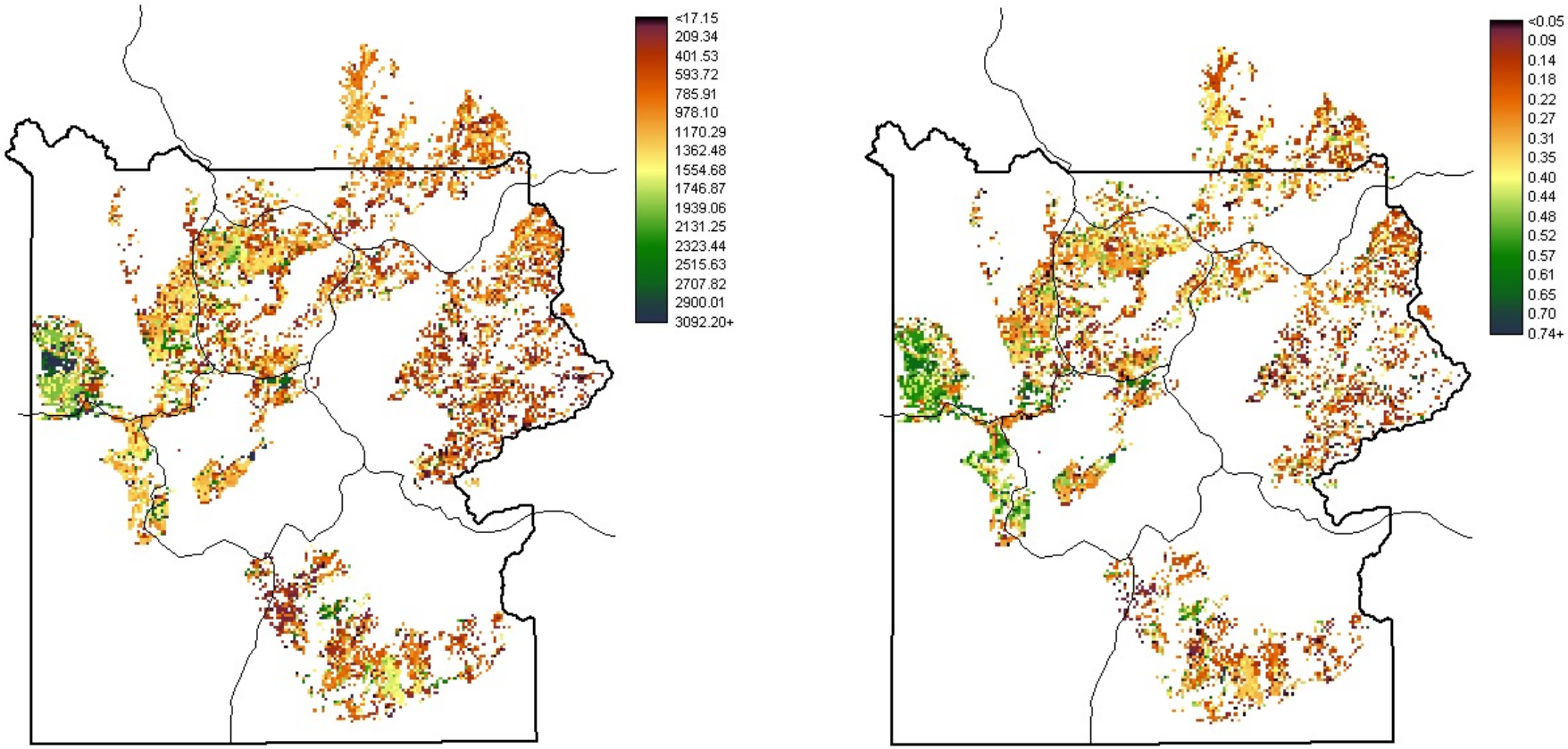


Figure 49. Reduction in total ANPP (kg ha^{-1} yr^{-1}) in burned areas after 1988 (left) and fractional reduction (right).