

PROJECT 3: DEVELOPMENT AND EVALUATION OF AQUATIC INDICATORS

3.D. ABSTRACT

Applying Spatial and Temporal Modeling of Statistical Surveys to Aquatic Resources

Research Category: Research Program on Statistical Survey Design and Analysis for Aquatic Resources

3.1. Sorting Code: 2001-STAR-D1, responding to Statistical Research Area 2

3.2. Title: Development and Evaluation of Aquatic Indicators

3.3. Investigators: David Theobald (CSU), N. Scott Urquhart (CSU), Kerry J. Ritter (SCCWRP)

3.4. Institutions: Colorado State University (CSU) and Southern California Coastal Water Research Project (SCCWRP)

3.5. Project Period: October 1, 2001 - September 30, 2005

3.6. Project Cost: \$210,929, first year cost
\$530,447, total cost over four years

3.7. Overall Summary:

Objectives of this Project will be to

- Develop, determine and evaluate landscape indicators suitable for spatial and temporal analyses of EMAP and similar data being examined in PROJECTS 1 and 2.
- Explore statistical aspects of the definition of regional species richness, or more generally, taxonomic richness.
- Evaluate protocols for economically determining site level aggregate indicators, including habitat features, macroinvertebrate assemblages, and chemical determinations
- Investigate the limitations of using current data which is widely available, but probably ill suited for regional statistical analyses.

Approach:

Seek input from various quarters, including literature, the EMAP Landscape Ecology Group, and the team. Potential landscape indicators will be evaluated a number of ways, but an important criteria will be how well they perform as predictors in the spatial, temporal and local prediction models developed in Projects 1 and 2. Regional indicators will explore what features of taxonomic richness submit to reasonable precise and accurate estimation. Site and point scale investigations are designed to provide design recommendations relative to the development of cost effective protocols for evaluating environmental responses.

Expected Results and Benefits:

Expected benefits of this Project will be an improved suite of environmental indicators, and perspectives on how they should be evaluated. Since one of the evaluation criteria of the indicators will be how well they are suited for supporting meaningful inferences for spatial and temporal analyses, the indicators developed and evaluated should be interpretable and usable. The results should also point directions for combining field and laboratory methods to achieve cost effective indicators. A handbook on uses of landscape metrics in environmental evaluation will be developed in conjunction with Project 4 if the needs assessment suggests users need such. Its form also would depend on the needs assessment.

3.8. Supplemental Keywords: water quality, land cover, land use, accuracy, precision

3.E. OVERALL DESCRIPTION

3.1. OBJECTIVES

- Develop, determine and evaluate landscape indicators suitable for spatial and temporal analyses of EMAP and similar data being examined in PROJECTS 1 and 2.
- Explore statistical aspects of the definition of regional species richness, or more generally, taxonomic richness.
- Evaluate protocols for economically determining site level aggregate indicators, including habitat features, macroinvertebrate assemblages, and chemical determinations
- Investigate the limitations of using current point-scale data which is widely available, but probably ill suited for regional statistical analyses.

3.2 APPROACH

This Project will develop data and approaches to which tools of statistics can be applied to solve important problems in the environmental sciences.

The indicators under consideration here cross four very diverse scales: landscape to region to site to point. PROJECT 1 includes consideration of how to relate indicators at different scales, including these. The mathematical and statistical aspects of PROJECT 1 can proceed prior to determining new indicators, especially at the landscape scale. However, before it can begin analysis of EMAP data using landscape indicators, those must be developed, both in a general conceptual way, and evaluated (computed) for landscapes associated with EMAP sites. Further, the Local Prediction, Project 2, also will use landscape and regional information in extending information from sampled points to unvisited points about which remotely sensed information is available.

LANDSCAPE SCALE:

Successful completion of this task requires three steps: identification of potentially useful landscape indicators, computation of indicators, and evaluation of utility in predicting relationships with site and point-scale EMAP data.

A useful landscape indicator has three attributes. First, it will be based on scientific understanding for associating a landscape factor (e.g., % land cover type) with an ecological response. Although the ultimate need of science is perhaps at a mechanistic or process-based understanding of how various landscape factors contribute to changes in aquatic ecosystems, at this juncture in scientific inquiry we seek to identify indicators that are at least correlative with aquatic measures. Narrowing the field of possible indicators through establishing correlatory factors is a necessary step to enable more mechanistic-based research to be conducted in the future. Second, the spatial data required to map that landscape factors thought to be important should be commonly available nationwide, or reasonably easy to generate if not readily available. Many landscape indicators appear to be great ideas on first blush, but fail because they cannot be implemented without the needed spatial data, at the appropriate spatial scale. Because of the vast time (and financial) investment required to produce large spatial databases, we are forced here to utilize commonly-available data sets. Third, calculation

of the algorithm used to implement an indicator must be computationally feasible. As finer-scale spatial data are increasingly made available, quantitative landscape ecologists are challenged to find techniques that not only allow the necessary spatial detail to be incorporated into a landscape metric, but also enable the indicator to be computed in a reasonable time frame (i.e. roughly less than days to weeks). Therefore, useful indicators developed in this project are those that fall within the intersection of these three attributes – they are salient, broadly applicable, and computationally feasible. Moreover, although the process of identifying, developing, and evaluating indicators is ideally conceived of as linear, in practice this process will be iterative, requiring close cooperation among team members. We will also initially settle on one or at most two representative pilot areas that are fairly small in geographic extent to investigate intensively. This enables more rapid development and testing of indicators, which will be scaled up hierarchically to larger watershed areas as we proceed.

To identify potentially useful indicators, we will solicit assistance from EPA personnel (e.g., landscape ecologists) and associated researchers. The Program Director has already established a working relation with Daniel Heggem, the Landscape lead for EMAP. He will help identify appropriate EPA personnel with whom the team should interact on landscape matters.

Once indicators have been identified, they will then be prioritized according to their strength in association with a target biological measure, availability of spatial-resolute data, and feasibility. Also, the indicators will be examined to determine how informative they are in a public policy context. That is, indicators that are readily understandable, and well linked to public and private land use policy levers, have greater potential for being ingested into various land planning and decision making processes (Theobald et al. 2000). Furthermore, it is especially critical to develop methods to estimate the cumulative effects of watershed and landscape changes, by linking forecasts of future land cover and use change to their ecological effects (Sengupta et al. 2000; Theobald et al. 1997; Theobald and Hobbs 1998). In particular, it would be useful to identify possible non-linear responses or thresholds to landscape change, and to build this into estimates of future ecological condition. Potential landscape indicators will likely include the following: proportion of different land cover types, road density, housing density, active and inactive mines, etc.

Although it is intuitively obvious that changes at the landscape-level trickle down to affect the quality of the aquatic resources (e.g, Bhaduri et al. 2000; Blanchard et al. 2000; Poiani et al. 1996), there are a number of complications that we will consider when attempting to establish a strong linkage between watershed changes and subsequent response in aquatic systems. First, there may be a time lag between when the change occurs in the watershed, and when the aquatic response can first be detected. Some responses occur nearly immediately, such as a fish kill from massive sediment discharge into a river, while other responses may take years to move through the environment to enter the aquatic system, or to ripple through an aquatic system by altering population dynamics or cascade through trophic levels. An important challenge to face here is recognize the relatively short duration (5 to 10 years) that the aquatic data has been sampled, in comparison to potentially longer-term responses of ecological systems. One technique that will be investigated to handle this shortcoming is to trade-off time for space. Analysis of relationships between indicators and aquatic responses can be grouped by watershed type. By grouping watersheds that are relatively homogenous in size, land cover setting, etc., but that vary in the spatial

extent and recency of land use change, we hope to reduce the sensitivity of the relationships to potential time lags in the ecological systems under study.

Second, although typically by default a linear relationship is assumed between an indicator and response, frequently natural systems exhibit either non-linear responses (e.g., Nikkolas et al. 1998) or a strong threshold (e.g., Cuffney et al. 2000). Identifying the form of the relationship, even approximately, between landscape indicator and biological response is critical because these are generally the source of “surprises” for land management and decision makers. Interactions between landscape analysis and spatial statistics should occur on this matter. Various forms of residual analysis can help identify highly nonlinear relations.

Third, landscape configuration and context, or the location and spatial relationship between different land cover types, is important to consider as well. Typically watershed indicators and aquatic responses are linked by lumping both within a watershed, because it is straightforward to represent and model in a GIS. However, evidence from landscape ecology is emerging that suggests (mostly from terrestrial examples, however) that configuration matters. Different locations within a watershed likely contribute disproportionately to changes in biological response (Jones et al. 2000), for example erosion from areas on steep slopes vs. flat slopes likely leads to much larger sedimentation, and having buffer strips along riparian areas likely leads to reduction of nutrient loading into surface water. While landscape configuration is linked to scale (or the watershed unit used to aggregate with), it also includes the notion that some adjacencies are more important than others, which likely alters inputs in an aquatic system.

The integration of traditional GIS methods and landscape ecology has generated numerous useful quantitative indices that attempt to relate landscape structure to process. For example, the standard approach to conceptualizing landscape patterns distinguishes between patches and the matrix surrounding them (Forman and Godron 1986), which is rooted in island biogeography theory (MacArthur and Wilson 1967). This approach has been useful largely because analysis of landscapes can be accomplished easily using GIS. However, it remains difficult to incorporate biological mechanisms and landscape-level processes that operate on a landscape in this traditional approach, and an important challenge for landscape ecologists is to move beyond simple representations of pattern that fail to reveal the consequences of pattern for ecological processes (Gustafson 1998; Wiens 1999). Gradient-based techniques can explicitly incorporate process scale and data uncertainty, providing a modeling environment to test the linkages between landscape structure and process (Theobald and Hobbs *in press*).

For example, a main deficiency in current use of GIS to model landscapes is that analytical techniques and data structures are limited in their ability to represent more complex, biologically realistic, spatial processes (Theobald and Hobbs 2001). A chief challenge for aquatic systems is to develop algorithms, and data structures to facilitate the algorithms, that accumulate effects across a landscape in a fashion that emulates hydrologic flow regimes. Although network graph theory has been usefully applied to stream networks, allowing simple accumulation of flow to be computed, more complex accumulation situations are difficult to model in current GIS. For example, non-point source pollution may accumulate through an aquatic system, but may attenuate over time and/or distance, depending on the condition and land cover types (e.g., presence of healthy wetlands to filter

pollutants?). However, modifying traditional GIS algorithms to attenuate flows is required to reflect the functional aspects of landscapes. One innovative approach developed in response to this need is the connectivity matrix (Theobald *in review*), which allows adjacent, distance-based, and disjunct spatial relations to be represented.

An important aspect of evaluating landscape metrics is to determine how well they work as predictors of aquatic responses in the spatial/temporal analyses to be developed in Projects 2 and 2. If they work only some of the time, under what conditions do they work?

REGION:

Focus area 2.8 raises the issue of estimating species richness at the regional level. We will take several approaches to this issue. Species richness is a relatively simple response to evaluate at a site for some taxonomic groups. However for other taxonomic groups, such as aquatic insects, many species may be indistinguishable based on a collection of individuals at one time. For example, a collection of insects in July may contain several species, but they can not be identified because distinctive features allowing determination of species may appear only on the adults. Classification of a sample, then may allow identification of only genus, rather than species; in other circumstances, classification may be possible only to the family level. Thus the remainder of this discussion will focus on the more general response of taxonomic richness rather than on species richness.

A fundamental problem is that rare taxa severely complicate the estimation of taxonomic richness from laboratory evaluation of field collections. A new sample collected in the same manner may display a very different number of taxa from another collected in nearly the same place at the same time. An additional problem is tied up in the laboratory protocols for evaluating the number of taxa. If the collection produces a large number of individuals, cost considerations often lead to a partial evaluation of the collections, followed by an expansion of the resulting counts back to the whole collection, based on the proportion of the collection evaluate. What can be estimated fairly precisely? That is what the next paragraph addresses.

Collection of large samples followed by evaluation of smaller fixed-sized subsamples has been used extensively in macroinvertebrate inventories to reduce costs associated with assessing taxa richness for large populations. A common measure of taxa richness employed by these fixed-count subsampling protocols is numerical taxa richness, ie. the number of taxa observed for a fixed (usually small) number of individuals subsampled from a larger collection. Rare taxa tend to be excluded from the metric for smaller subsamples due to their low inclusion probabilities. Numerical taxa richness, then, essentially targets the number of non-rare taxa, rather than total number of taxa. In addition, the level of rarity assessed by the metric depends on the size of the subsample. By specifying the target parameter that numerical taxa richness is “really” estimating, researchers may understand more precisely what is being assessed and compared. For example, comparing the total number of taxa observed in two subsamples of different sizes could impose unfair penalties because their target parameters are different. For a fair comparison, both estimators should be (approximately) unbiased for the same parameter. Therefore, determining the target parameter that numerical richness unbiasedly estimates is an important step toward detecting differences among collections. The focus of this paper is to provide a means for determining the parameter targeted by

numerical taxa richness and, for a given level of rarity, to offer approximately unbiased alternatives for estimation based on larger or smaller fixed counts.

That is, an approach to the taxa richness question is to find out what parameter can be estimated with reasonable precision. Kerry Ritter has been exploring this problem very closely. We propose to extend her ideas to a regional scale, and use available EMAP data sets to simulate the outcomes of various definitions and methods of estimating regional taxonomic richness.

SITE:

From the point of view of statistics, research in the environmental sciences can be classed broadly as experimental or observational; of course some cases may lie between these classes. The experimental work often deals with environmental effects or ecological mechanisms, and is conducted in controlled settings, sometimes even in laboratories. For example, EPA conducted a number of experiments to evaluate the impact of ozone on crop growth (*e.g.*, Heggstad and Lesser, 1990). These experiments posed some novel statistical problems, but techniques available from agricultural applications were applicable with a minimum of modification. This is generally true for experimentally-oriented studies in the environmental sciences.

However, the more observationally-oriented studies of environmental phenomena pose a substantial problem for statisticians. Virtually all of these situations share an important feature: The material of interest is distributed irregularly in one, two, three, or even four (if time is included) dimensions. No list of objects of interest can be developed. On the other hand, locations can be selected in some fashion: by judgement, randomly, or according to a well-defined probability mechanism. When the environmental investigator visits the selected site, the first step is to determine if the objects of interest are there; if there, evaluations proceed. Some such problems can be approached appropriately using the tools of finite population sampling. But the rigorous application of these tools sometimes lead to inferences on populations different from the ones of interest to the investigators. For example, suppose an environmental scientist wants to draw inferences to the population of all points along a set of streams. The theory of finite-population sampling can be applied to the finite population of stream segments, but that is not the population of interest. The theory of sampling for continuously distributed objects is only beginning to be developed (Cordy, 1993; Stevens and Urquhart, 2000).

Once an investigator arrives at a selected site, what protocol should he or she use to collect the information of interest? How many samples of material need to be collected? How should they be distributed spatially and temporally? Should compositing be used? If so, at what scale? Answers to such questions involve a number of statistical perspectives, but they have been applied to the environmental and ecological sciences to only a limited extent. The theory of components of variance from continuous statistics, and the approaches of error analysis (Lessler and Kalsbeek, 1992) from finite population sampling need to be adapted to problems arising in the environmental sciences.

Compositing (“physical averaging”) of collected material before expensive analysis: When an ORD/EPA State, or Tribal scientist reaches a site, she or he frequently collects material which is

subsequently submitted for laboratory evaluation. Often, the cost of this laboratory evaluation exceeds the cost of the field collection of the material by a substantial factor. After the evaluation, numerical results often are averaged. An alternative would be to composite, *i.e.*, physically average, some of the samples rather than numerically average the samples. We propose using the tools of spatial statistics to determine optimal sampling plans for various configurations of costs, spatial structure, and requirements for estimating variance. This will require research into change of support and the modifiable unit areal problem, an initiative already begun by Cressie (1996). We see such results as being relevant to problems ranging from sampling super fund sites to the collection of air toxics to the evaluation of stream health through the examination of macroinvertebrate communities.

Urquhart will have a research thrust in this area, especially relying on several sets of macroinvertebrate data currently available in the EMAP data sets, such as the indicator development studies conducted from 1992 - 1999. Compositing is widely practiced by many field disciplines, *e.g.*, soil science, but has received limited attention from statisticians (see *e.g.*, Elder, Thompson and Myers, 1980). Consequently, researchers planning to use it must base protocol decisions on experience; its effect on variance of estimates and related matters remains very obscure. Objective recommendations on how to design compositing protocols need to recognize at least these factors:

- Samples collected for compositing may exhibit substantial spatial correlation.
- Complete mixing may be practically impossible; if incomplete this introduces a potentially important, but rarely acknowledged component of variance.
- The mixed composite usually is subsampled to obtain a manageable amount of material to submit to analysis; the effect of this step appears to rarely be acknowledged, but can induce a major variance component for some kinds of responses.
- Measurement error induces another component of variance.
- Each of the steps has associated costs which accumulate in nonlinear manners.

We will investigate the problem outlined above, both analytically and using simulation. The spatial components will be examined relative to several different forms of variograms. Once recommendations for compositing patterns have been developed, we will seek collaborators within ORD to provide or develop relevant situations and data to allow field testing of the results. The results will become a component of the design system which will be prepared in response to focus area 2.3.

POINT:

Agencies and programs, within water and water-related agencies, employ monitoring in diverse ways, often driven by an interpretation of the mission and its need for information about water quality conditions in the environment. As a result, statistics, as a means of converting data into information, is employed in water quality monitoring in a variety of ways that are often uncoordinated and inconsistent. The resulting information is not transferable across agencies nor even across programs within the same agency. There is a need within government to develop comparable data analysis methods to insure information produced in different programs and by different agencies is presenting an accurate and consistent picture of water quality conditions over time and space. Only with such accuracy and consistency will confidence in the statistical

information reach the levels enjoyed in the economic and weather reporting sectors of our society.

The National Water Quality Monitoring Council (NWQMC) is a consortium of 35 organizations whose challenge is to identify, examine, and recommend water-quality monitoring strategies, science and technology that facilitates collaboration amongst all data-gathering organizations and yield comparable data and assessment results. Team members will collaborate in considering methods for analyzing these potentially large, and finally combinable, data sets.

3.3 EXPECTED RESULTS OR BENEFITS

Expected benefits of this Project will be an improved suite of environmental indicators, and perspectives on how they should be evaluated. Since one of the evaluation criteria of the indicators will be how well they are suited for supporting meaningful inferences for spatial and temporal analyses, the indicators developed and evaluated should be interpretable and usable. The results should also point directions for combining field and laboratory methods to achieve cost effective indicators.

3.4 MANAGEMENT PLAN AND MILESTONES

Serious development of the landscape indicators will occur the first year, and much of their evaluation will be completed the second year. The work on regional taxa richness will be conducted during the first year. Work on compositing will continue during the first two years. Thus much of the work on this Project should be completed by early in the third year, but reporting can begin somewhat earlier.

As some of the evaluation of landscape indicators will have to await the development of statistical approaches, the numerical evaluation of landscape indicators will extend into the latter years of the Program, but at a much lower level than in the first two years.

The latter years of the Program will emphasize outreach to various client groups. This Project will provide a handbook on the meaning and use of landscape indicators if the CUES determines that to be useful to users.

3.5 GENERAL INFORMATION

DAVID M. THEOBALD (CSU) - Principal Investigator, Project 3, is a Research Scientist, Natural Resource Ecology Laboratory at CSU. He has applied his training in geography to a variety of natural resource and environmental problems in the six years since his doctorate. He will provide the team's geographic perspective so that the work on spatial statistics can proceed in a suitable and relevant relation to the associated landscapes. His past work has been mainly in a terrestrial context; he welcomes the opportunity to expand that into an aquatics context. He will supervise a post-doctoral fellow in landscape ecology who will help define, develop and participate in the evaluation of landscape indicators, and will provide the team's expertise in managing large data bases.

KERRY J. RITTER (OSU and SCCWRP) will complete her doctorate in environmental statistics at OSU while this proposal is being considered at EPA; there after she will assume a position at SCCWRP, a major cooperator in this Program. Her research has focused on defining parameters related to species richness, or more generally to taxonomic richness - the approachable and related concept for macroinvertebrates in streams. Her current work has focused on site-level matters; in Project 3, she will extend her work to the regional scale. Further she will provide knowledgeable access to the near-coastal data-base assembled by SCCWRP. She also will provide a setting to test some of the ideas developed in Project 1. Collaboration with this program will allow her continued professional development in much the same way as the post-doctoral fellows, an opportunity welcomed by her director at SCCWRP.

N. SCOTT URQUHART (CSU and OSU) - An Investigator of the Project, is a research professor at OSU through September, 2001, but also holds an appointment as a visiting research professor at CSU. If the cooperative agreement proposed here is funded, he will assume an appointment as a research professor at CSU. He has worked as an applied statistician in agricultural experiment stations, and has taught graduate statistical methods at Cornell University and New Mexico State University. He has developed the trend detection perspective of EMAP, and worked with the development of many indicators.

3.6 *IMPORTANT ATTACHMENTS* - none

3.7. REFERENCES

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3.G. RESUMES

3.I. BUDGET

PROJECT 3: INDICATOR DEVELOPMENT					
Sponsor Contribution	Year 1	Year 2	Year 3	Year 4	Total
PERSONNEL SALARIES					
Academic Faculty:	\$14,066	\$14,629	\$6,561	\$6,889	\$42,145
Fringe Rate	\$2,687	\$2,809	\$1,293	\$1,392	\$8,179
Administrative	\$0	\$0	\$0	\$0	\$0
Fringe Rate	\$0	\$0	\$0	\$0	\$0
State Classified:	\$0	\$0	\$0	\$0	\$0
Fringe Rate	\$0	\$0	\$0	\$0	\$0
Post-Doctorates:	\$25,996	\$54,071	\$28,117	\$0	\$108,184
Fringe Rate	\$5,026	\$10,445	\$5,539	\$0	\$21,010
Non-Student Hourly:	\$31,200	\$16,224	\$16,873	\$17,717	\$82,014
Fringe Rate	\$3,931	\$1,898	\$2,059	\$2,250	\$10,138
Student Hourly:	\$0	\$0	\$0	\$0	\$0
Fringe Rate	\$0	\$0	\$0	\$0	\$0
GRA's:	\$0	\$0	\$0	\$0	\$0
Fringe Rate	\$0	\$0	\$0	\$0	\$0
TOTAL SALARIES:	\$71,262	\$84,924	\$51,551	\$24,606	\$232,343
TOTAL FRINGE:	\$11,644	\$15,152	\$8,891	\$3,642	\$39,329
TOTAL PERSONNEL:	\$82,906	\$100,076	\$60,442	\$28,248	\$271,672
DOMESTIC TRAVEL:	\$4,800	\$1,680	\$3,520	\$7,360	\$17,360
INTERNATIONAL TRAVEL:	\$0	\$0	\$0	\$0	\$0
MATERIALS AND SUPPLIES	\$2,000	\$368	\$385	\$403	\$3,156
OTHER DIRECT COSTS	\$1,325	\$2,550	\$1,457	\$254	\$5,586
In-State Tuition:	\$0	\$0	\$0	\$0	\$0
Out-State Tuition:	\$0	\$0	\$0	\$0	\$0
Publications:	\$0	\$210	\$220	\$230	\$660
Participant Stipends:	\$0	\$0	\$0	\$0	\$0
Participant	\$0	\$0	\$0	\$0	\$0
Participant Travel:	\$0	\$0	\$0	\$0	\$0
Equipment Use	\$1,325	\$2,550	\$1,457	\$254	\$5,586
Animal Care:	\$0	\$0	\$0	\$0	\$0
Consultants:	\$0	\$0	\$0	\$0	\$0
Other:	\$5,299	\$5,422	\$4,357	\$3,175	\$18,253
TOTAL OTHER DIRECT:	\$6,624	\$8,182	\$6,034	\$3,659	\$24,499
SUBCONTRACTS:	\$45,000	\$0	\$0	\$0	\$45,000
EQUIPMENT:	\$15,000	\$0	\$0	\$0	\$15,000
TOTAL DIRECT COSTS:	\$156,330	\$110,306	\$70,381	\$39,670	\$376,687
INDIRECT (F&A) COSTS:	\$54,599	\$49,638	\$31,671	\$17,852	\$153,760

TOTAL:	\$210,929	\$159,944	\$102,052	\$57,522	\$530,447
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3.J. BUDGET JUSTIFICATION

Personnel: Dr. Theobald will be responsible for directing the work on the landscape-level modeling for Project 5, writing project reports and scientific publications, and developing the models, for which 4 months of salary are requested. A post-doctoral fellow will be under the direction of Dr. Theobald, and is needed to bridge landscape-level GIS modeling with the spatial statistical aspects of the project. Funds are requested for the post-doc to cover 2 years of salary. Also, 2.5 years of salary is requested for a non-student hourly GIS technician to assist in data collection, maintenance, and dissemination to other project team members. Dr. Urquhart will work on the site scale indicator development for one month each of the first two years, and Dr. Ritter will work on the regional scale definition of taxa richness three months the first year, under a subcontract discussed below.

Fringe Benefits are calculated the same way for this Project as for all the other projects in this Program, namely at a starting rate of 19.1% for senior scientists, increasing by 0.5% annually, and at 12.6%, 11.7%, 12.2% and 12.7 over the life of the Program for support staff; indirect costs are expensed at 45%, again as with the other Projects.

Travel: Travel money is requested to cover the costs for Theobald and post-doc to travel to present research findings at national conferences as well as project-planning meetings. This will cover the costs for 10 three-day trips with airfare @\$450, per diem @\$38/day, lodging @\$95/night, ground transportation @\$100, parking tolls, etc. @\$40.

Equipment: Equipment money is requested to purchase 2 high-end workstations for the post-doc and GIS technician. Because we will be working with very large geographical databases (single files will likely exceed 1GB), we will require high-end workstations to provide reasonable performance for our work.

Network/system support: There is an NREL network hookup fee for each machine used on the project. The fee pays for internal support of the network manager, hardware and software purchases, updates, and installations for general systems use. This also includes maintenance of the network interfaces, file and computer servers, operating system upgrades, and general use equipment. The current rate is approximately \$190/month.

Hardware/Software Maintenance & Repair: This covers the cost of installation and repair, maintenance, diagnosis, and other technical services needed by project personnel.

Subcontract to Southern California Coastal Water Research Project (SCCWRP): The plan is for a member of SCCWRP, Dr. Ritter to invest about five months of effort and collaborate with the team, especially the members of this project, and Project 1 to some extent. Her activities will require at least four trips between the location of SCCWRP and her collaborators at CSU and OSU.