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Cascading ecohydrological transitions: Multiple changes in vegetation and hydrology over the past 500 years for a semiarid forest/woodland boundary zone in New Mexico, USA

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On decadal and centennial time scales, multiple drivers can cause substantial changes in vegetation cover, which can trigger associated changes in runoff and erosion patterns and processes, with consequent feedbacks to the vegetation – cumulatively this can lead to a cascading series of non-equilibrial ecosystem changes through time. The work reported here provides a relatively detailed 500-year perspective of such changes on the mesas the eastern Jemez Mountains in northern New Mexico (USA), which today exhibit vegetation transitions along an elevational gradient between semiarid ponderosa pine (*Pinus ponderosa*) forests, mixed woodlands dominated by piñon (*Pinus edulis*) and one-seed juniper (*Juniperus monosperma*), and juniper savannas. Using multiple lines of evidence, a history of major ecosystem changes since ca. 1500 A.D. is reconstructed for a dynamic transition zone on one such mesa (Frijolito Mesa). Evidence includes intensive archaeological surveys, dendrochronological reconstructions of the demographic and spatial patterns of establishment and mortality for these three main tree species, dendrochronological reconstructions of fire regimes and climate patterns, broad-scale mapping of vegetation changes from historic aerial photographs since 1935, monitoring of vegetation from permanent transects since 1991, detailed soil maps and interpretations, intensive ecohydrological studies since 1993 on portions of this mesa, and research on the ecosystem effects of an experimental tree-thinning experiment conducted in 1997.

Frijolito Mesa was fully occupied by large numbers of Native American farmers from the A.D. 1200's until the late 1500's, when they left these mesas for settlements in the adjoining Rio Grande Valley. Archaeological evidence and tree ages indicate that the mesa was likely quite deforested when abandoned, followed by episodic tree establishment dominated by ponderosa pine during the Little Ice Age. By the late 1700's Frijolito Mesa included ponderosa pine in open stands maintained by frequent surface fires burning through herbaceous ground cover adequate to maintain ancient (>100,000 year old) soils, interspersed with young piñon-juniper savannas and woodlands on rockier fire-safe sites. Intensive livestock grazing from the late 1800's thru 1932 reduced the herbaceous ground cover, interrupting the surface fire regime, triggering massive establishment of fire-sensitive piñon and juniper throughout much of the 1900's. Severe drought in the 1950's killed all the ponderosa pine across an irregular ecotone shift zone up to 2 km wide, with no subsequent regeneration, leaving piñon-juniper woodland with accelerated, unsustainable erosion in desertified areas between tree clumps (averaging ∼4 Mg/ha/year for the period 1995-2007 in a 1.09 ha study watershed). Warm drought in the early 2000's caused mass mortality of essentially all overstory piñon, leaving juniper as the only remaining tree dominant across huge areas. Ecohydrological processes are shifting again with declining runoff/erosion trends since 2003 as dead piñon skeletons fall and with increased abundances of shrubs and herbaceous surface cover, decreasing the connectivity of bare soil patches.

The history of Frijolito Mesa illustrates multiple major transitions in vegetation since 1500 A.D., and substantial changes in runoff and erosion processes. This research has been used by the National Park Service since 2007 to implement an ecosystem restoration treatment (mechanical thinning of small trees with chainsaws and application of branch slash mulch) at a landscape scale of ∼2000 ha. The treatments effectively conserve more water and soil onsite, increasing herbaceous ground cover and decreasing soil erosion rates 100-fold, stabilizing hundreds of archaeological sites and restoring the potential for natural surface fires. The ecohydrological history of this mesa also provides insight into how similar vegetation changes, such as episodes of widespread and intensive tree mortality that are now emerging with climate stress around the world, may significantly affect ecohydrological patterns and processes in other regions.