Measuring the sustainability of Artichoke Thistle (*Cynara cardunculus*) control efforts following suspension of control activities in historic southern California rangeland

Proposal to the Nature Reserve of Orange County (NROC)

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Artichoke Thistle (*Cynara cardunculus;* CYCA) is a deeply-rooted perennial thistle that is a problematic invader in disturbed grasslands, especially in coastal California regions. It has invaded large areas (over 4,000 acres) of the Nature Reserve of Orange County (NROC). The NROC, working with the Nature Conservancy (TNC), initiated a control program for CYCA involving direct application of herbicide to individual plants. Thousands of acres have been treated annually (and often continually) since 1994. While there is no question as to dramatic decline of CYCA due to this program, it is unclear 1) what is replacing CYCA in the control areas, and 2) whether the program will be sustainable following a major reduction in the active control program planned for 2015. Here, I propose to test important assumptions and questions necessary to better understand how the CYCA control program is influencing plant community dynamics. The overall aim of this proposed project is to help guide the NROC in predicting what might happen when the period of active control is complete and guide decisions concerning whether modifications or extensions of the current program are warranted.

Although concepts such as passive restoration, thresholds, and sustainable trajectories are critical to most restoration projects, there has been little research done in this realm. Passive restoration would be indicated if natives (or naturalized exotics, depending on goals) increase during the control period and then confer resistance to re-invasion once active CYCA control is terminated (Figure 1). Of the work that has been done, some find evidence for spontaneous vegetation succession which allows for passive restoration (Prach et al. 2001, Novak and Prach 2003, Prach 2003, De Steven et al. 2006) while others find evidence that systems gets "stuck" in a degraditive cycle, requiring active restoration (Prober et al. 2002, D'Antonio and Thomsen 2004, Cramer and Hobbs 2005). It is likely that dynamics depend on environmental conditions and may be variable within the NROC treatment areas. For example, in a study of heathland restoration in the UK, Mitchell and co-workers (1999) found that systems had to have a substantial compositional similarity to the goal community prior to management efforts in order for them to passively follow the desired successional trajectory following management. Other studies have found that passive restoration will work for some kinds of target species (high dispersal ability, disturbance tolerant) but not others (Kirkman et al. 2004, De Steven et al. 2006).

Thresholds and alternative trajectories may also affect the success of sustainable passive restoration. Exotic populations may have to be decreased to a sufficiently low level for a sufficient duration for the community to reorganize on a different trajectory and be able to resist further invasion. Although there have been few tests of whether sustained control efforts can redirect the community on a sustainable trajectory, they are gaining widespread use in restoration as heuristic devices (Hobbs and Harris 2001, Suding et al. 2004, Bestelmeyer 2006, Groffman et al. 2006, King and Hobbs 2006, Kulmatiski 2006). In addition to a desired scenario, a threshold effect leading to an alternative trajectory may be undesirable: the exotic addressed by the control efforts could be replaced by other problematic exotics rather than the desired native species (Figure 1). This cycle of degradation where exotics replace other exotics may be potentially widespread although there have been few published accounts for plants (Zavaleta et al. 2001).

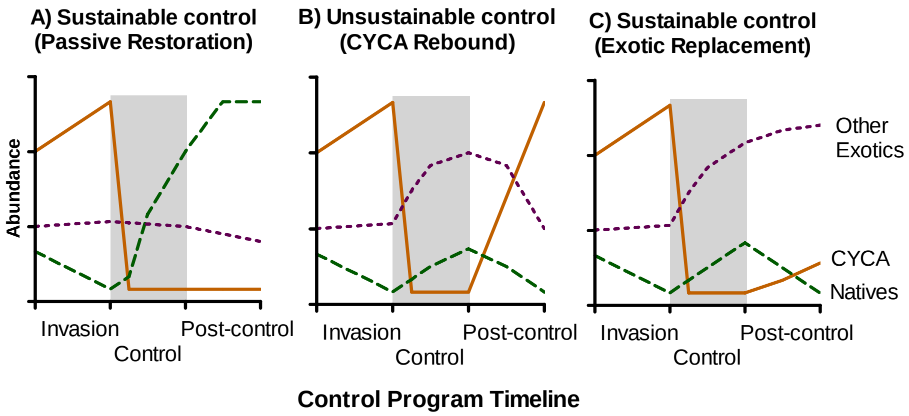

Figure 1. Three possible scenarios in the CYCA control program: a) decrease of CYCA leads to increase of natives that then resist post-control re-invasion; b) CYCA control leads to temporary recovery of natives but is not sustainable; c) CYCA control leads to a release of other problematic exotics which then dominate post-control.

Few, if any, studies that have followed the community response to an exotic control program after active control has been reduced. Distinguishing among the different scenarios of response during the control effort and re-organization following control (Figure 1) is critically important to management decisions such as those faced by the NROC.

Here, I first outline the major testable questions that arise from the NROC management needs, then describe preliminary analyses based on existing monitoring data, and finally detail an approach to better understand dynamics following CYCA control at the NROC. My approach combines the wealth of existing data with targeted field sampling and initiation of longer-term experimentation.

I. Key Questions. Below are questions that are important to meet the NROC's objective of predicting how these systems will respond when the current control program is discontinued. I break the questions into two groups: a) the community response to the sustained control program; and b) the community response after the suspension of active control. This section can be considered a first stab at listing the pieces of knowledge necessary for informed management decisions. One of the first efforts of this project will be to build a list -- by consensus of people involved in the program -- of high priority questions to guide analytical and monitoring efforts.

A. Success of the Control Program

- Is the active (herbicide) control program reducing artichoke thistle density and cover? Does the number of years treated influence success?

- If artichoke thistle is being reduced, is it being replaced by natives (passive restoration), other problematic exotics (e.g., fennel, mustard, other exotic thistles), or more "benign" exotics (e.g., annual grasses)?
- Does success vary depending on environmental or initial site conditions, such as soil type, slope and aspect, pre-control abundance of natives, initial thistle infestation, or landscape context (e.g., proximity to an untreated infestation or high native site)?

B. Suspension of Active Control.

- Once the active control is stopped, are sites on a sustainable trajectory or will artichoke thistle re-invade?
- Is there a threshold of artichoke thistle control (e.g., below 5% cover), that once crossed, makes the system resilient to further artichoke thistle invasion? Would long-term low-output management be able keep artichoke thistle at less than this control threshold?
- Does the sustainability outcome and/or control threshold level vary by site condition or treatment history?
- Where does passive restoration occur and where is further active restoration needed? If restoration following artichoke thistle control does not occur passively, what further restoration effort can be done in conjunction with CYCA control to shift these systems onto a sustainable trajectory?

II. Preliminary Analyses. Monitoring conducted by the Nature Conservancy and NROC provide data to begin answering some of these questions. To date, 42 monitoring sites have been established were density and cover estimations are made (usually annually) on treatment efforts initiated between 1996 and 2005. In five additional sites, cover has been monitored but no treatment has occurred. Of the 42 sites that assessed responses to CYCA treatment, 30 sites are used in this preliminary analysis. At these sites, cover data had been taken immediately prior to the first CYCA herbicide treatment and after at least two years of successive herbicide treatments, and there were no without additional restoration treatments (e.g., native topsoil addition). Of these 30 sites, pre-treatment CYCA cover averaged 45%, ranging from 7-85%. I grouped sites based on whether CYCA invasion was high (60-85%, n=7), moderate (40-60%, n=12) or low (7-40%, n=11) prior to control. This grouping also reflects other characteristics: sites that had high pre-treatment cover of CYCA also had lower cover of other exotic species, and only sites with low pre-treatment CYCA had any sizable cover of native species (Figure 2). There was not enough variability to group these sites based on soil type or aspect; this should be an aim of further sampling efforts (see section III).

Success of Control Program. Control reduced the cover of CYCA substantially after one year of treatment: CYCA abundance after one year was reduced to an average cover of 8% across 30 monitoring sites (range 0-61%, n=30)(Figure 2a). This decrease did not depend on pre-treatment CYCA cover ($F_{2,27}$=0.97, P=0.40); it was successful at every level of infestation. Herbicide maintained CYCA at low levels but did not cause further declines in cover past the first year (cover in years 1, 2, and 3 of treatment did not significantly differ from each other). After three years of herbicide treatment mean CYCA cover was 7% (range 0-42%, n=15). Because there were fewer sites to test the effects of three successive years of monitoring (n=15), and even less for longer time intervals, it is unclear whether CYCA would decline further after longer treatment efforts.

Do successive treatment years just maintain CYCA control (as indicated here) or whether they contribute to increased resistance to CYCA re-invasion once treatment is stopped (as possibly suggested below)? While this dataset doe not have enough long-term treatment sites (>5 years) to adequately resolve this question, it can be assessed with data obtained by further monitoring (sites stratified by years treated) and experimental manipulations (stopping treatment at sites with different control histories) (see section III below).

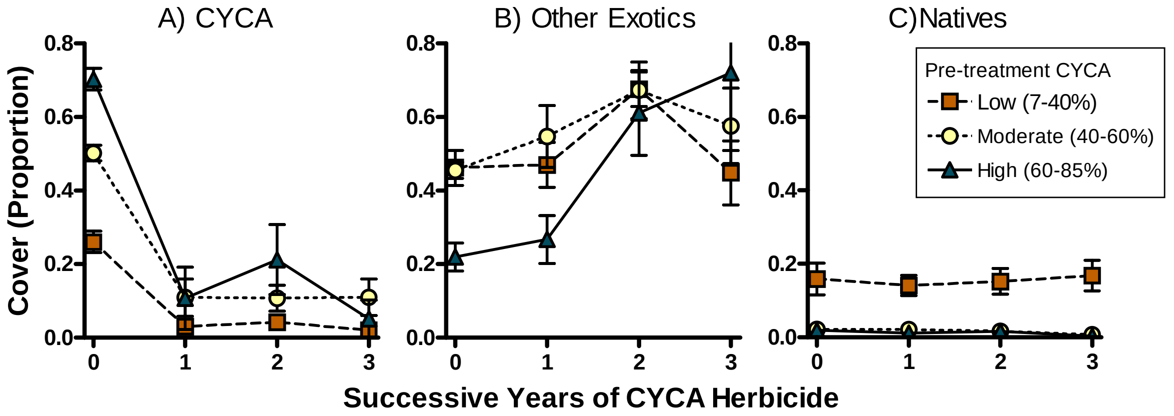

Figure 2. Cover (mean ± 1 standard error) of CYCA (Artichoke Thistle, a), other exotic species (b) and native species (c) prior to initiating herbicide treatments (t=0) and after 1, 2, and 3 years of successive treatment. Sites were grouped by the degree of pre-treatment CYCA invasion. Sample size ranged from 30 (pretreatment and year 1) to 15 (year 3).

Cover of other exotic species was not affected by CYCA control in low and moderately invaded areas (mean cover not significantly related to treatment years, n=4 time points, r^2=0.00, P=0.80 and r^2=0.24, P=0.29, respectively[1])(Figure 2b). However, mean cover of other exotic species increased due to CYCA control in areas that initially were highly invaded (n=4, r^2=0.88, P=0.04). In these badly invaded areas, cover of other exotics rose as CYCA abundance fell. Further analyses should determine whether more benign exotics such as annual grasses or exotics that are considered more problematic (e.g., mustards, other thistles) accounted for the increase in exotic cover. This distinction is important to future management recommendations.

Cover of native species was not positively nor negatively affected by 3 years of active CYCA control (Figure 2c). Sites that initially had high levels of native cover maintained these high levels, and those with lower levels remained low. The removal of CYCA did not release native species, even in areas of high native cover, indicating that restoration may either need more active intervention strategies (e.g., seeding, soil amendments) or that natural recovery of the natives occurs on a longer time scales than 3 years. Native perennial grasses are recruiting in some areas were CYCA has been reduced (T. Smith, personal communication), suggesting that native cover may start to increase following a recruitment phase. Further monitoring and analysis of the demography of particular focal species (e.g., recruitment of *Nassella*) may help forecast abundance trajectories.

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[1] This analysis was done as a regression with mean cover rather than with repeated measure of site data due to the lower sample size in year 3 (sites with less than 3 years of treatment would be dropped in a repeated measures ANOVA).

Thus, preliminary analyses indicate that the monitoring sites are following a scenario similar to Fig 1c during the initial period of control. Pre-treatment invasion history of the sites may be associated with restoration potential (i.e., a bad site to start off stays bad regardless of the level of CYCA control), suggesting that site factors that increase the susceptibility to CYCA invasion (perhaps past disturbance history, soil type, aspect) may also decrease the potential for passive restoration. These patterns should be validated with larger datasets and extended to answer related questions such as: What species are contributing to the exotic increase in sites with originally high CYCA infestations? Does the duration of treatment influence the response dynamics of the community? Does native cover increase following a recruitment lag? What site factors are associated with high initial infestation and low rates of recovery?

Suspension of Active Control. There were 13 cases where a monitoring site was treated for at least two consecutive years and then treatment was suspended for a year. The change in cover after one-year suspension of treatment may indicate the trajectory of the site once active control is stopped. A one-year suspension herbicide treatment generally caused an increase in CYCA cover (11% average increase, significantly greater than 0, t=3.9, P=0.002)(Figure 3). Native cover did not change after the suspension of CYCA control for one year (t=0.97, P=0.35) and suspension caused exotic cover to significantly decrease (25% mean decline, t=-2.7, P=0.02). The degree to which CYCA increased was only weakly dependent on its cover in the year prior (r^2 =0.16, P = 0.10; not shown) but was more strongly dependent on how infested the site was prior to starting treatment (r^2 = 0.49, P =0.005; Figure 3). It appears that control may more sustainable after a longer duration of active treatment: CYCA did not rebound at the two sites treated for 7 years prior to cessation of control efforts. More cases with long treatment histories are needed to evaluate this pattern. While it does not appear the variation in response across sites was not related to slope or aspect, more environmental variables would help resolve the variability among sites.

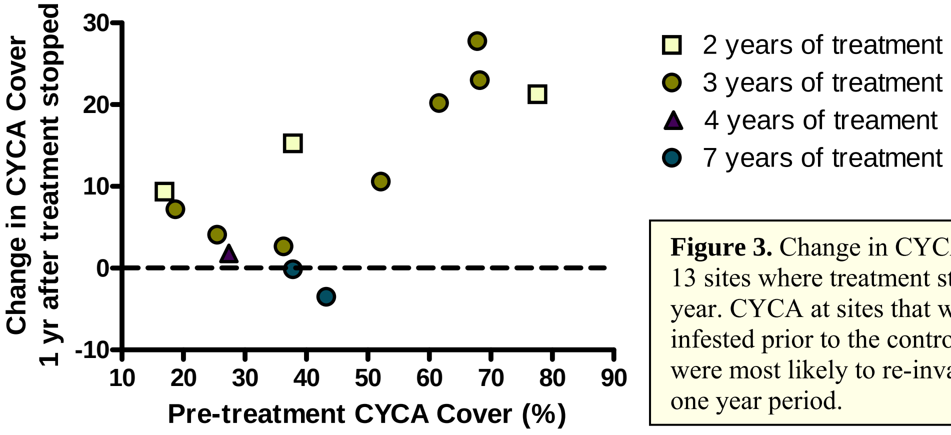

Figure 3. Change in CYCA cover at 13 sites where treatment stopped for a year. CYCA at sites that were most infested prior to the control program were most likely to re-invade over the one year period.

These results should be viewed as very preliminary and have several caveats that I hope to avoid in future work. The increase seen in this monitoring data could be due to interannual variation correlated with when the treatment was stopped (in 10 of 13 cases, it was in 2004). It was not possible to test whether soil type influenced recovery because 11 of the 13 sites were described as clay. It was also not possible to assess what would happen after two or three years following suspension of treatment because only sites with one year suspensions were not represented in the monitoring dataset. Longer treated plots were also ones with lower initial native cover and higher infestations, which may also influence these results.

In order to test whether these results are robust or whether other confounding factors are influential, an experimental approach is warranted. Sites could be selected across the reserve, accounting for other important variables such as soil type and native cover, that vary in length of treatment (see section III below). The selected sites then could be split, with treatment restricted to one portion of the site, while the other portion treatment is suspended. The trajectory of species cover at the sites could then be followed for several years and results could be more definitively guide recommendations about the response to suspension of the herbicide control.

III. Proposed Approach. Based on preliminary analyses such as above, it is clear that the answers to the NROC management questions are not straightforward. They demand an efficient, quantitative, and multifaceted approach. Here I outline a general approach to provide the NROC and its technical advisory board information that they can use to confidently make decisions regarding the success and sustainability of the CYCA control program. I describe the five components below.

1. Identify critical information needed to provide a rigorous and predictive assessment of the control program. As an initial attempt, I propose to start with the questions listed as key questions in Section I. However, I expect these to be modified and amended to reach consensus on what the important questions are prior to finalizing a data collection and analysis plan. This will be done immediately upon the start of this project via discussions with the NROC, its technical advisory board, and TNC.

2. Determine data needs to answer the identified questions. This step will include an assessment of statistical power and prioritization of goals for data collection. This planning will make the resulting field and analysis efforts as efficient as possible.

3. For questions that can be addressed with data that already exist, provide a rigorous quantitative assessment to the NROC within six months. I envision initial analysis for some questions can be started with the pre-existing monitoring data and GIS data layers. For instance, species-level responses can be assessed with the monitoring data collected by TNC. I expect most of these analyses will warrant further validation with larger datasets, but should provide a good start with understanding dynamics. I also will use the pre-existing monitoring data to determine the optimal number of subplots needed at each site to provide efficient but accurate field measurements (i.e., are 20 subplots/site too many? too few?). This optimization can be determined by constructing species area curves and variance assessments of species cover estimates at the monitoring sites.

4. For questions that require new data to be collected, prioritize data collection effort to provide an initial assessment within a year. Sites (i.e., polygons in the initial TNC survey) will be selected based on treatment histories (length of treatment, suspended versus continuous), environmental characteristics (aspect, soil type), and community characteristics (native cover, initial level of infestation) in an effort to vary each factor independently from the others, reduce confounding variables, and understand the relative importance of each of these factors. Possible sites will be identified with GIS queries and then a subset in each bin will be

randomly chosen for field measurements (approximately 60-90 in total). These field measurements will take place during April/May 2007 and will include cover and density estimations of CYCA, cover estimates of all other species (native and exotic; which can also be used to calculate richness). Information on soil type will also be taken. Protocols will follow TNC's initial monitoring protocols (led by M. Ervin at the start of the treatment program) as closely as possible to ensure comparability across datasets.

5. <u>Begin experimental efforts that will provide unequivocal information regarding program uncertainties within five years.</u> Based on the monitoring dataset, I anticipate that it may be difficult to find sites with suspended versus continuous treatments across the range of natural variability desired. Thus, I propose to conduct a "suspended control" experiment at a subset of the sites identified above that have experienced continuous control. This experiment will effectively simulate the scenario in 2015, and will allow the NROC to better anticipate responses when active control is suspended. These sites will be split (ideally in several replicate blocks, less ideally in half), where continuous herbicide treatment will be maintained in part of the site while in other parts it will be suspended[2] for several years. It would be important to conduct this experiment over a range of length of treatment, soil type, aspect, and native cover. To achieve this could require as much as 16 different site combinations (e.g., short treatment history, clay, south-facing, high native site), although I anticipate that many site combinations wont be applicable relative to much of the natural variation inherent to the NROC. While this determination would require further analysis, a more realistic case would be 6 site types each represented by four sites for a total of 24 sites. This effort in 2007 will require plot set up, delineation and initial monitoring (similar to what is done at the TNC monitoring sites).

   Based on preliminary results from the pre-existing monitoring plots, a second experiment that may warrant planning in 2007 and possible initiation in 2008 is to test a combination of active restoration treatment following control is needed to successfully direct sites on a sustainable trajectory. In possible conjunction with the experiment above, areas could be seeded with native propagules (with and without the continuation of the CYCA control program) to assess whether a combination of restoration strategies can create resilient systems, particularly in the cases that seem to be in a strong degradative cycle if only control treatments are continued.

Expected Outcomes. I expect this project will produce several deliverables and products over the first year, with the potential for several others over the next several years.

Finalization of the prioritized questions and data needs of the assessment effort (Steps 1 and 2) will be completed as soon as possible after the project start; the exact timing will depend on the degree of agreement among involved parties.

Analysis of this monitoring data set and other pre-existing data (Step 3) will be completed by September 2007. The monitoring dataset warrants publication in itself, and I would be willing to assist TNC and NROC in analyzing and communicating these results to a wider audience.

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[2] Discussions with the NROC will be important to determine if the appropriate experimental comparison is no further CYCA herbicide or rather a low level of treatment to simulate the reduced-effort long-term management that is planned to occur after 2015. While it will be harder to replicate what reduced management efforts will entail, management scenarios after 2015 will likely consist of some low-level control effort.

Field surveys will be conducted in Spring 2007 (Step 4), with a report of the results of this survey and implications for sustainability of the control program will also be completed by the end of September 2007. The timing of this report is critical to inform the next step of the assessment program prior to the start of the 2008 growing season. This report should contain at least initial results concerning all the identified key questions in section I. Results will be presented at the Cal-IPC meeting in San Diego September 2007.

Experimental manipulations of a "suspended CYCA control" (Step 5) will be initiated in 2007 and all applicable protocols and pre-manipulation data will be provided to the NROC by September 2007. I anticipate that several years of manipulation will be necessary for the board to confidently make recommendations concerning sustainability (perhaps by 2010).

Possible addition of an active restoration component to the control program may be initiated in December 2007.

Estimated Budget. Budget information will need to be approved by UCI contracts and grant office, but I anticipate a project with the following expenses over the period March 2007-December 2007.

Personnel: Support for one full time experienced research technician March-September who will take the lead in the field measurements and data analysis ($20,000 salary + $6000 benefits (30%) = $26,000). Support for 3 other technicians to assist in the field survey and data entry (8 weeks) ($13,000 salary + $4000 benefits = $17,000).

Travel: Minimal mileage expenses to get to the NROC sites ($200). Travel to Cal-IPC (or similar) conference to present results September 2007 ($700).

Supplies: Plot frames, tapes, voucher prep materials, permanent plot markers (if desired by NROC), treatment markers to indicate where herbicide control should not occur (expenses in this category may vary greatly depending on the markers that NROC would want us to use and what the herbicide contractors would see; perhaps as much as $3000)

Overhead: Depends on what is requested by NROC, but TNC requires it to be limited to 5% of the total direct costs (if so, it would be $2400).

Total Budget would be approximately $50,000.

References.

Bestelmeyer, B. T. 2006. Threshold concepts and their use in rangeland management and restoration: The good, the bad, and the insidious. Restoration Ecology 14:325-329.

Cramer, V. A., and R. J. Hobbs. 2005. Assessing the ecological risk from secondary salinity: A framework addressing questions of scale and threshold responses. Austral Ecology 30:537-545.

D'Antonio, C. M., and M. Thomsen. 2004. Ecological resistance in theory and practice. Weed Technology 18:1572-1577.

De Steven, D., R. R. Sharitz, J. H. Singer, and C. D. Barton. 2006. Testing a passive revegetation approach for restoring coastal plain depression wetlands. Restoration Ecology 14:452-460.

Groffman, P., J. Baron, T. Blett, A. Gold, I. Goodman, L. Gunderson, B. Levinson, M. Palmer, H. Paerl, G. Peterson, N. Poff, D. Rejeski, J. Reynolds, M. Turner, K. Weathers, and J. Wiens. 2006. Ecological thresholds: The key to successful environmental management or an important concept with no practical application? Ecosystems 9:1-13.

Hobbs, R. J., and J. A. Harris. 2001. Restoration ecology: Repairing the Earth's ecosystems in the new millennium. Restoration Ecology 9:239-246.

King, E. G., and R. J. Hobbs. 2006. Identifying linkages among conceptual models of ecosystem degradation and restoration: Towards an integrative framework. Restoration Ecology 14:369-378.

Kirkman, L. K., K. L. Coffey, R. J. Mitchell, and E. B. Moser. 2004. Ground cover recovery patterns and life-history traits: implications for restoration obstacles and opportunities in a species-rich savanna. Journal of Ecology 92:409-421.

Kulmatiski, A. 2006. Exotic plants establish persistent communities. Plant Ecology 187:261-275.

Mitchell, R. J., R. H. Marrs, M. G. Le Duc, and M. H. D. Auld. 1999. A study of the restoration of heathland on successional sites: changes in vegetation and soil chemical properties. Journal of Applied Ecology 36:770-783.

Novak, J., and K. Prach. 2003. Vegetation succession in basalt quarries: Pattern on a landscape scale. Applied Vegetation Science 6:111-116.

Prach, K. 2003. Spontaneous succession in Central-European man-made habitats: What information can be used in restoration practice? Applied Vegetation Science 6:125-129.

Prach, K., S. Bartha, C. B. Joyce, P. Pysek, R. van Diggelen, and G. Wiegleb. 2001. The role of spontaneous vegetation succession in ecosystem restoration: A perspective. Applied Vegetation Science 4:111-114.

Prober, S. M., K. R. Thiele, and I. D. Lunt. 2002. Identifying ecological barriers to restoration in temperate grassy woodlands: soil changes associated with different degradation states. Australian Journal of Botany 50:699-712.

Suding, K. N., K. L. Gross, and G. Houseman. 2004. Alternative states and positive feedbacks in restoration ecology. Trends in Ecology & Evolution 193:46-53.

Zavaleta, E. S., R. J. Hobbs, and H. A. Mooney. 2001. Viewing invasive species removal in a whole-ecosystem context. Trends in Ecology & Evolution 16:454-459.

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RESEARCH FUNDING IN RESTORATION AND ENVIRONMENTAL CHANGE:

Department of Energy, “Physiological, demographic, and competitive controls on the response of California ecosystems to environmental change.” May 2005-April 2008. Sole Co-PI.

Integrated Hardwood Management Program, University of California, “Landscape-scale Relationships between Oak Recruitment and Livestock Management” 2005-2010. PI.

Center for Invasive Plant Management, Bureau of Land Management, “Managing the spread of invasive plants: application of the threshold concept in a spatially-explicit model tool.” 2006- 2007. PI.

United States Department of Agriculture, CREES National Competitive Grants Program, “Mechanistic Foundations of State and Transition Models: Linking Application and Theory” 2006-2010. PI..

National Science Foundation, Division of Environmental Biology, “Multiple states in grassland systems: invasion and environmental feedbacks” 2006-2011. PI.

RELEVANT PUBLICATIONS:

Suding, K.N. and K.L. Gross. 2006. Modifying native and exotic species richness correlations: the influence of fire and seed addition. *Ecological Applications* 16:1319-1326.

Suding, KN, S.L. Collins, L. Gough, C. Clark, E.E. Cleland, K.L. Gross, D.G. Milchunas, and S. Pennings. 2005. Functional- and abundance-based mechanisms explain diversity loss due to N fertilization. *Proceedings of the National Academy of Science* 102: 4387-4392. Selected as editors choice, Science 308: 326-327.

Suding, K.N., K.L. Gross, and G. Houseman. 2004. Alternative states and positive feedbacks in restoration ecology. Trends in Ecology and Evolution 19: 46-53.

Suding, K.N. and K.L. Gross. 2006. "The dynamic nature of ecological systems: multiple states and restoration trajectories" pages 190-209 in Foundations of Restoration Ecology, D. Falk, M. Palmer, and J. Zedler, eds, Island Press.

Suding, K.N., K.D. LeJeune, and T.R. Seastedt. 2004. Competitive impacts and responses of an invasive weed: dependencies on nitrogen and phosphorus availability. *Oecologia* 141: 526-535.

Suding, K.N., J. Larson, E. Thorsos, H. Steltzer, and W.B. Bowman. 2004. Species effects on resource supply rates: do they influence competitive interactions? *Plant Ecology* 175: 47-58.

Clark, B.R., C. deMazancourt, **K.N. Suding**, and S.E. Hartley. 2005. The effect of recycling on plant competitive hierarchies. *American Naturalist* 165 (6): 609-622.

LeJeune, K.D., **K.N. Suding**, and T.R. Seastedt. 2006. Nutrient availability does not explain invasion and dominance of a mixed grass prairie by the exotic forb *Centaurea diffusa* Lam. *Applied Soil Ecology* 32: 98-110.

Suding, K.N., A. Miller, H. Bechtold, and W. Bowman. 2006. The consequence of species loss on ecosystem nitrogen cycling depends on community compensation dynamics. *Oecologia* 149: 141-149.

Suding, K.N., D.E. Goldberg, and K.M. Hartman. 2003. Relationships among species traits: separating levels of response and identifying linkages to abundance. *Ecology* 84: 1-16.

Book under Contract:
R. Hobbs, R. and **K.N. Suding**, eds. New models for ecosystem dynamics and restoration. Island Press. Expected publication 2008.

RECENT PROFESSIONAL ACTIVITIES

Project leader, NSF Long-term Ecological Research Network (LTER) cross-site synthesis program.
    "Predicting species response to nitrogen fertilization across LTER sites."
NSF Long-term Ecological Research Network, Conference Committee. Submit recommendations concerning
    the future direction and expansion of the US LTER network.
NSF Information Science Division, SEEK (Science Environment for Ecological Knowledge) Project,
    Biodiversity Core Group.
Subject Editor, *Oikos* and *Ecology Letters* Journals
Advisory Board, Ecological Flora of California, UC Berkeley, 2005-present.