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# Vegetation removal for achieving diverse water management goals

## Abstract

Water managers who create allocation plans are under immense pressure to support both ecological and human services under a changing political and physical climate. In the dynamic world, water plans must be effective and efficient. Understanding the systems from an ecohydrologic framework can provide insight into feedbacks between ecological and hydrologic processes. Two case studies of intensive invasive vegetation removal have confirmed that in arid systems significant water savings can be achieved. By restoring heavily invaded riparian areas water managers can create better habitats for aquatic and terrestrial biota while simultaneously increasing the quantity of surface and groundwater supplies. Additional costs of implementing programs would be minimal, as habitat restoration efforts are shifted to riparian areas for endangered plant species.

## Introduction

Humans have come to dominate all ecosystems, directly through land uses (Foley et al. 2005) and indirectly through consumption and generation of byproducts (Vitousek 1997, Foley et al. 2005). Our current patterns of consumption are unsustainable and detrimental to the environment around us (Crutzen 2002, Foley et al. 2005). One of the most pressing repercussions of increasing population and global climate change is the unsustainable use of fresh water (Gleick 2010). This is largely due to poor management, reallocation of water, and groundwater pollution (Gleick 1998, Wada et al. 2010). The gravity of overconsumption is made evident by the United Nation's designation of the years 2005 to 2015 as the Water for Life Decade, an effort to bring awareness to the general public about the decline in fresh water availability.

A primary way humans have altered land surfaces is by introducing invasive species. Invasive species have altered hydrology in many systems with these hydrologic consequences varying drastically with the environment and type of invasive species (Table 1). Phreatophytes, plants that can access the phreatic zone (ground water or saturated soil zone), can cause particularly large changes in stream flow because they can draw from multiple pools of water (Dawson and Ehleringer 1991). For example, invasive species often have higher rates of evapotranspiration than native systems (Cavaleri and Sack 2010). Depending on the rooting depths of the resulting riparian community composition, invasive plants can utilize recent precipitation, stored soil water, surface water, ground water, or a mix of these (Dawson 1993, Burgess et al. 1998).

*Table 1. Examples of riparian species that have been introduced throughout the world, threatening already vulnerable and highly altered riparian systems. (Doody et al. 2011).*

Table I. Global examples of introduced riparian plant species

| Species | Country of occupancy | Reference |
|---|---|---|
| Japanese knotweed (*Polygonum cuspidatum*) | North America and Europe | Bailey and Wisskirchen, 2006 |
| Himalayan blackberry (*Rubus armenicus*) | Western North America | Ringold *et al.*, 2008 |
| Reed canarygrass (*Phalaris arundinacea*) | North America (except Gulf of Mexico region) | Galatowitsch *et al.*, 1999 |
| Saltcedar (*Tamarix* spp.) | North America, particularly in western regions | Shafroth *et al.*, 2005 |
| Giant reed (*Arundo donax*) | Southern half of North America South Africa | Coffman, 2007; Dudley, 2000 |
| Willow (*Salix* spp.) | Australia | Greenwood *et al.*, 2004 |
| Russian olive (*Elaeagnus angustifolia*) | North America | Katz and Shafroth, 2003 |
| English ivy (*Hedera helix*) | North America urban riparian environments | Vidra *et al.*, 2006 |
| Common reed (*Phragmites australis*) | Widespread globally | Holm *et al.*, 1977 |
| Cattail (Typha spp.) | Widespread globally | Grace and Harrison, 1986 |
| Rubber vine (*Cryptostegia grandiflora Roxb. Ex R.Br.*) | Australia | Bengsen and Pearson, 2006 |
| Canada goldenrod (*Solidago altissima*) and black locust (*Robinia pseudoacacia*). | Japan | Miyawaki and Washitani, 2004 |
| Tree of Heaven (*Ailanthus altissima*), Giant goldenrod (*solidago gigantea*) | Europe | Schnitzler *et al.*, 2007 |
| Black wattle (*Acacia mearnsii*) | South Africa | Dye *et al.*, 2001 |
| Paperbark trees (*Melaleuca quinquenervia*) | Southern Florida | Chin, 1998; Franks *et al.*, 2008 |

In many areas, mandates of the Endangered Species Act (ESA) make water management decisions even more difficult. The ESA requires the preservation of individual endangered species, although there is significant debate over whether the ESA is effective and efficient in preserving species (Taylor et al. 2005). Many feel that the ESA is failing to achieve its goals, by employing reactive measures on individual species which ignore or degrade important ecosystem processes and services. Others feel the Act is effective due to the 'umbrella effect' of enforced conservation measures, where protected habitat for otherwise vulnerable species results in healthier habitats for many ecologically related species (Taylor et al. 2005). In a time of economic uncertainty and decreased budgets, making projects effective and monetarily efficient should increase positive outcomes. Therefore, riparian ecosystem managers can utilize process based habitat restoration to alleviate habitat loss pressure on endangered riparian plant species. Process based restoration focuses on restoring natural functions, so removing invasive plants which alter hydrologic processes should restore systems to native plant communities.

Water resource managers are under significant pressure to increase reliability and deliveries of surface water to maintain the co-equal goals of human and ecosystem water needs. Difficulties in providing demanded quantities of water may be further exacerbated under a changing climate, especially in systems with strongly seasonal precipitation. Areas that use snow melt, such as the Southwestern United States, will face decreasing water supplies due to earlier melt timing and increased precipitation on snow (Barnett et al. 2008).

Uncertainty under climate change is a large issue for managers, and synthetic reports that attempt to quantify global and regional changes have been a focus of much recent work. Recent evidence suggests humans can change hydrological processes through ecosystem changes on a regional scale, such as the Mississippi river basin. Humans have altered the basin in two major ways, through the direct draw of surface water and transitioning of previously farmed land back into forests (Huntington 2006). One would expect river discharges, an integrated signature of all hydrologic processes, to decrease with these perturbations; however, runoff has actually increased by 22% from 1949 to 1997. Huntington (2006) highlights strong regional evidence of an intensified hydrologic cycle, and highlights the many variables of the hydrologic cycle changing in response to global climate change (Table 2). However, most managers work on a sub-regional scale. Parameterizing or downscaling future climate with global climate models (GCMs) to a meaningful resolution has proven computationally not effective.

*Table 2. Summary of hydrologic variables and their change throughout the 20th century. (Huntington 2006).*

| Variable | 20th century | Latter half 20th century | Majority trend regional (R) or global (G) |
|---|---|---|---|
| Precipitation | √ | | Increasing (R,G) |
| Runoff | √ | √ | Increasing (R,G) |
| Tropospheric water vapor | | √ | Increasing (R) |
| Cloudiness | | √ | No change |
| Tropical Storm frequency and intensity | | √ | No change |
| Floods | √ | √ | No change/increasing (R) |
| Droughts | | √ | Increasing (R) |
| Soil moisture | | √ | Increasing (R) |
| Seasonal glacier mass balance | | √ | Increasing (G) |
| Pan evaporation | | √ | Decreasing (R) |
| Actual evapotranspiration | | √ | Increasing (R) |
| Growing-season length[a] | √ | √ | Increasing (R) |
| Growing-season length[b] | | √ | Increasing (R) |

[a] Based on records of temperature or agricultural killing frost.
[b] Based on satellite-derived 'onset of greenness' normalized difference vegetation index.

Given high levels of uncertainty related to climate change and protection for endangered species, managers should focus resources on projects that achieve co-equal goals. Towards this end, restoration of heavily invaded riparian systems can provide efficient and mutually beneficial outcomes. The restoration of riparian systems can allow managers to increase suitable habitat for species of interest (especially those under ESA protection) and reduce transpiration-based losses. From a conjunctive management perspective, decreasing transpirational losses from catchments will likely increase both groundwater and surface water supplies -- depending on the plant rooting pattern (phreatic vs. shallow rooted) – resulting in more water availability for both human and natural system use.

## Conjunctive management of riparian systems

Plants are often water-limited, and understanding the role of feedbacks between plants and water on a watershed scale can lead to better informed management decisions in how to best preserve endangered riparian plants. Many publications dealing with water management emphasize ecosystem services, but focus on surface water supplies or minimum environmental flows for aquatic species (Baron et al. 2002, Hanak et al. 2011). There is a growing body of literature that plant community composition often depends on groundwater level (Goedhart and Pataki 2011). Phreatophytes may be particularly sensitive to ground water levels in systems where groundwater levels have been pumped below their root zone (Pataki et al. 2008). Understanding the net effects of groundwater on ecosystem processes remain elusive due to biological processes such as hydraulic redistribution (Orellana et al. 2012). Groundwater level management needs to be a priority in areas with highly seasonal precipitation. This is especially true given that surface water shortage problems are typically alleviated with groundwater pumping.

## Identification and quantification of invasive species

Small scale restoration efforts are often limited by the high costs of identifying and quantifying invasive species on a catchment scale. Increasingly, remote sensing techniques are providing insight into ecosystems at large scales, including vegetation cover and evapotranspiration (Ustin et al. 2004). There is also a large emphasis in the literature on understanding invasive species dynamics; hyperspectral remote sensing packages allow researchers  to determine plant species composition, so they can differentiate between native and invasive species (Underwood et al. 2003). These remote sensing techniques can provide cost-effective results for large areas of the globe, identifying sites where riparian restoration could have the largest impacts in restoring hydrologic regimes by invasive plant removal.

**Case studies of process-based restoration of ecohydrologic processes**

**Invasive pines in South Africa**

Plantations of introduced and invasive pine species grown for timber products in South Africa have inadvertently invaded nearby riparian systems. The stands are now self-sustaining, leading to difficulty in removing the invasive species and restoring water balance in these water stressed ecosystems (Dzikiti et al. 2013). The effect is especially drastic in riparian areas, where there has been a 36% increase in measured evapotranspiration compared to non-riparian stands of pine (Figure 2) (Dzikiti et al. 2013). This is an important management problem because the increase in evapotranspiration can shift the water balance of riparian systems. The non-riparian pines evapotranspiration was measured to be 83% of mean annual precipitation (MAP), and the riparian pines evapotranspiration was 108% of MAP, with the ultimate effect of lowering surface water flows (Dzikiti et al. 2013). Currently there are efforts to remove these invasive pines through the Work for Water (WfW) program (www.dwaf.gov.za/wfw/). WfW removes invasive alien plants in South Africa, to increase surface water and groundwater levels to support native ecosystems displaced due to competition with invasive species for water resources.

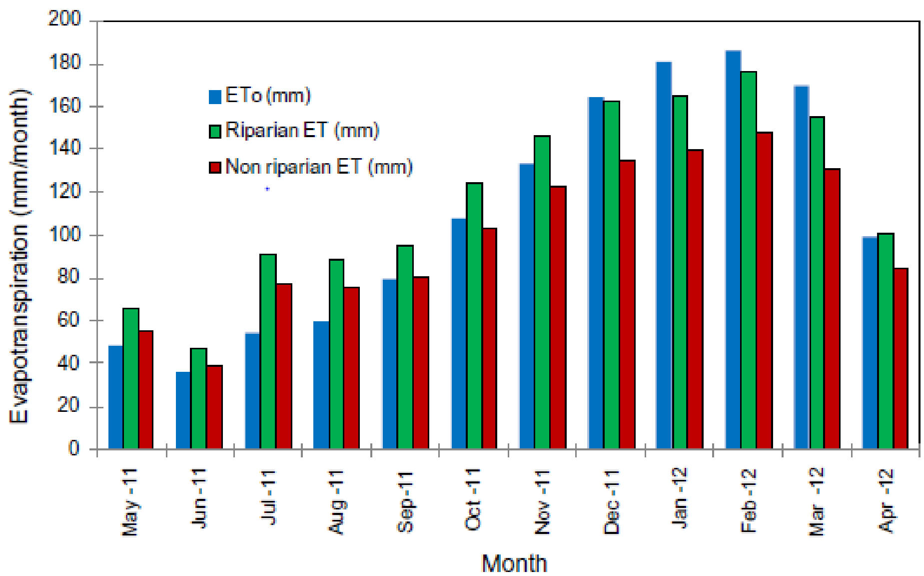


*Figure 1. Comparison of mean monthly evapotranspiration measurements compared to reference evapotranspiration ($ET_o$). Riparian evapotranspiration often exceeds $ET_o$, shifting the water balance of the system. (Dzikiti et al. 2013).*

**Willow removal in Australia**

Non-native willows (*Salix sp.*) are now a large proportion of in-stream and stream bank vegetation in Australian riparian areas (Figure 3). Although there is not currently scientific consensus that the invasive willows are transpiring more than native eucalyptus species, their abundance has led to a study investigating water savings from removal (Doody and Benyon 2011). Due to higher daily transpiration from in-stream willows, the authors suggest that an annual water savings of 5.5 million liters per year per hectare of willow is possible with removal (Doody and Benyon 2011). Interestingly, the authors suggest that there would be no net change in water balance from the removal of stream bank willows, as their transpiration is similar to the native eucalyptus (redgum) which would likely regrow on the banks in the absence of willows (Figure 4) (Doody and Benyon 2011a). These conclusions highlight the need for understanding dominant species-specific impacts on ecohydrologic processes that may have disproportionate effects on catchment hydrology.

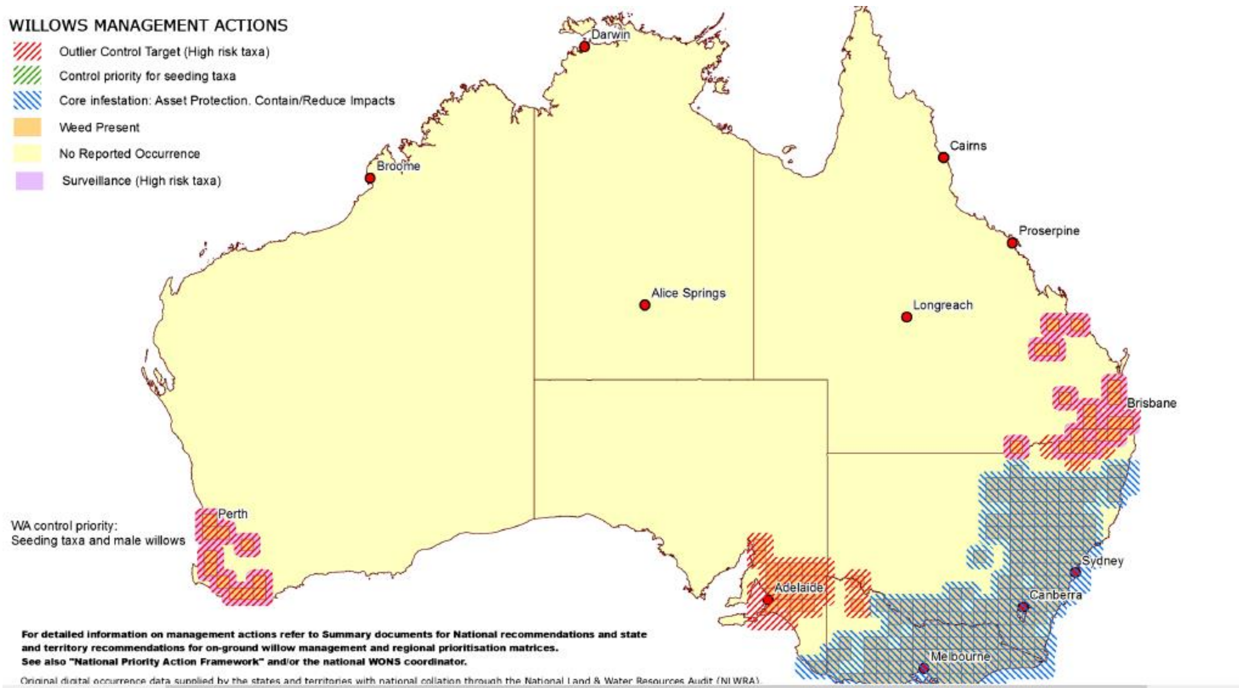


*Figure 2. Areal coverage of willows (Salix sp.) throughout Australia in addition to conservation and control status. (Doody et al. 2011)*

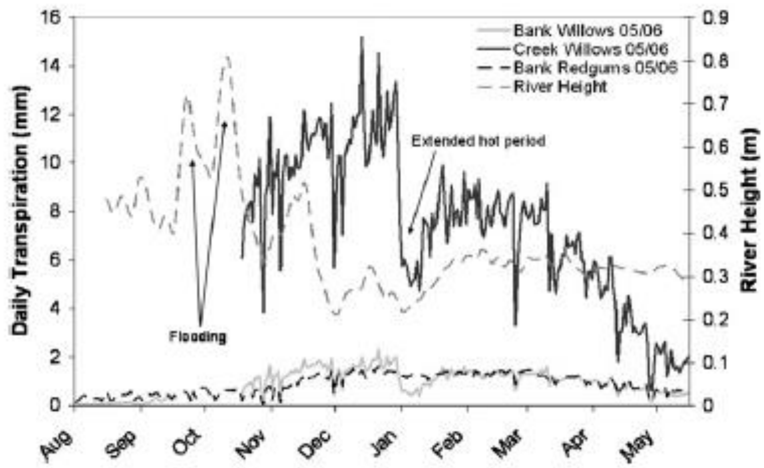


*Figure 3. Transpiration of in-stream willows (solid black) is substantially higher than both stream bank willows (grey) and stream bank eucalyptus (redgum). (Doody and Benyon 2011a, Figure 1).*

**Estimation of water savings in a theoretical riparian system**

The Colorado River basin had a very different plant community composition pre-European settlement. Invaded systems are mostly comprised of Russion olive (*Elaeagnus angustifolia*) and Saltcedar (*Tamarix sp.*) which transpire on average 100 mm of water $m^{-2}$ $day^{-1}$ (Sala et al. 1996, Griggs and Golet 2002). In addition, both species are phreatic. Transpiration by phreatic species is the dominant cause of reduction in upper levels of the ground water zone (Lou and Yuan-lai 2008). In order to assess the benefits of removal of these two species, I have examined the mass balance of a theoretical catchment of my own design (Figure 5). The only change in this figure is the average value of evapotranspiration, which is based on the average daily values (taken from the literature) for an annual cycle. As shown below, removing invasive species can save up to 33% of groundwater outflow from removal by transpiration. Although this is a simplified mass balance model, additional models could be devised and implemented using linear regression to compare changes based on environmental conditions (e.g., soil type, plant species composition, climatic conditions). These relationships could then be used by managers to identify species of interest for removal and inform management priorities on a catchment scale. Although this model is a crude approximation, more sophisticated models could be developed to produce more precise results in the future.

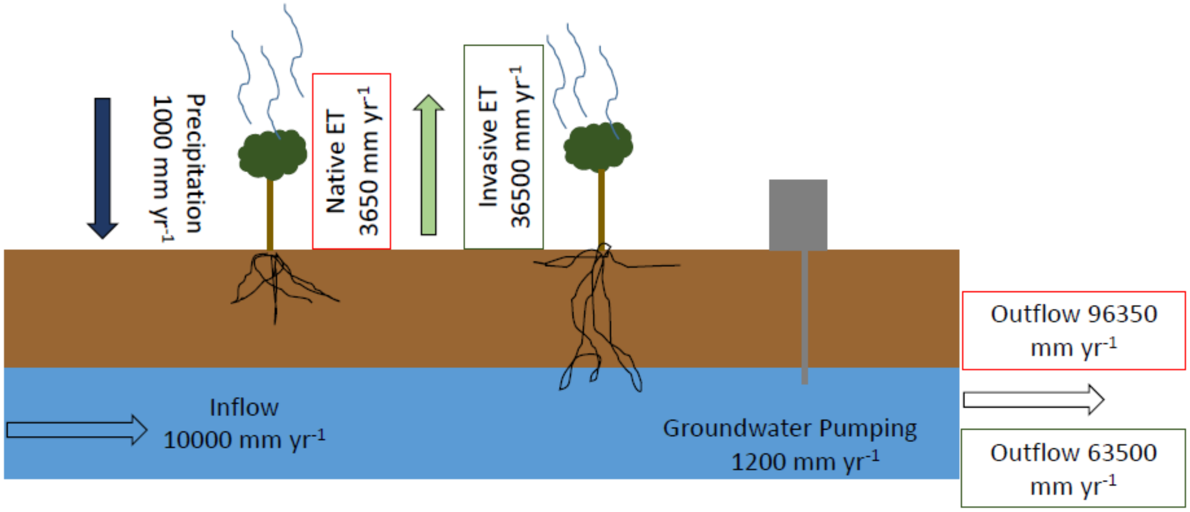


*Figure 5. Invasive ET reduces overall outflow of the system by 33%, drastically reducing downstream flows for human or ecosystem use.*

## Conclusion

For water resource management to be effective, managers need to fully understand ecohydrological processes, including the role vegetation plays on both surface and ground water stores. Ironically, much of the focus of improving water resources management has dealt with increasing agricultural and urban water use efficiency (Hanak et al. 2011), but until recently there has been little focus on increasing the water use efficiency of natural systems by removing invasive species that encroach on riparian habitats. Removal of invasive species can help alleviate pressure on vulnerable plant communities, and achieve ESA goals, while simultaneously increasing surface water minimum flows for ecologic and human uses. Removing invasive vegetation would have the added benefit of increasing flows while resulting in only marginal cost increases due to piggybacking on already existing restoration projects. These restoration projects would need to focus efforts on riparian habitats and plants that may be out-competing threatened or endangered plants. With an uncertain climate in the future, both fiscally and abiotically, adaptive management will enable water resource managers to pursue effective and efficient plans to deliver water under the co-equal goals framework.

# Literature Cited


Barnett, T. P., D. W. Pierce, H. G. Hidalgo, C. Bonfils, B. D. Santer, T. Das, G. Bala, A. W. Wood, T. Nozawa, A. A. Mirin, D. R. Cayan, and M. D. Dettinger. 2008. Human-induced changes in the hydrology of the western United States. Science **319**:1080-1083.

Baron, J. S., N. L. Poff, P. L. Angermeier, C. N. Dahm, P. H. Gleick, N. G. Hairston, R. B. Jackson, C. A. Johnston, B. D. Richter, and A. D. Steinman. 2002. Meeting ecological and societal needs for freshwater. ecological applications **12**:1247-1260.

Burgess, S. S. O., M. A. Adams, N. C. Turner, and C. K. Ong. 1998. The redistribution of soil water by tree root systems. Oecologia **115**:306-311.

Crutzen, P. J. 2002. Geology of mankind. Nature **415**:23.

Dawson, T. E. 1993. Hydraulic Lift and Water-Use by Plants - Implications for Water-Balance, Performance and Plant-Plant Interactions. Oecologia **95**:565-574.

Dawson, T. E., and J. R. Ehleringer. 1991. Streamside trees that do not use stream water. Nature.

Doody, T., and R. Benyon. 2011. Quantifying water savings from willow removal in Australian streams. J Environ Manage **92**:926-935.

Doody, T. M., P. L. Nagler, E. P. Glenn, G. W. Moore, K. Morino, K. R. Hultine, and R. G. Benyon. 2011. Potential for water salvage by removal of non-native woody vegetation from dryland river systems. Hydrological Processes **25**:4117-4131.

Dzikiti, S., K. Schachtschneider, V. Naiken, M. Gush, and D. Le Maitre. 2013. Comparison of water-use by alien invasive pine trees growing in riparian and non-riparian zones in the Western Cape Province, South Africa. Forest Ecology and Management **293**:92-102.

Foley, J. A., R. Defries, G. P. Asner, C. Barford, G. Bonan, S. R. Carpenter, F. S. Chapin, M. T. Coe, G. C. Daily, H. K. Gibbs, J. H. Helkowski, T. Holloway, E. A. Howard, C. J. Kucharik, C. Monfreda, J. A. Patz, I. C. Prentice, N. Ramankutty, and P. K. Snyder. 2005. Global consequences of land use. Science **309**:570-574.

Gleick, P. H. 1998. Water in crisis: Paths to sustainable water use. ecological applications **8**:571-579.

Gleick, P. H. 2010. Roadmap for sustainable water resources in southwestern North America. Proc Natl Acad Sci U S A **107**:21300-21305.

Goedhart, C. M., and D. E. Pataki. 2011. Ecosystem effects of groundwater depth in Owens Valley, California. Ecohydrology **4**:458-468.

Griggs, F., and G. Golet. 2002. Riparian Valley Oak (Quercus lobata) Forest Restoration on the Middle Sacramento River, California. USDA Forest Service Gen. Tech. Rep.

Hanak, E., J. Lund, A. Dinar, B. Gray, R. Howitt, J. Mount, P. Moyle, and B. B. Thompson. 2011. Managing California's Water From Conflict to Reconciliation. Publib Policy Institute of California, San Francisco, California.

Lou, Y.-F., and C. Yuan-lai. 2008. Rethinking conjunctive use of surface and groundwater. Effective utilization of agricultural soil & water resources and protection of environment.

Orellana, F., P. Verma, S. P. Loheide, and E. Daly. 2012. Monitoring and Modeling Water-Vegetation Interactions in Groundwater-Dependent Ecosystems. Reviews of Geophysics **50**.

Pataki, D. E., S. A. Billings, E. Naumburg, and C. M. Goedhart. 2008. Water sources and nitrogen relations of grasses and shrubs in phreatophytic communities of the Great Basin Desert. Journal of Arid Environments **72**:1581-1593.

Sala, A., S. D. Smith, and D. A. Devitt. 1996. Water use by Tamarix ramosissima and associated phreatophytes in a Mojave Desert floodplain. ecological applications **6**:888-898.

Taylor, M. F. J., K. F. Suckling, and J. J. Rachlinski. 2005. The effectiveness of the endangered species act: A quantitative analysis. BioScience **55**:360-367.

Underwood, E., S. Ustin, and D. DiPietro. 2003. Mapping nonnative plants using hyperspectral imagery. remote sensing of environment **86**:150-161.

Ustin, S. L., D. A. Roberts, J. A. Gamon, G. P. Asner, and R. O. Green. 2004. Using Imaging Spectroscopy to Study Ecosystem Processes and Properties. BioScience **54**:523.

Vitousek, P. M. 1997. Human Domination of Earth's Ecosystems. Science **277**:494-499.

Wada, Y., L. P. H. van Beek, C. M. van Kempen, J. W. T. M. Reckman, S. Vasak, and M. F. P. Bierkens. 2010. Global depletion of groundwater resources. Geophysical Research Letters **37**:n/a-n/a.