

Project Title: The Geoscience of Harmful Invasive Species: Integrating LANDFIRE And Invasive Species Data for Dynamic and Seamless Integration of Raster and Vector Data to Meet Management Needs at Multiple Scales.

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Project Description

Background

Integrating Geographic Information Systems (GIS), data management, remote sensing, spatial statistics, and visualization tools is critically important in documenting, mapping, predicting, and controlling harmful invasive species. GIS and the Internet have developed in relative isolation. With the increasing desire for GIS tools on the web, there exists an urgent need to merge the technologies to provide a more powerful toolset for researchers and resource managers. This is especially true for fast moving, rapidly spreading invasive plants, animals, and pathogens (Stohlgren and Schnase 2006). Based on the National Invasive Species Management Plan (Executive Order 13112; <http://www.invasivespeciesinfo.gov/council/nmp.shtml>), the U.S. Geological Survey was identified as the lead agency to document, map, and predict harmful invasive species at local, regional, and national scales. Unfortunately, different agencies and organizations have created independent solutions for serving GIS data on the web and providing internet mapping applications, with little standardization. With the proliferation of these websites, there is a developing need for real-time sharing of data among sites and for the ability to serve large datasets (i.e., the Global Organism Detection and Monitoring system) along with associated environmental data and GIS themes (i.e., LANDFIRE) in a timely manner. Integrating web services technologies for the biological and physical sciences will solve previously insurmountable problems in documenting, mapping, and predicting biological hazards (and many other ecological hazards and issues) with corresponding increases in performance and interoperability. These solutions must include effective communication of maps and models at various levels of resolution (with associated error and accuracy) for improved management of invasive species at local to global scales. Technological advances and products must be immediately useful to multiple agencies, states, counties, non-government organizations, Tribes, and the public.

LANDFIRE

LANDFIRE, also known as the Landscape Fire and Resource Management Planning Tools Project, is a five-year, multi-partner project producing consistent and comprehensive maps and data describing vegetation, wildland fuel, and fire regimes across the United States. It is a shared project between the wildland fire management programs of the U.S. Department of Agriculture Forest Service and U.S. Department of the Interior. The project has four components: the LANDFIRE Prototype, LANDFIRE Rapid Assessment, LANDFIRE National, and Training/Technology Transfer. LANDFIRE data products include layers of vegetation composition and structure, surface and canopy fuel characteristics, historical fire regimes, and ecosystem status. These data products are designed to facilitate national- and regional-level strategic planning and reporting of wildland fire management activities. Data products are created at a 30-meter spatial resolution raster data set. Because land use history, vegetation, and disturbances such as fire, floods, and hurricanes greatly affect the distribution and abundance of harmful invasive species, the data products generated by LANDFIRE are essential inputs into spatially explicit predictive models (i.e., ecological forecasts) of invaders.

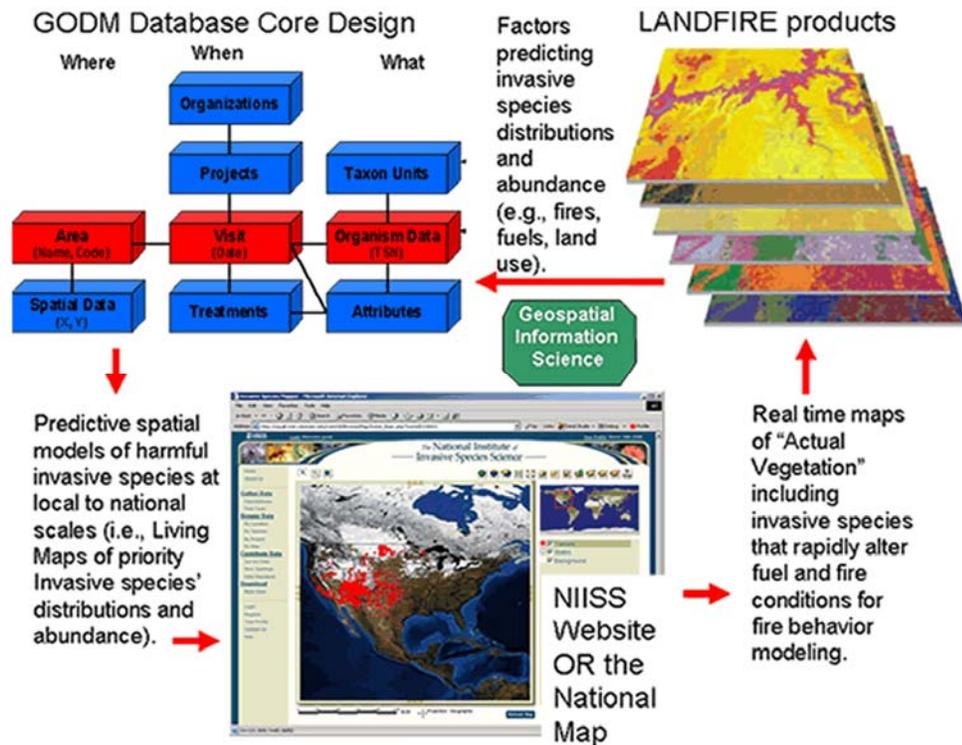


Figure 1. Thematic interdisciplinary integration of the geography discipline (LANDFIRE), biology discipline (Invasive Species), and new information technologies (Geospatial Information Office).

Over the past four years, the United States Geological Survey (USGS) and Colorado State University (CSU), in collaboration with other non-governmental and governmental agencies, have engaged in an ecoinformatics project to develop the Global Organism Detection and Monitoring system (GODM). The system was created in response to high priority needs for invasive non-native species research and management, and it is currently used by several governmental agencies and other land managers. GODM has provided these groups with a data management system, geographic information systems (GIS) capabilities, and analysis capabilities via the web. The four major subsystems of GODM provide dynamic links between the organism data, web pages, spatial data and modeling capabilities. GODM includes a real-time on-line mapping application, which allows for real-time display of location records for species along with other cartographic layers as soon as they are added to the supporting SQL-Server database. Along with users being able to add locations, the flexibility of layers derived from true database queries is a significant paradigm shift from "map servers" to true Internet-based GIS solutions. Additionally, raster files are needed for use as variables in predictive models for the distribution, abundance, and biomass of species. The size of the database, potential for interoperability with several smaller on-line data systems, the mix of multiple geometry vector data and raster data, and existing cyber infrastructure make GODM an excellent test bed for answering some important questions for moving GIS applications to the web. Thus, an interdisciplinary approach must be taken that integrates the geography discipline (LANDFIRE), biology discipline (Invasive Species), and new Information Technologies (Geospatial Information Office; Figure 1). This merger also supports Goal 4, Objective 1, Tasks 54 and 58 of the draft DOI strategic plan.

Hypotheses

1. Pervasive problems in data integration, interoperability, and performance resulting from integrating disparate spatial and biological databases containing large amounts of data at multiple spatial scales can be solved by an adopted protocol for data exchange, a harvest model, and performance optimized database design.
2. Generalization and gridding techniques including simplification and elimination will solve performance and communication of biological data issues related to displaying multi-scale, large vector data sets with an Internet mapping application.
3. Rapidly changing “dynamic” landscapes, due to land use change, fire, and habitat fragmentation, result in rapid invasions of harmful non-native plants and animals by affecting optimal conditions for establishment, growth, and spread from nearby populations.
4. The accuracy and precision of *local* information needed by resource managers to control invasive species is dependent on detailed information of biotic and abiotic drivers of productivity and diversity at *landscape and regional scales*.

Short Literature Review

Hypothesis 1: Data set synergy has been shown to improve biodiversity knowledge (Crosier 2004). A global on-line information system to integrate disparate datasets with information on invasive species distributions, abundance, and potential spread is needed (Ricciardi et al. 2000). Effective approaches to integrating disparate databases have eluded many information technology professionals because of the lack of simplifying the disparate datasets to a purpose (e.g., trying to maintain the whole original dataset) and standardization issues such as those related to taxonomy. Dataset integration maintaining the whole of the original has been accomplished (Halpin et al. 2006), but the amount of data focused on (large, charismatic ocean megafauna) is small compared to all invasive species on the earth. Harvesting over other models of data sharing can have improved performance, scalability and flexibility (Fox et al. 2004).

Hypothesis 2: For data to be served quickly on the internet at a coarse resolution, it needs to be generalized, by removing points, and therefore detail (Visvalingam and Whyatt 1993). This sort of technique will assist with the speed of the background display. Methods such as those presented by Venugopal et al. (2006) demonstrate that biological data can be presented in a grid form that will accentuate the importance of the data but not exaggerate the extent of it to accurately portray survey data at coarse scales.

Hypothesis 3: Patterns of invasion of non-native plants, birds, and fishes in the United States significantly correlate to environmental factors (e.g., temperature, precipitation, elevation, vegetation carbon), topographic factors (elevation, slope, aspect), and human factors (human population, road density, cropland, Stohlgren *et al.* 2005; 2006a, and references therein). In addition, recent studies have linked patterns of plant invasions to fuel conditions, fuel treatments, and fire in western landscapes (Freeman et al. 2006). Quantifying baseline and changing levels of habitat heterogeneity using GIS also appears to be of growing importance in quantifying and predicting patterns of plant invasions (Kumar et al. 2006). Additional data themes from

LANDFIRE and other GIS sources, along with new “scalable spatial models” are needed to confirm Hypothesis 3 at local, regional, and national scales.

Hypothesis 4: The scale of observation greatly influences investigations of the patterns and processes fire and invasions (Stohlgren et al. 2006b). Furthermore, nested hierarchy theory suggests that biodiversity at local scales (alpha diversity) is dependent of the biodiversity at large spatial scales (beta and gamma diversity). However, to date, there have been no studies quantifying the benefits of coarse-scale, wall-to-wall coverage of biotic and abiotic drivers of invasion to predict local biomass, cover, or abundance of invasive species that land managers need to develop cost-efficient strategies for control and restoration (Stohlgren and Schnase 2006). Addressing this hypothesis also requires real-time web-based integration of raster and vector data at multiple spatial resolutions.

Objective/Approach

Hypothesis 1

While several data holders such as some county weed managers and Fish and Wildlife service employees do not have a database system in place, there are several on-line database systems that have been created for single species or specific regions that include spatial information at multiple spatial extents and resolutions and that mix geometries (point, polyline, and polygon data; (Crall et al. 2006)). These data, however, are much more powerful when merged (Crosier and Stohlgren 2004). Integrating these systems poses challenging semantic interoperability issues along with many other database population and maintenance questions. For example, performance issues arise when data are queried on the fly from disparate databases or if data are harvested and held within a single large database without correct use of common tasks and indexes.

We will use GODM as a test bed for our hypotheses. The datasets we will be focusing on integrating with GODM to address hypothesis 1 include VegBank, the California Information Node of the National Biological Information Infrastructure data, and the Biota of North America Program (BONAP) data. Co-Investigator Peet is the principal architect and director of the VegBank plot archive project. VegBank (<http://vegbank.org>) is the vegetation plot database of the Ecological Society of America's (ESA's) Panel on Vegetation Classification. Most plots archived in VegBank contain complete floristic records, precise geocoordinates, and some measure of taxon importance. At present over 20,000 plots spanning 27 states and containing well in excess of 6,000 species are archived in VegBank, and in excessive of 10,000 more plots are scheduled to be added in the near future. Co-investigator Quinn's research team in California has assembled data from some 20,500 plots, representing a wide variety of organizations and studies from many sources including the National Park Service (>7000 plots in 6 parks), the USDA Forest Service (>8,000 Ecological Unit Inventory Plots), and the Mojave Desert Ecosystem Initiative (1,241 relevé plots), plus up to several hundred plots each from a variety of academic collaborators and others. We have identified another 3,200+ plots that have data in digital form, and some 1,600 more that are in various stages of development by the California Department of Fish and Game and the USGS. The BONAP data has been compiled by John Kartesz over several years. The database consists of plant species for counties, including over two million records for the 3,111 counties in the coterminous United States.

We will also work with Kathryn Thomas and her research team to integrate data from Arizona into the system if our project and hers are funded. Her proposal is entitled 'The invasive plant geospatial information network: Strengthening the information network topology that links citizens, governments, and invasive plant geodata'.

The invasive species community is currently working to develop a protocol to exchange biological spatial data, including attributes. This protocol will be similar to Distributed Generic Information Retrieval (DiGER; <http://digir.sourceforge.net/>), but will contain more specific information including taxonomic, spatial, temporal, abiotic (information associated with a visit such as soil data), organism attribute, and treatment (control efforts applied to invasive species) data. We will participate in the Taxonomic Databases Working Group (TDWG) meeting in October to discuss a protocol for this type of data. We will proceed with the tasks related to integrating these databases based on the outcome of this meeting. We will address semantic issues, accuracy issues, and projection issues among others. We will use a harvest model to integrate these datasets, and will conduct performance measures to compare a distributed system such as DiGER with a harvesting or caching system following the Google model. Data sharing will provide us with a very large vector dataset to develop our generalization and ecological forecasting tools.

Hypothesis 2

The issue of scale also affects many GIS layers including the background and cartographic layers. Existing web-based GIS systems such as MapQuest (www.mapquest.com) provide varying levels of detail based on the selected resolution. When the user is zoomed out to the greatest extent they see only a simple version of the world. Content is slowly added as they zoom in from the greatest extent including layers like state outlines and cities. When the user is zoomed in to a local level, each and every street in their neighborhood is visible.

Within GODM the user can select certain layers to include with their maps. Layers such as roads should display interstates at coarse resolution and then add highways and streets as the user zooms in. The same can be done for cities by showing major cities and then adding smaller cities as the user zooms in. While this provides a maximum number of elements for some layers, we do not have criteria that can be applied across all layers including all the survey data and we do not have criteria to determine what zoom level should change the roads or cities shown.

Generalizing background layers is important to increase the speed at which information is served to the public. Generalization can be displayed temporarily on-the-fly for display purposes only, or as a permanent change within the database (Longley et al. 2001). A temporary display will be slower to display while the permanent database change is slower to upload uses more storage, but is quick to display. There are two forms of generalization for vector data essential for us to examine. One involves clustering and the other involves simplification. Clustering reduces the number of objects that are displayed on a map at a coarse resolution while emphasizing the importance of the dataset itself, allowing the viewer to see the data at this reduced scale (Cecconi and Galanda 2002). There are four categories of clustering: partitioning, hierarchical, density-based and grid-based methods (Pilevar and Sukumar 2005). We will examine these different methods to cluster the data and weigh what method is best to communicate the data against performance to determine the solution.

The performance and visualization issues solved by clustering arise with large datasets at multiple scales that exist in spatial information for species locations. For example, our on-line Global Organism Detection and Monitoring (GODM; www.niiss.org) system currently holds

data for 61 projects including 37,945 field surveys, with the locations of 139,468 organisms representing 1562 different species. For the genera *Tamarix* alone there are over 11,000 records. Solving performance and visualization issues related to serving this quantity of data on a web mapping application involves issues of database design to query records quickly and rule sets for clustering data points at coarse resolutions. Currently when a user is zoomed out to the United States, a layer such as *Tamarix sp.* seems to engulf the entire Western United States (Figure 2). This is an issue of generalization, specifically selection, or elimination. We need to devise a method to aggregate points or areas when the user is zoomed out, and then increase the level of detail as the user zooms in.

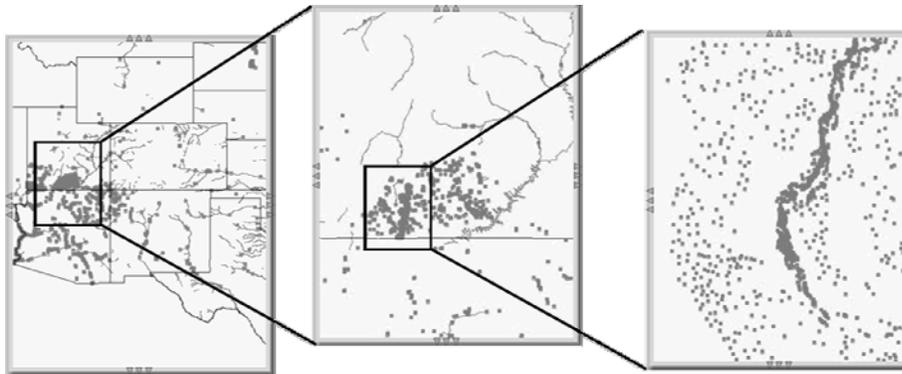


Fig. 2. Visualization of biological data presents an issue if several points are located in one area. In the first frame, all of Grand Staircase Escalante National Monument seems covered in *Tamarix*. As resolution becomes finer, it becomes clear that there are several dispersed locations, not locations covering the entire Monument.

In addition to adding more information to the maps as the user zooms in, it is also important to add more detail to the maps. This second form of generalization is called simplification. At a very fine spatial scale the coast of a state like California is very detailed, containing many bends and curves. While this is necessary if you are viewing the state from a very fine resolution, these details would not be noticed if the state were viewed at a coarser resolution, making the extra data time and data intensive to serve. The way to deal with this problem is to eliminate points in the data, removing much of the detail but maintaining the general shape of the feature (Visvalingam and Whyatt 1993). On a large website, covering the entire world, this could be a time consuming project to undertake as each feature would need attention and detail removal. We will use a customized generalization tool to create different resolutions of the same file. We will identify what cartographic layers are desired by our user base, locate sources for those layers, and make these processed layers available via the GODM website for others with similar issues. To serve the background layers quickly and efficiently and communicate biological data appropriately on the web we need to simplify the background layers for different resolutions.

Hypothesis 3 and 4

Once all of these data, including field data for species and GIS vector and raster layers, are integrated together in a single location, there are tools we can use to support decision making. These data can be used to generate predictive models of species distributions, abundance, and biomass that can aid resource managers and decision makers in prioritizing research and conservation need and in early detection/ rapid response activities for invasive, non-native species. Providing these capabilities on-line will make them accessible to managers and decision makers with limited resources.

First, by consolidating vegetation and plot data from Drs. Peet and Quinn, we will greatly improve the actual vegetation maps. Second, by adding individual invasive species (presence, absence, and abundance), we will improve our understanding of the very dynamic nature of vegetation change imposed by invasive species. Since many of these species alter disturbance frequencies (e.g., fire and cheatgrass), we will be able to more accurately map and model this dynamic system at national scales.

Once we have assembled a large database of biological spatial data, we need GIS and raster data layers to generate spatial statistical models on the web. LANDFIRE products will be used as inputs for predictive spatial models (Fig. 1). We will be able to improve the LANDFIRE actual vegetation maps in two important ways. These layers present challenges due to the large size of the files. We need the ability to allow website users to select a dependent variable from the biological data along with a suite of predictor variables from the GIS layers. Data then needs to be extracted from the GIS layers and merged with the biological data, statistical techniques need to be applied to the dataset, the final predictive surface needs to be generated from the model equation and the GIS layers, and the final surface needs to be displayed on the mapping application along with the error. This process requires a combination of GIS technology and statistical tools. Being able to effectively communicate the modeling results, including the error and uncertainty in the model through the mapping application, is another area to be explored. We will explore different visual techniques to communicate this information.

For Hypothesis 3

Both landscapes and invasive species are highly dynamic. Landscapes and species habitats are quickly modified with land use change, energy development, natural hazards such as fire, and habitat loss and fragmentation. Likewise, native and non-native species are generally highly mobile, but they are greatly affected locally and regionally by changing environmental conditions and human factors (Figure 3).

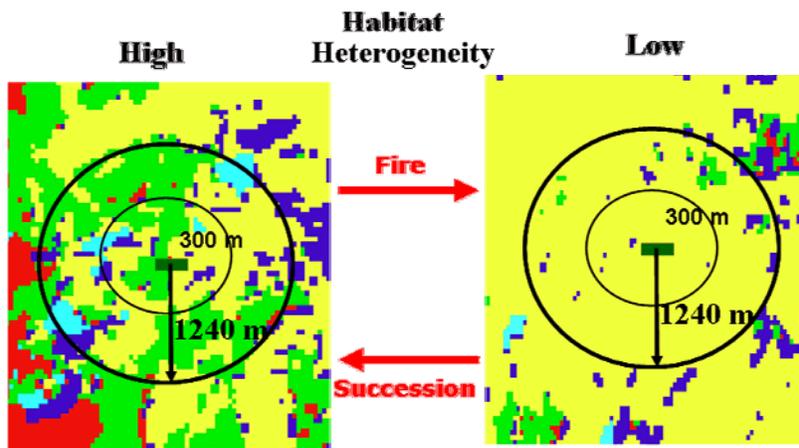


Figure 3. Disturbances like fire influence habitat heterogeneity across the landscape. The dynamic nature of landscapes and habitat heterogeneity affect the diversity and dynamics of native and non-native species. Species data (vector data in 0.1 ha plots; green rectangles) must be seamlessly integrated and modeled with raster data (e.g., vegetation type, cover, height) in a temporally changing landscape matrix (see Kumar et al. 2006). Scalable models are needed to evaluate appropriate scales.

Our approach will be to dynamically link the LANDFIRE products as inputs into GODM, and create web-based “scaleable” spatial modeling tools to predict habitats vulnerable to invasion for the top 100 invasive plants species in the country (list supplied by John Kartesz, Biota of North America Program). Our first models will be based on simple regression tree approaches, followed by more advanced spatial statistics. The models will be made available on

the web to provide “living maps” and predictive models of the top 100 plant invaders with enough available locations for *The National Map*. In a sense, we are creating “Google Maps for Invasive Species,” and with predictive capabilities to aid in the early detection and rapid response of these species as the spread across the United States into more parks, refuges, and natural areas. Any large change in landscape condition or structure, due to fire or other disturbance, will result in new projections of invasive species spread.

For Hypothesis 4

We will expand on landscape- and local-scale modeling capabilities to predict the local patterns and effects of fire and invasions based on broad-scale environmental drivers (Stohlgren et al. 2006b). For example, we just discovered that plant species invasions may be increasing steadily and predictably in the Pacific Northwest, and perhaps across the United States. If this is the case, then the patterns may be more predictable by using nested hierarchy theory to merge appropriate vector and raster datasets at multiple scales to better predict future invasions by testing “hind-casting” models in a few areas (e.g., Pacific Northwest). We will test whether land-use change, fire, human population change and other factors contributed significantly to patterns of invasion in the past. To our knowledge, this has never been done, partly due to the issues pertaining to effective data integration, visualization, and semantic interoperability which we addressed simultaneously in Hypotheses 1 and 2 (above).

Expected Results/Products

The vision of this research team is to develop techniques to enable serving “living maps” on the web including interoperability of disparate datasets and performance improvement of on-line GIS mapping tools using an existing cyberinfrastructure (i.e., the Global Organism Detection and Monitoring system (GODM)). We expect to resolve (or partially resolve) several key challenges in the geosciences. We fully expect to develop general guidelines for:

- 1) Integrating disparate datasets that include spatial and biological data by solving issues of interoperability.
- 2) Improving performance and visualization issues related to multi-scale, large vector datasets.
- 3) Combining GIS, database, and statistical capabilities on the web to provide a decision support system for resource managers and decision makers.

In addition, we expect to provide “living maps” of the top 100 invasive plant species with appropriate levels of field data to *The National Map*, such that the maps are automatically updated and new observations are confirmed. Furthermore, we expect to provide real time projections of the changing vulnerability of habitats to invasion as LANFIRE products are modified (Fig. 1).

Additional expected products from this research project include:

1. Develop interoperability through a protocol solution for several large regional or thematic datasets for biological data including different data resolutions, geometries, and format.
2. Develop a clustering rule-set with performance optimization dealing with large datasets of fine scale resolutions at multiple zoom resolutions. (e.g., how to display large amount of fine resolution data at coarse scales)
3. Develop a generalization rule set for dealing with layers at multiple scales. (e.g., how to display different levels of detail at different zoom levels)

4. Develop models using integrated biological database and GIS data and effectively communicate the results on the web.
5. Make available GIS vector and raster data for analyses of plant invasions.
6. Publish at least one peer-reviewed journal article per hypothesis that explains the research and results for each.
7. Demonstrate these results on the GODM website (www.niiss.org) served through the Fort Collins Science Center.

The results of this research project will serve the USGS mission by directly providing tools to make biological scientific information available to USGS scientists, other researchers, DOI and other resource managers, politicians, and the public. Invasive species and fire remain top priorities at local, regional, and national levels in the USGS, and they remain top priorities in DOI and across Departments (especially Agriculture and Commerce). We will be able to communicate these data through maps (and *The National Map*) with web links, something more easily understood by non-scientists than statistical output. Additionally, the answers to these research questions will enable other groups both within and outside of the USGS to provide the same capabilities for biological and other spatial information. We will also help meet two tasks from the 2006 draft DOI strategic plan:

Goal 4 — Intermediate Outcomes and Performance Measures

Objective 1: Ensure availability of long-term environmental and natural resource information, data, and systematic analyses needed by land and resource managers for informed decision making

Task 54: Percent of US surface area with contemporary land cover data needed for major environmental monitoring and assessment programs such as LANDFIRE, NAWQA, and Invasive Species [USGS]

Task 58: Percent of targeted invasive species for which scientific information and decision support models are available to improve early detection (including risk assessments) and invasive species management [USGS]

Timeline of products:

Product	Year 1	Year 2	Year 3
Protocol for biological spatial data	Develop with 3 test systems	Implement for other databases	Implement for other databases
Rule-set for generalization	Develop	Process Layers	Logic into GODM
Rule-set for clustering	Develop	Process Layers	Logic into GODM
Serve website at FORT	Implement		
Model		Develop	Implement
GODM website new version			Implement

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PROJECT SUPPORT

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Other Project Support

\$60,000/ yr – Ongoing – National Biological Information Infrastructure Invasive Species Node
GODM development including improving on-line mapping capabilities

\$300,000 / yr – Jan 2007 – Dec 2009 – National Science Foundation Cyberinfrastructure
GODM development funding Jim Graham, lead developer, and others

Fiscal Year 2007 Budget (if funded for only one year program)

	FORT (8327)	EROS (XXXX)	Total Year 1
Personnel Salary	\$13,500	\$35,313	
Other expenses: travel, equipment & supplies	\$2,500	\$2,000	\$4,500
Subcontract to academic partners (Peet and Quinn only)	\$50,000	\$0	\$50,000
TOTAL DIRECT	\$66,000	\$37,313	\$103,313
Gross Assessment Rate	34%	34%	34%
INDIRECT COSTS	\$34,000	\$12,687	\$46,687
TOTAL	\$100,000	\$50,000	\$150,000

Fiscal Year 2007 Budget (for three year program)

	FORT (8327)	EROS (XXXX)	Total Year 1
Personnel Salary	\$40,400	\$42,776	\$83,176
Other expenses: travel, equipment & supplies	\$10,000	\$2,000	\$12,000
Subcontract to academic partners	\$75,000	\$0	\$75,000
TOTAL DIRECT	\$125,400	\$44,776	\$170,176
Gross Assessment Rate	34%	34%	34%
INDIRECT COSTS	\$64,600	\$15,224	\$79,824
TOTAL	\$190,000	\$60,000	\$250,000

Fiscal Year 2008 Budget

	FORT (8327)	EROS (XXXX)	Total Year 1
Personnel Salary	\$45,400	\$42,776	\$88,176
Other expenses: travel, equipment & supplies	\$5,000	\$2,000	\$7,000
Subcontract to academic partners	\$75,000	\$0	\$75,000
TOTAL DIRECT	\$125,400	\$44,776	\$170,176
Gross Assessment Rate	34%	34%	34%
INDIRECT COSTS	\$64,600	\$15,224	\$79,824
TOTAL	\$190,000	\$60,000	\$250,000

Fiscal Year 2009 Budget

	FORT (8327)	EROS (XXXX)	Total Year 1
Personnel Salary	\$45,400	\$42,776	\$88,176
Other expenses: travel, equipment & supplies	\$5,000	\$2,000	\$7,000
Subcontract to academic partners	\$75,000	\$0	\$75,000
TOTAL DIRECT	\$125,400	\$44,776	\$170,176
Gross Assessment Rate	34%	34%	34%
INDIRECT COSTS	\$64,600	\$15,224	\$79,824
TOTAL	\$190,000	\$60,000	\$250,000

Three Year (FY07-09) Total Budget

	FORT (8327)	EROS (XXXX)	Total Year 1
Personnel Salary	\$131,200	\$128,328	\$259,528
Other expenses: travel, equipment & supplies	\$20,000	\$6,000	\$26,000
Subcontract to academic partners	\$225,000	\$0	\$225,000
TOTAL DIRECT	\$376,200	\$134,328	\$510,528
Gross Assessment	34%	34%	34%
INDIRECT COSTS	\$193,800	\$45,672	\$239,472
TOTAL	\$570,000	\$180,000	\$750,000