Biotic Prediction

Building the Computational Technology Infrastructure
for Public Health and Environmental Forecasting

First Annual Report
(January 29 – August 15, 2002)

BP-AP1-1.0

Task Agreement: GSFC-CT-1

August 15, 2002

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1 Overview

1.1 Introduction

This project will develop the high-performance, computational technology infrastructure needed to analyze the past, present, and future geospatial distributions of living components of Earth environments. This involves moving a suite of key predictive, geostatistical biological models into a scalable, cost-effective cluster computing framework; collecting and integrating diverse Earth observational datasets for input into these models; and deploying this functionality as a Web-based service. The resulting infrastructure will be used in the ecological analysis and prediction of exotic species invasions. This new capability will be deployed at the USGS Fort Collins Science Center and extended to other scientific communities through the USGS National Biological Information Infrastructure program.

1.2 Referenced Documents

Table 1. Referenced Documents

Document Title	Version	Date
Software Engineering / Development Plan	1.0	2002-04-08
Configuration Management Plan	1.0	2002-04-08
Quality Assurance Plan	1.0	2002-04-08
Risk Management Plan	1.0	2002-04-08
Baseline Software Design Document	1.0	2002-07-15
Concept of Operations	1.0	2002-07-15
Software Requirements Document	1.0	2002-07-15

1.3 Document Overview

This document, the *Annual Report (January 29 – August 15, 2002)*, describes the research accomplished during the report period.

Section 2 discusses the problem class and the objectives and approach of the project.

Section 3 describes first year progress, including scientific and technical accomplishments, progress toward milestones, current status, and plans for the next year.

Section 4 describes this year's publications and presentations related to the project.

Section 5 provides contact information and information about the project's website.

Section 6 provides a list of references.

Appendix A summarizes the project's overall milestone schedule.

2 Problem Class

USGS has implemented a heritage modeling process, which we refer to as *PlantDiversity*, that we are transforming into a coherent *Invasive Species Forecasting System* (ISFS). The ISFS will be used to analyze the past, present, and future geospatial distributions of living components of Earth environments.

2.1 Introduction

Many of the most important science questions we hope to address by modeling the Earth system involve understanding where a particular species or group of organisms exist at a given time. For example, in order to understand the effects of land cover and land use change, we may wish to know historically whether certain types of plants or animals were once present in a region of interest. In real-time, we may wish to know the public health risk for vector-mediated diseases, such as Hantavirus Pulmonary Syndrome or Lyme Disease. In these cases, it would be important to know the current distributions of deer mice and black-legged ticks, which are responsible, respectively, for transmitting these diseases to humans. In order to understand how the health and functioning of entire ecosystems are being influenced by the invasion of exotic species, we may wish to predict the future distribution patterns of key native and non-native organisms.

Determining the geospatial distribution of living things across various time frames and time scales requires an understanding of the natural history of the organisms in question. It involves the formulation of sometimes complex theory about their behavior, reproduction, and movements through the environment, and the subsequent reification of these theories into models, simulations, and computational analyses. It draws upon diverse and heterogeneous data, including remotely sensed data, ground-based point data, and data about past life from natural history collections. Increasingly, there is a need for interactive visualization of results and the ability to fold results into decision support systems and other mechanisms that enable the development of effective policy and action. From both a scientific and technological perspective, these are nontrivial problems.

Our overarching goal is to enable the ecological, environmental, and public health communities by expanding their participation in high-performance computing. We propose to start the development of a generalized computational technology infrastructure for these communities by focusing on a class of landscape-scale geostatistical models that predict the distributions of living organisms. We will work specifically with a well-understood ecological model, *PlantDiversity*. The *PlantDiversity* model is currently being used to perform landscape-scale assessments of plant diversity and to predict exotic plant invasions in US parks and wilderness areas. This is an important modeling process, and it represents an important class of codes. By working on the *PlantDiversity* model, we can characterize common elements and identify functionality that might be abstracted away from the core model and delivered as general Web-based services to the broader scientific community.

2.2 Objectives

The specific objectives of this work include the following:

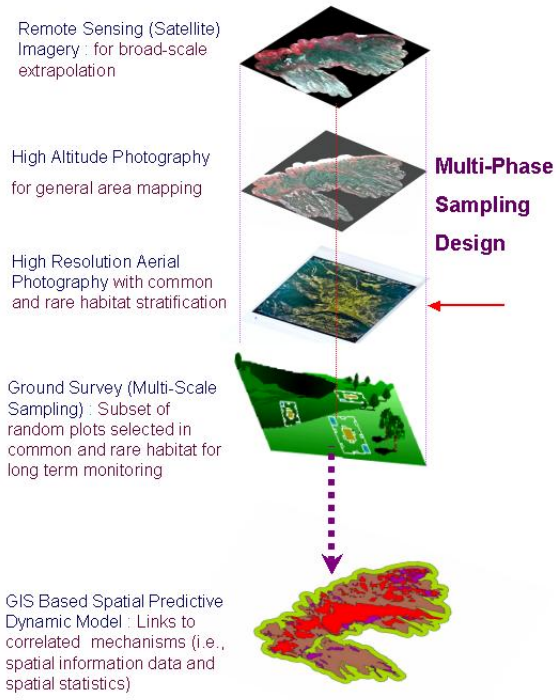
- Create a high-performance, parallel implementation of the *PlantDiversity* (invasive species) model code;
- Document the use of software engineering techniques that foster reproducibility and community-wide software process improvements in these domains;

- Engage an extended community of scientists through the established NBII community infrastructure program; and
- Empower the ecological, environmental, and public health communities by expanding their participation in high-performance computing and greater use of NASA data.

2.3 Approach

Predictive spatial models developed from multi-scale data are an excellent example of data synthesis for natural resource management and public health (Chong *et al.*, 2000; Glass, 2000; Kalkhan *et al.*, 2000a, 2000b). Spatial statistics and geostatistics provide a means to develop spatial models that can be used to correlate coarse scale geographic information (e.g., digital elevation models, burn areas, remotely sensed data) with multi-scale field measurements of biotic and abiotic variables (Kalkhan and Stohlgren, 2000). Integral to the creation of spatial models is the collection of appropriate data. Kalkhan *et al.* (1998) and Stohlgren *et al.* (1997a; 1997b; 1997c) have developed a multi-phase, multi-scale sampling approach that involves stratification of areas of interest from remotely sensed data, random location of field sampling points within strata, and sampling with multi-scale plots. Data collection from multi-scale plots allows extrapolation of results to larger scales with calculable error (Figure 1).

The ability to model small-scale variability in landscape characteristics requires the generation of full-coverage maps depicting characteristics measured in the field (Reich *et al.*, 1999). While many spatial datasets describing land characteristics have proven reliable for macro-scale ecological monitoring, these relatively coarse scale data fall short in providing the precision required by more refined ecosystem resource models (Gown *et al.*, 1994). Spatial statistics and geostatistics provide a means to develop spatial models that can be used to correlate coarse scale geographical data with field measurements of biotic variables. This general landscape analysis approach is being used successfully to address a range of natural resource and public health issues, including invasive species (Stohlgren *et al.*, 1998, 1999a,b; Kalkhan and Stohlgren, 2000; Kalkhan *et al.*, 2000a,b,c), detecting “hot spots” of native and exotic plan diveristy and rare/unique habitats (Agee and Johnson, 1988; Noss, 1983; LaRoe, 1993; McNaughton, 1993), detecting habitats vulnerable to invasive and rapid spread of exotic plant species (Stohlgren *et al.*, 1999a), and determining vegetation and soil response to fire (Kalkhan, *et al.*, 2002).



Multi-phase sampling refers to sampling at multiple levels from remotely sensed data (e.g. Landsat TM imagery, aerial photos) to ground data. Multi-scale sampling refers to the use of sampling plots that contain subplots of various sizes. This approach can be applied to biotic and abiotic variables such as exotic species abundance, native species distribution, fire conditions, and other ecological studies. (Adapted and modified from Kalkhan *et al*., 1995, 1998)

Figure 1. Multi-phase Sampling Design

3 First Year Progress

3.1 Scientific and Technical Accomplishments

Preliminary versions of seven key software engineering documents were produced during the first year of the project. They include Version 1.0 of our Software Engineering/Development Plan, Configuration Management Plan, Quality Assurance Plan, Risk Management Plan, Concept of Operations, Software Requirements Document, and Baseline Software Design Document. In addition, the *PlantDiversity* modeling environment, as originally configured by colleagues at USGS, was recreated at Goddard for learning purposes and to do baseline analyses. Datasets for three ”canonical” study sites were acquired, including those for the Cerro Grande Fire Site in Los Alamos, NM (CGFS), Rocky Mountain National Park, CO (RMNP), and Grand Staircase Escalante National Monument, UT (GSENM). Preliminary efforts have focused on replicating previous analyses of these data using the Goddard environment. Our results have been consistent with those obtained in the original USGS environment. Figure 2 shows an example of the type of output generated by the modeling system. Complete details of the baseline system are provided in the Baseline Software Design Document available from the project’s website (http://ltpwww.gsfc.nasa.gov/BP/deliverables.html). In addition, the baseline environment can be accessed on the project’s server as described in the Baseline document, and a tarfile, also available on the website, can be used to build the baseline environment on other machines.

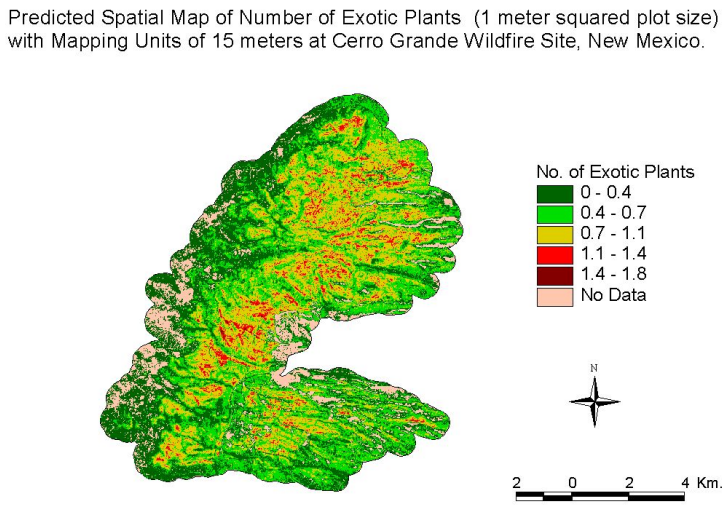


Figure 2. Predicted Spatial Map of Exotic Plants at Cerro Grande Wildfire Site

3.2 Progress toward Milestones

The project completed Milestones A (Software Engineering Plan Completed) and Milestone E (Code Baseline Completed) on schedule and according to plan. (See Appendix A for details.)

3.3 Current Status

Milestone E deliverables are currently under review by the CT Program, Preliminary feedback indicates that there are no major problems with these deliverables.

In the past month, the project completed staffing in preparation for next year's work. In addition to the core NASA/USGS team, Rob Baker will become the project's full-time systems analyst, David Kendig will work half-time as a programmer/data integration specialist for the project, and David Herring and his team will provide part-time assistance on the design and implementation of the project's public website. David Obler will continue to provide high-level system design guidance and coordination on a part-time basis. Obler, Herring, Kendig, and Baker are all employees of Science Systems Applications, Inc. (SSAI).

On August 24, 2002, USGS will dedicate its new Fort Collins Science Center in Fort Collins, CO. The event will be attended by NASA representatives from Goddard and Headquarters. The facility will house the new USGS National Institute for Invasive Species Science, which represents an important institutional investment on the part of USGS arising, in part, out of the collaboration supported by this project.

3.4 Plans for Coming Year

Work in year two will focus on five major areas:

(1) *Customer-Driven Collaborative Design and Outreach* — In year two, we will engage scientists and natural resource managers in USGS and partner agencies in a series of formal system design and review meetings. The input received during these sessions will guide the development of Version 2.0 of all of the project's software engineering documents, and will facilitate the buy-in and engagement of the end user client community. The entire NASA/USGS team will participate in this effort with Curt Tilmes, David Obler, and Rob Baker assuming lead responsibilities.

(2) *Milestone F – First Code Improvement* — Through a series of intermediate software releases, the project will improve the serial performance of the baseline software system and create a parallel implementation of the core kriging algorithms used in the *PlantDiversity* model. Jeff Pedelty, Jeff Morisette, David Kendig, and John Dorband will lead this effort with assistance form the CT Program staff.

(3) *Design, Construction, and Deployment of a Linux Cluster at USGS* — An important part of the year two effort will be to help colleagues at USGS become familiar with general hardware and software aspects of cluster computing. The project will build a Linux cluster for the USGS lab, which will become the first deployment host for the Milestone F improved software. John Dorband will lead this effort.

(4) *New Data/Algorithm/Science Development* — An important aspect of this project is developing and incorporating new algorithms, data, and science approaches that can extend the core capabilities of the *PlantDiversity* modeling system and allow it to exploit the potential of parallelization. All the scientists on the team will be involved in exploring new possibilities, with Tom Stohlgren, Jim Smith, Jeff Morisette, Jeff Pedelty, Mohammed Kalkhan, Robin Reich, and Jacqueline LeMoigne taking a lead in this area. Publication of research results is also an important part of this effort.

(5) *Public Delivery of Project Results* — Finally, we intend to take this effort public in year two by opening a comprehensive website describing our technological approach to invasive species predictive

science. The site will provide documentation, literature, and portal access to invasive species resources and will be a delivery point for online services and documented release software. The site will connect to other web-based biological information resources, principally the National Biological Information Infrastructure's (NBII) Invasive Species Node. Tom Stohlgren, David Herring, and Rob Baker will lead this effort with assistance from all members of the project team.

4 Publications and Presentations

This sections lists this year's publications and presentations relating to the project.

4.1 Publications

Printed and In Press:

Schnase, J.L., Stohlgren, T.J., & Smith, J.A. 2002. The National Invasive Species Forecasting System: A strategic NASA/USGS partnership to manage biological invasions. NASA Earth Science Enterprise Applications Division Special Issue. *Earth Observing Magazine*. (In Press).

Schnase, J.L., Smith, J.A., Stohlgren, T.J., Quinn, J.A., & Graves, S. 2002. Biological invasions: A challenge in ecological forecasting. In: *Proceedings of the International Geoscience and Remote Sensing Symposium, 2002* (IGARSS '02, Toronto, June). (In Press).

Birk, R., Hutchinson, C.F., Posson, D.R., Schnase, J.L., Stohlgren, T.J., Smith, J.A., & Turner, W. 2002. The National Invasive Specie Forecasting System — A Strategic NASA / USGS Partnership to Manage Biological Invasions. For the NASA Earth Science Applications Directorate.

Stohlgren, T.J., G. W. Chong, L.D. Schell, K.A. Rimar, Y. Otsuki, M. Lee, M.A. Kalkhan, and C.A. Villa. 2002. Assessing vulnerability to invasion by non-native plant species at multiple scales. Environmental Management 29:566–577.

Pielke, R.A., T. Stohlgren, L. Schell, W. Parton, N. Doesken, K. Redmond, J. Moeny, T. McKee, and T.G.F. Kittel. 2001. Problems in evaluating regional and local trends in temperature: An example from eastern Colorado. International Journal of Climatology 22:421–434.

Stohlgren, T. J., T. T. Veblen, K. Kendall, W. L. Baker, C. Allen, A. Logan, and M. Ryan. 2002. Montane and subalpine ecosystems. In: Rocky Mountain Futures: an Ecological Perspective. J. Baron (eds). Island Press. (In Press).

Barnett, D., and T.J. Stohlgren. 2002. A nested intensity sampling design for plant diversity. *Biodiversity and Conservation* (In Press).

Kalkhan, M.A., E.J. Martinson, P.N. Omi, G.W. Chong, M.A. Hunter, and T.J. Stohlgren. 2002. Fuels, fire severity, and invasive plants within the Cerra Grande Fire, Los Alamos, NM. Proceedings of the Tall Timbers Fire Ecology Conference, Tallahasse, FL. (In Press).

Omi, P.N., E.J. Martinson, M. Kalkhan, T.J. Stohlgren, G.W. Chong, and M.A. Hunter. 2002. Integration of spatial information and spatial statistics: a case study of invasive plants and wildfire on the Cerra Grande Fire, Los Alamos, New Mexico, USA. Proceedings of the Tall Timbers Fire Ecology Conference, Tallahasse, FL. (In Press).

Wagner, F. and T. Stohlgren. 2002. Regional Assessment of Climate Change Effects in the Rocky Mountains and Great Basin. Regional Report to the National Assessment of Climate Change Effects in the United States. (to be completed by September 2002). (In Press).

Stohlgren, T.J. 2002. Beyond Theory of Plant Invasions: lessons from the field. Comments on Theoretical Biology (In Press).

Bashkin, M., T.J. Stohlgren, Y. Otsuki, M. Lee, P. Evangelista, and J. Belnap. 2002. Soil characteristics and plant exotic species invasions in the Grand Staircase-Escalante National Monument, Utah, USA. Applied Soil Ecology (In Press).

In Review:

Kaye, M., D. Binkley, and T. Stohlgren. 2002. Estimating populations of aspen (Populus tremuloides) in Rocky Mountain National Park, Colorado. Landscape Ecology (In Review).

Evangelista, P., D. Guenther, T J. Stohlgren, and S. Stewart. 2002. Fire effects on cryptobiotic soil crusts in the Grand Staircase-Escalante National Monument, Utah. Proceedings of the Fifth Biennial Conference of Research on the Colorado Plateau Conference, Flagstaff, AZ. (In Review).

Guenther, D.A., T.J. Stohlgren and P. Evangelista. 2002. Relict sites compared to grazed landscapes in the Grand Staircase-Escalante National Monument, Utah. Proceedings of the Fifth Biennial Conference of Research on the Colorado Plateau Conference, Flagstaff, AZ. (In Review).

Stohlgren, T.J., C. Crosier, G. Chong, D. Guenther, and P. Evangelista. 2002. Native annual and perennial species characterize the vulnerability of sites to non-native plant invasions. Submitted to Ecology. (In Review).

Otsuki, Y., T.J. Stohlgren, D. Guenther, and C. Villa. 2002. Evaluating plant invasions from both habitat and species perspectives. Ecological Monographs. (In Review).

Fornwalt, P.J., M. Kaufmann, L.S. Huckaby, J.M. Stoker, and T.J. Stohlgren. 2002. Non-native plant invasions in managed and protected ponderosa pine/Douglas-fir forests of the Colorado Front Range. Forest Ecology and Management (In Review).

Draft Manuscripts and Book:

Stohlgren, T.J. 2002. Measuring Plant Diversity: Lessons from the Field. (Draft Book; 18 chapters written; 330 pages text).

Overlin, A., G.W. Chong, T.J. Stohlgren, and J. Rodgers. 2002. Monitoring vegetation and soil crusts in areas used by climbers: an example from Joshua Tree National Park, California, USA. *Environmental Management*. (Draft Manuscript).

Stohlgren, T.J., K.A. Rimar, R. Shory, and K. Stolte. 2002. Monitoring plant invasions in the National Forests of the United States. To be submitted.

Chong, G.W., T.J. Stohlgren. 2002. Species-area curves indicate the importance of habitats' contributions to landscape-scale biodiversity. *Biodiversity and Conservation* (In Review).

4.2 Presentations

Selected Talks:

Invited Speaker at the 40th Goddard Memorial Symposium: Partnering with NASA — The Wave of the Future. March 20–21, 2002, Greenbelt, MD. Title: Ecological Forecasting of Invasive Species — High Performance Computing Needs. (Stohlgren)

Invited Speaker at the at the Biology and Mapping meeting at EROS Data Center (April 30–May 2, 2002): Won Best Talk Award. (Stohlgren)

Movie Roll in "Plants out of Place II," a documentary about invasive plants in the US, by Information Television Network, Filmed May 16, 2002. (Stohlgren)

For Deputy Director US Fish and Wildlife Service and Refuge System Management Team entitled "The future of invasive species and information science." Washington, DC. May 29, 2002. (Stohlgren.)

At World Data Bank/NBII meeting in Denver, CO, June 18, 2002, entitled "Spatial Modeling and Ecological Forecasting — Putting Data to Work." (Stohlgren)

Ecology Forecasting of Biological Invasions. Report of the Earth Science Vision NASA Earth Science Vision 2010 – 2025: Biosphere, Ecosystems, & Human/Biosphere Interactions Working Group. Presented at the International Geoscience and Remote Sensing Symposium, 2002 (IGARSS '02), Toronto, June 24 – 27, 2002. (Schnase)

Ecology Forecasting of Biological Invasions. Report of the Earth Science Vision NASA Earth Science Vision 2010 – 2025: Biosphere, Ecosystems, & Human/Biosphere Interactions Working Group. Presented at the American Geophysical Union Conference, 2002 (AGU '02), Washington, DC, May 30, 2002. (Schnase)

Selected Meetings:

At National Biological Information Infrastructure (NBII) meetings, University of California, Davis. January 2002.

With Lee Balick, Los Alamos National Laboratory, Los Alamos, New Mexico, March 4–6, 2002.

With Jim Tate, Science Advisor to Secretary Norton, Washington DC. Morning, March 15, 2002.

With Director Chip Groat, USGS staff, and NASA scientists John Schnase and Jim Smith, March 21, 2002.

With National Invasive Species Council, Washington DC., Afternoon, March 15, 2002.

Presentations at the Ecological Society of America Meetings in Tucson, Arizona (August 4–9, 2002):

1. Next-generation spatial modeling for ecological forecasting. STOHLGREN, T., SCHNASE, J.L.∗, T.J. STOHLGREN, R.M. REICH, M.A. KALKHAN and J.A. SMITH.

2. Synthesizing and spatially linking disparate datasets. CROSIER, C.S.∗, G.J. NEWMAN and T.J. STOHLGREN.

3. The contribution of rare habitats and endemic plant species to overall plant diversity in the Grand Staircase-Escalante National Monument, Utah. GUENTHER, D.A.∗, T.J. STOHLGREN, P.H. EVANGELISTA and M. KALKHAN.

4. Integrating various data layers and multi-media in a comprehensive format for land managers: A case study at Grand Staircase-Escalante National Monument, Utah. THOMAS ALLEY, N.W.∗, R.O. COLEMAN, T.J. STOHLGREN, P.H. EVANGELISTA and D.A. GUENTHER.

5. From points to landscapes: regression tree analysis and estimates of species richness. CHONG, G.W.∗, M.A. KALKHAN, R.M. REICH and T.J. STOHLGREN.

6. Dataset integration and information sharing for improved prediction and detection of harmful invasive species. SIMONSON, S.E.∗, D.T. BARNETT, T.J. STOHLGREN and A. RANDELL.

7. Beyond theory: lessons from natural landscapes. STOHLGREN, T.J.∗, M.A. KALKHAN, D.T. BARNETT and S.E. SIMONSON.

8. Invasive plants and wildfire on the Cerro Grande fire, Los Alamos: Integration of spatial information and spatial and spatial statistics KALKHAN, M.A.∗, P.N. OMI, E.J. MARTINSON, T.J. STOHLGREN, G.W. CHONG and M.A. HUNTER.

9. Mapping the invasive plant species and cryptobiotic crust cover using spatial information and spatial statistics: A case study at Grand Staircase-Escalante National Monument, Utah. EVANGELISTA, P.H.∗, M.A. KALKHAN, D.A. GUNTHER and T.J. STOHLGREN.

10. Conifer invasion of quaking aspen stands in Rocky Mountain National Park, Colorado. KAYE, M.W.∗, D. BINKLEY and T.J. STOHLGREN.

ESA Workshops:

Stohlgren hosted a workshop called “Who wants to beat an invasive species” with Lori Hidinger, Guy McPherson, and Carolyn Seig from ESA.

ESA Meetings:

Stohlgren met with David Lodge and other ESA scientists to draft an ESA position paper on invasive species research needs.

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5.2 Document / System Access

ESTO/CT deliverables for this project are available at http://ltpwww.gsfc.nasa.gov/BP/deliverables.html. The baseline system along with complete documentation are available on the project's BPDEV computer (`frio.gsfc.nasa.gov`). Users may log on to the system to run the baseline program (please contact John Schnase at 6-4351 for userid and password). In addition, a tarfile is available from both the website and the ISFS home directory that can be used to build the baseline environment on a different machine.

6 References

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Association for Computing Machinery [ACM]. 2000. *Communications of the ACM*, Special Issue on Component-Based Enterprise Frameworks, Vol. 43, No. 10.

Bonham, C. D., R. M. Reich, and K. K. Leader. 1995. A spatial cross-correlation of *Bouteloua gracilis* with site factors. *Grasslands Science*, Vol. 41, pp. 196-201.

Chong, G. W., R. M. Reich, M. A. Kalkhan, and T. J. Stohlgren. 2000. New approaches for sampling and modeling native and exotic plant species richness. *Western North American Naturalist* (in review).

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Gown, S. N., R. H. Waring, D. G. Dye, and J. Yang. 1994. Ecological remote sensing at OTTER: Satellite Macroscale Observation. *Ecological Applications*, Vol. 4, pp. 322-343.

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A Milestones, Schedule, and Cost

	Milestone	Completion Date (expected)	Value
A)	**Software engineering plan completed** *Deliver Software Engineering / Development Plan, Configuration Management Plan, and Quality Assurance Plan.*	04/15/02	$ 100,000
E)	**Code baseline completed.** *Document performance characteristics and time/space complexity of existing* PlantDiversity *code and modeling process for two canonical examples: Rocky Mountain National Park (RMNP) and the Cerro Grande Fire Site (CGFS). Determine appropriate multipliers, $\underline{m}$ and $\underline{n}$, to be used in Milestones F and G respectively. Deliver initial version of Requirements and Software Design Documents. Documented source code made publicly available via the Web.*	07/15/02	$ 100,000
B)	**First Annual Report delivered.** *Submit FY02 Annual Report to CT via Web.*	08/15/02	$ 25,000
F)	**First code improvement completed.** *Improve implementation of PlantDiversity to deliver canonical products from Milestone E $\underline{m}$X faster than the baseline implementation. Provide code scaling curves. Deliver updates to Requirements and Design Documents. Deliver initial version of Test Plan / Procedures Document. Documented source code made publicly available via the Web.*	07/15/03	$ 300,000
Opt)	**Linux clusters installed.** *Install Linux clusters at USGS/CSU and NASA/GSFC. System configurations will be based on recommendations from CT at the time of purchase.*	07/15/03	$ 100,000
C)	**Second Annual Report delivered.** *Submit FY 03 Annual Report to CT via Web.*	08/15/03	$ 25,000
G)	**Second code improvement completed.** *Improve implementation of PlantDiversity to accommodate 10X more input data over Milestones E and F at $\underline{n}$X the time required in the baseline implementation. (Depending on the science problem, this enhanced capability may be used to increase spatial resolution, temporal resolution, or coverage.) Provide code scaling curves. Deliver updates to Requirements, Design, and Test Documents. Deliver initial User's Guide. Documented source code made publicly available via the Web.*	07/15/04	$ 300,000
C2)	**Third Annual Report delivered.** *Submit FY 04 Annual Report to CT via Web.*	08/15/04	$ 25,000
K)	**Customer delivery accomplished.**	12/15/04	$ 75,000
D)	**Final Report delivered.**	03/15/05	$ 25,000
		Total	$ 1,075,000