Annual Report
to the USDA Forest Service
under Sponsor Award #10-DG-11031600-050 for 2010 and 2011

(NAU Account Numbers ERI 34HT-34HZ and ERI34JU-34KA)


Submitted by:

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**Summary**

This report presents an integrated and coordinated series of actions for $3.0 million awarded to the ERI in Fiscal Years 2010 and 2011 under CFDA 10.694, Southwest Forest Health and Wildfire Prevention for the first two years in a 5-year domestic grant. The information provided herein reflects our annual progress as of 6/30/2011.

All of the activities (deliverables) summarized in this report were designed to be responsive to stakeholder needs and to be synthesized with the larger body of scientific evidence, translated into appropriate languages for target audiences, and delivered in a range of formats from in person one on one and group presentations and discussions, to printed and electronically accessible fact sheets, short technical reports, longer white papers and management reports, and peer reviewed archival literature.

# Table of Contents

# FY10 Plan of Work

| ***Project 1: Evidence-Based Conservation*** | |
|---|---|
| **Deliverable** | **Status** |
| **1. LEARN.**<br>Information will be analyzed using the rigorous standards of peer-reviewed scientific publications. One project will be completed for **professional publication** in 2010. This information, and all scientific information described throughout this work plan, will contribute to the practical, management-oriented outlets described in *Section 7: Service to the Intermountain West*. | ✓ Korb, J.E, P.Z. Fulé, and M.T. Stoddard. In review. Historical reference conditions as a guide for forest restoration: an example from a mixed conifer forest, USA. Journal of Applied Ecology. **Completed and in review.** |
| **2.** A **Systematic review** on a topic to be developed with input from affected entities served by ERI. | ✓ Springer, JD, CM McGlone, ML Daniels, MT Stoddard, JE Crouse, and E.L. Kalies. "Non-native plant encroachment in burned ponderosa pine forests: a mixed-methods systematic review of effects of prescribed and wild fires." 42 pp. **Complete** and draft in review as of 6-24-11. Preliminary copy available on request. |
| **3. Wildlife responses.**<br>One summary report and one journal manuscript. | ✓ **Annual progress report completed (link to report)**.<br>✓ Loberger, C. D., T. C. Theimer, S. S. Rosenstock, C. S. Wightman. Tassel-Eared Squirrel use of Restoration-treated Ponderosa Pine Forest. Tentative acceptance by Journal of Mammology with **final revisions in progress**. |
| **4. Rare Species.**<br>Report on restoration effects and implications for developing landscape-scale treatments that enhance rare species´ habitat. | ✓ Springer, J.D., P.Z. Fulé, and D.W. Huffman. In review. Long-term responses of Penstemon clutei (Sunset Crater beardtongue) to root trenching and prescribed fire: clues for population persistence. In Meyer, Susan, tech. ed. 2010. Southwestern rare and endangered plants: Proceedings of the Fifth Conference; 2009 March 16-20; Salt Lake City, UT. Gen. Tech. Rep. RM-GTR-XXX (to be assigned after review). Fort Collins, Co: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 14 pp. **Complete and in review**, draft as of 1-2011.<br><br>✓ Springer, J.D., M.T. Stoddard, D. C. Laughlin, D. L. Crisp, and B.G. Phillips. In review. Ecology of Rusby's Milkvetch (Astragalus rusbyi), a rare endemic of northern Arizona ponderosa pine forests. In Meyer, Susan, tech. ed. 2010. Southwestern rare and endangered plants: Proceedings of the |

# FY10 Plan of Work - Deliverables

| ***Project 1: Evidence-Based Conservation*** | |
|---|---|
| **Deliverable** | **Status** |
| | Fifth Conference; 2009 March 16-20; Salt Lake City, UT. Gen. Tech. Rep. RM-GTR-XXX (to be assigned after review). Fort Collins, Co: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 12 pp. **Complete and in review**, draft as of 1-2011 |
| **5. Fuel Treatments. Summary report on analysis of pre-treatment fire behavior data.** | ✓ Huffman, D., J.E. Crouse, W.K. Chancellor, P.Z. Fule. Stand- and landscape-level effects of fuel hazard reduction treatments on a pinyon-juniper-ponderosa pine landscape (Report on pre-treatment conditions). **Completed may be submitted for publication**. |

| ***Project 2: Stewards of Place*** | |
|---|---|
| **Deliverable** | **Status** |
| A document describing the design for landscape restoration handbook --an illustrated guide describing decision support information approaches and lessons learned useful in collaborative, place-based restoration workshops and agency trainings. | ✓ Egan, D. "Handbook for the Ecological Restoration of Frequent-fire Forests in the American West," an illustrated guide describing decision support information approaches and lessons learned useful in collaborative, place-based restoration workshops and agency trainings. **Design outline completed (link to outline).** |

| ***Project 3: Ecosystem Services*** | |
|---|---|
| **Deliverable** | **Status** |
| **1.** Systematic review of watershed impacts of wildfires and restoration treatments. | ✓ Draft has been reviewed and is in **final edit as of 6-30-11** (Allen/Ramstead) |
| **2. Ecosystem Sustainability.** Analysis of pinyon-juniper ecosystem sustainability at the landscape scale, prepared for professional publication. | ✓ Huffman, D. Analysis of pinyon-juniper ecosystem sustainability at the landscape scale. **Complete** and publishable-quality manuscript in progress as of 6-30-11. |

# FY10 Plan of Work - Deliverables

| ***Project 4: Climate*** | |
|---|---|
| **Deliverable** | **Status** |
| Report demonstrating the integration of existing and new information on fire/climate/fuels interactions. | ✓ Fulé, P.Z., L.L. Yocom, A. B. Stan. Interaction of Fire, Climate, and Fuels in Southwestern North America. **Completed (link to report).** |

| ***Project 5: Economies and Job Creation*** | |
|---|---|
| **Deliverable** | **Status** |
| **(FY10)** Report and fact sheet describing the financial feasibility of enhancing economic development of Arizona's Native American tribes through a tradable carbon rights system. | ✓ Huang, C., C. Sorensen. The Economic Value of Selling Carbon Credits from Restored Forests: A Case Study from the Navajo Nation's Tribal Forests. West. J. Appl. For. 26(1) 2011. Society of American Foresters. Report describing the financial feasibility of enhancing economic development of Arizona's Native American tribes through a tradable carbon rights system. **Completed (link to report).**<br>✓ Huang, C. H. Economic Value of Selling Carbon Credits: The Economic Value of Selling Carbon Credits by Restoring the Navajo Nation's Tribal Forests. Fact Sheet, Ecological Restoration Institute. January, 2011. **Completed:** http://library.eri.nau.edu/gsdl/collect/erilibra/index/assoc/HASH0135/74e4ff0a.dir/doc.pdf |

| ***Project 6: State and Private Forestry*** | |
|---|---|
| **Deliverable** | **Status** |
| A report on science support for the statewide assessment. Building on its track record with the Governor's Forest Health Council in the development of the Statewide Strategy for Restoring Arizona's Forests, ERI will work with its partners in the Rocky Mountain Research Station and other research institutes; institutions of higher education; and science-based NGO's to coordinate science support for the Division in its statewide assessment. | ✓ Greco, B. Executive Summary: A report on Science Support Provided by the Ecological Restoration Institute for the Arizona Forest Resource Assessment and Strategic Plan- CY 2010. **Completed (link to report).** |

# FY10 Plan of Work - Deliverables

| ***Project 7: Services to the Intermountain West*** | |
|---|---|
| **Deliverable** | **Status** |
| **Outreach to forest managers across the West.** | |
| Workshops for continuing professional education | ✓ Denton, C., D. Brewer, D. Lund. Conducted workshop for the Greater Ruidoso Area Wildland Urban Interface Working Group (GRAWUIWG) on Restoration Prescriptions and Desired Forest Condition Recommendations. Ruidoso, NM. March 16, 2010. 26 attendees.<br>✓ Greco, B., S. Masek Lopez, B. Stevens. Watershed/Water Users Workshop. Sedona, AZ. August 17, 2010. 21 attendees. |
| Continued Support for Forest Plan Revisions | ✓ Greco, B., M. Sensibaugh. One hour conference call meeting with 12 partners working on AZ Forest Resource Assessment and Strategic Plan. Discussion of document format and content. Flagstaff, AZ. January 19, 2010.<br>✓ Greco, B., M. Sensibaugh. Conference call meeting with partners working on AZ Forest Resource Assessment and Strategic Plan. Discussion of up-coming meeting. Flagstaff, AZ. January 25, 2010.<br>✓ Greco, B., M. Sensibaugh. Attended Forest Landscape Restoration Act meeting with Coconino National Forest to develop proposal. Flagstaff, AZ. January 28, 2010. 25 attendees.<br>✓ Greco, B., M. Sensibaugh. Conference call meeting with partners working on AZ Forest Resource Assessment and Strategic Plan. Discussion of up-coming Tribal meeting. Flagstaff, AZ. February 1, 2010.<br>✓ Greco, B., M. Sensibaugh. Attended meeting with partners working on AZ Forest Resource Assessment and Strategic Plan. Discussion of up-coming meeting. Flagstaff, AZ. February 3, 2010. 20 attendees<br>✓ Greco, B. Met with Mike Elson, Peaks-Mormon Lake District Ranger to coordinate Aspen Monitoring Strategy. Flagstaff, AZ. February 9, 2010.<br>✓ Greco, B., M. Sensibaugh, W. Greer. Participated in AZ Forest Resource Assessment (AZFRA) Tribal Workshop. Pinetop, AZ. February 18, 2010. 17 participants.<br>✓ Greco, B. Attended Natural Resources Working Group Presentation (4 FRI). Show Low, AZ. April 21, 2010. 23 attendees.<br>✓ Greco, B. Provided briefing and Fact Sheet on Carbon Credits |

# FY10 Plan of Work - Deliverables

| ***Project 7: Services to the Intermountain West*** | |
|---|---|
| **Deliverable** | **Status** |
| | and Sequestration to Forest Service Leadership. Flagstaff, AZ. April 22, 2010. 7 attendees.<br>✓ Greco, B. Attended NRWG Organization Design meeting. Flagstaff, AZ. April 26, 2010.<br>✓ Greco, B. Proposed Planning Rule Roundtable. Phoenix, AZ. April 28, 2010. 35 attendees.<br>✓ Greco, B. Workshop Participation- Cohesive Wildland Fire Strategy Field Forum. Phoenix, AZ. May 14, 2010. 40 participants.<br>✓ Crouse, J. Created GSI Remote Sensing for Adaptive Management in Frequent Fire Landscape Restoration in response to request from Henry Provencio of the USDA Forest Service. Flagstaff, AZ. December 7, 2010. **Report included as deliverable in Project 7** (Link to report)**.**<br>✓ Brewer, D. Reviewed remaining allotments for data input for 4-Forest effort. Assisted in data input, also. Peaks Ranger Station, Coconino National Forest, AZ. December 13-22, 2010. |
| Rapid Assessments<br>**Summary Reports included.** | ✓ Denton, C., D. Brewer, W. Greer. Rapid assessment for Mescalero Apache Tribe for the BIA. A workshop and a field trip included a training session on how to locate and identify pre-settlement evidence. They marked and used the GPS on 2 two acre plots and created maps. Mescalero, NM. May 11-12, 2010. *Note: conducted training and a presentation on restoration including a field visit and demonstration on how to do a restoration prescription. No formal report was written.*<br>✓ Denton, C., D. Brewer, B. Greco, M. Sensibaugh. Beaver Creek Rapid Assessment. Alpine, AZ. May 24-25, 2010. 5 attendees. (Link to summary)<br>✓ Greco, B. Show Low South Fuels Reduction Project. Show Low, AZ. August 1, 2010. (Link to summary)<br>✓ Clint's Rapid Assessment (Mogollon Rim RD, Coconino NF). (Link to summary)<br>✓ Timber Mesa Rapid Assessment (Lakeside RD, A/S NF**)** in progress and will transition into the FY11 programs. (Link to summary) |
| Information requests | ✓ Greco, B. Participated on the Joint Fire Sciences Panel. Flagstaff, AZ. January 20, 2010. 22 participants.<br>✓ Covington, W.W., B. Greco. Participated in 4FRI Coordination Meeting - Core Team. Flagstaff, AZ. February 22, 2010. 7 participants.<br>✓ Greco, B. Participated in 4FRI Landscape Strategy Working Group Meeting. Flagstaff, AZ. February 25, 2010. 10 |

# FY10 Plan of Work - Deliverables

| ***Project 7: Services to the Intermountain West*** | |
|---|---|
| **Deliverable** | **Status** |
| | participants.<br>✓ Greco, B. Conference call with R-3 Forest Supervisors & Regional Directors - 4FRI Support. Flagstaff, AZ. January 25, 2010. 12 participants.<br>✓ Covington, W.W., B. Greco, P. Fulé, D. Laughlin. Participated in 4FRI Science & Monitoring Working Group Meeting. Flagstaff, AZ. March 1, 2010. 12 participants.<br>✓ Greco, B., B. Stevens. Participated in 4FRI Communication Working Group Meeting. Flagstaff, AZ. March 5, 2010. 6 participants.<br>✓ Covington, W.W., B. Greco, P. Fulé, D. Laughlin. Participated in 4FRI Science & Monitoring Working Group Meeting. Flagstaff, AZ. March 9, 2010. 12 participants.<br>✓ Brewer, D. Met with Forest Service to discuss stratification scheme based Terrestrial Ecosystem Map Units groupings to facilitate determination of existing conditions for the four Forest Restoration Proposal. Flagstaff, AZ. April 7, 2010.<br>✓ Brewer, D. Assisted Mark Herron of the Kaibab National Forest in preparation of literature search for McCracken Project. Made copies of documents and sent to Forest. Flagstaff, AZ. April 9, 2010.<br>✓ Stevens, B. Inside NAU runs "Historic agreement boosts forest health," about ERI and 4FRI efforts in special Earth Day edition. Written by Bonnie Stevens. Flagstaff, AZ. April 22, 2010.<br>✓ Greco, B. Attended meeting with FS Silvicultural Staff & ID Team. Springerville, AZ. May 19, 2010.<br>✓ Greco, B. M. Sensibaugh. Met with Carl Sewestewa - Hopi Tribe. May 20, 2010. Flagstaff, AZ.<br>✓ Greco, B. M. Sensibaugh. Drafting AZ Forest Resource Strategy. Phoenix, AZ. May 24, 2010. 12 attendees.<br>✓ Greco, B. Four Forest Restoration Initiative Working Group. Flagstaff, AZ. June 3, 2010. 25 attendees.<br>✓ Greco, B. Attended 4 FRI Fire Module Working Group meeting. Flagstaff, AZ. June 8, 2010. 6 in attendance.<br>✓ Covington, W. W., B. Greco, C. Denton. Attended Forest Health Council Field Assessment. Springerville, AZ. June 10, 2010. 25 attendees.<br>✓ Greco, B. Beaver Creek Assessment ID Team Meeting. Alpine, AZ. June 11, 2010. 11 attendees.<br>✓ Vosick, D., B. Stevens, B. Greco. Attended 4 FRI Collaborative Meeting. Payson, AZ. June 23, 2010. 40 |

# FY10 Plan of Work - Deliverables

| ***Project 7: Services to the Intermountain West*** | |
|---|---|
| **Deliverable** | **Status** |
| | attendees.<br>✓ Greco, B., P. Fulé. Attended Needs Assessment Meeting with Forest Service Supervisors. Flagstaff, AZ. July 21, 2010. 8 in attendance.<br>✓ Greco, B., P. Fulé, D. Vosick. Attended Needs Assessment Meeting with BLM. Marble Canyon, AZ. July 22, 2010. 6 in attendance.<br>✓ Greco, B. Needs Assessment meeting with RMRS, Flagstaff, AZ. August 3, 2010. 2 attendees.<br>✓ Greco, B. White Mountain Stewardship MB Ecological Monitoring Working Group meeting. Pinetop, AZ. August 10, 2010. 7 in attendance.<br>✓ Greco, B. Facilitated Restoration Stewardship Working Group meeting. Show Low, AZ. September 27, 2010. 12 attendees.<br>✓ Gilbreath, K. Carol Ayer, Program Manager for the National Forest Service Library, asked for a copy of all of ERI's Working Papers, White Papers, and Homeowners' Guides for the library. All were sent to her and her information was added to the address database to receive hard copies of future ERI publications. Albuquerque, NM. October 28, 2010.<br>✓ Covington, W.W. Sent publications to use reference conditions and lines of evidence to guide restoration treatments to Tom Sensenig, the WS Oregon Regional Ecologist for the USFS Region 6. Flagstaff, AZ. November 5, 2010.<br>✓ Brewer, D. Discussed with members of team how stratification of TESU data could facilitate development of proposed action and effects analysis. Coconino National Forest Supervisor's office. November 16, 2010.<br>✓ Greco, B. Consultation with 4 FRI Collaborative group on Desired Forest Conditions development. Flagstaff, AZ. November 18, 2010. 12 attendees.<br>✓ Greco, B., J. Crouse. Met with Henry Provencio from the 4 FRI group to develop GIS/Remote Sensing Strategy for 4 FRI. Flagstaff, AZ. November 18, 2010.<br>✓ Vosick, D., Assistance to Henry Provencio to help compile the value of stakeholder contributions to the 4FRI. 11/19/10<br>✓ Vosick, D. Sent information to S. Friedman at the Forest Service requested for research and synthesis of wildlife and fish response to restoration. November 22, 2010.<br>✓ Greco, B. Attended 4FRI Landscape Strategy Working Group Meeting. Flagstaff, AZ. November 30, 2010. 13 attendees.<br>✓ Greco, B., M. Sensibaugh. 4FRI Treatment Area Portfolio |

# FY10 Plan of Work - Deliverables

| Project 7: Services to the Intermountain West | |
|---|---|
| **Deliverable** | **Status** |
| | Working Group meeting. (This represents multiple meetings in Nov - Dec, 2010.) Flagstaff, AZ. November - December, 2010. 12 attendees.<br>✓ Covington, W. W., B. Greco, B. Stevens. Attended joint Flagstaff City Council/ Coconino County Board of Supervisors meeting. Flagstaff, AZ. December 6, 2010. 30 attendees.<br>✓ Covington, W. W., B. Greco. Attended Large Tree Retention Strategy Meeting for 4FRI. Flagstaff, AZ. December 8, 2010. 8 attendees.<br>✓ Vosick, D. Follow up to Jeff Jarvis regarding whether or not fire could be safely used at Mt Trumbull. 12/22/10<br>✓ Covington, W. W., B. Greco. Large Tree Retention Strategy Working Group for 4FRI. Flagstaff, AZ. January 6, 7, 2011. 7 attendees.<br>✓ Greco, B. 4 FRI Treatment Area Portfolio Working Group Meeting. Flagstaff, AZ. January 3, 2011. 15 attendees<br>✓ Greco, B. Joint White Mountain Stewardship Monitoring Board and NRWG meeting. Show Low, AZ. January 4, 2011. 18 attendees.<br>✓ Vosick, D. Request from Oregon TNC to provide information on CROP and Catherine Mater. 1/10/11 |
| Associated field visits/training | ✓ Denton, C. Attended and presented at Greater Ruidoso Area Wildland Urban Interface Working Group (GRAWUIWG). Ruidoso, NM. January 26, 2010. 25 attendees.<br>✓ Greco, B. Conducted training for NPS Fire Staff on Ecological Restoration & AZFRA Program. Flagstaff, AZ. March 4, 2010. 4 participants.<br>✓ Greco, B. Congressional & USDA Field visit. Pinetop, AZ. June 4, 2010. 30 attendees.<br>✓ Greco, B., M. Sensibaugh. CFI (continuous forest inventory), Hopi lands inventory. Kykotsmovi, AZ. August 16, 2010. 10 attendees.<br>✓ Sensibaugh, M. Met with USFS to develop Landscape Strategy/Rapid Assessment process for Timber Mesa Assessment. Lakeside, AZ. November 30, 2010. Seven attendees.<br>✓ Sensibaugh, M. Met with USFS to finalize Landscape Strategy/Rapid Assessment process for Beaver Creek Assessment. Alpine, AZ. December 1, 2010. 9 attendees.<br>✓ Brewer, D., M. Sensibaugh, M. Stoddard, W. Chancellor. Completed Rapid Assessment of the Clint's Assessment Area. Long Valley, AZ. December 3, 2010. |

# FY10 Plan of Work - Deliverables

| ***Project 7: Services to the Intermountain West*** | |
|---|---|
| **Deliverable** | **Status** |
| | ✓ Greco, B., D. Brewer, L. Kalies. Conducted Systematic Review developmental meeting with USFS. Flagstaff, AZ. December 8, 2010. 9 attendees. |
| Three field trips/training (non-RAP related) | ✓ Greco, B., M. Sensibaugh. Met with Hopi DNR to select Forester position - Interview Panel.Kykotsmovi, AZ. February 9, 2010. 9 participants.<br>✓ Stevens, B. Took NAZ Today television crew to Fort Valley to discuss 4FRI efforts toward landscape scale restoration and results 100 years of changes to western forests. Flagstaff, AZ. April 7, 2010.<br>✓ Smith, H. B., Sensibaugh, M. Stevens, B. Sustainable Forest Field Trip – Flagstaff Festival of Science , Field trip to Doney Park/Sunset Crater area (Smith, Sensibaugh, Stevens) and Highlands Fire Department (City of Flagstaff) topics discussed: Schultz/Hardy Fires, unnatural/natural fire, pre-settlement conditions, healthy/unhealthy forests, need for landscape-scale restoration, 4FRI effort . Flagstaff, AZ. October 2, 2010. 20 public participants.<br>✓ Brewer, D. Reviewed information collected by contractor that will be used in 4-Forest effort. Coconino National Forest, AZ. November 16, 2010. |
| **Knowledge Services** | |
| ERI website. | ✓ Coquia, K. Summary report on ERI web support with 2010 Search Engine Optimization (SEO) and 2010 ERI website Statistic Analysis. **Completed.** (Link to summary) |
| White paper(s) | ✓ Integrating Domestic and Wild Ungulate Grazing into Forest Restoration Plans at the Landscape Level**. Completed.** http://library.eri.nau.edu/gsdl/collect/erilibra/index/assoc/HASH01ef.dir/doc.pdf |
| Working papers | ✓ Egan, D. "Protecting Old Trees from Prescribed Burning". Working Paper 24, Winter 2011. **Completed.** **http://library.eri.nau.edu/gsdl/collect/erilibra/index/assoc/HASH7f2a.dir/doc.pdf**<br>✓ Stoddard, M. "A Compilation of Historical Forest Structural Characteristics across the Southern Colorado Plateau". **Completed and in review** by M. Moore (at request of W. Covington) |

# FY10 Plan of Work - Deliverables

| Project 7: Services to the Intermountain West | |
|---|---|
| **Deliverable** | **Status** |
| Fact sheets | ✓ Stoddard, M.T. and M.D Hurteau. Carbon cost of mitigating high-severity wildfires. Fact Sheet, Ecological Restoration Institute. **Completed.** http://library.eri.nau.edu/gsdl/collect/erilibra/index/assoc/HASH010b/cd429bd6.dir/doc.pdf<br>✓ Mt. Trumbull: Climate Change May Affect Tree Production, Burn Frequency. **Trial abstract to BLM**.<br>✓ Roccaforte, John Paul. Fact Sheet: Post-Wildfire Fuels and Regeneration Dynamics. **Completed**. http://library.eri.nau.edu/gsdl/collect/erilibra/index/assoc/HASH017c/241f5228.dir/doc.pdf<br>✓ Hunter, M. Methods for Estimating Surface Live Fuel Loads. **Completed**. http://library.eri.nau.edu/gsdl/collect/erilibra/index/assoc/HASH7e6f.dir/doc.pdf |
| Presentations | ✓ Egan D., J. Seidenberg. Participated in the Kaibab Fire Awareness Fair by having an informational booth that provided the public with information on forest restoration. Williams, AZ. April 10, 2010. 30 participants.<br>✓ Roccaforte, J.P., P.Z. Fulé, and W.W. Covington. "Monitoring landscape-scale ponderosa pine restoration treatment implementation and effectiveness." A Decade of Discovery NLCS Science Symposium, Albuquerque, NM. May 24 – 28, 2010. 200 attendees.<br>✓ Greco, B. Presentation to White Mountain Stewardship group on adaptive monitoring framework. Show Low, AZ. September 20, 2010. 17 attendees.<br>✓ Stevens, B. Earth, Wind & Fire Panel Presentation – Flagstaff Festival of Science - ERI-hosted panel discussing the need and 4FRI effort for landscape-scale restoration and unnatural fire (Schultz/Hardy Fires) – High Country Conference Center, NAU – Covington, Stevens and members of 4FRI (The Grand Canyon Trust, The Nature Conservancy, U.S. Fish & Wildlife Service, Forest Service) reaching 60 members of the general public. September 28, 2010.<br>✓ Greco, B. Presentation on Southwest Ponderosa Pine Restoration and Research made to the USDA Forest Service. Flagstaff, AZ. September 29, 2010. 40 attendees.<br>✓ Greco, B. Presentation to private industry bio-fuel representatives on 4 FRI and small diameter wood supply study. Flagstaff, AZ. September 30, 2010. 5 attendees.<br>✓ Stevens, B. Flagstaff First Friday Art Walk – ERI |

| ***Project 7: Services to the Intermountain West*** | |
|---|---|
| **Deliverable** | **Status** |
| | representative (Stevens) and materials (Pocket Facts and 4FRI posters) presented to participants. Topics discussed – fire ecology, reference conditions, need for landscape-scale restoration, 4FRI efforts. Collaborative effort with Forest Service 4FRI team members. Estimated reach – 300 people – community members. October 1, 2010.<br>✓ Covington, W.W. "Developing Science to Inform and Guide Collaborative Planning," presented at the "Solutions for Forests: Active Management Perspectives for Southwest Oregon." Ashland, OR. October 19, 2010. 120 people in attendance.<br>✓ Vosick, D. Participated on panel summarizing observations from the conference and the field trip, and a one hour sessions to develop a blueprint for restoration of SW Oregon forests. "Solutions for Forests: Active Management Perspectives for Southwest Oregon." Ashland, OR. October 22, 2010<br>✓ Greco, B. Presentation on Southwest Ponderosa Pine Restoration and Research made to the Western Watershed Managers Association conference. Flagstaff, AZ. October 28, 2010. 70 attendees.<br>✓ Stevens, B., K. Gilbreath. Society of American Foresters Convention , Albuquerque Oct. 27 – 29 – 300 visitors to booth – landscape scale restoration + 4FRI Poster Session (Stevens) |
| Field trips | ✓ Vosick, D., P. Z. Fulé, B. Greco, J. Seidenberg, W. Greer. 4 FRI Desired Future Conditions (DFC) field trip. Flagstaff, AZ. July 24, 2010. 55 participants.<br>✓ Smith, H.B. At the request of the Park Service and Forest Service, led a four hour field trip/presentation/lecture entitled, "Among the Giant Ponderosas." Flagstaff, AZ. June 28, 2010. 13 attendees.<br>✓ Greco, B. Presentation to Ethiopian delegation on "Restoration of Southwest Ponderosa Pine." Bellmont, AZ. August 23, 2010. 15 attendees.<br>✓ Vosick, D., B. Greco, J. Seidenberg. 4 FRI White Mountain field trip. Pinetop, AZ. August 26, 2010.<br>✓ Greco, B. Conducted field review of Restoration and Fire Applications. Silver City, NM. October 18-21, 2010. 5 attendees.<br>✓ Greco, B., D. Brewer, M. Sensibaugh. Conducted field review of Restoration and Fire Applications on the Clint's Assessment area. Happy Jack, AZ. November 3, 2010. 4 attendees.<br>✓ Covington, W. W., B. Greco, D. Brewer, M. Sensibaugh. |

# FY10 Plan of Work - Deliverables

| ***Project 7: Services to the Intermountain West*** | |
|---|---|
| **Deliverable** | **Status** |
| | Conducted field review of Long Valley Experimental Goshawk guidelines for treatments. Happy Jack, AZ. November 4, 2010. 20 attendees. |

| ***Project 8: Provide annual peer-reviewed reports*** | |
|---|---|
| **Deliverable** | **Status** |
| **1.** Peer-reviewed report 60 days after completion of the agreement. | ✓ **In progress**. |

# FY11 Plan of Work - Deliverables

## FY11 Plan of Work

| ***Project 1: Evidence-Based Conservation*** | |
|---|---|
| **Deliverable** | **Status** |
| **1. LEARN.** Data analysis and submission of journal article based on FY10 and FY11 field seasons. | ✓ Working Title (Huffman): "Using a network of long-term monitoring sites to evaluate the success of forest restoration treatments in the American Southwest." **In progress.** |
| **2. Wildlife responses.** Description of a new research initiative and one journal manuscript that synthesizes wildlife responses to restoration. | ✓ AZ Game and Fish work **in progress**.<br>✓ Working title: Small mammal community occupancy responses to restoration treatments in ponderosa three pine forests, northern Arizona, USA" . **In progress.** |
| **3. Rare Species.** One working paper that reports on restoration effects and implications for developing landscape-scale treatments that enhance rare species' habitat. | ✓ Working title (Springer/Egan): "Rare Species….." |
| **4. Fuel Treatments. One journal manuscript for publication.** | ✓ In progress (D. Huffman). Working title: "Understory community responses to alternative fuel hazard reduction treatments in pinyon-juniper woodlands." |

| ***Project 2: Stewards of Place*** | |
|---|---|
| **Deliverable** | **Status** |
| A working paper describing design of an adaptive management approach that includes ecological and socio-economic monitoring of restoration treatments on a landscape scale that builds upon results from the 2009 SWERI monitoring workshop and is consistent with the long-term CFRP monitoring objectives.<br><br>A working paper describing methodologies to achieve ecological restoration at the landscape scale.<br><br>Provide services to the 4FRI | ✓ "Monitoring" in progress (Egan) and reported in Project 7, Working Papers<br><br>✓ "Restoration Strategies" in progress (Egan) and reported in Project 7, Working Papers<br><br>✓ Greco, B., D. Vosick. 4FRI MOU Development Meeting |

# FY11 Plan of Work - Deliverables

| Project 2: Stewards of Place | |
|---|---|
| **Deliverable** | **Status** |
| Stakeholder Group. ***Note that the budget reduction in FY11 will result in reduced service to the 4FRI*** | with Forest Supervisors. Flagstaff, AZ. January 10, 2011. 15 attendees.<br>✓ Stevens, B. 4FRI Web site goes live through ERI efforts: Krista Coquia, Joe Seidenberg, Bonnie Stevens and 4FRI Communications Working Group. Flagstaff, AZ. January 19, 2011.<br>✓ Greco, B. 4FRI Firescape development meeting. Flagstaff, AZ. February 1, 2011. 12 attendees.<br>✓ Greco, B., D. Vosick. 4FRI Collaborative Meeting. Flagstaff, AZ. February 23, 2011. 30 attendees.<br>✓ Greco, B. and ERI staff. Ongoing support and coordination with Southwest Crown of the Continent CFLRP (Bozeman, Mt).<br>✓ Greco, B. and ERI staff. Support to the CFLRP with a variety of place-based forums, Rapid Assessments, transfer of best-science, Systematic Reviews, etc.<br>✓ Dave Brewer conducted an extensive analysis for 4FRI, that included data collection, analysis, development of a database & report that will be utilized in the 4FRI NEPA EIS Proposed Action and in the Forest Plan revision for the Kaibab & Coconino NF's. This was a long-term project that took 4 months of Dave's time. The benefit to the FS was extensive savings in $ and 1 professional FTE. The work included the following:<br>1. Development of an access database for 80 clusters for the Kaibab and 52 from the Coconino that track changes in understory species diversity from 1950 to 2010.<br>2. Analysis of each cluster through the period of record looking at understory diversity and changes in ground cover separates.<br>3. Determination of existing range conditions for the sites found within the project area.<br>4. For the Kaibab only, reproduction of the historical photos showing the plot at the earliest and latest read date.<br>5. Analysis of all clusters found in the project area and determination of which ones will be used in the assessment.<br>6. Development of numerous pivot tables to determine species frequency within the individual allotments, strata, TESU, and clusters. And development of a final report for the Forest Service.<br>✓ |

# FY11 Plan of Work - Deliverables

| ***Project 3: Ecosystem Services*** | |
|---|---|
| **Deliverable** | **Status** |
| **1. Ecosystem Sustainability.** One journal manuscript for publication of pinyon-juniper ecosystem sustainability at the landscape scale. **Due to reduced funding in FY11 this project will be completed w/leveraged state funds (Prop 301)** | ✓ Working title (Huffman): "Historical fuels and fire behavior in ponderosa pine and pinyon-juniper ecosystems on Anderson Mesa, Arizona: implications for sustainability." In progress. |

| ***Project 4: Climate*** | |
|---|---|
| **Deliverable** | **Status** |
| **Cancelled in FY11** | |

| ***Project 5: Economies and Job Creation*** | |
|---|---|
| **Deliverable** | **Status** |
| A white paper summarizing successful approaches to job creation and a white paper analyzing the tipping point between investment in restoration treatments and realizing savings in suppression costs. | ✓ Pending and also reported in P-7 (Vosick/Egan)<br>✓ Pending and also reported in P-7 (Vosick/Egan) |

# FY11 Plan of Work - Deliverables

| ***Project 6: State and Private Forestry*** | |
|---|---|
| **Deliverable** | **Status** |
| Science and technical support to Arizona State Forestry and Science support and technical assistance to tribes (Greco). | ✓Greco, B., D. Huffman. Southwest Fire Science Consortium Coordination Meeting. Flagstaff, AZ. April 13, 2011. 4 attendees.<br>✓Covington, W.W. Congressional Field Hearing re: Wallow Fire. Springerville, AZ. June 29, 2011. 25 people in attendance, including Secretary of Agriculture, Vilsack.<br>✓ERI outreach/research staff. Coordinated the Fisher-Rock Prescribed burn (Centennial Forest, NAU/AZ State Department of Forestry). 350 acre prescribed burn on State Land, for resource & research objectives. 4/26-4/28/11.<br>✓ERI outreach/research staff. Facilitated a partner-based forum on development of a Fire-use Council for the State of Arizona. Multiple meetings were held with the FS and fire Management Organizations. 5/17/11 and ongoing. |

| ***Project 7: Services to the Intermountain West*** | |
|---|---|
| **Deliverable** | **Status** |
| **Outreach to forest managers across the West.** | |
| Continued Support for Forest Plan Revisions | ✓ Greco, B. USDA FS Coordination-Rx Fire Council Organization meeting. Flagstaff, AZ. March 21, 2011. 4 attendees. |
| Rapid Assessments | **FY11**<br>✓ Timber Mesa Rapid Assessment (Lakeside RD, A/S NF) ERI conducted Field training & 2 workshops for FS personnel. ERI collected data from several plots and identified sites for establishing LEARN research plots. ERI reestablished several long-term Range cluster sites for the FS & will update FS databases.<br>✓ Bluewater Monitoring Project (Grants RD, Cibola NF) ERI implemented a series of data collection plots and measurements to establish baseline data to monitor the Bluewater Ecosystem Management Project. A series of RA sites were established for pre & post treatment monitoring. A report was prepared for the FS. The effort involved several field trips to the site for District, Forest & RO Directors to view Restoration and Goshawk Guideline prescriptions & treatment prescription alternatives. 50 people attended.<br>✓ Wildcat Rapid Assessment (Black Mesa Rd, A/S NF) ERI |

# FY11 Plan of Work - Deliverables

| ***Project 7: Services to the Intermountain West*** | |
|---|---|
| **Deliverable** | **Status** |
| | initiated a workshop & field visits as a preliminary phase to conducting a Rapid Assessment for use in the NEPA process (Proposed Action). Data collection sites were visited with FS personnel prior to RA being conducted this summer. 12 personnel attended |
| Information requests | ✓ Covington, W. W. , B. Stevens. Conference call with western forest restoration and media relations staff, The Nature Conservancy – Colorado/NM) (Stevens, Covington) regional landscape-scale, CFLRP, SWERI projects for public awareness/media news. January 25, 2011.<br>✓ Vosick, D. Assistance to Henry Provencio to help compile info for CFLRP work plan. 1/27/11<br>✓ Covington, W. W. B. Stevens. Conference call with Forest Service Regional Office Public Affairs Officer regional landscape-scale, CFLRP, SWERI projects for public awareness/media news. January 28, 2011.<br>✓ Vosick, D. Request from TNC for citations related to water yield. 2/23/11<br>✓ Vosick, D. Request from Gwen Garcylon with the Roaring Fork Project in Colorado concerning a collaborative start-up. 2/28/11<br>✓ Greco, B. Congression meeting with Congressman Gosar. Show Low, AZ March 16, 2011. 17 attendees.<br>✓ Vosick, D. Mose Jones-Yellin- Dinkey Project--Request for resources on Monitoring. 4/19/11<br>✓ Vosick, D. Cam Hunter Request for the TNC analysis of language of fire. 4/29/11<br>✓ Vosick, D. Paula Cote request for assistance with information about Chad Hanson. 4/29/11<br>✓ Vosick, D. and A. Waltz. 15 hours invested to assist with the CFLR national monitoring workshop. 5/1/11<br>✓ Vosick, D. Lucy Murfitt, request for review of HR 4200. 6/20/11<br>✓ Vosick, D. Lucy Murfitt, request for more information on salvage logging. 7/1/11<br>✓ Vosick, D. Request from Chandler Morse on information concerning BAER. 7/1/11<br>✓ Vosick, D. Jim Devos elk group for link to study on the efficacy of post-fire seeding. 7/5/11<br>✓ Vosick, D. Request for information from CEQ via Marcus on how lessons will be shared. 7/18/11<br>✓ Vosick, D. Dick Fleishman asked for additional information on economics and utilization pertaining to 4FRI for the CEQ. |

# FY11 Plan of Work - Deliverables

| ***Project 7: Services to the Intermountain West*** | |
|---|---|
| **Deliverable** | **Status** |
| | 7/25/11<br>✓ Vosick, D. Facilitation assistance with the White Mountain Forest Restoration Partners. Ongoing |
| Associated field visits/training | ✓ Greco, B. Black Mesa Restoration Workshop. Overgaard, AZ. February 10, 2011. 16 attendees. |
| Three field trips/training (non-RAP related) | ✓ Pending |
| **Knowledge Services** | |
| ERI and SWERI (*new in FY11)* websites. | ✓ Coquia, K. Summary report on ERI web support with 2011 Search Engine Optimization (SEO) and 2011 ERI website Statistic Analysis. **In progress. (Link to summary)** |
| White paper(s) | ✓ Pending. Working Title: "Job Creation" based on analysis in Project 5. (Vosick/Egan)<br>✓ Pending. Working Title: "Tipping Point" based on analysis in Project 5. (Vosick/Egan) |
| Working papers | ✓ "Monitoring" and "Restoration Strategies" (Egan) pending based on analysis performed in Project 2 |
| Fact sheets | In progress (Egan,Vosick, Huffman)<br>✓ Kalies, L. Fact Sheet: Evidence-Based Restoration Systematic Review: Effects of Restoration on Wildlife Density and Populations. http://library.eri.nau.edu/gsdl/collect/erilibra/index/assoc/HASH2138.dir/doc.pdf<br>✓ Vosick, D., D. Egan. Fact Sheet:Lessons Learned from the Wallow Fire. 7/2011 (pending post on ERI website)<br>✓ *Working Title: Grand Canyon-Parashant National Monument*<br>✓ *Working Title:* Climate Change: What a Land Manager Needs to Know.<br>✓ *Working Title*: Organizing a Landscape-scale Restoration Monitoring Program<br>✓ *Working Title*: Forest Service Timber Sale Procedures: A Stakeholder's Guide<br>✓ *Working Title*:Workforce Development Prospects in the 4FRI Region |
| Presentations | ✓ Kalies, E.L., C.L. Chambers, and S.R. Rosenstock. 2011. Multi-season occupancy modeling: applications to avian- |

| ***Project 7: Services to the Intermountain West*** | |
|---|---|
| **Deliverable** | **Status** |
| | habitat relationships. The Wildlife Society's Arizona and New Mexico 44th Joint Annual Meeting, Pinetop, Arizona. February 3-5, 2011.<br>✓ Chambers, C.L. and E.L. Kalies. 2011. Bird communities in wildfire-burned ponderosa pine landscapes 14 years post fire. Presentation to the USFS Williams District. 3/7/11. 20 attendees.<br>✓ Greco, B. "Utilizing Restoration Research in Development of Fire Management Plans." Presentation made at Southwest Interagency Fuels Conference. Flagstaff, AZ. March 8, 9, 2011. 85 attendees<br>✓ Greco, B. "Fire Strategies in Fire Adapted Ecosystems." Presentation made at Tri-Regional Fire Managers Conference. Flagstaff, AZ. February 24, 2011. 75 attendees.<br>✓ Covington, W. W. "Ecological Restoration: A Practical Imperative for Arizona's Future." Presentation made to the Greater Phoenix Area Chamber of Commerce. Phoenix, AZ. April 15, 2011. 29 attendees.<br>✓ Masek Lopez, S. Poster presentation at National Workshop on Climate & Forests: Planning Tools and Perspectives on Adaption and Mitigation Options, sponsored by USDA Forest Service. Poster titled, "Designing Effective Forest Restoration Treatments to Augment Snow Water." Northern Arizona University. Flagstaff, AZ. May 17, 2011. 50 attendees.<br>✓ Roccaforte, J.P. "Ponderosa pine ecological primer." Presentation for Grand Canyon-Parashant Partnership Workshop, St. George, UT. May 17-19, 2011. 50 participants<br>✓ Huffman, D. "Pinyon-Juniper". Presentation for Grand Canyon-Parashant Partnership Workshop, St. George, UT. May 17-19, 2011 |
| Field trips | ✓ Roccaforte, J.P. "Ponderosa pine ecological primer." Presentation and field trip for Grand Canyon-Parashant Partnership Workshop, St. George, UT. May 17-19, 2011. 50 participants.<br>✓ Huffman, D., D. Smith, W. Greer. Field trip in association w/presentation on "Pinyon-Juniper". May 18, 2011 |

# FY11 Plan of Work - Deliverables

| ***Project 8: Provide annual peer-reviewed reports*** | |
|---|---|
| **Deliverable** | **Status** |
| **1.** Peer-reviewed report 60 days after completion of the agreement. | ✓ **In progress**. |

Referenced Documents not yet available on ERI (or other) websites

# WILDLIFE RESPONSES TO RESTORATION TREATMENTS IN NORTHERN ARIZONA FOREST AND GRASSLAND HABITATS

Annual Progress Report

July 13, 2010 to January 18, 2011

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Yarborough, R. F, B. G. Dickson, C. D. Loberger, and S. S. Rosenstock. 2011. Wildlife responses to restoration treatments in Northern Arizona forest and grassland habitats. Unpublished report to Ecological Restoration Institute, Northern Arizona University. Research Branch, Arizona Game and Fish Department, Phoenix, AZ.

**Acknowledgments**

We thank the Ecological Restoration Institute (ERI) at Northern Arizona University (NAU) for their continuing cooperation and support. The NAU ERI and Greater Flagstaff Forests Partnership provided funding for this research, along with the Arizona Game and Fish Department through Pittman-Robertson Federal Aid Project W78-R. Jill Rundall and Steven Sesnie (NAU School of Earth Sciences and Environmental Sustainability, Lab of Landscape Ecology and Conservation Biology) helped develop spatial data and models for collaborative efforts on Anderson Mesa.

# INTRODUCTION

Ponderosa pine (*Pinus ponderosa*) forests of the southwestern U.S. have changed dramatically over the past century, primarily in response to grazing, logging, and fire suppression (Covington and Moore 1994). Currently, ponderosa pine forests tend to be composed of single age stands, which lack structural and composition diversity. These homogeneous, crowded forests are stressed by competition for resources and bark beetle infestations, and are increasingly vulnerable to uncharacteristic, high intensity wildfire. High intensity wildfires can significantly alter Northern Arizona's communities and forests, as the 460,000-acre Rodeo-Chediski fire in 2002 demonstrated. As a result, forest restoration treatments are gaining attention as a forest management tool for reducing fire risk and improving ecological function of the forest.

Restoration treatments, which modify the existing homogeneous forest structure, will affect wildlife species, and other components of the ecosystem, in various ways (Allen et al. 2002). For example, thinning may reduce vertical structure for nesting or foraging birds, but an increase of herbaceous vegetation following prescribed fire may provide improved foraging conditions for herbivores and/or insectivores (Chambers and Germaine 2003). Thus, when developing forest management plans, it is critical to identify the structural and compositional features of the forest that are important to wildlife (Lindenmayer and Franklin 2002).

In 1997, the Arizona Game and Fish Department (AGFD) partnered with the NAU Ecological Restoration Institute (ERI) and Bureau of Land Management to investigate wildlife responses to forest restoration on the Grand Canyon-Parashant National Monument in northwestern Arizona. Associated studies on Mount Trumbull area were completed in 2006. Since then, AGFD efforts have been focused on forest treatments in the Flagstaff wildland-urban interface (WUI) and grassland restoration areas on Anderson Mesa. This report covers activities from July 13, 2010 to January 18, 2011.

# TASSEL-EARED SQUIRRELS

The tassel-eared squirrel (*Sciurus aberti*) is considered a ponderosa pine "obligate" species. It relies on ponderosa pine and associated hypogenous fungi (Keith 1965, Stephenson 1975, States et al. 1988, Austin 1990, Snyder 1992) for most of its diet, and its nests are placed almost exclusively in these pines (Halloran and Bekoff 1994, Snyder and Linhart 1994), which also provide escape cover from predators and movement corridors created by interlocking tree canopies (Stephenson and Brown 1980).

Given the dependence of tassel-eared squirrels on ponderosa pine, previous studies have suggested that restoration treatments can modify forest density and structure in ways that could affect the tassel-eared squirrels' food supply, nest availability, and predation risk. Squirrels occupying commercially harvested areas have larger home ranges (Patton 1985, Lema

2001), reduced body condition (Pederson et al. 1987), lower density (Patten et al. 1985, Pederson et al. 1987), and lower recruitment (Dodd et al. 2003). In addition, restoration could reduce the amount of interlocking canopy that squirrels use as pathways for escaping predators (Austin 1990, Dodd et al. 2003).

Management recommendations following from these and other studies have led some researchers to postulate that restoration resulting in a forest mosaic with approximately 40% optimal squirrel habitat could enhance or maintain viable squirrel populations (Chambers and Germaine 2003) or that up to 75% of a forested landscape could be treated and still provide suitable squirrel habitat if treatments were applied as a mosaic of patches (Dodd et al. 2006). We have further refined this concept, examining squirrel responses to embedded untreated or lightly-treated patches of varying size.

Our objectives during this contract period were to: 1) quantify squirrel habitat use and movements in restored forests 2) continue to work on revised manuscripts from previous research.

## Study Area

The Mountainaire study site experimental prescription includes 3 distinct forest components: winter core areas (WCAs, formerly referred to as “meso-reserves”), matrix, and full restoration (Dodd 2003; Figure 2) modified to accommodate existing stand conditions and fuel reduction objectives specific to the Mountainaire Project. This combination of components was developed to maximize tassel-eared squirrel density and recruitment while meeting other ecological restoration goals, such as fire risk reduction and improved tree vigor. WCAs have higher basal area and extensive interlocking canopies that provide habitat for squirrel nest placement, movements, and protection from predators. These conditions also are correlated with the increased productivity of hypogeous fungi (States and Gaud 1997), an important food source for squirrels. Results from previous research (Loberger 2009) suggest that these core areas located in denser forest patches are important to squirrel survival throughout the winter months. WCAs also provide structural characteristics that may benefit other wildlife species that use denser habitat (e.g., mule deer, elk, and some migratory song birds). Ladder fuels can be removed from WCAs to reduce fire risk without compromising squirrel habitat. The adjacent matrix and full restoration treatments provide a buffer against the fire risk associated with denser conditions within WCAs. Matrix and full restoration treatments can improve cone production, which would benefit squirrels. However, research at Mt. Trumbull suggests that squirrels may not use matrix and full restoration areas for foraging if stands with structure resembling WCAs are not present at the appropriate scale (AGFD, unpubl. data). The Airport project area encompasses approximately 134 acres immediately adjacent to Pulliam Airport, east of Interstate 17, on lands owned by the City of Flagstaff. The project was developed collaboratively by the Flagstaff Fire Department, Arizona Game and Fish Department, Greater Flagstaff Forests Partnership, and NAU-ERI, and NAU School of Forestry. The prescription emphasized mechanical thinning to re-create pre-settlement forest conditions on 107 acres. Leave trees were arranged in a mosaic pattern of clumps and groups of variable size, using a replacement ratio of 1.5 leave trees per pre-settlement evidence. All trees >24" dbh were retained. Groups and clumps varied in shape, size, and number of trees and were irregularly shaped. Groups were located perpendicular to prevailing wind to reduce fire hazard. Basal area within groups ranged from 27–54 $ft^2$/acre. Slash from harvested trees is being chipped and hauled off-site. The experimental prescription included retention of 2 WCAs (17 and 10 acres in size) within the treatment area. These WCAs are considerably smaller than those implemented on the Mountainaire project (67–223 acres) and will provide insight into the value of smaller, dense patches to tassel-eared squirrels.

## Methods

We relocated 32 telemetered squirrels $\geq$2 times per week from August 2010 to January 2011 obtaining a visual location whenever possible. We allocated tracking equally across morning, afternoon, and late-afternoon periods. We recorded animal locations with a hand-held Global Positioning System unit after the unit achieved an accuracy of $\leq$8 m. We recorded habitat attributes (treated or untreated, tree species, tree height) at each location and also noted if the squirrel was in a nest.

## Results and Discussion

We tracked a total of 32 squirrels (11 females, 21 males) and obtained over 600 locations. Preliminary results from August – January 2011 tracking indicate that a majority of squirrels left the Airport study area during treatment activities. After mechanical harvest and chipping was completed, squirrels returned in proximity to the study area. We had 15 squirrel mortalities due to predation, road kill, and unknown causes. The majority of recovered collars were located in full restoration treatments. This could be due to lack of cover in the treated areas making the squirrels more susceptible to predation or may have reflected locations where the collars were left by predators.

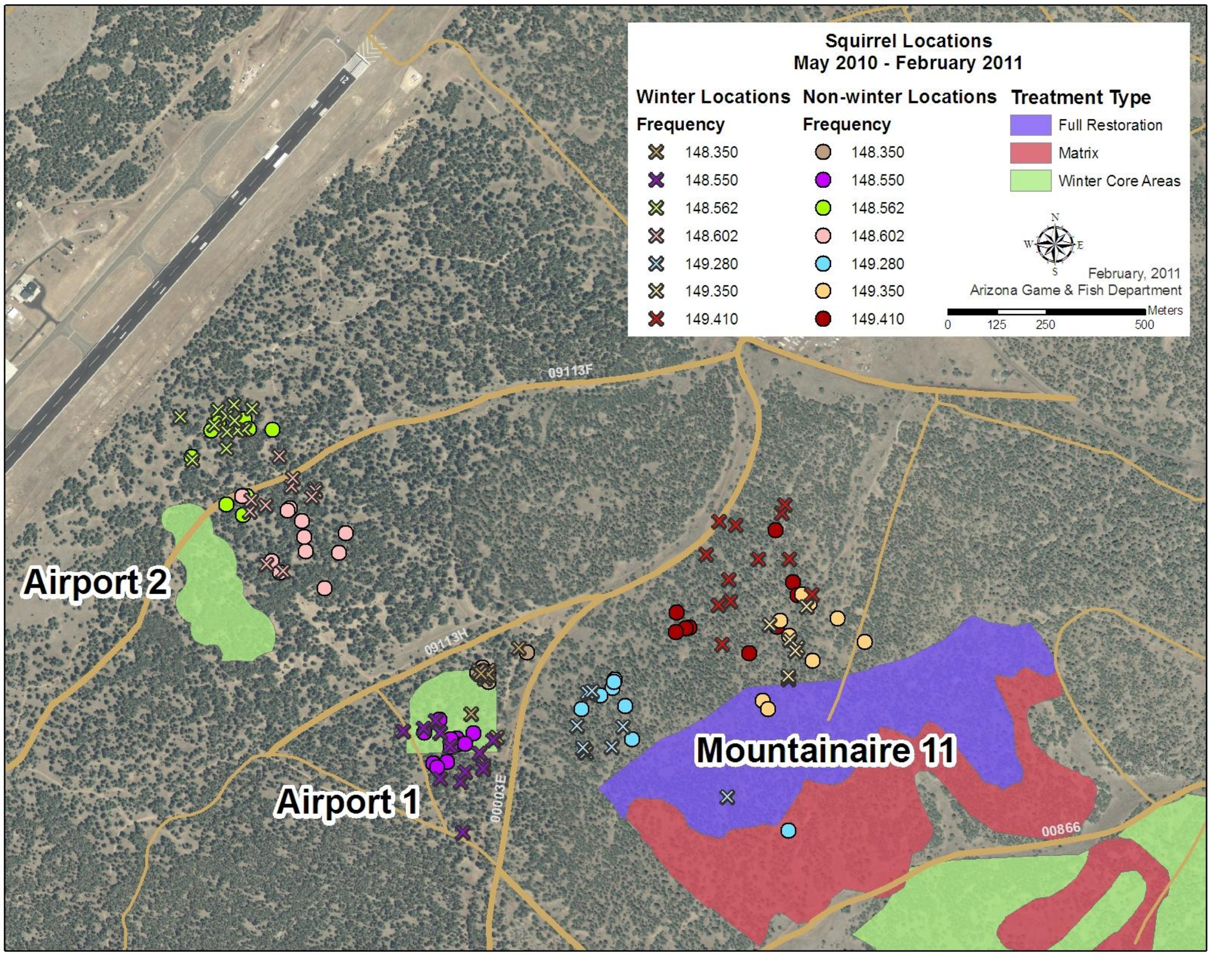


Figure 1. Examples of squirrel movements in Airport and Mountainaire Study site near Flagstaff AZ, May 2010 – February 2011.

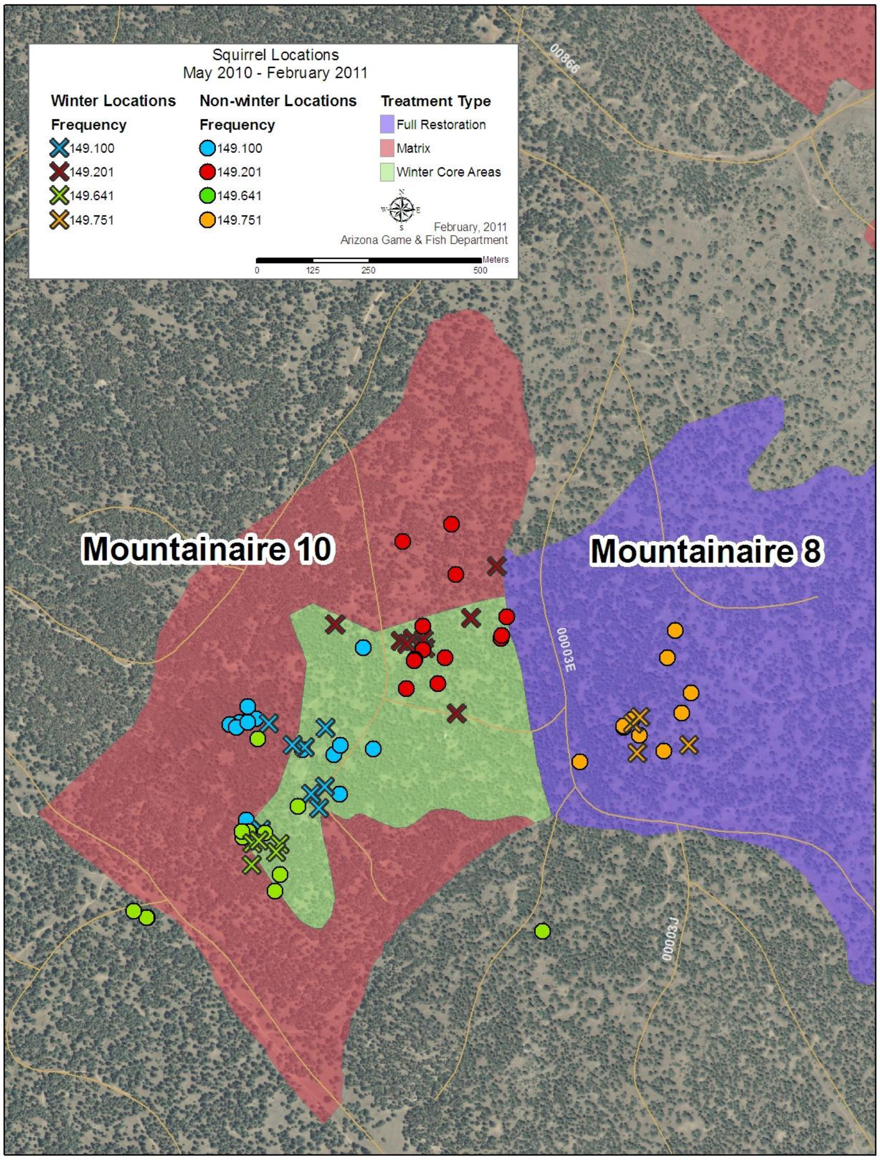


Figure 2. Examples of squirrel movements in Mountainaire Study site near Flagstaff AZ, May 2010 –February 2011.

## Upcoming Work

We plan to continue to tracking squirrels through November 2011, the expected battery life of currently deployed radio collars. We will also recover further mortalities that may occur and attempt to ascertain cause of death. Following completion of the field portion of the study, we will begin analyzing data and preparing one or more manuscripts derived from this effort.

Depending on snow cover and access, we will initiate squirrel feeding sign surveys at the Mountainaire, Fort Valley, and Airport study areas. These surveys have been ongoing since 2005 and provide estimates of squirrel abundance across treated and untreated areas.

## ANDERSON MESA PRONGHORN

Anderson Mesa, located east of Flagstaff, Arizona, historically supported one of the largest pronghorn (*Antilocapra americana*) populations within the state. The herd has declined significantly in recent decades, likely in response to a suite of biotic and abiotic factors. To improve habitat for pronghorn, AGFD, USFS, and others initiated extensive efforts in 2003 to restore grassland areas encroached by woodland vegetation (primarily pinyon-juniper). These efforts have been constrained by the limited understanding of pronghorn habitat use and the absence of the robust spatial data for the Anderson Mesa area. Subsequently, AGFD initiated a cooperative spatial analysis project with the NAU Lab of Landscape Ecology and Conservation Biology. The overall objectives were to develop data layers and models for analyzing pronghorn habitat use before and after implementation of grassland restoration treatments on Anderson Mesa. Funding provided to AGFD by NAU-ERI has been used to support this analysis.

### Methods

We continued development of a spatial database describing environmental and habitat conditions across a 4,180-$km^2$ extent of Anderson Mesa. During this reporting period, we focused on developing models of surface water available to pronghorn and a spatially explicit model of space and resource use during the summer season.

*Modeling and mapping reliable waters* - Orthorectified four band color infrared (CIR) aerial photographs from year 2007 were used to map reliable waters, defined for this project as water sources likely to be available throughout the year. NDVI was added as a fifth band to enhance mapping algorithms applied to the images. A spectral mixture analysis or match-tuned filtering was applied using spectral end members collected from known water body locations, grass and shrubs, shadow, and tree canopy. Resulting gray-scale indicated a perfect match to water end members with values close to one. Pixel values for water and cut-off thresholds were identified by interactively stretching histogram data and comparing outputs to existing US Forest Service maps of known water features. Results of these modeling efforts (i.e., distance to reliable waters) were integrated into statistical a statistical model of pronghorn habitat use in the summer season.

*Models of space and resource use by pronghorn* - Within a standardized and structured framework, we compiled expert-based sets of competing models for estimating the intensity of seasonal space and resource use by pronghorn occupying the study area. We used species experts in the model development phase and assignment of habitat variables to multiple competing hypotheses or “candidate models.” Some habitat variables and candidate models were iteratively refined through discussions with individual experts. Variables included, but were not limited to: distance to reliable waters, fenceline distance, fenceline density, grassland patch area, grassland/shrubland patch area, dominant native vegetation type, slope, tree canopy cover, treated area footprint (binary, updated each year 2003-2006), and major road barriers.

We used spatial mixed-effect models and a hierarchical approach to estimate patterns of pronghorn space and resource use (and drawing on the 95%FK UDs described above) as a function of <11 habitat variables (i.e., fixed effects) and the expert-based models. To hierarchically account for broad-scale spatial structuring (e.g., positive spatial autocorrelation) in the location data, our mixed-model approach treated animals within years as a subject-level random effect (i.e., the sampling unit).

For each set of expert-based candidate, we used an information-theoretic approach and multi-model inference to identify the best mixed-effect model(s) and compute model-averaged regression coefficients and their unconditional standard errors. We used AIC (Akaike's Information Criterion) to rank the relative importance of models in each candidate set, and AIC weights to rank and evaluate the weight of evidence in favor of each variable. For each variable, we summed the AIC weights across all possible models in which a given variable ($j$) occurred and considered a cumulative AIC weight ($w_+(j)$) ≥ 0.50 to be strong evidence for a response by pronghorn to that variable.

To predict intensity of space and resource use (i.e., 'intensity of use') by pronghorn across the study area, we assembled a single synthetic statistical model that included the model-averaged habitat predictor variables identified within the candidate model set (see summer season variables detailed in Table 1). This synthetic model was then implemented within a GIS to produce a probabilistic, spatially explicit response surface for each season of analysis (summer season is presented in Figure 1).

Table 1. Model-averaged regression coefficients ( $\tilde{\bar{\beta}}$ ), unconditional standard errors (SE), and cumulative AIC weights ($w_+(j)$) for habitat variables (mean fixed effects) used to model habitat use by 12 American pronghorn on Anderson Mesa, Arizona, 2003-2006. All estimates based on standardization and rescaling of all continuous variables prior to analysis, and conditioned on covariance parameters. Squared term represents quadratic form of variable used for inference.

| | Summer season | | |
|---|---|---|---|
| Habitat variable | $\tilde{\bar{\beta}}$ | SE | $w_+(j)$ |
| Grassland patch area (ha) | 0.032 | 0.016 | 0.605 |
| Tree canopy cover (%) | -0.005 | 0.002 | 0.669 |
| Slope (deg.) | -0.004 | 0.002 | 0.473 |
| Distance to fenceline (m) | 0.080 | 0.033 | 1.000 |
| Distance to fenceline$^2$ | -0.105 | 0.055 | 1.000 |
| Fenceline density (km/10 km$^2$) | -0.031 | 0.016 | 0.679 |
| Distance to reliable water (m) | -0.323 | 0.082 | 0.964 |
| Treated area | 0.044 | 0.016 | 0.979 |

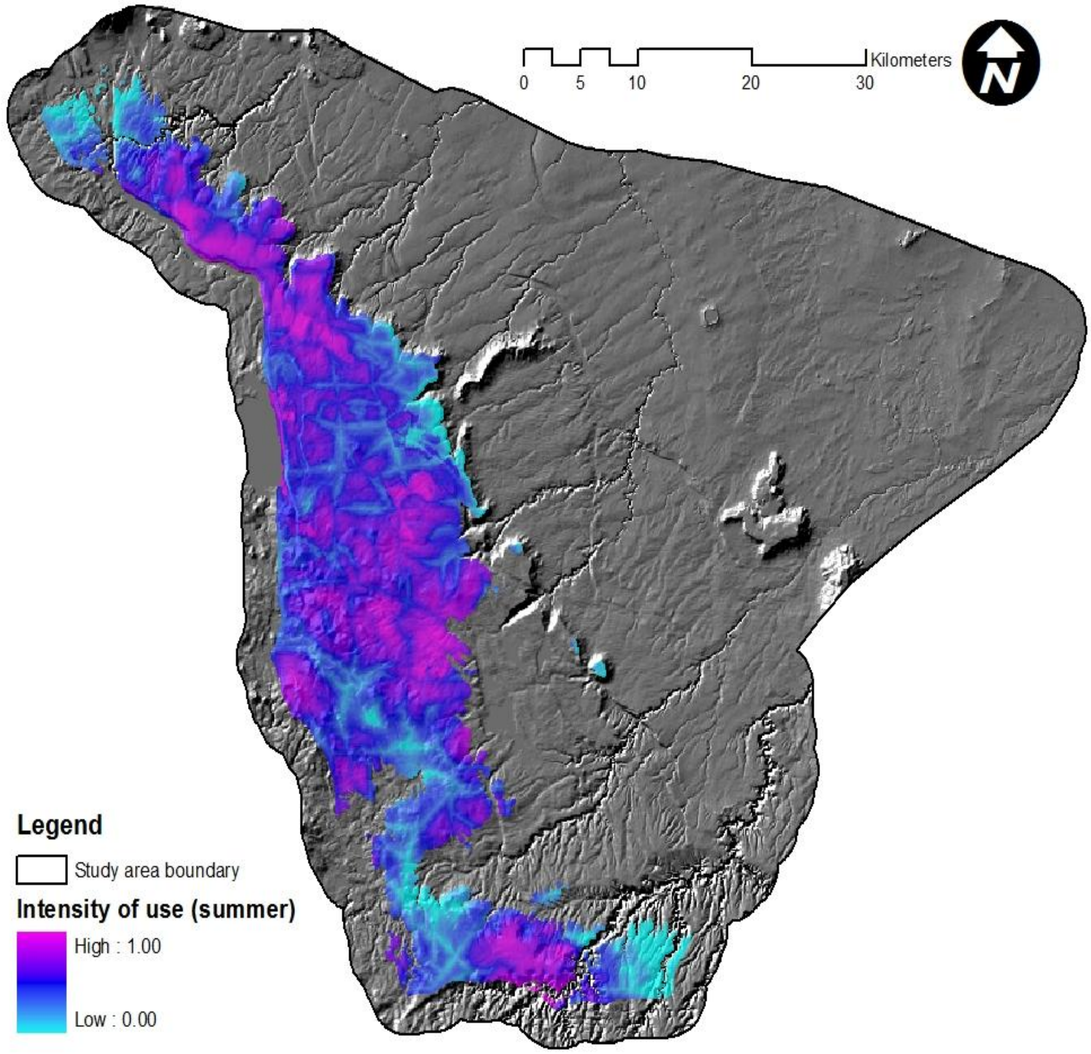


Figure 1. Updated model of summer season (areas >2100m in elevation) intensity of space and resource use by American pronghorn on Anderson Mesa, 2003-2006.

## Upcoming Work

During the next project segment, we will complete analyses of pronghorn habitat use for summer and winter periods, and submit the results in 1 or more peer-reviewed journal manuscripts. AGFD has also tentatively approved funding for a post-treatment habitat-use study of pronghorn on Anderson Mesa. If given final approval, we will initiate this effort in fall 2011, capturing and GPS-collaring a new cohort of animals that will be monitored for 2-3 years.

## RECENT PUBLICATIONS

Loberger, C. D., T. C. Theimer, S. S. Rosenstock, and C. W. Wightman. *Revised manuscript in review.* Tassel-eared squirrels use of a restoration-treated ponderosa pine forest. Journal of Mammalogy.

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**Handbook for the Ecological Restoration of Frequent-fire Forests in the American West**

Directive

From the FY10 and FY11 ERI work plans: "Development of a landscape restoration handbook. The handbook will be an illustrated guide describing decision support, information approaches, and lessons learned that will be useful in collaborative, place-based restoration workshops and agency trainings."

General principles

- The main audience is practitioners, land managers, and, to a lesser extent, members of the public who are actively involved in the restoration process.
- Each of the chapters will be relatively short (5-8 pages) with a 50/50 blend of text and graphics (i.e., photos, diagrams, "cartoons"). Side boxes and "pull quotes" will be used to emphasize or explain important concepts or practices.
- The text will be accessible while still conveying important facts and scientific information.
- Chapters will draw heavily on the work and experiences of the ERI and other like-minded organizations in the American West.
- Three items will be emphasized: 1) the importance of restoration treatments for improving overall forest health, 2) how to implement a restoration treatment, and 3) the need for monitoring and education to provide support and long-term sustainability.
- The tone will be positive and encouraging.
- The handbook will cover frequent-fire forest restoration in Arizona, New Mexico, Colorado, California, Oregon, Washington, Idaho, Montana, Nevada, Wyoming, and South Dakota (i.e., the American West).

Proposed outline

I. Preface (written by/signed by SWERI directors and/or FS regional foresters in the West)

    a. Emphasis on "pioneers" and the importance of this pioneering work

II. Introduction

    a. Ecological restoration

        i. Forest Service policy regarding ecological restoration

        ii. Working definitions of ecological restoration

            a. strict

            b. liberal

            c. comparison with conservation

        iii. evolution and use of reference conditions

        iv. stand- vs. landscape-level restoration

- b. Characteristics and spatial extent of frequent-fire forests in the American West
    - i. definition of frequent-fire forests and landscapes
        - a. ponderosa pine
        - b. dry, mixed conifer
        - c. transition zones
    - ii. ecological characteristics and keystone processes
    - iii. geographic context
    - iv. distinctive plant and animal communities
    - v. importance in terms of biodiversity and economics
- c. Need to restore frequent-fire forests of the American West
    - i. unnatural crown fires
    - ii. unnatural levels of tree mortality due to insects/pathogens
    - iii. loss of diverse understory and wildlife habitat
    - iv. threat to human infrastructure and communities
    - v. climate change
- d. Benefits of restoring frequent-fire forests of the American West at the landscape scale
    - i. Save ecosystems, watersheds, and critical habitat
    - ii. Help local economies by reviving a wood products industry
    - iii. Protect human infrastructure and communities from wildfires
    - iv. Create ecosystem resiliency to climate change
    - v. Increase the level of ecosystem services

III. Planning
- a. Identifying a common vision
- b. Baseline-Goals/Objectives-Outcomes Model
    - i. Identify existing baseline
    - ii. Develop goals and objectives
    - iii. Choose strategies/actions to meet goals/objectives
    - iv. Analyze likely outcomes of proposed actions
        - a. examples of B-G/O-O Model
- c. Landscape-scale level analysis
    - i. GIS
    - ii. FVS/Landscape Dynamic Simulation models
    - iii. Terrestrial Ecosystem Surveys
    - iv. Identify and groundtruth existing restoration areas and priority treatment areas
    - v. Developing a spatial and temporal treatment schedule
- d. Meeting legal requirements
    - i. Preparing NEPA documents

IV. Implementation
- a. Forest structure and processes restoration
    - i. How forest structure affects forest processes

ii. Potential management actions
    a. Thinning
    b. Thinning and prescribed burning
    c. Prescibed burning only
    d. Resource-benefit fires (Wildland Fire Use fires)
iii. Marking for thinning
    a. Strict restoration/use of historic evidences
    b. Goshhawk guidelines
    c. Fuels treatments
    d. Clumpy40
    e. Special cases
iv. Slash removal
v. Long-term maintenance

b. Forest understory restoration
    i. Natural recovery
    ii. Seeding
    iii. Invasive species
    iv. Herbivory
    v. Road revegetation

c. Wildlife restoration
    i. Natural recovery/increasers and decreasers
    ii. Reintroduction
    iii. Endangered species

d Watershed restoration
    i. Springs and seeps
    ii. Riparian
    iii. Grassland

V. Relating stand-level treatments to landscape-scale goals
    a. Developing a mosaic of treatment types
    b. Watershed connections and animal corridors
    c. Building resilience

VI. Monitoring
    a. Relation to planning process and adaptive management
    b. Effectiveness monitoring
    c. Implementation monitoring
    d. Multiparty monitoring
    e. Develop a strategic plan for monitoring
        i. Identify goals and key objectives that will require monitoring
        ii. Develop a budget for monitoring
        iii. Develop a monitoring protocol
    f. Create a learning environment

i. Conduct evaluations at appropriate times
ii. Provide a safe environment for conducting experiments
iii. Share successes and failures

VII. Capture and Share Learned Information and Experiences
a. Document key results and lessons
b. Identify key audiences
c. Develop communication strategy

VIII. Conclusion
d. One size fits all/cookbook approach doesn't work
e. Landscape mosaic should be goal

IX. Glossary

X. References

XI. Further Reading

XII. Acknowledgments

# INTERACTION OF FIRE, CLIMATE, AND FUELS IN SOUTHWESTERN NORTH AMERICA

Peter Z. Fulé, Larissa L. Yocom, Amanda B. Stan

## SUMMARY

Climate change is expected to have substantial impacts on forest ecosystems of the interior West in the near-term and throughout the 21st century. Warming will increase moisture stress and drought-caused forest dieback, facilitate insect outbreaks, and foster increasingly large, frequent, and severe wildfires. Restoration of the natural resiliency of fire-adapted forests is expected to significantly improve their ability to persist under warming conditions, but a variety of lines of research suggest that plant communities will have to track changing climatic envelopes. Restoration is likely to have to encompass new approaches, including facilitated shifts of species upwards on elevational gradients and perhaps *ex situ* conservation or translocation of high-elevation, mesic species. Considerable uncertainty is inherent in the situation, but thoughtful analysis of the probable effects of climate change will increase the likelihood that the best possible management plans can be developed.

Fire and climate have been closely linked throughout the evolution of the forests that cover the western landscape. The connections between fire and climate remain imperfectly understood, however, because of the relatively scattered locations of fire regime reconstruction studies and the geographical and temporal patterns of climate forcing factors such as El Niño/Southern Oscillation (ENSO). As is being done elsewhere, improving our understanding of the historical fire-climate link will improve the capability for forecasting future fire regimes.

Four methods for assessing fire/climate/fuels interactions in the past, present, and future are described in this report. Each approach can stand alone, but the greatest utility for management will come from integrating these approaches on large landscapes. (1) Restrospective analysis of historic forest structure, composition, and fire regime through tree-ring analysis of forest samples and proxy (fire-scarred) data. (2) Long-term assessment of climate controls on fire regime using historic fire data and reconstructed data on precipitation, Palmer Drought Severity Index, El Niño/Southern Oscillation, Pacific Decadal Oscillation, Atlantic Multi-Decadal Oscillation, and the North American Monsoon. (3) Assessment of contemporary fire regime and fuel/forest conditions, based on modern measurements, including documentary and remotely sensed fire events (e.g., Modis). (4) Modeling of the fire/forest system under future climate and management scenarios, using climate-sensitive models.

The unique data sets and fire behavior information assembled by ERI will permit an enhanced prediction of future fire regimes with and without restoration treatments, allowing for a more comprehensive evaluation of the long-term and large-scale impacts of restoration.

# INTERACTION OF FIRE, CLIMATE, AND FUELS IN SOUTHWESTERN NORTH AMERICA

Peter Z. Fulé, Amanda B. Stan, Larissa L. Yocom
March 31, 2011

Final Report to the Ecological Restoration Institute under USDA Forest Service
Sponsor Award #10-DG-11031600-050 for 2010, Project 4: Climate

## CONTENTS



Shultz Fire, Coconino National Forest, Arizona, 2010

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## INTRODUCTION

Forests represent the greatest aboveground carbon stocks of any terrestrial ecosystem, can occupy critical locations at the crests of watersheds, and have extraordinary ecological, social, and economic value. For these reasons, forest ecosystems have been at the forefront of research to understand climate change impacts, especially in semi-arid regions such as the American Southwest where the ecological and social importance of mesic forests is disproportionately high compared to the relatively small fraction of the landscape they cover.

This report suggests ways to apply existing and new research data to enhance the management of ecosystems on U.S. public lands and lands under other ownerships by improving fundamental scientific knowledge of past, present, and modeled future forest distributions and disturbance regimes. This research is needed for a number of practical reasons: 1) Past and present forest distributions and disturbance regimes are important but have received limited study in some areas of the U.S. Reconstructing structural, compositional, and fire histories of forest stands and forest landscapes will provide basic data on how conditions have changed over time. Although some areas of the Southwest have been studied in this way (northern Arizona, sky islands, Jemez Mountains), other lands with distinct biophysical and management histories constitute a significant proportion of the Southwest. 2) In particular, tribal and private lands have a different management history than U.S. public lands. Historical differences in fire and timber management practices between tribal and private ownerships vs. federal land management agencies mean that some non-federal forests have different structural and compositional characteristics than those on nearby U.S. public lands. 3) Interlinked landscapes share common boundaries. The connectivity of these lands suggests a need for a better understanding of the linkages and sustainability of forest ecosystems, particularly with respect to changes in climate, forming the basis for large-scale landscape conservation.

Deleterious changes to the montane forest ecosystems that occupy over 6 million ha in Arizona and New Mexico have been well-documented: exclusion of natural fire regimes by fire suppression, livestock grazing, and cutting of old trees have led to extensive regions of dense, young forests that are susceptible to severe wildfires and mortality associated with long-term drought and increased pathogens (Covington and Moore 1994, Breshears et al. 2005). Forest managers are testing ecological restoration treatments to reverse negative trends (e.g., Allen et al. 2002) and foster landscapes that will be sustainable in the warmer, drier climate conditions that are forecast for the Southwest (Seager et al. 2007, Fulé 2008). Howevernew management strategies are needed quickly: the scale of the largest severe forest fires in these states has risen by two orders of magnitude (from circa 1 X $10^3$ ha to 1 X $10^5$ ha) in the past two decades.

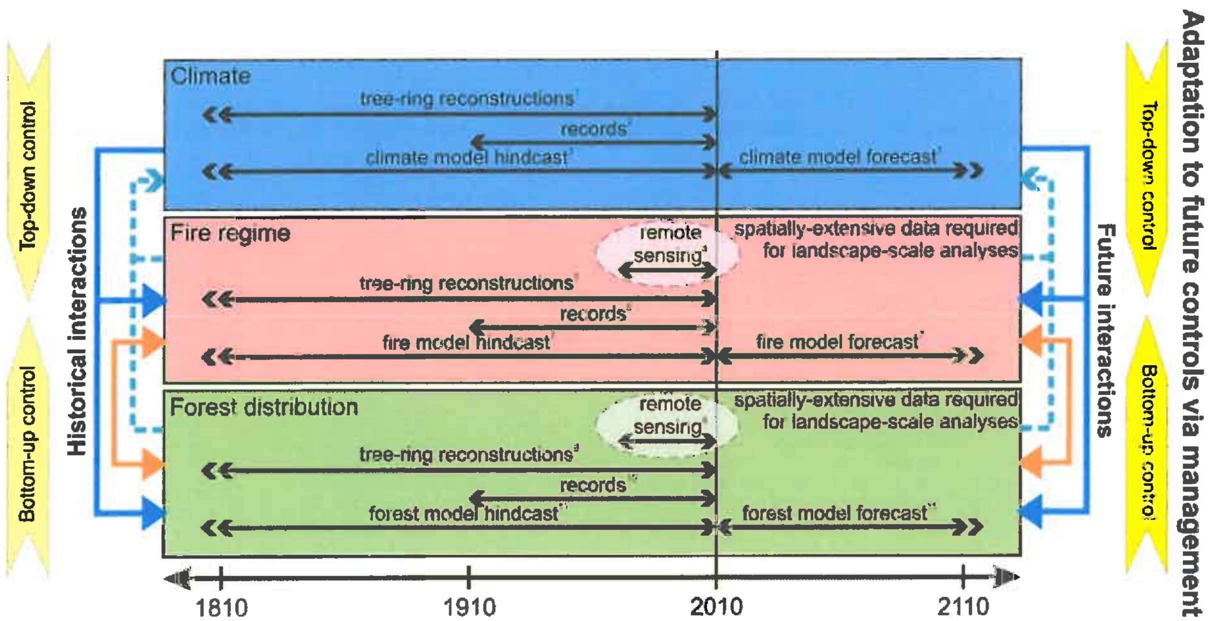
Southwestern forest species have adaptations to drought, fire, and other disturbances, necessary for perpetuating these ecosystems in highly variable, semi-arid climates. Society also places high value on these forests for natural resources, environmental services, and spiritual values. The combination of relatively resilient ecosystems and strong social significance indicates that effective management strategies can be developed if there is a strong scientific basis for understanding top-down (climate) and bottom-up (fuels, management) ecological drivers. This report suggests that the combination of site-specific data and generalizable practical modeling techniques will strengthen the scientific basis for conservation on frequent-fire-adapted forest lands in the Southwest: forest biodiversity, carbon stocks, and cultural and ecosystem values are most likely to be conserved by managing for forest conditions that are both resilient and resistant to uncharacteristically severe disturbances (Fulé 2008).

We suggest a framework for assessing fire/climate/fuels interactions in the past, present, and future involving multiple, interacting themes and approaches (Figure 1). These themes combine synergistically for a better understanding of the interconnected roles of climate and biological systems and can be developed into forecasting tools for society to manage ecosystems under a changing climate. Each component of the integrated study is described in the subsequent sections of this report. Each approach can stand alone, but the greatest utility for management will come from integrating these approaches on large landscapes. (1) Restrospective analysis of historic forest structure, composition, and fire regime through tree-ring analysis of forest samples and proxy (fire-scarred) data. (2) Long-term assessment of climate controls on fire regime using historic fire data and reconstructed data on precipitation, Palmer Drought Severity Index, El Niño/Southern Oscillation, Pacific Decadal Oscillation, Atlantic Multi-Decadal Oscillation, and the North American Monsoon. (3) Assessment of contemporary fire regime and fuel/forest conditions, based on modern measurements, including documentary and remotely sensed fire events (e.g., Modis). (4) Modeling of the fire/forest system under future climate and management scenarios, using climate-sensitive models.

Several steps are proposed to develop and integrate data sets for fire/climate/fuels analysis:

1) Select study areas representing important forest landscapes, drawing on existing landscape-scale study sites (e.g., Mt Trumbull ecosystem) and adding new sites in areas of high

management interest (e.g., Four Forest Restoration Initiative) or representing geographical regions that have been inadequately studied (e.g., tribal lands).




Notes: [1]temperature, precipitation, PDSI; [2]instrumental records, PRISM; [3]IPCC models/scenarios; [4]Landsat TM and ETM+; [5]fire scars, tree-age structures, initial growth rates; [6]MTBS, atlases, NAIP 2007 and 2010 CIR digital aerial photographs; [7]FVS-FFE, LANDIS-II; [8]Landsat TM and ETM+; [9]past forest structure and composition; [10]aerial photographs, forest inventory, land survey records; [11]FVS-FEE, LANDIS-II.

**Figure 1.** Schematic of the three key themes (climate, fire regime, and forest characteristics) and examples of time series of climate-relevant and biological observations useful for assessing past, present, and future forest ecosystems on southwestern forested lands. Solid arrows on the margins of the diagram indicate the interactions of the key themes at spatial scales of interest (sites to landscapes); broken arrows indicate global-scale interactions such as feedback loops of carbon uptake or release from terrestrial landscapes to the atmosphere.

2) Develop long-term and landscape-scale climate and fire regime data sets from remotely sensed data and management records and extend these data sets 3-4 centuries into the past with existing and new tree-ring data.

3) Develop a long-term and landscape-scale biological data set of forest distribution from contemporary remotely sensed data linked to locally collected tree-ring data that extends back to the pre-fire-exclusion, pre-logging condition.
4) Apply the climate and biological data sets to precise simulation models that incorporate top-down and bottom-up controls of fire regime to develop a range of realistic predictions of future forest distributions under alternative scenarios.
5) Provide fundamental scientific knowledge that will enable ecosystems and societies to adapt, via landscape-scale forest management, to future controls of fire regime.
6) Incorporate collaborations among institutions of higher education, resource managers, and federal and non-federal agencies to maximize the educational, cultural, and human resources benefits of this partnership.

It is worth noting that the integration of fire/climate/fuels data over large spatial scales and long temporal scales links well with contemporary initiatives to extend ecological restoration (Covington 2003), such as the Four Forest Restoration Initiative, White Mountains Stewardship Project, and Southwest Jemez Mountains Collaborative Forest Landscape Restoration project. The approach is also consistent with the development of the Landscape Conservation Cooperatives (LCC) for the Southern Rockies and Desert geographic areas. U.S. DOI agencies are currently developing a network of collaborative LCCs, which are applied-science partnerships among various stakeholders (e.g., federal and state agencies, tribes, universities, conservation and environmental organizations) that will provide support for effective adaptive management within and across landscapes as climate changes (U.S. Fish and Wildlife Service 2010). The applied, collaborative, and multi-scaled nature of fire/climate/fuels analysis fits well with the LCC concept.

## RESTROSPECTIVE ANALYSIS OF HISTORIC CONDITIONS

This section presents detailed methods for retrospective analysis of historic conditions. These approaches have been carried out at several study sites in North America and elsewhere. Fire regime reconstructions using dendrochronological techniques were initiated early in the Southwest and have expanded into the largest tree-ring-based, regional fire-climate network in the world (Swetnam and Baisan 2003). Sampling has extended from relatively small study sites to large landscapes, often arrayed over elevational gradients (Fulé et al. 2003, Margolis and Balmat 2009). Research supported through the Ecological Restoration Institute (ERI) has been particularly useful for southwestern landscapes because ERI projects have installed large, permanent plots over large sampling grids at sites such as Mt Trumbull (Roccaforte et al. 2010), the Kaibab Plateau (Fulé et al. 2003), and the San Francisco Peaks (Cocke et al. 2005). The methods presented here are not qualitatively different from those used in previous study. Rather, the emphasis is on linking data on historic conditions to current and future conditions at landscape scales.

The past fire regime can be reconstructed from fire-scarred trees and tree age data. Fire records typically extend 300-400+ years into the past with dendrochronological analysis of fire-scarred trees and forest age structure. Past fire dates, including year and seasonality, and locations can be reconstructed from fire-scarred trees, sampled to obtain as complete as possible an inventory of fire dates and scarred tree locations (Swetnam and Baisan 2003). Study sites can be comprehensively surveyed to observe all fire-scarred trees or larger landscapes can be stratified and representative sites can be sampled. Trees with the longest and most complete fire records should be sampled to efficiently capture the most complete record of fire events (Van Horne and

Fulé 2006). Partial cross-sections can be cut from scarred trees, logs, and stumps. Data on ponderosa pine and warm/dry mixed conifer fire ecology in the Southwest show that the forests are characterized by surface-fire regimes (Swetnam and Baisan 2003). However, some forests with predominantly surface-fire regimes can have even-aged tree patches, reflecting locally severe burning within the matrix of frequent lower-intensity events (Brown et al. 2008). Therefore, in conjunction with the forest structure measurements, it is appropriate to sample stands by coring to pith to reconstruct the distribution of tree ages for evidence of even-aged or uneven-aged cohorts.

Laboratory analysis is done with fire-scarred samples that are mounted, surfaced, and crossdated (Stokes and Smiley 1968). Fire dates must be chronologically absolute, based on crossdated material. The season of fire occurrence, used to estimate the likelihood of human- vs. lightning-caused fires (Kaye and Swetnam 1999), is based on the relative position of each fire lesion within the annual ring. Fire interval data are usually analyzed in different categories because years in which only one or two samples were scarred probably represented smaller fires, while years in which a greater proportion of samples were scarred likely represented larger fires (Swetnam and Baisan 2003). Accordingly, fire data are typically filtered to test for temporal patterns in sub-samples of progressively greater proportional scarring from all fire years to those in which 25% or more of the recording samples were scarred. To assess the synchrony of fire, which may represent top-down influences of climate , temporal homogeneity of fire regimes should be tested for significantly different means (t-test or non-parametric equivalent), variances (F-test or non-parametric equivalent), and distributions (Kolmogorov-Smirnov test) during time periods set by moving 20-yr windows. Multivariate similarity indices should be used to identify patterns of persistent synchrony among sites and for cluster analysis at multiple scales from sites to regions. Spatial homogeneity of fires should be tested by comparing the synchrony of fire years (chi-square tests, 2 X 2 and 2 X 1 contingency tables) (Grissino-Mayer 2001). Spatial dependence of fire synchrony at scales from sites to mountain ranges to the entire region can be tested with Mantel's tests and semivariogram analysis following the methods of Kellogg et al. (2008).

To characterize historic forest structure and composition, field plots and tree-ring sampling are necessary. An appropriate approach is to establish permanent plots in the same study sites from which fire-scarred samples are collected. Fixed sampling grids (e.g., 200 X 200 m) are often used to measure the landscape with sampling intensity proportional to area; even-spacing is an advantage for interpolating data. A typical approach to plot measurement, similar to that done by Waltz et al. (2003) or Roccaforte et al. (2009), is as follows: trees above breast height (1.37 m) are measured on circular fixed-area 400 $m^2$ (or larger) plots. Species, condition, height, crown ratio, crown base height, and diameter at breast height (dbh) are recorded for all live and dead trees over breast height, as well as for stumps and downed trees that surpassed breast height while alive. All trees with dbh > 35 cm and a random 10% subsample of smaller trees are cored with an increment borer at 40 cm above ground level. Tree cores are prepared and crossdated to determine ages and growth rates. All trees below breast height (1.37 m) and shrubs are tallied by species and height class (0-40 cm, 40.1-80 cm, and 80.1-1.37 cm) on a nested 100 m2 subplot. Dead woody biomass and forest floor depth are measured using a 15-m planar transect laid out in a randomly-selected direction from the center of each sample plot. Fire behavior and canopy fuel models (Scott and Reinhardt 2005) are assigned for modeling fire behavior.

In the laboratory, past forest structure can be reconstructed at the time of disruption of the frequent fire regime, circa 1870, following dendroecological methods described in detail in Fulé et al. (1997). Tree diameters in 1870 can be reconstructed for all living trees by subtracting the radial growth measured on increment cores since 1870 (Bakker 2005). For dead trees, the date of death may be estimated based on tree condition class using diameter-dependent models of snag decomposition rates (Thomas et al. 1979). These models are widely used in ponderosa pine forests and have been tested in the Southwest (Fulé et al. 1997, Mast et al. 1999, Moore et al. 2004). To estimate growth between 1870 and death date, scientists develop local species-specific relationships between tree diameter and basal area increment. Tree biomass and carbon stock, including canopy fuel load and bulk density (Cruz et al. 2003, Roccaforte et al. 2008), are estimated from allometric equations (Ter-Mikaelian and Korzhukin 1997, Kaye et al. 2005), while forest floor and woody debris biomass are calculated from planar transects (Brown 1974, Sackett 1980).

## LONG-TERM ASSESSMENT OF CLIMATE CONTROLS ON FIRE REGIME

Fire-climate relationships help us understand how fire has been influenced by past climatic variability, offering insight into future fire responses to climate change. As the network of fire/climate sites grows, insights related to large-scale forcing factors are likely to become more clearly resolved (Falk et al. in press). Recent research provides evidence for the synoptic interconnection of ENSO effects across North and South America (Kitzberger et al. 2007). The scaling factors that link climatic influences from landscapes to regions to subcontinental and continental scales are an active area of research. As these linkages become better understood and forecasts of future climatic variability are improved (Seager et al. 2007), the strength of forecasts of future climate changes on future fire regimes will be improved (Honig and Fulé, in review).

A goal of analyzing fire-climate relationships is to apply a consistent approach over the entire period from the oldest reconstructed fire dates up through modern fire records. However, the integration of long-term data reconstructed from proxy sources, such as tree rings, with modern instrumental records is challenging. Reconstructions are developed with model-fitting procedures that smooth extreme values, reducing the amplitude of the time series as compared with instrumental data (Schoennagel et al. 2007). Statistical techniques should be applied to bring climatic time series (Schoennagel et al. 2007) or climatic extremes (Yocom et al. 2010) up to the present. Contemporary fire data from mapped records or the Monitoring Trends in Burn Severity project (MTBS, mtbs.gov, see below) is more spatially precise than reconstructed dendrochronological data, but linkages between climate patterns and fire occurrence should be tested using both data types.

Climate forcing of fire can be tested using superposed epoch analysis (SEA in FHX2 version 3.02; Grissino-Mayer 2001) and bivariate event analysis (BEA in K1D; D.G. Gavin unpublished software). SEA compares climate of the years leading up to the fire and the fire year itself. The test window, or epoch, is typically seven to eleven years, taking into account several years before the fire year, the fire year, and several years after the fire. Following the approach used by Brown and Wu (2005), we suggest using two independently derived tree-ring based climate reconstructions for the SEA: 1) an annual precipitation reconstruction from northern New Mexico (Grissino-Mayer and Swetnam 2000) or other local reconstructions as appropriate for specific study areas (e.g., Salzer and Kipfmueller 2005), and 2) a summer Palmer Drought Severity Index reconstruction (Cook et al. 2004). We also suggest assessment of the relationship between fire dates and the NIÑO3 sea surface temperature index (Cook 2000), which is a reconstruction of the El Niño/Southern Oscillation (ENSO). In addition, lower-frequency relationships between fire and

ENSO, Pacific Decadal Oscillation (D'Arrigo and Wilson 2006), and the Atlantic Multidecadal Oscillation (Gray et al. 2004) can be tested with SEA (Schoennagel et al. 2007). Statistical significance may be determined with bootstrapped confidence intervals ($\alpha = 0.01$).

## ASSESSMENT OF CONTEMPORARY CONDITIONS

Contemporary forest structure and composition at site to landscape scales can be characterized with remotely sensed imagery supported by field plot data, including the same plots that provided historical data on forest structure and composition. Data on contemporary and historic changes in forest structure and composition across landscapes of interest, coupled with data on anthropogenic land use, altered fire regimes, and climate trends, will form the basis for forecasting future changes (Figure 2). As described above, the study sites within each landscape that have been sampled for forest structure, composition, and biomass, will provide data that serve multiple purposes: reconstructing contemporary and past forest conditions, as well as parameterizing and validating remote-sensing based vegetation models to project future forest conditions.

NASA multispectral and multitemporal satellite image archives provide a primary source of long-term repeated environmental data that are useful for monitoring changes in forest composition and structure from landscape to regional scales (Ohman and Gregory 2002, Kenney et al. 2007). For example, NASA satellite images are useful for assessing uncharacteristically large and severe fires, such as the Rodeo-Chediski fire (168,000 ha; Figure 3), and other recent wildland fires, that have resulted in dramatic changes in forest successional status in southwestern forests and impact present and future ecosystem values and functions. We suggest the use of multitemporal Landsat TM and ETM+ image data archives to characterize contemporary forest structure and composition (Hampton et al. 2011). These data may be combined with data on forest fire history, and forest structure and composition, to quantify landscape-level shifts in forest conditions. Drawing on previously developed methods for NASA data and satellite image classification (e.g., Sesnie et al. 2008a, b, Thessler et al. 2008, Sesnie et al. in press, Hampton et al. 2010, Sesnie et al. in prep.), analysts can repeatedly and retrospectively characterize decadal shifts in tree species composition and structure due to factors such as contemporary land management and altered fire regimes, which are principal disturbance agents in southwestern forest types.

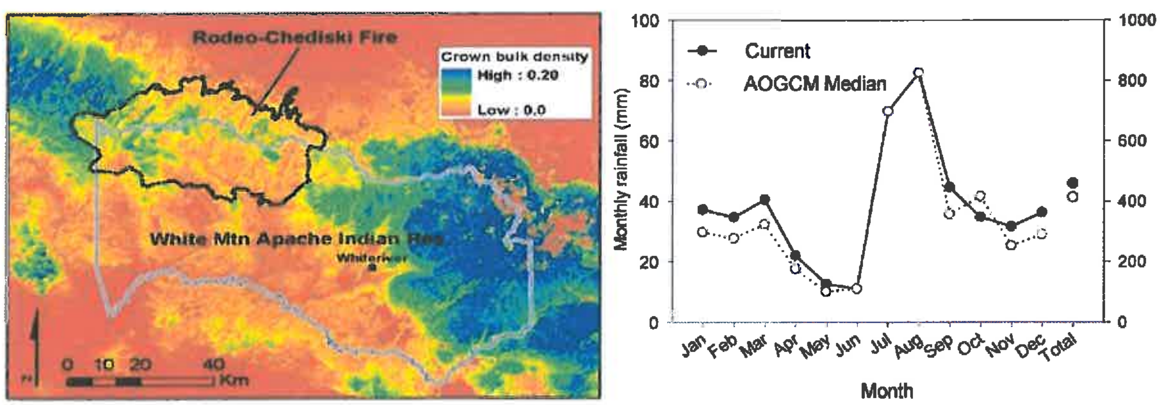



**Figure 2.** Left panel: Crown bulk density, a key variable for the spread of intense wildfires, estimated from 2006 leaf-on and leaf-off imagery for White Mountain Apache tribal lands. Right panel: Current precipitation in northern Arizona (Whiteriver Meteorological Station) and median precipitation projection for 2100 using 10 Atmosphere-Ocean General Circulation Models (AOGCMs) with the SRES A1B emission scenario. Forecasts of reduced precipitation in winter and spring imply drought, longer wildfire seasons, and vegetation change.

Assessment of the contemporary fire regime should draw upon the existing compilation of fire record data and remotely sensed fire severity measurements through the Monitoring Trends in Burn Severity (MTBS, mtbs.gov) project, which is conducted through a partnership between U.S.

Geological Survey's Earth Resources Observation and Science (EROS) Center and the U.S. Forest Service's Remote Sensing Applications Center (RSAC). The MTBS project integrates satellite-based determination of fire severity with fire records from management agencies. MTBS data are linked with LANDFIRE and other national-level fire assessment programs, providing a common platform for cross-agency and cross-regional comparisons. In MTBS, pre- and post-fire Landsat scenes are selected with the Global Visualization Image Selection (GLOVIS) browser developed by EROS. Fire severity is assessed with the differenced Normalized Burn Ratio (dNBR; Key and Benson 2006, Cocke et al. 2005) and the Relativized dNBR (RdNBR; Miller and Thode 2007), which allows the scale of the data sets to be comparable across multiple years. These data provide fire maps, boundaries, dNBR, and RdNBR values at 30-m pixel resolution, along with distributions of fire severity, for thorough assessment of large fire occurrence (>400 ha) and effects (Miller et al. 2009). However, the temporal depth of MTBS is limited to 26 years when using Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper (ETM+) (1984-2010) data and, depending on data quality and availability, can be substantially shorter in many cases. Data for the Southwest is partially complete. We suggest supplementing the MTBS data with historical fire data from local and national records (accurate back to mid-1900s in much of the Southwest) and then substantially father into the past with tree-ring data.

## MODELING OF THE FIRE/FOREST/CLIMATE SYSTEM

The ultimate value of integrating historical and contemporary data over large southwestern landscapes lies in its application to predicting future ecosystem conditions under alternative climate and management scenarios. Models that predict forest development fall into two general classes: statistical models, based on well-measured growth patterns, which can be quite accurate over short time periods; and, process models, which simulate physiological processes involved in growth and competition and thus can incorporate environmental change, but require much more complex initiation parameters (Strom and Fulé 2007). Here we describe a potential approach using two complementary models. Other model systems exist; a review is available in Keane et al. (2004). However, the specific models described below offer a useful combination of reliable information over management-relevant time horizons, accessibility to managers (including support for training), and widespread acceptance in the scientific literature.

We suggest that future forest conditions at site to landscape scales be assessed using two models: 1) Forest Vegetation Simulator (FVS) with the Fire and Fuels Extension (FFE), which is an empirical statistical model (Dixon 2002), and 2) Forest Landscape Disturbance and Succession (LANDIS-II) model, which is a spatially explicit stochastic forest succession model (Mladenoff 2004). The two modeling approaches complement each other: FVS is a highly precise, stand-level model that allows managers to test near-term treatments such as tree thinning and prescribed fire, while LANDIS-II provides a dynamic long-term, landscape-scale successional modeling approach. Setting the detailed short-term modeling in a long-term context gives scientists and managers tools for understanding climate change effects across a range of scales of space and time. Both models are well-documented, supported online, have programs for training opportunities for tribal, federal, and private land managers, and are widely used in research and management across the U.S. Both FVS-FFE and LANDIS-II are linked to submodels for estimating productivity, aboveground biomass, and carbon fluxes over time as a result of forest growth, mortality, succession, and disturbance (Reinhardt and Crookston 2003, Scheller and Mlandenoff 2004).

**Forest Vegetation Simulator.** The Forest Vegetation Simulator (FVS) with the Fire and Fuels Extension (FFE), an individual tree growth and yield statistical model (Dixon 2002) with fire behavior simulation capability, will be used to project future stand conditions under different scenarios. Since its initial development in 1973, the basic FVS model structure has been calibrated to unique geographic areas to produce regional variants which include well-known growth and yield models. Because of its applicability to a wide range of treatments and forest stand conditions, FVS is the most widely used forest stand simulator in the U.S. Robinson and Monserud (2003) developed criteria to determine the adaptability of various forest growth simulation models and concluded that FVS was the most adaptable, especially because of its source code availability and well-documented model fitting process. Forest managers with tribal and Federal agencies in the Southwest currently receive training and software support for FVS-FFE. Statistical models are not necessarily preferred to predict the effects of climate change because environmental conditions are changing. However, statistical models are valuable in assessing the potential impacts of climate change because of their high precision, because empirical relationships of climate-vegetation patterns may still be useful in predicting vegetation distribution following climate change (Iverson and Prasad 2001), and because techniques are available to simulate climate change effects by manipulating growth, mortality, and species occurrence (Crookston et al. 2010, Diggins et al. 2010).

For southwestern forests, the appropriate FVS variant is the Central Rockies variant of FVS with the Southwest Ponderosa Pine model, which uses local tree growth, mortality, and volume equations from National Forests in the Southwest (Arizona and New Mexico) (Edminster et al. 1991). Model simulations of forest structure, composition, biomass, and carbon stock can be projected in 10 year increments for 100 years into the future. The effects of climate change on stand development can be predicted with FVS by specifying how tree growth and mortality will respond to changing climate (Crookston and Dixon 2005, Crookston et al. 2010, Diggins et al. 2010). Under the Climate-FVS system, the standard FVS model is modified to simulate the effects of predicted climate change, following the example of Stage et al. (2001) and Diggins et al. (2010), who modified FVS to reflect the ecological effects of climate change. The FVS keywords regulating tree growth and mortality can be modified (Stage et al. 2001, 2002). These changes simulate effects of warmer and drier conditions predicted for the southwestern United States in the 21st century (Seager et al. 2007). Reduced tree growth expected under climate change may be simulated with the FVS keyword BAIMult, a multiplier used to adjust basal area increment. Tree mortality is expected to increase under drought conditions (Breshears et al. 2005), so we suggest adjusting the keyword FIXMORT to set a defined proportion of additional mortality. Similar to Diggins et al. (2010), another southwestern modeling study, we will adjust growth and mortality parameters using the best-documented local empirical data (e.g., Breahears et al. 2005, McDowell et al. 2006) and apply sensitivity analyses to bracket simulation results for greater clarity in management applications. The Climate-FVS modeling approach permits the incorporation of the findings of regional studies projecting climate change impacts on habitat envelopes of forest species. In the modeling process, this means incorporating species adapted to warmer conditions (e.g., *Juniperus*) into regeneration scenarios, permitting forest composition to change over time. But unlike habitat envelope models, which are based on projections of future climates alone, the altered species composition in the Climate-FVS model framework can be subject to competition and disturbance in a realistic and precise forest dynamics simulation environment.

**LANDIS-II.** Tree species life history traits (e.g., longevity, fire adaptation and shade tolerance, dispersal distance and reproduction) may be used to parameterize forest succession modeling in a geographic information system (GIS). A stochastic forest succession model, LANDIS-

II, can be applied to model and map future forest tree species and successional trajectories by incorporating ecosystems processes such as disturbance, forest biomass growth, climate change scenarios, and seed dispersal (Maladenoff 2004, Lafon et al. 2007, Xu et al. 2010). LANDIS differs from the empirical forest growth model FVS in that it provides a spatially explicit and dynamic model of landscape-scale forest succession pathways that can include common forest disturbance agents in addition to region-specific climate change scenarios (Xu et al. 2010). Combining LANDIS with the generalizable PnET-II ecosystem process model would permit simulation of aboveground net primary productivity (ANPP), disturbances such as harvesting, fire, and wind as well as biomass growth, mortality, and inter- and intraspecific competition (Aber and Federer 1992, Mlandenoff 2004). In contrast, FVS provides an efficient means to project site-level forest conditions, simulate forest restoration treatments, and establish tree regeneration patterns using contemporary and reconstructed historical tree data (Peng 2000). Both of the two forest modeling approaches provide a means to evaluate changes in forest biomass and succession over time in the presence or absence of disturbance factors.

Successional patterns of dominant tree species on southwestern forests such as *P. ponderosa*, *Pinus edulis*, *Abies concolor*, *Populus tremuloides*, *Quercus* spp., *Juniperus* spp., *Pseudotsuga menziesii*, and *Pinus strobiformis* may be modeled under century-long scenarios. Retrospective and prospective analyses should be performed in a stepwise fashion to 1) parameterize LANDIS-II to simulate forest succession pathways and biomass estimates, 2) investigate the combined role of fire disturbances and climate change on forest composition, structure, and above ground biomass production, and 3) highlight areas of southwestern forests vulnerable to vegetation type conversion and identify opportunities for landscape-scale forest restoration. Characterization of historical, contemporary, and potential future forest changes across all landscapes of interest will provide baseline information to land managers on forest status, trends, and vulnerability to compositional and structural changes. These data can be used to evaluate current forest conditions and determine desired outcomes of forest restoration activities (Xi et al. 2008).

**Future Climate, Fire, and Management Scenarios.** Future climate for ecological modeling may be represented by low, medium, and high scenarios of potential emissions, a standard technique given the imprecision of current climate modeling science. Using the IPCC SRES A1B "middle of the road" emission scenario (Nakicenovic and Swart 2000, IPCC 2007) as an example, northern Arizona may lose up to 20% of its winter and spring precipitation by 2100, with summer monsoon precipitation largely unchanged (Figure 2). Using a range of low to high emission scenarios is appropriate to explore the impacts of best-case and worst-case climate change projections on future forest conditions in the region and produce outputs comparable to other regional and national forecasts (e.g., McKenzie et al. 2004). Because improvements in climate modeling are ongoing, analysts should stay in touch with regional climate modelers to ensure the use of the most appropriate emission scenarios and climate projections in ecological models.

Future fire scenarios should be based on a composite of current and future fire trends by McKenzie et al. (2004), Westerling et al. (2006), and Littell et al. (2009). While past relationships between fire and climatic oscillations such as ENSO are well understood in the western U.S. (e.g., Swetnam and Betancourt 1998), the missing link in future projections is uncertainty about how climate change will affect El Niño, La Niña, and other climatic drivers of fire. This is an area of rapidly expanding research among climatologists (e.g., Kug et al. 2010), and we expect that the combination of existing data plus the emerging findings likely to be available as soon as 8-12 months will provide a good basis for creating a range of future fire scenarios.

Management actions that can affect vegetation growth and fire severity include tree thinning and prescribed burning at various scales and schedules. Realistic management options can be developed in collaboration with tribal, federal, and private land managers. Examples of management options for the western Grand Canyon region developed by Diggins et al. (2010) included a range of thinning regimes, burning regimes, combined treatments, and no-action.

Validation of results from both models is inherently uncertain because the modeling extends into the future and requires estimates of future climate effects. However, we suggest following the example of Fulé et al. (2004) in initializing FVS-FFE with reconstructed forest data from circa 1870 and modeling up to the present (2011), providing a detailed assessment of model performance over 140+ years and a solid basis for extending simulations into the next century. The site-scale forest conditions projected with FVS will also be corroborated with satellite-derived forest metrics (e.g., tree species basal area and changes in above ground biomass) in the time period of satellite image coverage, using spatial autoregressive models and correlative analysis (Lickstein et al. 2002) at decadal time steps and Landsat image anniversary dates (circa 1985, 1995, 2005 and 2011). Landsat images from the same month at each time interval are used to control sun illumination differences between image dates (e.g., changes in sun elevation angle) and reduce the intensity of radiometric corrections needed for consistent and reliable vegetation mapping over time.

The ultimate purpose of applying the landscape-level contemporary data and site-level historical data in the modeling exercises is to link climate drivers to biological responses in southwestern forests and evaluate ecological restoration management options. The work would expand upon existing and tested tools for image analysis, dendrochronological techniques, and simulation modeling. The outcomes would apply directly to supporting management decision-making for tribal lands and the larger landscapes of Federal and other ownerships that are interconnected. The detailed field work, dendrochronological data, and multiple modeling approaches complement broad-scale regional and national programs such as the Integrated Landscape Assessment Project and LANDFIRE that cover larger areas but with less precision and temporal depth. By using available modeling tools in a supported and transparent framework, together with training and educational opportunities for current and future resource managers, the approach described here will provide information that is immediately useful as well as lay a foundation for long-term collaboration between research scientists, resource managers, and stakeholders in southwestern forests.

## CONCLUSIONS

The linkages between fire regimes, forest attributes, and climatic patterns described in this report have been critical to the development of these ecosystems over evolutionary and ecological time scales. These relationships are also critical in a time when human pressures on ecosystems and global change are occurring at a rapid pace, creating unprecedented threats to ecosystem sustainability. There are numerous obstacles to the integration of fire/forest/climate data over large scales in space and long scales in time: proxy data are imperfect recorders from a temporally fading record. Future assessments are also limited by the imprecision of scientific understanding of global change and its effects on climatic variability in the Southwest. However, we suggest that a combination of reliable dendrochronological and modeling techniques, together with a realistic range of potential future climate and management scenarios, offers a useful approach for delineating the range of variability in future fire regimes and forest conditions.

The Ecological Restoration Institute and other sources of research and inventory data have already assembled and tested many of the components of this approach. The challenge is to integrate the data and tools to develop analyses over large landscapes at a pace and scale that matches the threats to ecosystem sustainability and provide a credible range of future scenarios to resource managers and stakeholders of southwestern forest ecosystems.

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# The Economic Value of Selling Carbon Credits from Restored Forests: A Case Study from the Navajo Nation's Tribal Forests

Ching-Hsun Huang and Christopher Sorensen

ABSTRACT

The goals of this study were to promote restoration of forest ecosystems through fire hazard reduction treatments and to evaluate potential economic benefits of carbon credits to the Navajo Nation. We used the historic Navajo Nation's Continuous Forest Inventory data to calibrate the Forest Vegetation Simulator (FVS) with growth increments and used the FVS to run simulations that encompass the next 50 years. We calculated C revenues using two carbon accounting approaches: (1) reduced buffer pool under the Climate Action Reserve protocol and (2) increased C stocks based on with-and-without analysis. We investigated nine C price scenarios, including constant- and rising-price trajectories; performed discounted cash flow analyses; and calculated net present worth (NPW). When timber was the only marketable output, using a real alternative rate of return (ARR) of 4%, the NPW of target basal area (BA) 40, 70, and 100 $ft^2$/ac were −$144.89, −$267.98, and −$308.57/ac, respectively. When both timber and C were marketable outputs, with a C price of $3/ton, the NPW of target BAs of 40, 70, and 100 $ft^2$/ac were increased to −$119.26, −$256.83, and −$306.31, respectively, under the first accounting approach, and were increased to $168.62, −$57.29, and −$184.09, respectively, under the second accounting approach. Our results indicate that C accounting method, C price, and landowner's ARR affect forest landowner's profitability in participating in the C market.

**Keywords:** Native American tribal forests, carbon accounting method, net present worth analysis, forest project's reversal risk rating, ecological restoration treatment

Human-induced climate change driven by increased consumption of fossil fuels that contribute to higher concentrations of atmospheric carbon dioxide (Canadell et al. 2007) has been linked to warming temperatures and changing precipitation patterns (Osborn and Briffa 2006, Intergovernmental Panel on Climate Change 2007). These climatic changes are affecting forest ecosystem services, such as water and land resources, carbon (C) sequestration, and biodiversity (Backlund et al. 2008). Climate change can cause warmer summer temperatures in the western United States and result in increased summer drought stress, vulnerability to insect pests, and fire hazard. Arid areas, especially, have a high likelihood of experiencing increased fire risk. Records indicate that the number and frequency of forest fires and insect outbreaks have increased in the interior West, the Southwest, and Alaska (Backlund et al. 2008). Ecological restoration of southwestern ponderosa pine (*Pinus ponderosa*) forests is an emerging issue because of an abundance of dense thickets of young trees, decline of old-growth stands, loss of biodiversity, and increased vulnerability of human and ecological communities to destructive wildfires (Allen et al. 2002). Furthermore, the Southwest is a region of extremely rapid population growth, which not only tends to increase the occurrence of human-caused fires but also exposes newly built developments to catastrophic fire. These fires threaten the economic and social well-being of rural communities and forest ecosystem services (Governor's Arizona Forest Health Councils 2007). For example, the massive Rodeo-Chediski fire in east-central Arizona in 2002 consumed more than 450,000 ac of largely ponderosa pine forest (Neary and Zieroth 2007) at an estimated cost of more than $400 million (Governor's Arizona Forest Health Councils 2007).

Wildfires release substantial amounts of greenhouse gases (GHGs), particulate matter, and other air pollutants to the atmosphere, and they may cause long-term declines in C sequestration potential for increasingly large proportions of western landscapes (Dore et al. 2008). The probability and intensity of wildfire can be reduced by fuel reduction treatments or restoration treatments that reduce fuel buildup using mechanical thinning and prescribed burning. This presents substantial opportunities to prevent catastrophic C loss and increase C storage in terrestrial ecosystems while achieving high levels of environmental cobenefits. In addition to wildfire-related C emissions, intense wildfire can result in the unplanned loss of both C stored in harvested wood products and C storage potential attributable to managed stand growth (Kuenzi et al. 2008). Therefore, intense wildfires can influence the net terrestrial uptake of C. Fuel reduction programs, including forest thinning treatments, have the potential to reduce net C emissions by reducing direct emissions by wildfire and increasing sequestration in wood products and managed stands.

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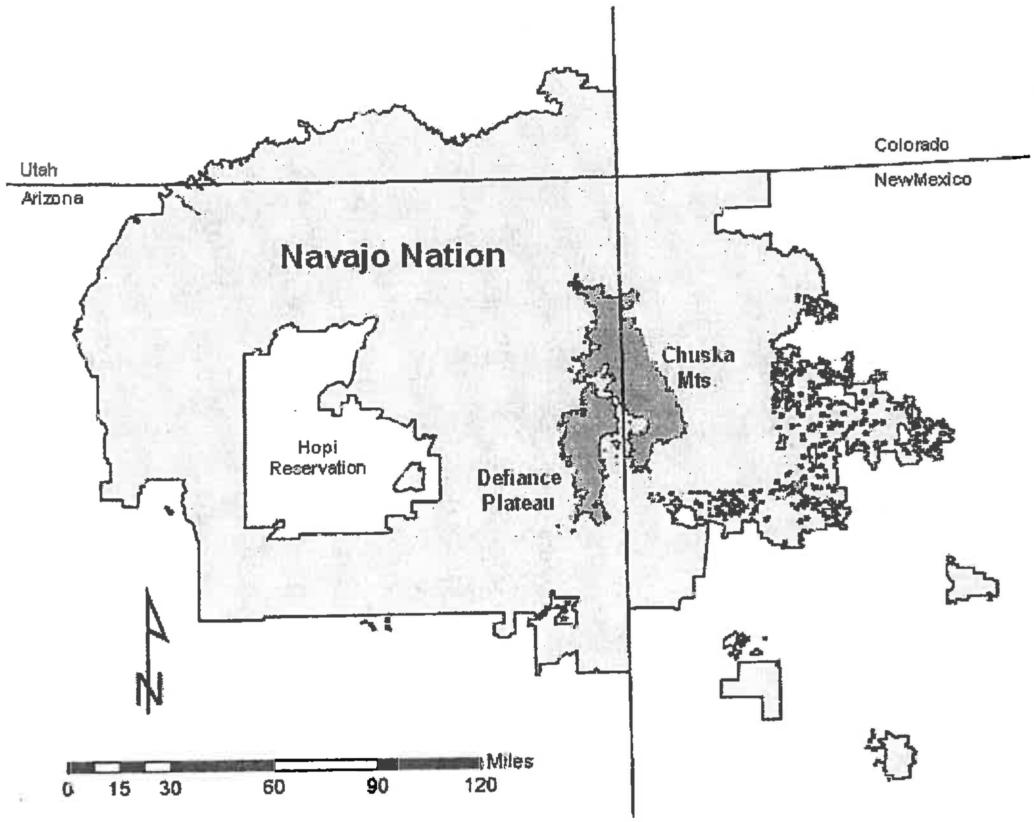


**Figure 1. Defiance Plateau/Chuska Mountains forest area.**

A variety of forest project protocols (FPPs) have been developed to quantify and monitor the C benefits of forest projects (Galik et al. 2008) and have included financial compensation for landowners who manage their lands to sequester more C and offset anthropogenic GHG emissions. This potential income source will improve local and regional economies and may have particular value for Native Americans, who live on the nation's more than 300 reservations and are among the most impoverished people in the United States. Most Native Americans live on Social Security or welfare, with an unemployment rate of 49% (US Department of the Interior 2003) and a poverty rate of 41% (USDA Economic Research Service 2009). A full one-fifth of the total population in Native American high-poverty counties have incomes below 75% of the poverty line (USDA Economic Research Service 2009).

Arizona is home to 21 federally recognized tribes and more than 250,000 Native Americans. Poverty rates of Arizona's Native American high-poverty counties range from 45% to 49% (USDA Economic Research Service 2009). Reservations and tribal communities make up over a quarter of Arizona's lands. The total land area of Arizona is almost 73 million ac; 27%, or 19.4 million ac, is forestland (O'Brien 2002). Nonreserved forestland owned by the Indian Trust accounts for almost 6 million ac in Arizona (O'Brien 2002). The majority of tribal forests are located within the Navajo Nation and the White Mountain Apache Tribe reservations and are managed in cooperation with the Bureau of Indian Affairs. The Navajo Nation, which is larger than 10 of the 50 states in the United States, extends into Arizona, New Mexico, and Utah and covers more than 15,522,492 ac. However, much of its land base is very remote and isolated. With an annual per capita income about $7,000, the unemployment rate of the Navajo Nation in 2003 was 54%, and of those employed, 15% were below poverty guidelines (US Department of the Interior 2003).

Studies have been conducted to investigate how a C subsidy, tax, or credit regime related to C fluxes in a forest stand may affect the economic aspects of forest management (van Kooten et al. 1995, Hoen and Solberg 1997, Huang and Kronrad 2001, 2006, Stainback and Alavalapati 2002). However, research on the financial feasibility of C sequestration on Native American forests is unprecedented. Therefore, the goals of this study were to protect, enhance, and restore forest ecosystems through fuel reduction treatments, to evaluate economic benefits of fire hazard reduction treatments derived on the Navajo Nation, and to introduce financial incentives to enhance economic development of Arizona's Native American tribes. The objectives of the study and the methods to be used were to (1) perform project analysis to quantify C emission reduction resulting from conducting forest restoration treatments to control fire hazard and (2) perform discounted cash flow analysis to determine the net present worth (NPW) of fuel reduction programs and examine the financial feasibility of trading C sequestered in the Navajo Nation forests.

**Study Area**

Located in northwest New Mexico, northeast Arizona, and southeast Utah, the Navajo Nation is the largest Native American Reservation in the United States. It is bordered on the north by the San Juan River, on the east by the 108°15′W longitude, on the south by the 35°15′N latitude, and on the west by the Colorado River (US Department of the Interior 1995) (Figure

**Table 1. Acres of ponderosa pine timberland in each fire hazard level on the Navajo Nation timberland, 2009.**

| Risk level | Torching index[a] | Crowning index (CI)[a] | Condition rating[a] | Area (ac) | Assumed annual percentage burned (%) |
|---|---|---|---|---|---|
| Very low | ≥25 | ≥25 | In condition | 307,667 | 0.2 |
| Low | <25 | ≥40 | In condition | 60,091 | 1.0 |
| Medium | <25 | 25 ≤ CI < 40 | Out of condition | 0 | NA[b] |
| Medium high | ≥25 | <25 | Out of condition | 4,807 | 6.8 |
| High | <25 | <25 | Out of condition | 0 | NA |
| Total | | | | 372,566 | |

[a] From Huggett et al. (2008).
[b] NA, not applicable.

1). The Navajo Forest, our study area, traditionally refers to the timberland areas of the Defiance Plateau and the Chuska Mountains and accounts for nearly 600,000 ac across Arizona and New Mexico (Figure 1). Approximately 428,011 ac of the Navajo Forest are unreserved, accessible, commercial timberland with at least 5% crown cover of commercial timber species and a growth rate of ≥15 $ft^3$/ac per year. The commercial timberland lies in the Defiance Plateau/Chuska Mountains forest area across Arizona and New Mexico, including 55,445 ac of mixed conifer forest (Douglas-fir/ponderosa pine/aspen stand type) and 372,566 ac of ponderosa pine forest, the focus of this study. Accounting for 95% of the standing sawtimber volume, ponderosa pine is the most important timber species on the Navajo Nation; it far exceeds board-foot production derived from Douglas-fir (4%) and other species (1%). Site indices (base age 100) of the ponderosa pine stand type range from 41 to 100 ft on the Defiance Plateau/Chuska Mountains forest area (US Department of the Interior 1995).

## Methods

The Navajo Forestry Department of the Navajo Nation granted us access to the 1974, 1980, and 1989 Continuous Forest Inventory (CFI) data of the Navajo Nation timberland. The CFI database, measured by the staff of the Navajo Forestry Department, is a collection of relatively high-precision snapshots of forest conditions and provides the information needed for updating the forest management plan for the Defiance Plateau/Chuska Mountains. Even though the most recent CFI measurements were taken in 2004, at the time of writing, the data had not been prepared for analysis and were therefore unavailable for this study (Bill Yemma, Bureau of Indian Affairs, US Department of the Interior, pers. comm., Apr. 21, 2010). According to Alexious Becenti, forest manager with the Navajo Forestry Department, no significant treatments had occurred since 1989, primarily because of low stumpage prices and weak sawlog demand in the region (personal communication, Sept. 26, 2008). Therefore, we used the 1974, 1980, and 1989 CFI data, the most valid data available, of the Navajo Nation timberland to conduct our analysis. We input the 1974, 1980, and 1989 CFI data of the Navajo Forest into the Central Rockies/Southwestern Ponderosa Pine variant of the Forest Vegetation Simulator (FVS), which allowed the FVS to calibrate the following models: tree mortality rates, regeneration rates, incremental diameter growth, and incremental height growth (Crookston and Dixon 2005). We then modeled stand growth and development to project stand conditions at the time of the study, 2009. Unlike studies that performed analysis based on forest conditions at one point in time, our analysis benefited from having historic data sets measured from three different points in time, which reduced any variability inherent in baseline FVS models related to differences in site-specific conditions and improved the accuracy of using the FVS for future projections. Although the FVS is a highly precise model of ponderosa pine growth, it is a statistical model that does not incorporate fluctuating climatic conditions. Therefore, the effects of climate change on projections of tree growth are not reflected (Diggons et al. 2005) and are likely overestimated at the end of relatively long simulation periods (Waring et al. 2009). We used the Fire and Fuels Extension (FFE) to the FVS (Reinhardt and Crookston 2003), a model that simulates fuel dynamics and potential fire behavior over time, to simulate fuel treatments, including prescribed fire, thinning, and mechanical treatments and wildland fires.

We used a fire hazard risk classification system developed by Huggett et al. (2008) to classify stands as having fire hazard risk levels of very low, low, medium, medium high, or high depending on their torching index (TI) and crowning index (CI) (Table 1). TI is calculated in the FFE-FVS as the wind speed at a height of 20 ft at which crown fires are expected to initiate in a specified fire environment. CI is the wind speed at a height of 20 ft at which active crown fire behavior is expected (Scott and Reinhardt 2001). Lower values of TI and CI correspond to higher hazardous fuel conditions. For stands classified as in condition, no treatment would be performed. For stands classified as out of condition, thinning treatments would be conducted to change their condition rating.

On the basis of average annual forested acres burned from 1996 to 2006 in Arizona and New Mexico reported by the Monitoring Trends in Burn Severity (MTBS) (US Forest Service Remote Sensing Applications Center 2009), we made the following projections. We projected that the percentages of acres burned annually of ponderosa pine forest were 0.2%, 1.0%, and 6.8% for very low, low, and medium high fire risk levels, respectively (Table 1). No projections were made for medium and high fire risk levels because no acres of ponderosa pine forests in the Navajo Nation were projected to be in those two fire risk levels. The Navajo Nation was actively managing its forests into the late 1980s (Alexious Becenti, Navajo Forestry Department, pers. comm., Sept. 26, 2008), which likely explains the disproportionate amount of acres in the less severe fire risk levels. Having no acres fall into the medium fire risk level as opposed to no acres falling into the medium high fire risk level is largely an artifact of classification. Lower wind speeds are required to initiate a crown fire in the medium fire risk level, but higher levels are required to sustain active crown fire behavior. The opposite is true for the medium high fire risk level, which has the same TI threshold as the very low fire risk level. It would make sense, then, that a stand could jump from the very low fire risk level to the medium high fire risk level if forest floor and ladder fuel conditions remain relatively constant but gaps in the canopy close and create favorable conditions for active crown fire behavior. In terms of fire severity, we projected that 5%, 25%, and 75% mortality of overstory trees would occur on very low, low, and medium high fire risk levels, respectively, which corresponds to burn severity levels used in the MTBS report (Schwind 2008).

We chose three target basal areas (BA) of 40, 70, and 100 $ft^2$/ac to include a historically wide range of target BAs in restoration treatments throughout the Southwest (Hunter et al. 2007). We assumed that a stand would be thinned in 2011 if it was projected to reach a fire hazard severity level that was out of condition, slash piles would be burned immediately after treatments, and only branch wood would be left on the site. We included C emissions resulting from pile burning in the analyses. If treatments did occur in the stands in medium high fire hazard risk level, the percentages of acres burned annually and fire severity would be lowered to those of the new fire risk levels. If no treatment occurred, wildfires would take place with the percentage of acres burned annually of 6.8% and fire severity of 75% mortality of overstory trees.

We evaluated whether the benefit of wildfire avoidance resulting from restoration treatments could be the basis for C credits. Version 3.1 of the 2009 Climate Action Reserve (CAR) FPP provides requirements and guidance for quantifying the net climate benefits of activities that sequester C on forestland, under Improved Forest Management Projects, which are "management activities that maintain or increase carbon stocks on forested land relative to baseline levels of carbon stocks" (Climate Action Reserve 2009). Even though restoration treatments are management activities that could maintain or increase C stocks relative to baseline levels, currently, this type of C offset activity is unsupported by any FPPs in the market. A with-and-without analysis is a relevant comparison of the net benefit of treatment versus no treatment. Simply performing a with-and-without analysis to calculate the C storage difference between scenarios with and without restoration treatments might raise a concern regarding future C losses due to wildfires that would not occur with certainty. Therefore, we calculated potential C revenues using the following two C accounting approaches: (1) reduced buffer pool under the CAR protocol and (2) increased C stocks based on with-and-without analysis.

Under the first accounting approach, we determined a forest project's reversal risk rating, which affects yearly contributions to the buffer pool, a holding account for forest project climate reserve tonnes (CRT) under the CAR protocol. This protocol requires all forest projects to contribute a percentage of CRTs to the buffer pool as they are issued CRTs for verified GHG reductions and removals. The size of the contribution to the buffer pool will depend on the forest project's risk rating for reversals, which are defined as the decrease between project and baseline onsite C stocks from one year to the next. Forest project risk categories include financial failure, management (illegal harvesting, conversion to nonforest uses, and overharvesting), social (changing government policies, regulations, and general economic conditions), and natural disturbance (wildfire, disease/insects, and other episodic events). The CAR protocol adjusts the long-term fire risk potential of a forest project by a percentage depending on the level of fuel treatment. The wildfire risk rating was multiplied by 50, 66.3, 82.6, and 100% for high, medium, and low levels of fuel treatment and no fuel treatments, respectively. We used the default ratings provided in the CAR protocol for the rest of the forest project's reversal risk ratings. They were risks of financial failure, conversion, overharvesting, social, disease or insect outbreak, and other catastrophic events, with corresponding ratings of 5, 2, 2, 2, 3, and 3%, respectively. We determined the total reversal risk ratings of the project to be 18.73, 19.66, 20.59, and 21.59% for high, medium, and low levels of fuel treatments and no fuel treatments, respectively. In comparison with no fuel treatments, the percentages of wildfire risk reduction were 2.86% (= 21.59% − 18.73%), 1.93% (= 21.59% − 19.66%), and 1.00% (= 21.59% − 20.59%), respectively, when high, medium, and low levels of fuel treatments were conducted. We assumed that target BAs of 40, 70, and 100 $ft^2$/ac would be considered high, medium, and low levels of fuel treatment, respectively. Using the second accounting approach, we identified and measured C stocks on the basis of the difference in a given situation—with or without the restoration treatments. We used the FVS to simulate stand conditions over the next 50 years (2011–2061). The simulations included the treatment and no-treatment options. We assumed that as long as treatments were conducted, landowners were eligible to claim C credits based on the difference in C stocks between scenarios with and without treatments.

We estimated that the costs associated with treatments were $125/ac for thinning, $120/ac for piling of fuels, and $80/ac for burning of slash piles, and we used the same costs regardless of treatment level (Joe Seidenberg, Ecological Restoration Institute, unpublished data, 2008). The 2008 timber cut and sold prices on national forests in region 3 for pulpwood (≤9 in. in diameter) and sawtimber (≥10 in. in diameter) were $1.02 and $13.09 per hundred cubic feet (CCF), respectively (US Forest Service 2008). Annual compound softwood sawtimber and pulpwood stumpage price growth was projected at 0.2 and 0%, respectively (Haynes 2007). Labor costs were assumed to increase at a real rate of 1.5% per year (Council of Economic Advisers 2009). We did not include the fees (i.e., costs of measuring, monitoring, and verifying) associated with trading because they were the same with and without treatments and would cancel out of the economic gain calculations. We used a range of real alternative rates of return (ARRs) of 2, 4, 6, and 10, representing average real before-tax rates of return, to perform discounted cash flow analyses and calculate NPW. The ARR is the percentage rate of return on capital in an investor's best alternative, at a risk similar to that of new ventures being considered. The NPW of a project is the present value of its revenues minus the present value of its costs over project life. After deriving biological data from the FVS for discounted cash flow analyses, we then calculated and compared NPWs, including timber and/or C revenues.

We investigated a total of nine C price ($/short ton of C) scenarios using the projections made by the US Environmental Protection Agency and Department of Energy (Table 2). C price scenarios 1 and 3–9 were based on the core price scenarios projected by the Environmental Protection Agency (2005). Scenario 2, $10/ton of C, was added to coincide with the goal of the Department of Energy's Carbon Sequestration Program aiming at reducing the cost of C sequestration from $100–300/ton to $10 or less per ton by 2015 (US Department of Energy 2010). This wide range of C price scenarios included both the constant- and rising-price trajectories: a constant initial price of $3/ton of C in 2010 (scenario 1) and a fairly aggressive price path, with an initial price of $67 rising at $1.30 per year (scenario 9).

To account for C in growing stock volume and the long-term C storage of wood products, we adapted the methodologies from the US Department of Energy publication 1605(b)—*Technical Guidelines for Voluntary Reporting of Greenhouse Gas Program* (Chapter 1: Emission Inventories, Section 1; US Department of Energy 2007).

**Table 2. C price ($/ton) scenarios for ponderosa pine on the Navajo Nation timberland, 2009.**

| Scenario[a] | Trend | Initial price in 2010 ($/ton of C) | Annual price growth (%/year) | Price cap |
|---|---|---|---|---|
| 1 | Constant | 3 | 0 | None |
| 2 | Constant | 10 | 0 | None |
| 3 | Constant | 17 | 0 | None |
| 4 | Constant | 50 | 0 | None |
| 5 | Constant | 100 | 0 | None |
| 6 | Constant | 167 | 0 | None |
| 7 | Rising | 10 | 1.5 | None |
| 8 | Rising | 10 | 4 | $100 |
| 9 | Rising | 67 | 1.30 | $250 |

[a] C price scenarios 1 and 3–9 were based on the core price scenarios projected by the Environmental Protection Agency (2005). Scenario 2, $10/ton of C, was added to coincide with the goal of the Department of Energy's Carbon Sequestration Program aiming at reducing the cost of C sequestration from $100-$300/ton to $10 or less per ton by 2015 (US Department of Energy 2010).

The Voluntary Reporting of Greenhouse Gases Program, established by Section 1605(b) of the Energy Policy Act of 1992, provides a means for organizations and individuals, including forest landowners and other land managers, to record their baseline emissions and emission reductions. We assumed that only C stored in the standing merchantable timber and pulpwood or sawtimber products harvested would be counted as C credits, and no C revenues would be derived from other forest components, such as soil, dead trees, coarse tree roots, litter layer, and understory vegetation (Huang and Kronrad 2001). We used the average disposition patterns of C in softwood for the Rocky Mountain region provided in the guidelines to calculate the average C remaining in wood in use (durable wood products) and wood products disposed in landfills over a 50-year study period. Carbon emitted with energy capture (combustion of wood products with concomitant energy capture) and C emitted without energy capture (C in harvested wood emitted through combustion or decay without concomitant energy capture) are outside the scope of this study.

## Results

According to the fire hazard risk level developed by Huggett et al. (2008), the majority, 83% (307,667 ac), of the Navajo Forest's ponderosa pine timberland were in the very low risk level; however, approximately 4,807 ac of the Navajo Nation timberland was in the medium high fire hazard risk level and classified as out-of-condition (Table 1). This indicates that restoring these fire-prone timberlands to their historical fire regimes would likely be the priority of the Navajo Nation's forest management. Therefore, we focused our economic analysis on the stands representing the approximately 4,807 out-of-condition acres. These stands were dominated by ponderosa pine with an average of 249 trees/ac, a BA of 130 $ft^2$/ac, and a quadratic mean diameter of 9.8 in. Only a minor proportion (<1%) of these stands was composed of juniper species.

We compared the growth of the standing timber volume resulting from the three levels of treatments with that of no-treatment option. Our results indicate that treatments would stimulate the timber growth of the residual stands. During the 50-year study time period, an additional 180.93 to 492.17 CCF/ac could be produced because of thinnings (Table 3). Furthermore, we estimated that an additional 121.58 to 327.18 tons of C/ac would be stored under various restoration treatments (Table 3). The production function of aboveground C storage for different levels of treatments and no treatment are presented in Figure 2. The downward-sloping curve of C sequestration for no treatment, target BA 70 $ft^2$/ac, and target BA 100 $ft^2$/ac indicate that the mortality of overstory trees resulting from wildfires exceeded the growth. In detail, the C storage curve gradually increased from 19.37 to 29.01 tons/ac for target BA 40 $ft^2$/ac; however, the C storage curves decreased from 19.37 to 18.91, 14.56, and 10.04 tons/ac for target BA 70 $ft^2$/ac, target BA 100 $ft^2$/ac, and no treatment, respectively (Figure 2). This indicates that, at the end of the 50-year study time frame, in comparison with no treatment, the increases in C storage are 189% [= (29.01 − 10.04)/10.04], 88% [= (18.91 − 10.04)/10.04], and 45% [= (14.56 − 10.04)/10.04) for the target BAs of 40, 70, and 100 $ft^2$/ac, respectively. In terms of aboveground live tree C storage, the three treatment options outperformed the no-treatment option throughout the study period.

We calculated and compared per-acre NPWs using the two C accounting approaches. Under the first accounting approach, using a 4% ARR as an example when timber was the only marketable output, the NPWs derived from timber revenues only (NPWt) of target BAs 40, 70, and 100 $ft^2$/ac were −$144.89, −$267.98, and −$308.57/ac, respectively (Tables 4, 5, and 6). The negative NPWt indicate that timber revenues derived from the restoration treatments alone were not enough to offset the costs of treatments because of low stumpage values. When both timber production and C sequestration were marketable outputs, with a C price of $3/ton (scenario 1) and an ARR of 4%, the NPWs derived from both timber revenues and C credits (NPWtc) of target BAs of 40, 70, and 100 $ft^2$/ac were increased to −$119.26, −$256.83, and −$306.31/ac, respectively (Tables 4–6). When the price of C is $17/ton (scenario 3), for target BA 40 $ft^2$/ac, including C revenues would turn NPW from a negative NPWt of −$144.89/ac to a positive NPWtc of $0.33/ac, with an economic gain of $145.22/ac (Table 4). Under the second accounting approach, if the target BA was 40 $ft^2$/ac, regardless of ARRs and C prices, NPWtc were all positive except for when ARR was 10% and C price was $3/ton (scenario 1). In comparison with target BA 40 $ft^2$/ac, NPWtc of target BAs of 70 and 100 $ft^2$/ac were smaller. Using an ARR of 2% and a C price of $10/ton (scenario 2) as an example, the NPWtc were $1,634.67, $886.89, and $361.31/ac for target BA 40, 70, and 100 $ft^2$/ac, respectively (Tables 4–6). As expected, NPWtc calculated using the second accounting approach were significantly higher than those derived using the first accounting approach because of the difference in the calculation of wildfire risk reduction and eligible C credits.

We generated break-even C prices at which timber and C revenues would equal costs for the treatments. Under the first accounting approach, when ARR was 2%, break-even C prices ranged from $14.46 to $318.66/ton; however, they ranged from $19.87 to $582.36/ton as the ARR increased to 10% (Table 7). Under the second accounting approach, break-even prices were much smaller, ranging from $0.84 to $4.70/ton using a 2% ARR or $3.90 to $20.72/ton using a 10% ARR (Table 7). The decrease in break-even C prices was the result of increased eligible C credits under the second accounting approach. In addition, Table 7 indicates the internal rates of return, the interest rate at which NPW equals 0, in the ARR row given the break-even C prices, and various treatment levels under two C accounting approaches.

## Discussion and Conclusions

This study was conducted for the Navajo Nation's forests; however, the methods and management implications could be applied

Table 3. Volume (CCF/ac) removed from the treatments in the 4,807 out-of-condition acres, and additional standing tree volume (CCF/ac) and C stored (tons/ac) because of the treatments projected for the following 50 years for ponderosa pine on the Navajo Nation timberland, 2009.[a]

| | Volume removed from the treatment | | Standing volume during the 50-year study period | | C storage during the 50-year study period (tons/ac) | |
|---|---|---|---|---|---|---|
| Treatment level[b] | Pulpwood | Sawtimber | Additional | Additional/year | Additional | Additional/year |
| | ........(CCF/ac)........ | | | | | |
| Target BA 40 | | 13.22 | 492.17 | 9.84 | 327.18 | 6.54 |
| Target BA 70 | | 3.09 | 311.85 | 6.24 | 207.98 | 4.16 |
| Target BA 100 | | 0 | 180.93 | 3.62 | 121.58 | 2.43 |

[a] CCF, hundred cubic feet; BA, basal area.
[b] BA levels measured in $ft^2$/ac.

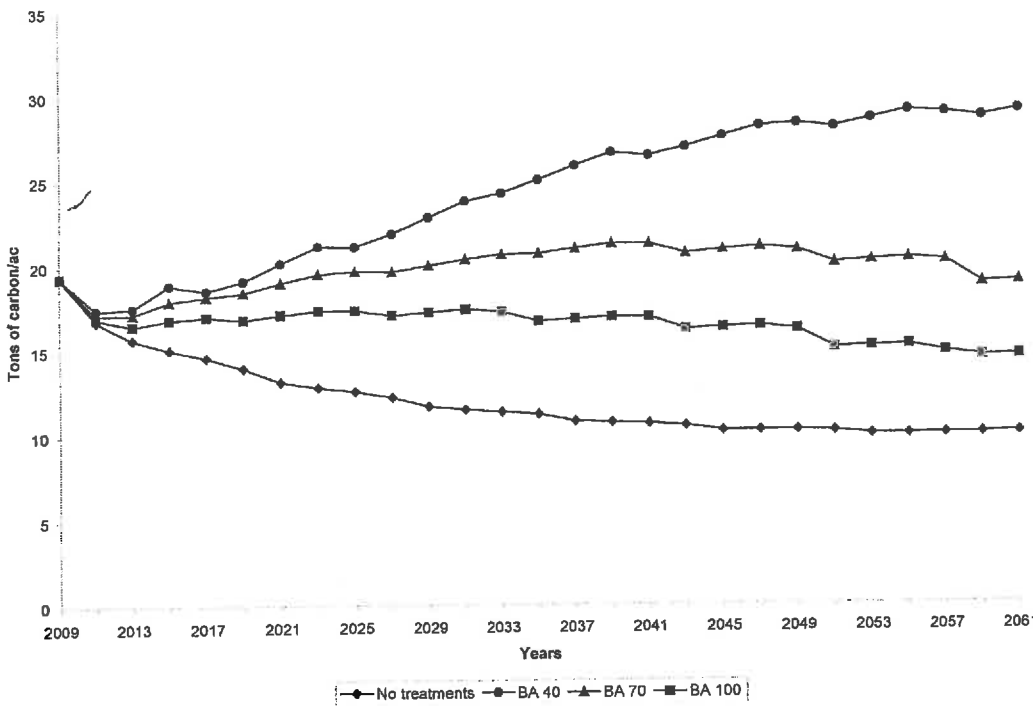


Figure 2. Production functions of C sequestration (aboveground biomass; tons/ac) for no treatment and residual BAs of 40, 70, and 100 $ft^2$/ac for ponderosa pine on the Navajo Nation timberland, 2009.

throughout the Southwest, where large wildfires have caused significant C losses. The idea of performing fuel reduction programs to reduce the potential for C emissions from catastrophic fires and claim the amount of C emissions avoided as tradable C credits has been well discussed in this region (i.e., Egan and Seidenberg 2009). Because timber revenues alone do not cover the costs of the treatments in this study region, the possibility that C revenues will provide an additional source of revenue to offset costs is encouraging with respect to aboveground live tree carbon stocks. The concept proposed in this case study is radical in the sense that it intends to incorporate the growing awareness of the urgency of fire-related forest management and the recurring hope of incorporating C revenues into management goals. We conducted a comprehensive C accounting and economic analysis considering both sequestration and release of C and fate of C stored in products after forest harvests. Under the first accounting approach, supported by the CAR protocol, we quantified the profits or losses of restoration treatments on the basis of the percentages of wildfire risk reduction associated with fuel treatment levels given landowner's ARR and projected C price scenarios. Under the second accounting approach, currently unsupported by the FPPs, we conducted an experiment that will be useful as avoided deforestation or degradation offset projects vis-à-vis fire are recognized by the FPPs in the future.

The changing role of forests in society provides new challenges to forest management planners through timber and C management strategies. The results of this study indicate that the effect of revenues from C sequestration on forest management is significant. Four main conclusions can be drawn. First, the current poor to nonexistent timber market in northern Arizona has not provided the needed financial incentives to entice land managers to conduct necessary fuel reduction treatments to reduce fuel buildup and catastrophic wildfires. The inclusion of C revenues in forest management could change the current negative NPWs to positive ones. The wide variation of NPWtc in Tables 4–6 indicates that C credit revenues would play a key role in the profitability of forest management. Second, the amount and trend (constant or rising) of future C prices will affect the financial gains associated with C emissions reduction. On the basis of our assumptions, a target BA of 40 $ft^2$/ac would

**Table 4. Given the target basal area of 40 ft²/ac for the 4,807 out-of-condition acres, the table shows the net present worth (NPW; $/ac) difference between timber revenues only (NPWt) and both timber revenues and C credits (NPWtc) under nine C price scenarios and two C accounting approaches.**

| | Real alternative rate of return | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2% | | | 4% | | | 6% | | | 10% | | |
| SN[a] | NPWtc | NPWt | Gain[b] | NPWtc | NPWt | Gain | NPWtc | NPWt | Gain | NPWtc | NPWt | Gain |
| 1st accounting approach: reduced buffer pool under the Climate Action Reserve protocol | | | | | | | | | | | | |
| 1 | −119.39 | −150.63 | 31.24 | −119.26 | −144.89 | 25.63 | −116.88 | −139.48 | 22.60 | −109.97 | −129.52 | 19.55 |
| 2 | −46.49 | −150.63 | 104.14 | −59.46 | −144.89 | 85.43 | −64.14 | −139.48 | 75.34 | −64.34 | −129.52 | 65.18 |
| 3 | 26.41 | −150.63 | 177.04 | 0.33 | −144.89 | 145.22 | −11.40 | −139.48 | 128.08 | −18.72 | −129.52 | 110.80 |
| 4 | 370.09 | −150.63 | 520.72 | 282.23 | −144.89 | 427.12 | 237.22 | −139.48 | 376.70 | 196.38 | −129.52 | 325.90 |
| 5 | 890.80 | −150.63 | 1,041.43 | 709.35 | −144.89 | 854.24 | 613.91 | −139.48 | 753.39 | 522.28 | −129.52 | 651.80 |
| 6 | 1,588.57 | −150.63 | 1,739.20 | 1,281.68 | −144.89 | 1,426.57 | 1,118.68 | −139.48 | 1,258.16 | 958.99 | −129.52 | 1,088.51 |
| 7 | −17.76 | −150.63 | 132.87 | −45.17 | −144.89 | 99.72 | −56.58 | −139.48 | 82.90 | −61.81 | −129.52 | 67.71 |
| 8 | 82.17 | −150.63 | 232.80 | 2.23 | −144.89 | 147.12 | −32.77 | −139.48 | 106.71 | −54.63 | −129.52 | 74.89 |
| 9 | 737.03 | −150.63 | 887.66 | 523.81 | −144.89 | 668.70 | 417.35 | −139.48 | 556.83 | 325.38 | −129.52 | 454.90 |
| 2nd accounting approach: increased C stocks based on with-and-without analysis | | | | | | | | | | | | |
| 1 | 384.96 | −150.63 | 535.59 | 168.62 | −144.89 | 313.51 | 59.72 | −139.48 | 199.20 | −29.88 | −129.52 | 99.64 |
| 2 | 1,634.67 | −150.63 | 1,785.30 | 900.14 | −144.89 | 1,045.03 | 524.51 | −139.48 | 663.99 | 202.61 | −129.52 | 332.13 |
| 3 | 2,884.38 | −150.63 | 3,035.01 | 1,631.67 | −144.89 | 1,776.56 | 989.29 | −139.48 | 1,128.77 | 435.11 | −129.52 | 564.63 |
| 4 | 8,775.86 | −150.63 | 8,926.49 | 5,080.27 | −144.89 | 5,225.16 | 3,180.44 | −139.48 | 3,319.92 | 1,531.17 | −129.52 | 1,660.69 |
| 5 | 17,702.36 | −150.63 | 17,852.99 | 10,305.42 | −144.89 | 10,450.31 | 6,500.35 | −139.48 | 6,639.83 | 3,191.86 | −129.52 | 3,321.38 |
| 6 | 29,663.87 | −150.63 | 29,814.50 | 17,307.13 | −144.89 | 17,452.02 | 10,949.03 | −139.48 | 11,088.51 | 5,417.18 | −129.52 | 5,546.70 |
| 7 | 2,639.30 | −150.63 | 2,789.93 | 1,399.83 | −144.89 | 1,544.72 | 788.81 | −139.48 | 928.29 | 291.23 | −129.52 | 420.75 |
| 8 | 6,133.27 | −150.63 | 6,283.90 | 3,057.15 | −144.89 | 3,202.04 | 1,621.45 | −139.48 | 1,760.93 | 542.13 | −129.52 | 671.65 |
| 9 | 18,450.75 | −150.63 | 18,601.38 | 10,226.16 | −144.89 | 10,371.05 | 6,129.30 | −139.48 | 6,268.78 | 2,731.93 | −129.52 | 2,861.45 |

[a] C price scenario number.
[b] Gain = NPWtc − NPWt.

**Table 5. Given the target basal area of 70 ft²/ac for the 4,807 out-of-condition acres, the table shows the net present worth (NPW; $/ac) difference between timber revenues only (NPWt) and both timber revenues and C credits (NPWtc) under nine C price scenarios and two C accounting approaches.**

| | Real alternative rate of return | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2% | | | 4% | | | 6% | | | 10% | | |
| SN[a] | NPWtc | NPWt | Gain[b] | NPWtc | NPWt | Gain | NPWtc | NPWt | Gain | NPWtc | NPWt | Gain |
| 1st accounting approach: reduced buffer pool under the Climate Action Reserve protocol | | | | | | | | | | | | |
| 1 | −265.07 | −278.59 | 13.52 | −256.83 | −267.98 | 11.15 | −248.14 | −257.96 | 9.82 | −231.10 | −239.54 | 8.44 |
| 2 | −233.52 | −278.59 | 45.07 | −230.81 | −267.98 | 37.17 | −225.22 | −257.96 | 32.74 | −211.42 | −239.54 | 28.12 |
| 3 | −201.98 | −278.59 | 76.61 | −204.80 | −267.98 | 63.18 | −202.30 | −257.96 | 55.66 | −191.74 | −239.54 | 47.80 |
| 4 | −53.27 | −278.59 | 225.32 | −82.15 | −267.98 | 185.83 | −94.24 | −257.96 | 163.72 | −98.95 | −239.54 | 140.59 |
| 5 | 172.05 | −278.59 | 450.64 | 103.69 | −267.98 | 371.67 | 69.49 | −257.96 | 327.45 | 41.63 | −239.54 | 281.17 |
| 6 | 473.98 | −278.59 | 752.57 | 352.70 | −267.98 | 620.68 | 288.88 | −257.96 | 546.84 | 230.00 | −239.54 | 469.54 |
| 7 | −221.78 | −278.59 | 56.81 | −224.77 | −267.98 | 43.21 | −221.91 | −257.96 | 36.05 | −210.23 | −239.54 | 29.31 |
| 8 | −182.28 | −278.59 | 96.31 | −205.44 | −267.98 | 62.54 | −211.87 | −257.96 | 46.09 | −207.00 | −239.54 | 32.54 |
| 9 | 102.01 | −278.59 | 380.60 | 22.37 | −267.98 | 290.35 | −15.45 | −257.96 | 242.51 | −42.54 | −239.54 | 197.00 |
| 2nd accounting approach: increased C stocks based on with-and-without analysis | | | | | | | | | | | | |
| 1 | 71.06 | −278.59 | 349.65 | −57.29 | −267.98 | 210.69 | −121.37 | −257.96 | 136.59 | −170.49 | −239.54 | 69.05 |
| 2 | 886.89 | −278.59 | 1,165.48 | 434.31 | −267.98 | 702.29 | 197.34 | −257.96 | 455.30 | −9.38 | −239.54 | 230.16 |
| 3 | 1,702.73 | −278.59 | 1,981.32 | 925.91 | −267.98 | 1,193.89 | 516.05 | −257.96 | 774.01 | 151.72 | −239.54 | 391.26 |
| 4 | 5,548.82 | −278.59 | 5,827.41 | 3,243.45 | −267.98 | 3,511.43 | 2,018.54 | −257.96 | 2,276.50 | 911.22 | −239.54 | 1,150.76 |
| 5 | 11,376.23 | −278.59 | 11,654.82 | 6,754.88 | −267.98 | 7,022.86 | 4,295.05 | −257.96 | 4,553.01 | 2,061.97 | −239.54 | 2,301.51 |
| 6 | 19,184.95 | −278.59 | 19,463.54 | 11,460.20 | −267.98 | 11,728.18 | 7,345.57 | −257.96 | 7,603.53 | 3,603.98 | −239.54 | 3,843.52 |
| 7 | 1,495.16 | −278.59 | 1,773.75 | 747.29 | −267.98 | 1,015.27 | 368.76 | −257.96 | 626.72 | 52.03 | −239.54 | 291.57 |
| 8 | 3,541.99 | −278.59 | 3,820.58 | 1,748.73 | −267.98 | 2,016.71 | 888.87 | −257.96 | 1,146.83 | 219.77 | −239.54 | 459.31 |
| 9 | 11,606.11 | −278.59 | 11,884.70 | 6,578.74 | −267.98 | 6,846.72 | 3,990.53 | −257.96 | 4,248.49 | 1,749.18 | −239.54 | 1,988.72 |

[a] C price scenario number.
[b] Gain = NPWtc − NPWt.

generate the highest NPWs under all nine C price scenarios. Third, restoration treatments will enhance long-term C storage, and the target BA of the treatments will affect the magnitude of this increase. Our results indicate that a target BA of 40 ft²/ac is most efficient, with an additional 327.18 tons/ac of C storage during the 50-year projected period, equivalent to an additional 6.54 tons of C storage per year (Table 3). At the end of the project period, this increase is 189% higher than that of the no-treatment option. Finally, as the demand for C credits increases, it is critical to advance societal awareness of C in forest ecosystems and consequently the impacts of management strategies on long-term C storage. Land managers need to be aware of changes in C prices and their stand fire hazard risk levels, and adjust their management practices accordingly to minimize catastrophic wildfires and maximize their revenues from the management of timber production and C sequestration.

The price of C on the Chicago Climate Exchange dropped from a high of more than $7 in 2008 to $0.10/tonne of $CO_2$ in 2010. The current state of the economy, the various costs of participating in a

**Table 6. Given the target basal area of 100 ft²/ac for the 4,807 out-of-condition acres, the table shows the net present worth (NPW; $/ac) difference between timber revenues only (NPWt) and both timber revenues and C credits (NPWtc) under nine C price scenarios and two C accounting approaches.**

| | Real alternative rate of return | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2% | | | 4% | | | 6% | | | 10% | | |
| SN[a] | NPWtc | NPWt | Gain[b] | NPWtc | NPWt | Gain | NPWtc | NPWt | Gain | NPWtc | NPWt | Gain |
| 1st accounting approach: reduced buffer pool under the Climate Action Reserve protocol | | | | | | | | | | | | |
| 1 | −317.77 | −320.79 | 3.02 | −306.31 | −308.57 | 2.26 | −295.20 | −297.04 | 1.84 | −274.41 | −275.83 | 1.42 |
| 2 | −310.73 | −320.79 | 10.06 | −301.03 | −308.57 | 7.54 | −290.90 | −297.04 | 6.14 | −271.09 | −275.83 | 4.74 |
| 3 | −303.68 | −320.79 | 17.11 | −295.75 | −308.57 | 12.82 | −286.60 | −297.04 | 10.44 | −267.78 | −275.83 | 8.05 |
| 4 | −270.46 | −320.79 | 50.33 | −270.85 | −308.57 | 37.72 | −266.34 | −297.04 | 30.70 | −252.15 | −275.83 | 23.68 |
| 5 | −220.12 | −320.79 | 100.67 | −233.12 | −308.57 | 75.45 | −235.65 | −297.04 | 61.39 | −228.46 | −275.83 | 47.37 |
| 6 | −152.67 | −320.79 | 168.12 | −182.57 | −308.57 | 126.00 | −194.52 | −297.04 | 102.52 | −196.73 | −275.83 | 79.10 |
| 7 | −307.29 | −320.79 | 13.50 | −299.22 | −308.57 | 9.35 | −289.89 | −297.04 | 7.15 | −270.72 | −275.83 | 5.11 |
| 8 | −296.00 | −320.79 | 24.79 | −293.58 | −308.57 | 14.99 | −286.89 | −297.04 | 10.15 | −269.71 | −275.83 | 6.12 |
| 9 | −230.14 | −320.79 | 90.65 | −245.56 | −308.57 | 63.01 | −248.78 | −297.04 | 48.26 | −241.34 | −275.83 | 34.49 |
| 2nd accounting approach: increased C stocks based on with-and-without analysis | | | | | | | | | | | | |
| 1 | −116.16 | −320.79 | 204.63 | −184.09 | −308.57 | 124.48 | −216.24 | −297.04 | 80.80 | −235.88 | −275.83 | 39.95 |
| 2 | 361.31 | −320.79 | 682.10 | 106.35 | −308.57 | 414.92 | −27.70 | −297.04 | 269.34 | −142.68 | −275.83 | 133.15 |
| 3 | 838.78 | −320.79 | 1,159.57 | 396.80 | −308.57 | 705.37 | 160.84 | −297.04 | 457.88 | −49.47 | −275.83 | 226.36 |
| 4 | 3,089.71 | −320.79 | 3,410.50 | 1,766.06 | −308.57 | 2,074.63 | 1,049.65 | −297.04 | 1,346.69 | 389.94 | −275.83 | 665.77 |
| 5 | 6,500.22 | −320.79 | 6,821.01 | 3,840.70 | −308.57 | 4,149.27 | 2,396.34 | −297.04 | 2,693.38 | 1,055.70 | −275.83 | 1,331.53 |
| 6 | 11,070.29 | −320.79 | 11,391.08 | 6,620.71 | −308.57 | 6,929.28 | 4,200.91 | −297.04 | 4,497.95 | 1,947.82 | −275.83 | 2,223.65 |
| 7 | 704.39 | −320.79 | 1,025.18 | 286.85 | −308.57 | 595.42 | 73.35 | −297.04 | 370.39 | −105.04 | −275.83 | 170.79 |
| 8 | 1,833.83 | −320.79 | 2,154.62 | 850.96 | −308.57 | 1,159.53 | 372.76 | −297.04 | 669.80 | −4.34 | −275.83 | 271.49 |
| 9 | 6,569.18 | −320.79 | 6,889.97 | 3,717.84 | −308.57 | 4,026.41 | 2,220.07 | −297.04 | 2,517.11 | 891.96 | −275.83 | 1,167.79 |

[a] C price scenario number.
[b] Gain = NPWtc − NPWt.

**Table 7. Break-even C prices ($/ton) for various treatment levels and a range of real alternative rates of return under two C accounting approaches for out-of-condition acres of ponderosa pine on the Navajo Nation timberland, 2009.**

| | Real alternative rate of return | | | |
|---|---|---|---|---|
| Treatment level[a] | 2% | 4% | 6% | 10% |
| 1st accounting approach: reduced buffer pool under the Climate Action Reserve protocol | | | | |
| BA 40 | 14.46 | 16.96 | 18.51 | 19.87 |
| BA 70 | 61.82 | 72.10 | 78.78 | 85.20 |
| BA 100 | 318.66 | 408.97 | 483.85 | 582.36 |
| 2nd accounting approach: increased C stocks based on with-and-without analysis | | | | |
| BA 40 | 0.84 | 1.39 | 2.10 | 3.90 |
| BA 70 | 2.39 | 3.82 | 5.67 | 10.41 |
| BA 100 | 4.70 | 7.44 | 11.03 | 20.72 |

[a] BA 40, 70, and 100 indicate basal area of 40, 70, and 100 ft²/ac, respectively.

C protocol, and the doubts that some stakeholders have regarding the validity of the C credits have been the economic constraints that have exerted downward pressure on the price. Several climate change bills aiming to curtail global warming, set a price on $CO_2$ emissions and create clean energy jobs had been introduced in the Senate. In addition, a renewable portfolio standard (RPS) (a state policy requiring electricity providers to obtain a minimum percentage of their power from renewable energy resources by a certain date) presents an example of using both economic instruments and regulatory approaches to curb $CO_2$ emissions. Currently, there are 24 states accounting for more than half of the electricity sales in the United States that have RPS policies in place. Even if there are no specific, viable legislative actions at the federal level that are on the verge of implementing cap and trade at the time of writing, the trend of using a cost-effective, market-based approach to provide economic incentives of offsetting emissions will ultimately create income opportunities for land managers and the market forces needed in voluntary C markets. If the U.S. C credit policy is tightened and appropriate and timely treatments are encouraged and financially compensated, C sequestration can be enhanced and maintained in forest ecosystems through sound forest management. This approach presents a solution to reduce $CO_2$ emissions and mitigate global climate change while avoiding future fire suppression costs, decreasing the threat of destructive wildfires to forests, and providing income opportunities and generating regional output and employment for Arizona's Native Americans and in rural America.

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## Executive Summary

# A Report on Science Support Provided by The Ecological Restoration Institute for the Arizona Forest Resource Assessment and Strategic Plan – CY 2010

**FS FY 10 – Project 6: State and Private Forestry (ERI 34HY)**


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**Background:**
The Food, Conservation, and Energy Act of2008 (commonly referred to as the Farm Bill) was enacted on June 19, 2008. The legislation amended the Cooperative Forestry Assistance Act of 1978 and required each state to complete a Statewide Forest Resource Assessment, followed by the development of a Statewide Forest Resource Strategy to receive, or continue to receive, funds under the Cooperative Forestry Assistance Act (CFAA). CFAA funds are provided to states through the State and Private Forestry (S&PF) organization of the USDA Forest Service. Currently, Arizona receives several million dollars annually to protect communities from wildfire, assist private forest landowners, promote healthy forest practices, and assist communities with their urban forests. Most of the CFAA funding received by the Arizona State Forestry Division is passed by way of grants to local organizations that provide matching funds and additional implementation resources. The combination of state and local efforts along with coordination and collaboration with federal, tribal, and other land management agencies provides substantial leveraging of these funds to benefit Arizona forests and citizens.

**Legislative Requirements:**
The amended Cooperative Forestry Assistance Act of 2008 added new requirements for the states to identify priority forest landscape areas and highlight work needed to address national, regional and state forest management priorities. Agencies, organizations and representatives of public and private forested land holdings were invited to participate in a collaborative process a state-wide assessment and strategic plan. The Ecological Restoration Institute was a principal partner and contributor in this collaborative process, representing Arizona's Universities.

The state-wide Assessment and Resource Strategy was required to be completed by June 2010 and later approved by the US Secretary of Agriculture. Annual accomplishment reporting will begin in 2011. The required timeline was met and the Assessment and Strategic Plan was reviewed and approved in August 2010.

**National Priorities:**
For State and Private Forestry program funding, the 2008 legislation also requires focus on landscape level outcomes to achieve national private forest conservation priorities. These focus areas include:

- **Conserve and manage working forest landscapes**
- **Protect forests from threats**
- **Enhance public benefits from private forests**

**Forest Resource Assessment:**
The first step in the overall process was the completion of the Forest Resource Assessment. The National Association of State Foresters (NASF) and the State and Private Forestry (S&PF) organization of the USDA Forest Service collaborated to provide specific guidance to states for completion of the assessment. The guidance provided the following minimum requirements for the Resource Assessment:

- Provide an analysis of present and future forest conditions, trends, and threats on all ownerships in the state using publicly available information.
- Identify forest related threats, benefits, and services consistent with the S&PF Redesign national themes.
- Delineate priority rural and urban forest landscape areas to be addressed by the state forest resource strategy.
- Work with neighboring states and governments to identify any multi-state areas that are a regional priority.
- Incorporate existing statewide plans including Wildlife Action Plans, Community Wildfire Protection Plans, and address existing S&PF program planning requirements.

In Arizona, considerable analysis and planning has been completed by state and federal agencies, non-profit organizations, academic institutions, and collaborative groups. It was anticipated that a large portion of the required new assessment work would build upon these earlier activities. It was also the goal of the Arizona Forestry Division for the Resource Assessment and Strategy to address not only the national private forest conservation priorities, but also to be a useful tool to a wide range of organizations and the basis of future work in

Arizona to address our forest resource issues. It was also anticipated that the Statewide Strategy would be merged with the update of the *Statewide Strategy for Restoring Arizona's Forests* at some future date.

**Assessment Task Group:**
In July 2009 the Arizona State Forester appointed a Forest Resource Assessment Task Group to work with Forestry Division staff in developing recommendations for an Arizona Forest Resource Assessment. The Task Group began meeting in August 2009 and continued work until the Assessment was completed in June 2010. Task Group Membership included representatives from:

- **Arizona State Forestry Division**
- **Arizona Community Tree Council**
- **Arizona Forest Health Council**
- **Arizona Forest Stewardship Committee**
- **Arizona Game and Fish Department**
- **Ecological Restoration Institute at NAU**
- **The Nature Conservancy**
- **USDA Forest Service**
- **USDA Natural Resource Conservation Service**
- **U.S. Bureau of Land Management**
- **U.S. Fish and Wildlife Service**

**Forest Resource Strategy:**
Work began on the Arizona Forest Resource Strategy in late 2009, once the Assessment was substantially underway. The Arizona State Forester appointed a second interagency task group, which was primarily the same representatives as the Assessment Task Group, to work with Forestry Division staff to provide assistance with this strategy component. Where possible, the strategy complemented other state and federal agency assessment and planning work previously completed.

**Support provided by the Ecological Restoration Institute:**
ERI provided approximately 1.5 FTE's equivalent, in direct contribution to the Assessment and Strategy. Ensuring best-science, providing data and inventory methods & monitoring technical support regarding restoration, fire ecology, cultural heritage, and watershed restoration principles and processes were integrated into the process, as a priority. GIS and remote sensing, providing writer/editor support, mapping, analysis of cultural dependency and interactions with forested lands and facilitation are examples of the diverse and continual contribution by ERI personnel. ERI has been requested by Arizona State Forestry Department to remain involved with implementation and monitoring of the Strategy into FY 2011.

**Annual Reporting:**
Annual reporting will be required to commence in 2011 and will include information about activities of the Arizona State Forestry Division as well as activities by other agencies and organizations working toward the common objectives and goals identified in the Strategic Plan.

## Executive Summary

### Introduction

Arizona is a land of diverse landscapes. The diversity of Arizona forests ranges from riparian gallery forests traversing the low desert to sub-alpine and montane forests above 9,000 feet in elevation (O'Brien 2002). Forests cover roughly 27% of the state and occupy 19.4 million acres. These forests are comprised of 37 species of coniferous and hardwood trees. The majority of forestland is located above the Mogollon Rim with distinct areas scattered throughout the rest of the state. Juniper (*Juniperus* spp.) and pinyonjuniper (*Pinusedulis-Juniperus*spp.) woodlands are the most abundant forest type in Arizona, occupying approximately 14.8 million acres, or 20.3% of the state. The rarest and most significant in ecological terms is riparian forest, which occupies less than one-half of 1% of Arizona's land.

Land ownership within Arizona is also quite diverse. Federal and state agencies and Native American Tribes manage the majority of lands. Only a small portion is privately owned. *Arizona's Forest Resource Assessment* and *Strategy* are truly reflective of this diverse land base and draw on the strong relationships with many organizations and agencies. This collaborative "all lands" approach for the *Assessment* and *Strategy* is critical for successful near-term and long-term outcomes on the landscape.

The development of this *Assessment* and *Strategy* was prompted by federal legislative requirements. The amended Cooperative Forestry Assistance Act of 2008 (commonly referred to as the Farm Bill) added new requirements for the states to identify priority forest landscape areas (i.e., a statewide assessment of forest resources) and highlight work needed to address national, regional, and state forest management priorities (i.e., a statewide forest resource strategy).

States must complete the assessment and strategy in order to qualify to receive funds under the Cooperative Forestry Assistance Act (CFAA). The CFAA funds are provided to states through the State and Private Forestry (S&PF) program of the USDA Forest Service. Currently, Arizona receives several million dollars annually to protect communities from wildfire, assist private forest landowners, promote healthy forest practices, and assist communities with their urban forests. Most of the CFAA funding received by the Arizona State Forestry Division (AZSFD) is given as grants to local organizations that provide matching funds and additional implementation resources. The combination of state and local efforts, along with coordination and collaboration with federal, tribal and other land management agencies, provides substantial leveraging of these funds to benefit Arizona forests and citizens.

The responsibility for developing the statewide assessment and strategy belongs to the State Forester and the AZSFD. The State Forester appointed a task group with diverse representation to work with AZSFD staff to develop the *Arizona Forest Resource Assessment* and make recommendations for the *Arizona Forest Resource Strategy*.

Basic principles for the *Assessment* were identified early in the process:

1. Build upon a strong collaborative foundation
2. Use and leverage existing work to the fullest extent possible
3. Develop a strong framework for future work.

**Overview of Issues**

The Arizona Forest Resource Assessment Task Group devoted hundreds of hours reviewing existing planning and assessment documents, gathering input from partner agencies and stakeholders, and discussing the classification of Arizona forest issues. The group ultimately decided to organize the state's critical forest resource issues into seven major categories:

1. People and Forests
2. Ecosystem Health
3. Water & Air
4. Fire
5. Economics
6. Climate Change

7. Culture

As forest resource issues were identified, evaluated and classified, it became clear that there were three overarching needs that cut across all issue categories:

1. Funding to accomplish forest management activities
2. Developing the capacity to collaboratively accomplish forest management goals
3. Educating the public about forest management.

It is clear that various aspects of funding, capacity and education must be considered as strategies are developed and implemented and priority/focus areas addressed.

**Purposes and Uses**

The *Assessment* and *Strategy* put forth a broad array of issues, goals, and necessary actions. In short, these documents attempt to address those things that forests affect as well as those things that affect forests**.** The assessment also addresses the three national themes outlined in the Farm Bill:

1. Conserve working forest lands
2. Protecting forests from harm
3. Enhance public benefits from trees and forests

The *Assessment* provides the following information as a foundation for the *Strategy*:

- An analysis of present and future forest conditions, trends, and threats on all ownerships in the state using publicly available information.
- Identification of forest-related threats, benefits, and services consistent with the Farm Bill national themes.
- A delineation of priority rural and urban forest landscape areas that will be addressed in the *Strategy*.
- Identification of opportunities for working with neighboring states and governments to address multi-state priority areas.
- An analysis of how to incorporate existing statewide plans, including Wildlife Action plans and Community Wildfire Protection plans, and planning for existing State Forestry programs and initiatives.

The *Strategy*:

- Outlines long-term coordinated approaches for addressing forest resource issues and opportunities in priority landscapes.
- Describes how the state proposes to invest federal funding and other resources to address state, regional, and national forest management priorities.
- Identifies key partners and stakeholders for future program, agency, and partner coordination.
- Incorporates existing statewide plans including the State Wildlife Action Plan (SWAP) and Community Wildfire Protection plans (CWPP), and
- Discusses the resources necessary for implementation.

**Collaborative Goals for Arizona**

A total of 20 broad collaborative Goals are identified for Arizona. The strategy also identifies a long list of more specific Objectives and Actions to focus ongoing work to accomplishing these goals.

**People and Forests**

- People and communities receive maximum benefits from forests and trees.
- Minimized negative impacts to trees and forests.

**Ecosystem Health**

- Resilient and diverse forest ecosystem structures, processes, and functions
- Progress toward landscape scale outcomes, restoration of unhealthy ecosystems, and enhanced sustainability with negative impacts.

**Water and Air**

- Improved water quality and quantity from forested watersheds.
- Improved health and resiliency of forested aquatic systems (riparian areas, springs, and wet meadows)
- Increased public understanding of the importance of forests to Arizona's water quality.
- Improved air quality.

**Fire**

- Wildland ecosystems where appropriate fire regimes maintain health and resiliency of natural vegetation.
- "Fire Adapted Communities" that provide shared stakeholder responsibility for healthy landscapes and wildfire prepared communities.
- Enhanced wildland fire management capacity in Arizona.
- An Arizona public and government leadership that is well informed about wildland fire management, science, and prevention issues.

**Economics**

- Realized long-term economic potential of sustainable forest products and bioenergy (while achieving Ecosystem health goals)
- Protection of areas with economic development potential related to ecosystem services.
- Community recognition of the economic importance to protecting healthy natural systems.

**Climate Change**

- Increased resilience of ecosystems to climate change.
- Reduced rate of future climate change through maximized carbon sequestration in Arizona forests and trees.
- Broad public and community understanding of climate change science – Arizona's variable climate and current and future impacts.

**Culture**

- Improved communication between all land management agencies, indigenous tribes, and other cultural groups about varying perspectives and beliefs related to forests, trees, and other natural resources.
- Effective collaboration mechanisms for sharing of information about resources, priorities, policies, and management strategies between Tribes and non-Tribal organizations.

## Overview of the Arizona Forest resource Strategy:

**Introduction and Background**

**Introduction**

The forests and trees of Arizona are an invaluable asset vital to all of the state's citizens. Arizona has more than the typical image of saguaro cactus in the Sonoran Desert. It is a land of diverse landscapes and diverse forests. There is an array of forests and woodlands from the cottonwood bosques hugging our river courses to the subalpine firs cloaking our tallest peaks to the paloverdes shading our urban communities To many, it comes as a surprise to learn that Arizona has more than 20 million acres of forest land. These forests provide substantial benefits or "ecosystem services" to the people of Arizona. Many of these goods and services are traditionally viewed as free benefits to society. One of many examples of such an "ecosystem service" is clean drinking water. According to the National Academies, forests in the United States provide two-thirds of the nation's drinking water. This is an extremely critical function in an arid state undergoing rapid population growth. In 2000 , the Arizona census recorded 5.1 million people and that number is expected to double by the year 2030. Other ecosystem services provided by forests include wildlife habitats, clean air, recreation and renewable energy.

The management of lands within Arizona is very diverse. Federal and state agencies and Native American Tribes manage the majority of Arizona lands. Only a small portion is owned privately. Different federal agencies have responsibility for specific lands including the USDA Forest Service, USDI Bureau of Land Management, and USDI National Park Service. The USDI Bureau of Indian Affairs also assists certain tribes with the management of tribal lands. There are also forest areas under the jurisdiction of the Department of Defense. These multiple ownerships can create substantial complexity when trying to address forest issues on a larger scale that affect lands under different ownerships or jurisdictions in the same area of the state. Thus, it is critical to develop and draw upon strong relationships with many organizations and agencies for any statewide assessment or strategy to be truly reflective of this diverse land base. This collaboration will be critical to both the short- and long-term success of this process.

In Secretary of Agriculture Tom Vilsack's speech outlining his vision for our nation's forests, he said, "a healthy and prosperous America relies on the health of our natural resources, and particularly our forests. America's forests supply communities with clean and abundant water, shelter wildlife, and help us mitigate and adapt to climate change. Forests help generate rural wealth through recreation and tourism, through the creation of green jobs, and through the production of wood products and energy. They are a source of cultural heritage for Americans and American Indians alike. And they are a national treasure--requiring all of us to protect and preserve them for future generations." Secretary Vilsack has further articulated that the threats facing our forests don't recognize property boundaries. In developing a shared vision for our forests, we must also be willing to look across property boundaries and we must operate at a landscape-scale by taking an 'all-lands' approach. The *Assessment* and *Strategy* follow this approach. They also build upon and broaden the 2007 *Statewide Strategy for Restoring Arizona's Forests* created by the Governor's Forest Health Council.

Vast areas of the 20 million acres of Arizona's forest lands are unhealthy and vulnerable to unnatural fire because of accumulated fuels, overcrowding, and drought. In 2002, the catastrophic Rodeo-Chediski Fire burned 470,000 acres, destroyed more than 400 homes, and threatened many others. The containment and suppression costs exceeded $50 million as well as other immeasurable costs of rebuilding the communities and restoring the ecosystems destroyed by the fire.

The challenge of addressing these threats is compounded by Arizona's rapidly increasing population and shrinking state and municipal budgets. This stark reality helps to further emphasize the need to set funding priorities according to which landscapes and ecosystems are most critical. It also brings to light the importance of collaboration with agencies, organizations, and citizens working together to address similar or common issues. Such approaches are being emphasized more and more across all sectors of government and funding in the United States. Performance that demonstrates limited dollars are being used effectively to address the most important of needs now carries a great premium. It is our intent, through the implementation of this *Strategy*, that we make the best use of limited dollars to meet the greatest needs for Arizona's citizens and forest resources. Arizona will be positioned to improve funding, demonstrate results and achieve priority outcomes.

**Background**

**Farm Bill and Cooperative Forestry Assistance Act**

Commonly referred to as the Farm Bill, the Food, Conservation and Energy Act of 2008 was enacted on June 19, 2008. This legislation amends the Cooperative Forestry Assistance Act of 1978 and requires each state to complete a statewide forest resource assessment and a statewide forest resource strategy to receive, or continue to receive, funds under the Cooperative Forestry Assistance Act (CFAA).

The CFAA funds are provided to states through the State and Private Forestry (S&PF) section of the USDA Forest Service (USFS). Currently, Arizona receives several million dollars annually to protect communities from wildfire, assist private forest landowners, promote healthy forest practices, and assist communities with their urban forests. Most CFAA funding received by the Arizona State Forestry Division (ASFD) is passed through to local organizations by way of grants that require matching funds and additional implementation resources. The combination of state and local efforts along with coordination and collaboration with federal, tribal, and other land management agencies provides substantial leveraging of these funds to benefit Arizona forests and citizens.

To receive CFAA funding, the 2008 legislation also requires that states focus on landscape-level outcomes to achieve national private forest conservation priorities. These priorities, which are a result of the "redesign" effort within the S&PF section of the USFS, include:

- **Conserve working forest landscapes**
- **Protect forests from threats**
- **Enhance public benefits from trees and forests**

The amended CFAA of 2008 also requires states to identify priority forest landscape areas and highlight work needed to address national, regional, and state forest management priorities. The State Strategy was submitted to the U.S. Secretary of Agriculture or designee for final approval in June 2010.

**Federal Guidance**

The National Association of State Foresters (NASF) and US Forest Service S&PF collaborated to provide specific guidance to states beyond that provided in legislation. Their guidance identified the following minimum requirements for the Resource Assessment:

- **Provide an analysis of present and future forest conditions, trends, and threats** on all ownerships in the state using publicly available information.
- **Identify forest-related threats, benefits, and services** consistent with the S&PF Redesign national themes.

- **Delineate priority rural and urban forest landscape areas** to be addressed by the state forest resource strategy.
- **Work with neighboring states and governments** to identify any multi-state areas that are a regional priority.
- **Incorporate existing statewide plans**, including Wildlife Action plans and Community Wildfire Protection plans, and address existing S&PF program planning requirements.

**Forest Resource Strategy, Annual Reporting, and Updates**

The *Strategy* was developed as a separate companion document to the *Assessment* and, where possible, complemented other state and federal agency assessment and planning work. Annual reporting will be required by the Arizona State Forestry Division (ASFD), beginning in 2011. Reporting is expected to include information about activities of ASFD as well as activities of other agencies and organizations working toward common forest resource objectives and outcomes. ERI has been requested by AZSFD to provide participation and input into the implementation, and monitoring of the Strategy beginning in FY 2011 and beyond.

The 2008 Farm Bill requires states to update their Forest Resource Assessment and Strategy every five years or as required by the Secretary of Agriculture. Work will continue with partner agencies and organizations to coordinate further refinement of the ongoing assessment and strategy

**Assessment Methodology and Outreach**

Basic principles for the *Arizona Forest Resource Assessment* were identified early in the process:

1. **Build upon a strong collaborative foundation.** The management of lands within Arizona is very diverse. Federal and state agencies and Native American Tribes manage the majority of Arizona lands. Only a small portion is owned privately. For any assessment or strategy to be truly reflective of this diverse land base, it must take an “all-lands” approach. It will be imperative to develop and draw upon strong relationships with many organizations and agencies. This collaboration will be critical to both the short- and long-term success of this process.
2. **Use and leverage existing work to the fullest extent possible.** Substantial assessment and planning work has already been completed in Arizona by a number of federal and state agencies, non-governmental organizations, academic institutions, and collaborative groups. This existing work should be relied on wherever possible, and not duplicated.
3. **Develop a strong framework for future work.** The short-term requirements for development of the *Assessment* will be met, but more importantly, these documents need to be flexible enough to refine and develop over time. As additional resources are applied and new information developed, the *Assessment* and *Strategy* will be refined and strengthened. A strong framework for this future work is critical.

**Task Group**

In July 2009, the Arizona State Forester appointed a task group to work with ASFD staff to develop the *Assessment* and make recommendations for the *Strategy*. The Arizona Forest Resource Assessment Task Group (Task Group) was developed with the above principles in mind. The diverse composition of many existing collaborative organizations was leveraged to keep the size of the Task Group manageable. Representation was sought from all of the largest land management agencies and organizations, statewide councils and collaborative groups, statewide academic community, and non-governmental organizations. The Task Group includes representation from these key agencies:

- **Arizona State Forestry Division -** Responsible for implementation of cooperative forestry programs as well as wildland fire suppression and management on approximately 22 million acres of state and private land outside of municipal jurisdictions.
- **Arizona State Land Department -** Responsible for management and administration of 9.2 million acres of State Trust Land (13% of Arizona's land base) for 13 beneficiaries. The primary beneficiary is the Common Schools (K-12). Revenue is generated through the sale and lease of Trust Land and products from those lands (i.e., mineral materials, water, wood products, etc.).
- **Arizona Game and Fish Department -** Primary responsibility is to conserve, enhance, and restore all of Arizona's diverse wildlife resources and habitats through collaborative management programs focused on wildlife resources for the benefit of the public. Through resource management, the AZGFD provides recreational opportunities for wildlife enthusiasts and citizens to enjoy the diversity of wildlife found in Arizona.
- **Arizona Department of Agriculture -** Responsible for supporting and regulating the agricultural industry in Arizona, including providing compliance assistance and conducting inspections to protect consumers and natural resources.
- **USDA Forest Service –** A federal land management and service agency that manages approximately 11 million acres on six national forests in Arizona for a variety of resource uses. The USFS also provides assistance through the ASFD to private landowners and communities in the areas of forestry, forest health, and fire assistance through state and private forestry programs.
- **USDA Natural Resource Conservation Service -** A federal agency providing both technical and financial assistance to private and tribal landowners for the conservation of natural resources and the environment. The conservation delivery system is a collaborative effort with Arizona's 41 Natural Resource Conservation districts. Participation of NRCS staff on this Task Group, along with other direct communications, reinforced the important link with the State Technical Advisory Committee (an NRCS lead organization that provides recommendations to carry out conservation provisions of the Farm Bill).
- **USDI Bureau of Land Management –**A federal multiple-use agency that administers 12.2 million surface acres of public land (five national monuments, three national conservation areas, two national historic trails, a portion of a national scenic trail, 47 wilderness areas and two wilderness study areas), and another 17.5 million subsurface (mineral) acres within the state. The BLM balances recreational, commercial, scientific, and cultural interests while striving for long-term protection of renewable and nonrenewable resources, including range, timber, minerals, recreation, watersheds, fish and wildlife, wilderness, wild horses and burros, and natural, scenic, scientific, and cultural values. Direction for management of public land administered by the BLM can be found in approved land use plans.
- **USDI Fish and Wildlife Service -** The Arizona Ecological Services Office of the U.S. Fish and Wildlife Service works with public and private partners to protect endangered and threatened species, migratory birds, freshwater fish, and wildlife habitat in Arizona. The Service implements all facets of the Endangered Species Act (ESA), including listing, recovery, and delisting of native flora and fauna. It also works with the various land management agencies to ensure that their projects are in compliance with the ESA. The Task Group includes representation from these key collaborative groups:
- **Arizona Community Tree Council -** A non-profit organization that promotes communication and the exchange of information about trees and the essential role trees play in the well-being of all Arizona communities. The Council is composed of representatives from individual Arizona counties, tribal communities, government agencies, professional organizations, and other individuals who have a statewide interest in the Council's mission. With a membership of nearly 500 individuals, the Council serves in an advisory capacity to the ASFD Urban & Community Forestry Program.

- **Arizona Forest Health Council –** A statewide council appointed by the Governor to address forest issues. Composed of a broad cross-section of forest resource stakeholders, the Council is primarily tasked with implementing the *Statewide Strategy for Restoring Arizona's Forests*, which it developed and published in 2007, and integrating that strategy with the present effort.
- **Arizona Forest Stewardship Committee - A** state-level committee that assists the Arizona State Forester with development, implementation, and oversight of cooperative forestry programs, and serves as a clearinghouse for information about landowner assistance.
- The Task Group includes representation from other key sectors:
- **Academia -**The University of Arizona (UA), Arizona State University (ASU) and Northern Arizona University (NAU) are represented by the Ecological Restoration Institute (ERI) at NAU. The ERI is a research and resource management institute positioned to collaborate within the state university system to garner and share resources and expertise from these institutions.
- **Conservation NGOs -** Represented by The Nature Conservancy, this group includes many conservation organizations, such as the Sky Island Alliance, the Central Arizona Land and Water Trust, and the Desert Foothills Land Trust.
- **Other participants -** During the course of this project, many additional contributors assisted with development of both the *Assessment* and *Strategy.*

**Summary:** ERI will continue to contribute to the implementation and monitoring of the Arizona Forest resource Strategy as a key partner with the Arizona State Forestry Department. ERI Work Plans and deliverables will identify relationships and objectives in the FY 2011 Work Plan. We will allocate the needed resources and personnel to assist the State on meeting the stated objectives of the Strategy. We will also explore opportunities to integrate the Strategy with the future update of the *Statewide Strategy for Restoring Arizona's Forests.*

# GIS/Remote Sensing (Science-support) for Adaptive Management in Frequent Fire Landscape Restoration

## Summary

Monitoring ecological changes is crucial for informing adaptive management in large landscape restoration. Efficient and effective monitoring will allow management strategies to be implemented by adapting to unforeseen treatment effects and to address changing social or environmental concerns through the life of the project. The Ecological Restoration Institute has the experience, know-how and resources to apply place-based science and provide a lead role monitoring treatment effects. We recommend a Landsat based monitoring approach, supplemented by LIDAR as needed.

## Satellite image options

There are a variety of options available for landscape monitoring with probably the least complicated and the lowest cost option being the use of readily available Landsat satellite imagery (Collins and Woodcock 1996, Kennedy et al. 2007, Vogelmann et al. 2009). Higher-resolution data such as SPOT imagery have been merged with Landsat imagery (Rogan and Chen 2004) for forest and landcover mapping. Landsat imagery has also been merged with LIDAR to successfully map forest structure, change and canopy fuels (Hudak et al. 2002, Wulder et al. 2007, Erody and Moskal 2010). High spatial resolution data such as Quickbird and IKONOS have been used in vegetation studies (Mallinis et al. 2008, Wang et al. 2008) Finally, LIDAR has been used alone, or merged with high-resolution data to map forest structure and canopy fuels (Mutlu et al. 2008). MODIS satellite imagery (250, 500 and 1000 m spatial resolution) has also been used to estimate forest change (Wulder et al. 2009) but Landsat, due to its higher spatial resolution, is better suited to detect the changes in structure, pattern and composition that is the goal of the landscape scale monitoring.

There are pros and cons with all the above mentioned landscape monitoring options. Landsat satellite imagery has become the standard for landscape monitoring and change detection since the launch of Landsat 1, in 1972. Archived Landsat data from the 1970s (although 30 m resolution wasn't available until Landsat 4 in 1982) to the present and the planned launch of Landsat 8 in late 2012 ensures that it will be available for future monitoring projects well into the future.

Merging high spectral resolution Landsat imagery with higher spatial resolution imagery such as SPOT has been common for many years (Welch and Ehlers 1987, Yokey 1996). These merged datasets have been used in urban studies but not as commonly in vegetation mapping projects (Lu et al. 2008). The high cost of SPOT data are likely a main factor in these types of merged datasets not often being used in landscape scale vegetation studies.

Quickbird imagery has sub-meter resolution in the panchromatic band and 2.4 m resolution in the multispectral (blue, green, red, near infrared) bands. While it has successfully been used in vegetation mapping studies, its high cost of roughly $14.00/km$^2$ for archived data and $20.00/km$^2$ for new data acquisition, may make it impractical for the roughly 24,000 km$^2$ 4FRI area. Used alone, Quickbird, with its low spectral resolution, wouldn't be the best choice for landscape monitoring but, merged with Landsat, would be a good option. IKONOS imagery has similar spatial resolution as Quickbird and has the same spectral resolution. Price at this point is unknown as price inquiries have not yet been answered.

Worldview 2 data available from DigitalGlobe is an exciting new 8 band imagery with sub-meter panchromatic and 1.8 m multispectral spatial resolution. This dataset includes yellow and "red edge" bands as well as two near infrared bands that were designed to aid in vegetation analysis. Price is unknown (inquiries have not yet been answered) but, due to the greater spectral resolution, it would likely be considerably more expensive than Quickbird.

LIDAR data, merged with Landsat or higher-resolution data such as National Agriculture imagery Program (NAIP) imagery, or used alone, is becoming increasingly popular. This option would be particularly attractive if mapping canopy fuels as well as forest structure, composition, and pattern was a desired goal. Another advantage is that a detailed Digital Elevation Model (DEM), useful for modeling purposes, can be developed with LIDAR. Important considerations with LIDAR are its high cost (~1.00 acre) and the steep learning curve when beginning to work with it. There is a growing number of papers that describe processing and mapping methods. FUSION software, designed by the Forest Service and available for free download (http://forsys.cfr.washington.edu/fusion/fusionlatest.html), can be used to develop canopy and ground-level surface models, characterize tree attributes over large landscapes and merge, or "fuse", LIDAR with aerial photos, satellite imagery etc. (McGaughey et al. 2004).

**Recommendations**

Landsat imagery, depending on the forest variables that end up being the priority for monitoring, is likely the best choice for monitoring treatment effects for landscape scale restoration. Landsat is well suited to landscape monitoring and change detection for a number of reasons:

1) data for each point on the earth are acquired every 16 days so the chance of getting cloud-free imagery during the periods of interest, particularly here in the Southwest, is very good,

2) data can be downloaded for no charge (http://glovis.usgs.gov/),

3) complete Landsat scenes are only ~500 mb (there are portions of 7 scenes in a typical large landscape restoration project area such at the 4 Forests Restoration Initiative area (Figure 1). With current and future data storage options, the file sizes will not be overwhelming and processing these files will take relatively little time,

4) image preprocessing (radiometric correction and image matching) methods are well described in the literature,

5) there are several well established data transformation and derived spectral vegetation indices,

6) change detection using these data has been done extensively for many years and the methods and techniques are well documented,

7) the large footprint (185 km x 185 km) of each Landsat scene ensures complete coverage of all the various ownerships within the project area, and

8) the Region 3 Existing Vegetation Mid-Scale Mapping Project (size/structure, canopy cover, species) data layers recently completed by the Region 3 remote sensing staff were developed using Landsat data. These data layers could be used as a baseline of existing conditions. Perhaps the greatest limitation to Landsat data in the context of the landscape restoration project is that small, potentially unique habitats such as wet meadows or narrow drainages may not be detected.

LIDAR has been shown to estimate canopy fuels both efficiently and accurately (Anderson et al. 2005). If it was determined that more detailed and accurate canopy fuel data layers than those available from the LANDFIRE program are needed, then LIDAR data should be seriously considered. As noted previously, it can also be merged with Landsat data to take advantage of the unique properties of each data type to more accurately map forest structure. The purchase of LIDAR imagery only covering buffered treated areas is a potential strategy that would allow for the development of canopy fuel data layers that could be used for fire behavior modeling in high priority areas.

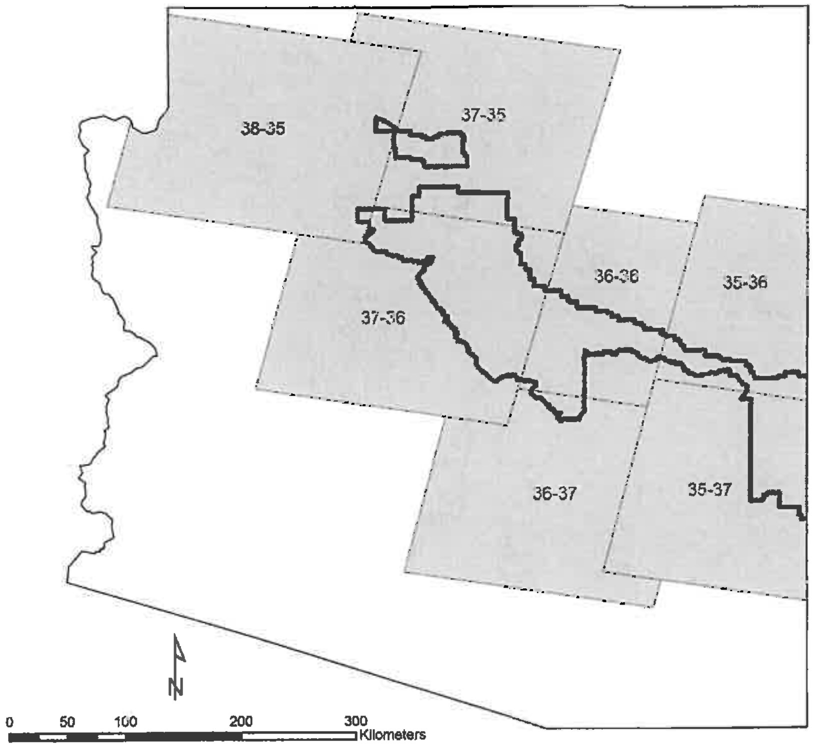


Figure 1.

**Change detection methods**

Specific methods can be established once the monitoring goals and satellite image type is determined. A pilot project to ascertain the most efficient methodology could be conducted at the Ft. Valley restoration site where the ERI has extensive pre and post treatment plot data. This pilot phase could take upwards of 2 months to determine and document the most efficient preprocessing (radiometric correction, image matching) and actual change detection methods (Kennedy et al. 2007). Time spent on future change detection work would be substantially reduced once the methods were established.

**Accuracy assessment**

FIA plots, supplemented by additional plots installed by ERI personnel, can be used to assess accuracy of the change detection data layers. To make the use of FIA plots possible, they would need to be remeasured post treatment. The FIA plot remeasurement schedule might have to be modified to make them available for accuracy assessment purposes but, as they are remeasured anyway, it would make sense to incorporate them into the landscape monitoring aspect of the 4FRI project. The use of these FIA data and the above mentioned Region 3 Existing Vegetation Mid-Scale Mapping Project data would be an efficient use of available resources and project funds. Large-scale aerial photo acquisition to coincide with the change detection/monitoring schedule would also aid in the accuracy assessment process.

**Monitoring schedule**

The current stated variables of interest to monitor are forest structure, composition and pattern. Pattern is easily detectible with Landsat imagery alone soon after treatment. Forest structure can be estimated with Landsat only but, when merged with LIDAR, a more accurate estimation would be achievable. Forest composition is a more difficult variable to measure, regardless of the type of imagery used. Discriminating between conifer and hardwood is relatively easy but distinguishing among the various conifers would prove more difficult. Merged Landsat and LIDAR data may improve accuracy of forest composition change. Large-scale aerial photographs and skilled photo interpreters would greatly aid in this process.

For monitoring landscape restoration projects, we suggest the three variables should be measured 1 and 5 years post treatment. Continued monitoring should continue at 5 year intervals through the life of the project. This schedule should be flexible to allow for variations in treatment response due to precipitation variations, any disturbance such as fire or large areas of blowdown or changes in treatment goals. Landsat availability allows for change detection to be done at whatever intervals are deemed necessary.

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# Summary Report for Beaver Creek Project

**Prepared by: Charlie Denton, Dave Brewer, and Mark Sensibaugh**

**Ecological Restoration Institute**

**Northern Arizona University**

## History – Background

The proposed Beaver Creek Project is located on the Alpine District, Apache-Sitgreaves (A-S) National Forest. This project is located within the boundary of the Four Forest Restoration Initiative (4FRI) project area, and is a part of the 4FRI planning effort. The Beaver Creek project is in the early stages of planning, with the environmental analysis process scheduled to start in the fall of 2010. The proposed project area is approximately 35,000 acres. Vegetation is predominately ponderosa pine, although there are some mixed conifer stands dispersed on the north-facing slopes and wetter sites.

In consulation with Jim Pitts, forest silviculturalist on the A-S, and staff from the Outreach Unit of the Ecological Restoration Institute (ERI), there was a meeting with the District personnel and District Ranger, Richard Davalos. At this June 14th meeting, we discussed ways that ERI could provide assistance in the development of Beaver Creek project. The Forest/District was interested in having ERI do field surveys to determine what the historic range of natural variation was in the timber stands within the Beaver Creek planning area. Using maps provided by the District, ERI staff put in a series of rapid assessment plots in the different forest stand types to determine the historical "reference conditions" within these different stands. This paper is a summary of the information collected from that assessment.

## Methods

To capture data across the entire project area, 25 plots were established (see plot location map Appendix B). Plot location was designed to capture a wide range of conditions (elevation, aspect, topography, potential historical fire patterns, and existing vegetation data). Data were collected from these plots the week of June 28 and the week of July 12. In addition to collecting data about historical tree evidence, information about the existing vegetation, slope, aspect, elevation, estimated fuel loading, current canopy closure, and general soil type was also collected on most of the plots. Plot data were collected by ERI staff with the assistance of Jim Schroeder, the assistant fire management officer on the Alpine District.

There was some variation in the collection of the plot data. Plot size varied with the need to capture data and included these data collection methods and plot sizes: a walk-thru, 1-, 2-, and 2.5-acre plots. On some plots we only collected information about pre-settlement tree conditions (i.e., information about plants, slope, aspect, etc. was not collected).

To reconstruct stand densities in pre-settlement conditions, we located and recorded physical remains of old trees (snags, stumps, downed logs, and stump holes). We also examined living trees in the plots to determine if they germinated prior to European settlement. The process for determining live, pre-settlement trees involved establishing a minimum age for pre-settlement trees, which we decided was 120 years, and then, by boring trees at each plot, establishing a diameter at breast height (DBH) that we estimated would represent that age for that given species. We counted all live trees that had old tree characteristics above that diameter within the plot as pre-settlement trees. Tallied pre-settlement trees were recorded by species and the number of trees per acre. The physical location of pre-settlement trees was not recorded, however, we did note general observations about the historical stand configuration.

The individual plots were not permanently established, however, three or four photos were taken at most plots. The plot record sheets and photos for each plot are attached in Appendix A. The number of plots was based on the scope of the evaluation, which was a rapid assessment designed to get a quick overview of the historical reference conditions.

## Fire History

To obtain fire history data, the ERI staff looked at the report, Historical Fire Regime Patterns in the Southwestern United States Since AD 1700 (USDA Forest Service 1994). Fire scar studies from this report indicate that the project area was subject to frequent surface fire from 1700-1900. The Castle Creek Study shows a fire return interval of approximately three to seven years. The Thomas Creek Study shows a fire return interval of approximately three to nine years. This is very frequent when compared to other mixed conifer areas. Wind-driven (high intensity, short duration), lightning-caused wildfires were frequent prior to monsoonal rains in mid- to late June (Native American activity in the area may have aided this process). These fires were fed by fine fuels (grasses and pine needles). A majority of the fires ignited in the lower elevations along the Blue River and Black River drainages, and followed topographic features as they burned through the project area. For example, the Castle Creek area has a very low number of historic trees per acre. We assume this was because of fires coming out of the Blue River drainage.

Along Beaver Creek from Black River almost to the edge of the Blue River drainage east of highway 191, there is a large meadow area that fires kept free of trees. The edges of those meadows were kept at lower tree densities as a direct result of these grass fires.

The top of Middle Mountain also has a low historic number of trees per acre. This is believed to be due to the high number of lightning fires on the top of the mountain and fires running up the south face of the mountain from the meadow area along Beaver Creek. Many of the fires in the project area occurred during the monsoon period where, with associated increases in relative humidity and rainfall, tree density was minimally affected.

The assumed historical conditions would have included a frequent-fire regime that would have killed the majority of regenerating pine, stimulated aspen regeneration, and eliminated most of the conifer regeneration within the project area.

**Results**

Densities

The historical tree densities were significantly lower than the current stand conditions. The historical tree densities varied from a low of 10 trees per acre (TPA) to a high of 36 TPA. The average density was 20-25 TPA. Total historical trees per acre by plot location are displayed in Appendix B. Current stand conditions were estimated to have between 150 - >800 TPA with all diameter classes represented.

**Photo shows current stand conditions with an estimated 300-450 tree per acre. The photo also shows some historical evidence: burned stumps and down trees.**

Historic tree densities across the landscape varied with the lower historic densities occurring in the lower part of the drainages and along the ridge top of Middle Mountain. This is a result of historic fire movement. As a direct result of historic fire, lower tree densities were also noted around meadows and above the rim on the Blue River where fires came out of the drainage, and over the top of the Rim. The historic tree densities tended to be higher across the mid-slope areas of the Beaver Creek drainage. Historically, the trees were grown in a clumpy/group configuration, although most of the groups were loosely spaced (lots of interspace) and there were multiple scattered, individual trees.

**Historic ponderosa pine stand with current mixed conifer regeneration invasion as a result of the elimination of frequent fire.**

Composition

Historically, most of the project area was covered with ponderosa pine or pine- oak stands, with scattered aspen stands on the wetter sites. Areas classified as non-pine stands (from the District type map), were determined to historically have been predominately ponderosa pine (PP) - Douglas fir (DF) or DF-PP stands. In the areas identified as spruce or spruce and associated species, the historical evidence indicated they were originally ponderosa pine (PP) – Douglas fir (DF) stands or DF-PP with a few spruce. In those areas classified as mixed conifer or white pine, evidence indicates they were PP-DF or DF-PP in the wetter areas. In these stands there is evidence of old oak clumps and aspen. With the reduction in frequent fire, those species (oak and aspen) are being forced out by Douglas fir, white pine, white fir, spruce, and southwestern white pine.

## Fire, Insect and Disease Risks

All the stands within the project area have elevated fire, insect, and disease risks. This is due to the dense stocking, reduced tree growth, and multistoried stand conditions. There is also mistletoe in the pine, which was extensive in some plots. Aspen stands are in decadent conditions and are being invaded by mixed conifer regeneration. Without the influence of fire the conifers will eventually establish dominance and out-compete the aspen.

## Understory

Throughout the project area there is good tree regeneration; most of the stands are multi-aged. As noted above the lack of frequent fire has allowed the increased establishment of mixed conifer regeneration in the wetter sites.

Understory species diversity is dependent on tree densities and, as the photo below demonstrates, once tree densities exceed 125 to 150 per acre these sites did not have many grasses, forbs, or shrubs. However, where there was some reduction of tree concentrations a variety of grasses were found with the most dominant species being Arizona fescue, screw-leaf muhly, squirreltail, western wheatgrass, and Junegrass. Normally, grasses made up roughly 80 percent of the composition with the remaining 20 percent being classified as forbs. Common forbs included common yarrow, pussytoes, fleabane, strawberry, geranium, Rocky Mountain iris, cinquefoil, common dandelion, and meadow rue. Where shrubs were found in the composition, they were typically members of the Rose family (Rosaceae). Only one plot had buckbrush or ceanothus. Overall forage production ranged from a low of zero pounds per acre within dense stands to roughly 400 to 500 pounds per acre (air dry) in the more open areas.

**Photo shows a change in the understory, stocking, and lack of open areas, from pre-European conditions.**

**Photo shows historic evidence and post-fire regime stocking.**

## Summary

Historically, the project area was generally a ponderosa pine forest type. The predominate species was Pinus ponderosa var. *scopulorum*, which occurred in pure stands or in stands with Gamble oaks and aspen. There were some ecotone areas where ponderosa pine was the dominant species intermingled with Douglas fir. The historic range of natural variation was determined to be between 10-36 trees per acre. The trees were established in a somewhat clumpy/group configuration with a number of single trees and open areas. The trees would have been multi-aged and surviving regeneration would have been sparse. The vertical diversity was dominated by mature yellow pines with minimal regeneration and intermediate-sized trees that grew in small clumps or as scattered individual trees.

The fire frequency was approximately every 3-9 years. The disruption of the frequent-fire regime during the last 120-140 years has resulted in a dramatic increase in the number of trees per acre, the amount of surviving regeneration, the loss of aspen and large tree oak stands, and a shift to mixed conifer stands on the wetter, north-facing sites. Compared to historical conditions, there has been a substantial decrease in the number and type of understory species, plant vigor, and structure. Based on historical data collected on similar sites, we know grasses in general constituted a higher percentage of cover along with legumes and shrubs on frequently burned sites. As overstory densities increased, understory species richness declined.

## Considerations and Possible Treatments

The intent of this Assessment is not to provide specific management direction but rather to identify historic conditions as an informational tool to consider in the strategic analysis of the Beaver Creek Project. Some points of consideration, based on the historic conditions, that we would recommend are:

1. Consider restoring historical composition, spacial structure, and age distribution (eliminate thinning from below).

2. Consider reducing tree density closer to historical conditions to reduce fire, insect and disease risks, and improve overall ecosystem health.

3. Consider the re-introduction of frequent fire as a management tool for the project area.

When considering management treatments, there are different opportunities to manage the mixed conifer stands. These stands can be managed as mixed conifer stands with spruce and fir or they can be managed as dry, mixed conifer with a Douglas fir – ponderosa pine composition and more frequent fire. If these stands are managed as dry, mixed conifer stands there will be more opportunity to return the aspen and oak components to these areas.

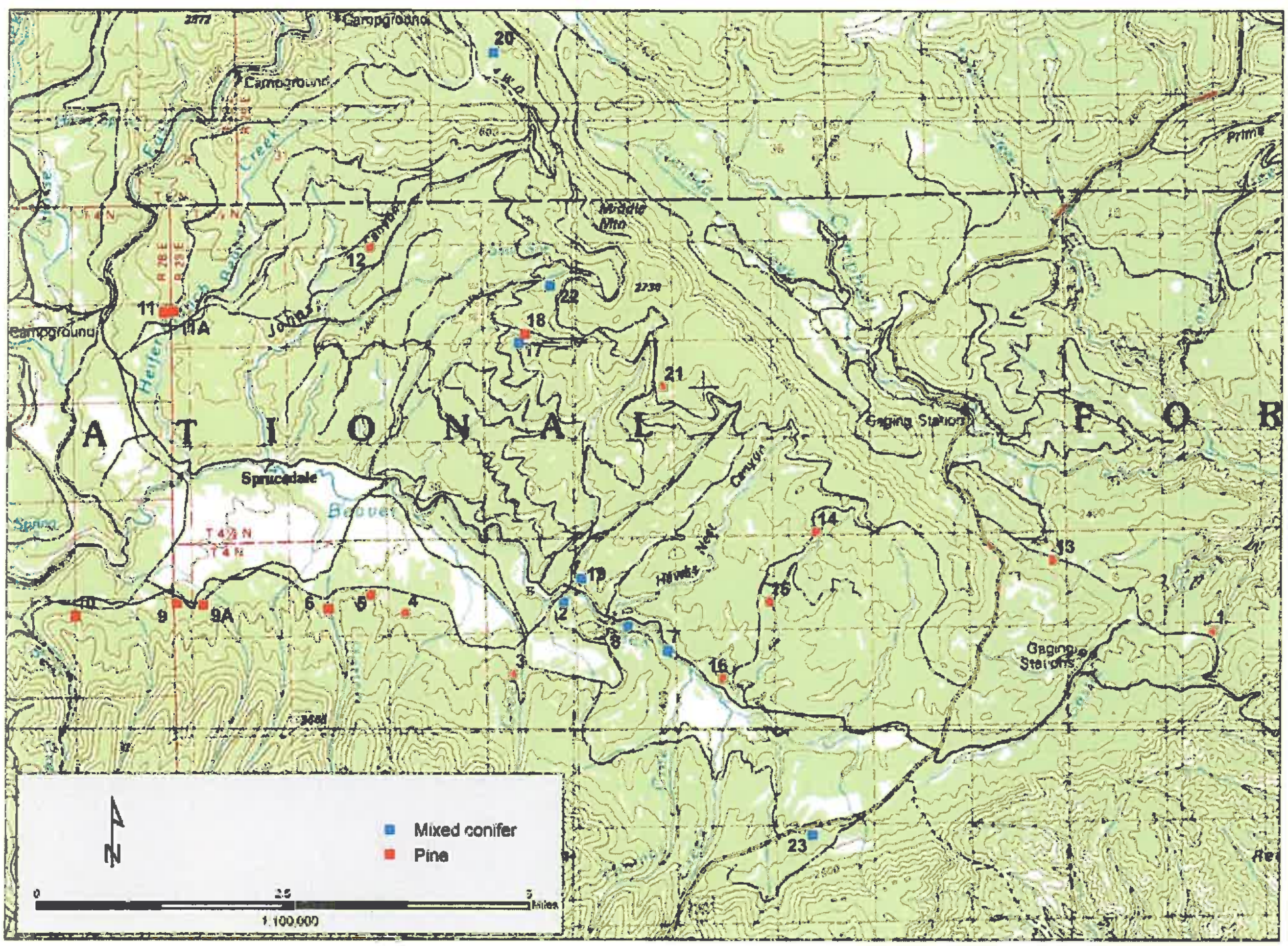
## Appendix

Appendix A – Plot sheets and photos; these are attached by way of a separate disk

Appendix B – Map showing total trees per acre by plot location.

**Appendix B**

| Plot | Historic density |
|---|---|
| 1 | 10 |
| 2 | <20 |
| 3 | 8 |
| 4 | 28 |
| 5 | 36 |
| 6 | 12-15 |
| 7 | 15-20 |
| 8 | <20 |
| 9 | 17 |
| 9A | 24 |
| 10 | 14 |
| 11 | 22 |
| 11A | 29 |
| 12 | 20 |
| 13 | 21 |
| 14 | 11 |
| 15 | 25 |
| 16 | 20 |
| 17 | 26 |
| 18 | 23 |
| 19 | 7 |
| 20 | 30 |
| 21 | 13 |
| 22 | 27 |
| 23 | 30-40 |



NORTHERN ARIZONA UNIVERSITY
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Mr. Edward Collins, District Ranger
Lakeside Ranger District, A/S National Forests
2022 W. White Mountain Boulevard
Lakeside, AZ 85929

August 30, 2010

Dear Ed:

The Ecological Restoration Institute (ERI) appreciates the opportunity to review and comment on the proposed Show Low South Fuels Reduction Project. We have conducted a site evaluation of the project as outlined in the project Proposed Action, and offer the following comments.

In reviewing the proposed objectives and outcomes being considered, and the specific considerations required to meet the fuel reduction objectives in the context of this project, ERI believes this is a sound proposal and commends the Lakeside Ranger District for moving this project forward. We believe that the stated objectives to reduce fuels and fire risk are attainable and the proposed area is in need of having the vegetative & fuels component treated to reduce the threat of unwanted fire to the Show Low community and associated sub-divisions.

Preliminary data collected on the project by ERI Foresters, indicate the fire burn interval and the vegetative structure was significantly altered, beginning in the early 1880's. Prior to this era, there were approximately 17 – 25 trees per acre, consisting of ponderosa pine (*Pinus ponderosa)*, Gambel oak (*Quercus gambelii)* and Alligator juniper (*Juniperus deppeana)* across the project area. It appears fire has continued to play a significant role with most fires being of low intensity, short duration, but with less frequency than the historic range of variability for this area.

As treatments are implemented, it is reasonable to expect an increase in regeneration and growth of Manzanita (*Arctostaphylos patula)*, alligator juniper & gamble oak vegetation. Introduction of more frequent managed fire will help to maintain targeted structure densities of overstory vegetation. Also, as more frequent fire is utilized to maintain the desired vegetative structure, ponderosa pine regeneration would normally be eliminated as well. We recommend considering maintaining adequate replacement ponderosa pine trees that may be needed to replace mortality trees in the future, utilizing the historic range of variation as a guide.

The current OHV and recreational use in the Bagnal Draw area poses additional interesting management considerations that are needed to successfully achieve the project objectives. Proposals to reduce the risk of unwanted fire in this area should be a priority in the analysis process.

ERI is available to assist you further in this analysis process, if desired, to help provide site specific data, determination of the historical range of conditions, inform the prescription process, provide scientific findings, assist with public education and information, etc. Please feel free to contact me at 928-523-4663 or bruce.greco@nau.edu for additional information or assistance.

Bruce Greco
Director of Outreach
Ecological Restoration Institute
Northern Arizona University

Summary Report for the Clint's Well Restoration Project

Prepared by: Mark R. Sensibaugh, Dave Brewer, Walker Chancellor, and Mike Stoddard

**Ecological Restoration Institute**

**Northern Arizona University**

## Background

This report is a summary of information collected on December 3, 2010. In it we compare the approximate pre-settlement forest structure and the restoration-based prescriptions created by the Mogollon District Silviculturist. The goal of the Clint Well Restoration Project is to implement restoration based treatments across the proposed project area to reestablish to the extent possible the structure, function, and integrity of indigenous ecosystems. Specifically there is a need to implement the Mexican Spotted Owl (MSO), old growth, and Goshawk Guidelines from the Forest Plan per the 1996 amendment, and recreate stand structure and functionality that will support the reestablishment of a frequent-fire regime. The project is in the initial stages of the NEPA process and, therefore, subject to review. As a result of field reviews, concerns about the prescription and the removal of specific trees suggested that additional information be gathered with regards to the site-specific pre-settlement structure.

The Ecological Restoration Institute was asked by the District to provide assistance in collecting information with regard to the pre-settlement forest structure. The intent was to provide approximate pre-settlement structural data and create stem maps showing the spatial distribution of the pre-settlement evidences found within the demonstration area and the distribution of trees retained as proposed by District's restoration prescription.

Soils within the experimental blocks are considered moderately deep too deep over bedrock (20 to 60 inches to lithic contact), fine textured, strongly developed, and are well suited for timber management. Soil classifications to the family level are Typic Eutroboralfs, fine montmorillonitic. The soil condition is considered satisfactory with a slight erosion hazard. This unit has oone of the highest production potentials of any TESU found on the Forest[1].

## Methods

The demonstration site was located in the Mogollon Rim District of the Coconino National Forest (34°32'34"N, 111°19'59"W). The elevation was approximately 7000ft with gentle slopes, averaging less than 15%. The forest overstory is dominated by ponderosa pine that represented all VSS size classes, and intermixed with Gambel oak and juniper species. Pockets of mistletoe were evident through the plots.

The demonstration sites were predetermined by the Mogollon rim district silviculturist where he used colored flagging to mark trees to be retained using the district's restoration based prescriptions. Two adjacent plots were established within the first site to account for two different prescriptions. The first plot was 4.2-acres in the uneven-aged maintained prescription area while the second plot consisted of 5.2-acres within the uneven-aged developed prescription area. Following tree marking, all pre-settlement evidences (e.g., snags, stumps, downed logs, and stump holes), live pre-settlement trees,

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[1] USDA – Coconino National Forest. 1993. Terrestrial Ecosystem Survey of the Coconino National Forest. USDA Coconino National Forest. Flagstaff, AZ. 405 pages.

and marked trees were flagged and their position fixed. In addition, all trees that were marked under the prescription had their DBH recorded. From this data, we generated a stem map (see Appendix A). To produce the map, we grouped the marked tree points by VSS classes (combining VSS 1-2, VSS 3-4, and VSS 5-6) as well as the live pre-settlement trees, the pre-settlement evidence, and pre-settlement snags. Other tree species, including Gambel oak, pinyons and junipers, were not recorded. The intent was to create several stem maps for the different treatment areas showing the relationship of the pre-settlement stand distribution and the proposed new stand distribution.

The two plots were adjacent to each other but they represented different stand conditions. The smaller stand was marked to maintain and enhance the existing uneven-aged conditions (i.e., uneven-aged maintained prescription). The other stand was marked to develop an uneven-aged structure (i.e., uneven-aged developed prescription). At the time of the field work a written prescriptions had not been developed for the proposed treatments. Both stands are pine-oak, each had some pockets of mistletoe, and both had representation of all VSS classes. Both stands had stocking levels significantly higher than historical conditions, with trees per acre (TPA) in the 250-300 range and basal area (BA) in the 80-140 range with a mean of 91.

**Results**

The stem map of the two plots indicates there are some interesting results. The things that we found to be of interest with this data are:

- The pre-settlement trees (evidence) that were historically in place and the trees that were marked to replace them (prescription mark), are within the historical range of variability (note how many trees marked compared to evidences) in the uneven-aged maintained plot (Fule' et al. 2002). This is interesting given the fact that the District was not using the evidence as a specific guide. It is also our view that, given the objective of maintaining the historic structure, a 1:1 ratio is acceptable especially with the oak component, which was not tallied in the tree data.
- In the uneven-aged developed plot the ratio was closer to 1:1.5 (21 TPA: 37 TPA), which again, given the objectives, is an acceptable ratio.
- The 'to be established' stand composition provides for a groupy/clumpy configuration with well-designed openings that closely mimic the historical patterns. Again, this was not a direct evidence-based mark (where the evidence was used to locate replacement trees), but the prescription design still meets restoration objectives.
- The proposed mark will help promote the growth and development of the oak component and understory response.
- Looking at the current stand data, the grouping of the different VSS classes appears to be appropriate. There is a high percentage of VSS 3 and VSS 4. Given the current stand densities, there are not many VSS 2, so these percentages seem appropriate. The current treatment, if implemented will create good openings where the oak component and VSS 1 and VSS 2 can develop. The groups also contain different VSS classes, which fits from an ERI restoration

**References**

Restoration:

The following references are good information sources for restoration management.

ERI Working Paper 7: Establishing Reference Conditions for Southwestern Ponderosa Pine Forests, April 2004.

ERI Working Paper 9: Restoration of Ponderosa Pine Forests to Pre-settlement Conditions, February 2005.

ERI Working Paper 22: Restoring Spatial Pattern to Southwestern Ponderosa Pine Forests, June 2008.

ERI Working Papers can be found at library.eri.nau.edu/

Management of Gambel Oak:

Abella, S.R. 2008. Gambel oak growth forms: Management opportunities for increasing ecosystem diversity. Research Note. RMRS-RN-37. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Abella, S.R. and P.Z. Fule. 2008. Fire effects on Gambel oak in southwestern ponderosa pine-oak Forests. Research Note. RMRS-RN-34. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

## Appendix A

| | Uneven age maintained | Uneven age developed |
|---|---|---|
| Presettlement | 22 TPA | 21 TPA |
| Prescription mark | 22 TPA | 37 TPA |
| VSS 1 and 2 | 20% | 6% |
| VSS 3 and 4 | 56% | 66% |
| VSS 5 and 6 | 23% | 38% |

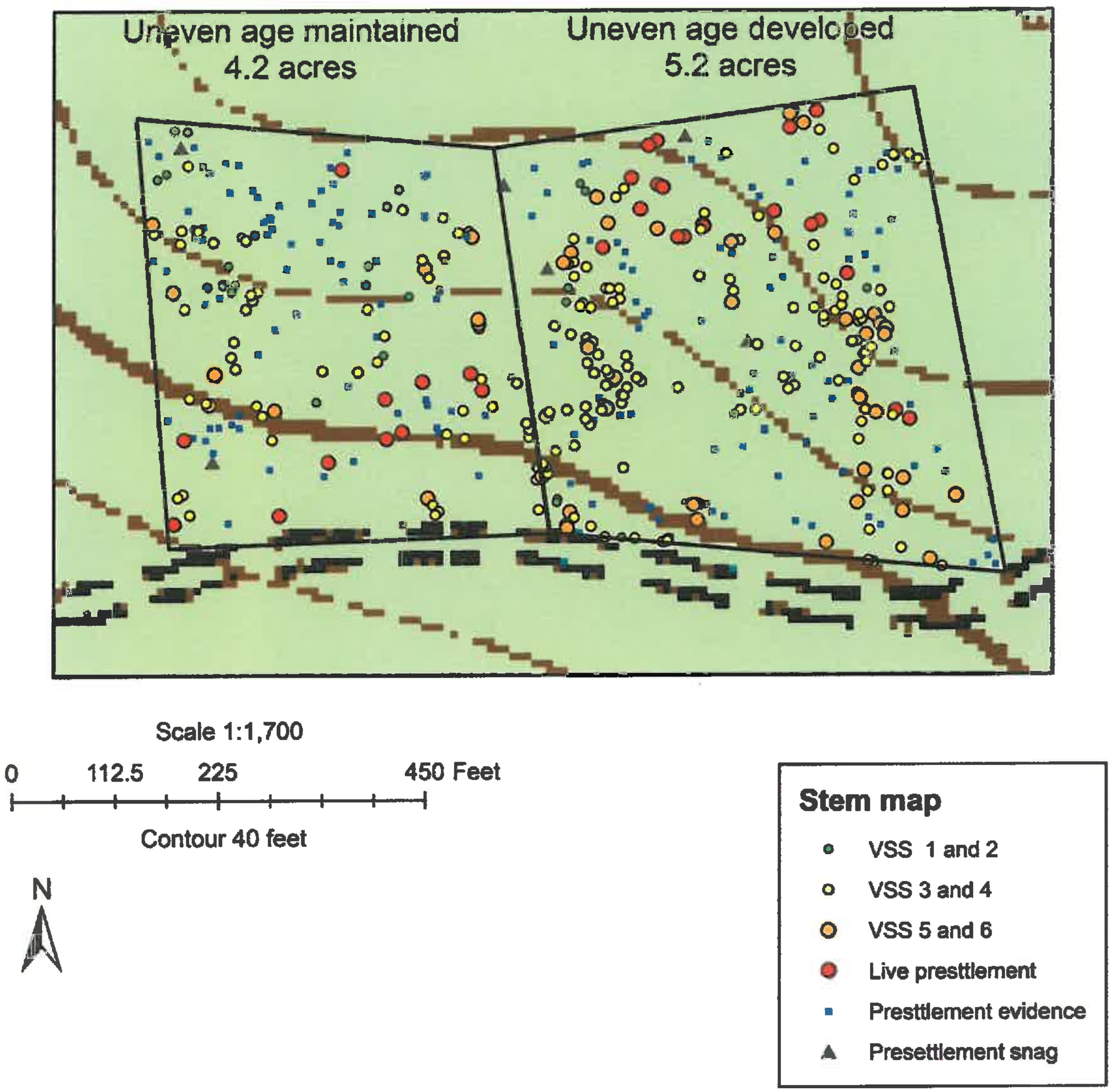


**Figure 1: Stem map of the Uneven-Aged Maintained and Developed Plots – Clint's Well Project.**

**Photo 1: Current stand structure associated with Stand 653-17, uneven-aged maintained prescription.**

**Photo 2: Mistletoe-infected pre-settlement ponderosa pine.**

**Photo 3: Note the high density of small-diameter ponderosa pine trees in the background and general lack of understory forage production in foreground. This condition contributes to a high fire hazard, poor nutrient cycling, and low water runoff potential.**

**Photo 4: Note the Gambel oak component within the uneven-aged stand development, with the mistletoe infestation in the pre-settlement ponderosa pine on the left. Any attempt for regeneration around these infected trees will promote contamination in the pine seedlings.**

**Photo 5: Old oak clump that has been adversely affected by the encroachment of ponderosa pine.**

# Initial Report for Timber Mesa- Vernon Fuel Treatment

# And Fire Risk Reduction Project

Prepared by Mark Sensibaugh, Program Coordinator

Ecological Restoration Institute

Northern Arizona University

**History – Background**

The Ecological Restoration Institute (ERI) coordinated with the Lakeside District Ranger Ed Collins about having ERI provide science based assistance with the planning and development of the Timber Mesa – Vernon Fuel Treatment and Fire Risk Reduction Project. This coordination began in August of 2010. ERI made a commitment to provide assistance in this restoration planning effort. Since that time ERI has meet with the district interdisciplinary team (IDT) several times to get an understanding of the projects purpose and need, where ERI support is needed, and what the project timelines were. ERI has also made two field visits to the project area to look at the vegetative structure and composition and become familiar with the project area. Actual field work has not started.

The project area is situated north and east of the communities of Show Low, Pinetop, and Lakeside and west of Vernon, Arizona. The vegetation includes juniper, pinyon-juniper, ponderosa pine, some oak woodlands, and pine-oak and pine-juniper transition zones. The vegetative densities and fuel loads are excessive and would not with stand a high intensity fire or lengthened periods of drought. The project is being designed to determine and implement the appropriate tree thinning and fuel reduction treatments while considering the habitats of species of concern, protection of private property, and the desire to restore the ecosystem towards good health, sustainability, and one that will support a natural fire regime of frequent low intensity fires (Fire Regime Condition Class I).

As part of implementing this project the district asked ERI to provide the following work products:

ERI will produce a written report that will capture the following information:

1. Information on pinyon – juniper (PJ) management.
    a. Provide an over view of the historic presettlement (natural) structural conditions; what has been invaded, versus what was persistent woodland. Also provide some soils analysis as it pertains to historic conditions.
    b. Provide information and help in developing management strategies to meet the restoration objectives of the PJ. Information on the effects of burning, thinning, seeding, and exotic species control as it relates to restoration and conservation of PJ. They want to develop treatments that simultaneously reduce wildfire hazard and conserve the natural integrity of the PJ ecosystems.

c. Provide any general information we can on natural disturbance regimes, so they can develop baseline reference conditions, evaluate current trends and develop restoration goals.
d. Provide science based information to help determine the appropriate composition, structure, and management strategies, for the PJ – pine transition zone that will re-establish and maintain the historic conditions (structure and composition).
e. Provide information to help the FS accomplish the main objectives for PJ management within the project, which are; fuel reduction/fire protection, improve vegetative health and resilience, wildlife habitat improvement, and restoration of a fire adapted ecosystem.

2. Information on ponderosa pine.
   a. Provide an over view of the historic presettlement (natural) structural conditions.
   b. Provide information and help in developing management strategies to meet restoration objectives for the pine. Information on the effects of burning, thinning, seeding, and exotic species control as it relates to restoration and conservation of ponderosa pine.
   c. For areas of pine-oak provide science based information to determine the proper management strategies that will re-establish historic conditions and the return to a frequent fire regime.
   d. Provide information to help the FS accomplish the main objectives for ponderosa pine management within the project, which are; fuel reduction/fire protection, improved vegetative health and resilience, wildlife habitat improvement, and restoration that will facilitate a fire adapted ecosystem.

In addition, as part of collecting the data to address these needs the ERI will work with the district ID Team in the field to share these concepts and information to craft the management needs and develop management strategies. There is also the possibility that ERI will establish some long term research plots within the project area.

This work will be occurring in the spring of 2011 to coincide with the environmental analysis process that the district is implementing. As the project is completed this written report will be finalized.

**Methods**

As the field work is completed, this section will summarize the data collection methods ERI used to develop the written report.

**Fire History**

This section will provide information on fire history and how that links with future management actions and project objectives.

**Results**

***Tree densities, Composition, and Structure***

This section will provide an overview of the historic conditions, current conditions and appropriate structural conditions that should be achieved as part of meeting project objectives.

***Fire, Insect, and Disease Risks***

This section will provide general summary information on current fire insect and disease risks within the project by vegetation type.

***Understory Vegetation***

This section will summarize the type and general condition of the understory vegetation

***Soils***

This section will cover critical soils information within the project area and how it correlates with vegetation and management considerations.

**Summary**

There will be a short summary of the findings associated with the field work.

**Considerations and Recommended Treatments**

This section will contain some recommended treatments and management considerations based on the field work and associated research.

**References**

The document will contain an electronic link to references of scientific papers that support the findings and recommendations of the field work.

## Website content and general maintenance

In FY 2010 the website grew in content and in viewers

- The library gained 45 new documents, and the new media of audio was added, with 7 audio interviews
- Five new video clips, mainly from ERI research featured on news programs, were added to the site, under Video on the homepage
- Upcoming meetings and events section was maintained
- Thirty-four news stories added to the website
- Links were regularly checked and maintained, and SEO was regularly monitored, with metatags being altered to improve SEO
- Work plans were added to the site (2005 through 2010)

## Statistics for website and library

See appendix for detailed statistics on the website for January through December, 2010.

## New features

We also added many new features to the website:

- Calendar
- RSS syndication of news stories
- Podcasts

## Social Media

We enabled a Twitter account (@eri_nau) to post events, meetings, and new publications.

## New sections within the website

- We added a Google field site map for ERI and for SWERI projects, under Ecological Restoration. We also added a section under Ecological Restoration for LEARN projects.
- A new tab and main section was added to the website for Evidence-based Restoration
- We completed a major revision to the education area of the site (did not launch)

## Server development

SSL (secure sockets layer) was added to the server to provide a secure log-in feature for submitting information to the site.

# 2010 Search Engine Optimization (SEO) Rankings

| | | | | |
|---|---|---|---|---|
| 5/19/2010: | | | | |
| SEARCH TERM: | ERI | Ecological Restoration | Ecological Restoration Institute | ERI NAU |
| Google (Firefox) | 10 | 2 | 1 | 1 |
| Google (IE) | 5 | 3 | 1 | 1 |
| Yahoo | 12 | 5 | 1 | 1 |
| Bing | 36 | 5 | 1 | 1 |
| Ask | 35 | 6 | 1 | 1 |
| | | | | |
| 11/27/2010: | | | | |
| SEARCH TERM: | ERI | Ecological Restoration | Ecological Restoration Institute | ERI NAU |
| Google (Firefox) | 10 | 4 | 1 | 1 |
| Google (IE) | 10 | 5 | 1 | 1 |
| Yahoo | 2 | 6 | 1 | 1 |
| Bing | 21 | 6 | 1 | 1 |
| Ask | 15 | 5 | 1 | 1 |

## 2010 WEBSITE STATISTIC ANALYSIS

| | # hits | hits/day | # visits | ave visit | # unique visitors | % from US | % errors | most visited p | most common entry page |
|---|---|---|---|---|---|---|---|---|---|
| January | 491,966 | 16,964 | 23,974 | 38 min | 3,097 | 61 | 30 | | |
| February | 355,867 | 13,687 | 31,216 | 36 | 3,167 | 65 | 11 | | |
| March | 494,167 | 15,941 | 50,404 | 33 | 3,915 | 64 | 5 | | |
| April | 608,266 | 19,621 | 50,470 | 33 | 4,294 | 62 | 3 | | |
| May | 582,563 | 18,205 | 53,320 | 44 | 3,912 | 58 | 3 | library | library |
| June | 532,083 | 17,164 | 37,139 | 73 | 4,711 | 61 | 10 | library | home |
| July | 412,904 | 12,903 | 28,108 | 64 | 3,937 | 50 | 16 | library | library |
| August | 370,253 | 11,570 | 27,451 | 54 | 3,838 | 56 | 15 | library | library |
| September | 891,805 | 28,768 | 27,305 | 50 | 4,178 | 56 | 2 | home | home |
| October | 315,902 | 9,872 | 24,873 | 55 | 4,521 | 55 | 10 | library | home |
| November | 517,228 | 16,685 | 25,178 | 51 | 4,734 | 51 | 6 | library | home |
| December | 401,031 | 12,532 | 25,761 | 56 | 4,143 | 52 | 3 | library | home |

## ERI Search Engine Optimization (SEO) Summary

**7/27/2011:**

| SEARCH TERM: | ERI | Ecological Restoration | Ecological Restoration Institute | ERI NAU | SWERI |
|---|---|---|---|---|---|
| Google (Firefox) | 6 | 5 | 1 | 1 | 13 |
| Google (IE) | 6 | 6 | 1 | 1 | 13 |
| Yahoo | 2 | 5 | 1 | 1 | 1 |
| Bing | 2 | 6 | 1 | 1 | 1 |
| Ask | 10 | 7 | 1 | 1 | 27 |

**5/19/2010: (Prior Report Summary)**

| SEARCH TERM: | ERI | Ecological Restoration | Ecological Restoration Institute | ERI NAU |
|---|---|---|---|---|
| Google (Firefox) | 10 | 2 | 1 | 1 |
| Google (IE) | 5 | 3 | 1 | 1 |
| Yahoo | 12 | 5 | 1 | 1 |
| Bing | 36 | 5 | 1 | 1 |
| Ask | 35 | 6 | 1 | 1 |

**Note**: Search Engine Optimization demonstrates placement in the search engine. "1" is the very first item to show up. The above shows a significant improvement in ERI's SEO between the last report in May, 2010 and the current report.

## 2011 WEBSITE STATISTIC ANALYSIS

| | # hits | # visits | New visits | Ave time on site | most visited |
|---|---|---|---|---|---|
| January | 396,394 | 25,670 | 64 | 2:11 | homepage; directory;publications |
| February | 357,652 | 23,871 | 64 | 1:50 | directory; publications; evidence based restoration |
| March | 380,745 | 25,266 | 67 | 1:53 | directory; publications; undergrad |
| April | 360,155 | 22,361 | 66 | 1:39 | directory; publications; evidence based restoration |
| May | 445,031 | 21,349 | 68 | 1:49 | directory; evidence based restoration; publications |
| June | 409,020 | 25,628 | 73 | 1:32 | rodeo-chediski; urban interface; directory |
| July | 355,178 | 19,394 | 66 | 1:33 | directory; publications; news (santa fe national forest) |