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PRIMENet

Ultraviolet Radiation/ Amphibian Populations Research Planning Workshop February 1-3, 1999

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PRIMENet UV / Declining Amphibian Research Planning Workshop
February 1-3, 1999
USEPA Mid-Continent Ecology Division Lab, Duluth, MN
Draft Final Report

Executive Summary

The PRIMENet (Parks Research and Intensive Monitoring of Ecosystems Network) is a system of 14 national parks, established as index sites for long-term monitoring of environmental quality and use as outdoor laboratories. From February 1-3, 1999, biologists from various Federal agencies and academia gathered in Duluth, MN to discuss research to be conducted at PRIMENet sites under a new interagency agreement (IAG) between the U.S. Environmental Protection Agency and the U.S. National Park Service. Pursuant to the recommendations of the IAG, participants were asked to formulate a research program that would address issues of amphibian malformations and declines and the potential role of ultraviolet radiation. Prior to this meeting biologists from EPA's Mid-Continent Ecology Division compiled data on amphibian populations and park characteristics, and determined that Acadia, Smoky Mountains, Rocky Mountains, Glacier, Sequoia-Kings Canyon, and Olympic National Parks were the feasible sites for this research.

Plenary session presentations and follow-up discussions elaborated the key issues to be addressed under this IAG, and representatives from each of the 6 candidate sites further described the relevant characteristics of their parks. Hypotheses to be addressed by this research fell under two broad headings: 1) the importance of metapopulation dynamics for amphibian surveys and monitoring; and 2) the potential effects of ultraviolet radiation on amphibians. During the past decade concerns about amphibian population declines and malformations have increased because both appear to be on the rise. Metapopulation biology deals with organisms that occupy patchy habitats where individual patch populations are vulnerable to extinction. Biologists have suggested that the metapopulation structure of wetland-breeding amphibians may make them susceptible to declines. In addition, because current survey and monitoring methods assume that individual wetlands support independent populations, revisions to these protocols may be warranted. Ultraviolet radiation has also been suggested as possibly contributing to both amphibian declines and malformations, but many of the relevant experiments have produced ambiguous and apparently contradictory results. The absence of good UV dose measurements in these experiments, however, makes comparison virtually impossible.

Although various controlled experiments were discussed, the participants agreed that the resources of this IAG should be focused on field surveys to close important empirical data gaps. Because intensive amphibian surveys could not be funded in all parks, a hierarchical design was suggested that would allow for UV dosimetry work in all 6 candidate parks and amphibian surveys in a subset of these. Amphibian surveys will be designed to encompass networks of potentially interacting wetland habitats. Estimates of aquatic UV dose and other habitat associated measurements will be made for each surveyed wetland. Using this approach, a metapopulation

survey framework will be tested as a means to evaluate the relationship between UV dose and amphibian habitat utilization in nature; this relationship has yet to be evaluated empirically. Through the collection of UV and associated habitat data in wetlands at all 6 parks, the potential for amphibian exposure to damaging levels of solar radiation will also be established. This work will also contribute to basic knowledge of amphibian distributions within national parks, amphibian metapopulation structure, UV levels in aquatic environments, and UV measurement technology.

I. Research Objectives

A. Agency objectives/roles

The EPA and NPS's objective in organizing a workshop on solar ultraviolet (UV) radiation-related amphibian research was three-fold: 1) to review the state of science in UV dosimetry, amphibian population monitoring, and amphibian UV-effects research, 2) to engage the Federal and academic scientific communities in planning a strategy for UV-dosimetry and amphibian effects research at PRIMENet (Park Research and Intensive Monitoring of Ecosystems Network) sites to be carried out through an existing interagency agreement (IAG) between the Environmental Protection Agency and National Park Service, and 3) to identify opportunities for collaboration among Federal agencies engaged in this research now and in the future. The EPA has collaborated with the NPS to establish a network of sites for intensive long-term monitoring of atmospheric pollutants and stress-response research on environmental effects related to atmospheric pollutants (including UV effects) and climate change. The EPA has supported the establishment and maintenance of Brewer spectrophotometers at 14 PRIMENet sites to measure UV-A, UV-B and ozone. The NPS contributes to air and deposition monitoring at theses sites with NADP (wet deposition) and CASTNET (dry deposition) monitoring stations. In addition, meteorological and visibility (selected sites) parameters are also monitored at the PRIMENet sites.

Effects research currently underway at PRIMENet sites through a past IAG between NPS and EPA includes research on the extrapolation of environmental measurements across natural landscapes, development of indicators of environmental change, contaminant screening, and development of amphibian monitoring methods. The latter was rated among the top 10 research needs by the NPS. Amphibian monitoring work at PRIMENet sites is nested within the NPS nationwide Inventory and Monitoring (I & M) Program, which involves establishing inventories of all major natural resources in 250 major resource areas over a 10 year period. The FY2000 DOI (Department of the Interior) budget initiative includes a substantial addition to the I & M Program to augment the inventory.

EPA has been involved in UV-dosimetry and UV-effects work with amphibians over the past few years. In addition, EPA has a strong interest in developing methods of extrapolating dose and effects measurements from sites to regions, across regions, across species, and from the organism to population and metapopulation levels, concordant with the goals of EMAP (Environmental Monitoring and Assessment Program) and CENR (Committee on the Environment and Natural Resources).

In response to nationwide concern over amphibian declines and malformations, the Secretary of the Interior has recommended that the DOI take the lead on this issue. A draft budget proposal for FY2000 has been submitted in support of a 20-year amphibian initiative that includes both monitoring and research elements. A number of BRD (Biological Resources Division of the U.S. Geological Survey) researchers who have been active in amphibian research and planning the future

DOI strategy were invited to this workshop to facilitate collaboration among the three Federal agencies involved and coordination and continuity of research efforts at PRIMENet sites. A full list of workshop attendees and scheduled presentations and discussion groups are included as Appendices 1a and 1b.

B. Research hypotheses

Prior to the February 1999 meeting, representatives from EPA's Mid-Continent Ecology Division (MED) compiled short lists of hypotheses that this research effort might address (Appendix 2). These hypotheses focused on issues of amphibian exposure to UV radiation and amphibian population monitoring. During the meeting several of these hypotheses were determined to be untestable during the 2 to 3 year time-frame of the IAG. Final lists of hypotheses to be addressed were agreed upon. There was discussion about whether the primary goals of this IAG are research or monitoring. Due to the short duration of the present IAG and uncertain availability of future resources, everyone agreed that this effort must focus on answering specific research questions. However, because monitoring is a concern of both the EPA and NPS, components of this work will be designed to evaluate the feasibility of novel approaches for future monitoring.

The subgroup discussing population survey issues agreed that wetland-breeding amphibians theoretically resemble metapopulations, and that survey and monitoring efforts that focus on networks of potentially interacting subpopulations should be investigated. It was also agreed that, unless extensive historical amphibian survey data are available, hypotheses relating to extinction and colonization could not be addressed. Thus, these studies will generally focus on patterns of habitat occupancy. Four testable hypotheses were identified for further discussion in the research planning phase:
(1) the distribution of occupied and unoccupied wetland breeding habitats conforms to the expectations of metapopulation theory;
(2) when effects of wetland isolation and size are accounted for, the probability of wetland occupancy is inversely related to estimates of UV dose;
(3) rates of local extinction are significantly higher in more isolated and smaller wetlands (only if historic data exists); and
(4) the spatial distribution of a species is a suitable surrogate for diagnosing temporal population trends in amphibians.

The group discussing amphibian UV-effects research decided that the hypothesis on which we should focus this research is: developmental stages exhibit greater frequencies of morphological abnormalities and/or lower survivorship in wetlands where higher aquatic doses of UV are received. There were also suggestions to add immuno-suppression to the list of potential effects, and to consider UV as only one of many potential stressors in these systems. The group identified UV exposure issues as a key to evaluating the hypothesis, and listed several related tasks that could be addressed under the IAG:
(1) measure UV in amphibians habitats;

(2) calibrate habitat-specific measurements to the local Brewer spectrophotometer measurements;
(3) consider a broader light spectrum than just UV-B because other wavelengths may exacerbate or ameliorate effects; and
(4) characterize amphibian behavior as it relates to potential exposure during sensitive developmental windows.

C. Objectives of research performed under this IAG

Each of the PRIMENet sites is currently equipped with UV monitoring equipment to gather systematic data on the potential effect of ozone depletion on ecological resources. In association with the collection of this data, one of the objectives of the IAG is to investigate relationships between UV exposure and effects on amphibian populations. The workshop participants were asked to develop a collaborative research plan that advances techniques for measuring and extrapolating UV exposures, monitoring and modeling amphibian populations, and assessing associations between population responses, UV exposure and co-correlated stressors.

II. Background

A. Amphibian monitoring/surveys

1. General background

Inventory and monitoring efforts are costly and require long-term or permanent dedication of resources. Such efforts should not be initiated without first establishing the ultimate project goals and the commitment required to achieve these goals. The determination of the number of sites to be sampled and their locations should be shaped by the goals of the project and not individual biases or resources. Without the resources to achieve the stated goal(s), the project is virtually certain to fail.

Monitoring programs are generally able to detect deterministic trends over time. Because populations fluctuate annually due to weather and random events, monitoring efforts should concentrate on trends occurring over longer intervals. Ideally the length of the interval over which trends are reported should be based on empirical observations of natural variability in the species of interest or a closely related species. In addition the magnitude of the trend considered biologically significant (e.g., X% per year) should be determined. The reporting interval and magnitude of interest, along with the chosen alpha and beta levels, are then used to determine the number of sites required to avoid detecting false trends and failing to detect meaningful trends. Finally the spatial extent over which trends are of interest (e.g., individual wetland, park-wide) will influence the area over which survey sites are distributed.

The next consideration is the sampling methodology to be used. It is important to demonstrate that the methods to be used provide accurate and repeatable estimates of the numbers of individuals present at a site. Repeatability can be determined by repeated sampling at a single site, while accuracy is more difficult because it requires that the actual number of individuals present is known. Because the work we are proposing will be based primarily on presence/absence surveys, repeatability will be more important than accuracy. Resampling a subset of sites throughout the season would be useful to assess seasonal variability in detection. Species that cannot be sampled reliably should be avoided.

2. Metapopulation structure and surveys

As noted above, traditional monitoring programs require long-term commitments to detect trends in regional distribution or abundance. In addition, natural features of the life history and regional distribution of amphibians further complicate these attempts to detect significant shifts in abundance. However, by altering the amphibian inventory and monitoring paradigm to better fit the natural history of these animals, we may be able to increase our power to rapidly detect regional trends and distributional patterns of biological significance.

Many theoretical and empirical studies of organisms that occupy patchily distributed habitats, such as wetlands, suggest that regular localized extinctions and recolonizations may be a natural feature of these 'metapopulations' (see Hanski 1998 for additional background). As such, the spatial configuration of habitat patches may determine the likelihood of regional extinction in networks of patches, and certainly influences the extinction and colonization probabilities of individual habitat patches. Pond breeding amphibians utilize inherently patchy aquatic breeding habitats, and studies have found various species to exhibit characteristics consistent with metapopulation models. Thus, any attempt to monitor amphibian populations for regional declines must recognize that local extinctions are probably a natural feature of even healthy amphibian metapopulations.

Traditional estimates of local amphibian abundance and current regional monitoring efforts have been shown to possess little power to detect meaningful population trends in a timely manner (Reed and Blaustein 1997; Mossman et al. 1998). Because declines at the level of the metapopulation would be manifested by local extinctions in excess of colonizations and may produce detectable spatial patterns of habitat occupancy, surveys that encompass all potential breeding sites within defined regions may provide a more tractable means for detecting on-going declines. While extinction and colonization will not be balanced over short intervals, a strength of this type of data is its potential to reveal landscape-level patterns beginning with a single year's data collection. For example, if occupancy is primarily driven by random extinction and colonization, occupancy will be strongly related to pond isolation. However, the influence of other stressors, such as elevated UV dose, on pond occupancy could also be evaluated using this approach and multiple logistic regression or other analyses. This approach could be used to screen for the effects of candidate stressors and to guide future experimental work.

In controlled experiments, researchers have demonstrated that a variety of stressors (e.g., UV-B, anthropogenic organic compounds) could potentially produce amphibian population declines, but in most cases the relative distribution of amphibian populations and these stressors has yet to be established. One exception is the established allotropic distribution of introduced trout and Rana muscosa in Sequoia-Kings Canyon National Park (Bradford 1989, Bradford et al. 1998). Two notable amphibian studies have also made explicit use of spatial models to better understand changes in regional species distributions. First, using an extensive distributional time-series for Rana lessonae, Sjögren-Gulve and Ray (1996) used a stepwise logistic regression approach and simulation modeling to evaluate factors hypothesized to drive observed patterns of population turnover in ponds. Second, Skelly and Meir (1997) compared observed patterns of amphibian population turnover in breeding ponds at a Michigan reserve with the patterns predicted if: 1) metapopulation forces are driving turnover; 2) habitat succession is driving turnover; and 3) turnover occurs at random. Because some rate of local extinction must be expected in a program designed to monitor species exhibiting metapopulation characteristics, and especially one designed to detect declines, protocols should be designed such that patterns of habitat occupancy or turnover can be used to test alternative models such as described above.

Current amphibian monitoring protocols focus on roadside calling surveys, where individual

wetlands separated by a minimum of 0.5 miles are identified and visited several times throughout the spring and summer. These surveys are well suited to determining broad species distributions and detecting changes occurring over large regions and long periods of time. However, data collected using this approach are poorly suited to evaluate factors correlated with regional shifts because potentially crucial local features of individual wetlands or wetland networks are largely ignored. If an objective of surveys and monitoring is to understand the factors influencing regional patterns of habitat occupancy and turnover, surveys should include additional data collection, such as isolation distance, water chemistry, and vegetation characteristics. While this approach is novel and unproven, the above examples suggest that data collected using a geographically comprehensive survey framework will allow improved power to evaluate factors suspected to drive current distributions. The power of geographically comprehensive surveys for improved detection of trends over time will have to be evaluated using simulated data, because of the absence of sufficient data sets and the immediate practical interest in the power of this approach. With the proposed increase in DOI resources for amphibian monitoring and research, a new sampling approach that facilitates regional inventories and pattern analysis would be a valuable tool.

The implementation of geographically comprehensive survey and monitoring protocols would first require the identification of survey regions in which all patches would be sampled. Patch sampling would involve determining amphibian presence or absence and collecting data on associated habitat characteristics and potential stressors. Regions could be defined by watershed or other boundaries likely to limit most individuals to within-region movements. Densities of potentially suitable amphibian breeding habitat could be identified from wetland inventory maps for selection of regions optimal for surveys. Because habitats are only surveyed for presence or absence, and the effects of multiple factors (e.g., isolation and UV dose) will be analyzed simultaneously, a large number of patches (e.g., >100) will need to be sampled to attain sufficient statistical power.

B. Ultraviolet radiation: effects and dosimetry

1. Effects of UV on amphibians

Solar ultraviolet (UV) radiation, and more specifically the UV-B region of the spectrum (see below for further definition), has been cited as a potential contributor to the recent apparent declines of, as well as malformations in, amphibian taxa. There are several factors associated with UV radiation that make such hypotheses particularly worthy of investigation. First, there is little argument that the expected chlorofluorocarbon-caused reduction in the stratospheric ozone layer has occurred as predicted and has resulted in the expected significant increases in terrestrial UV-B intensity (UNEP, 1998). Second, the capacity of UV-B radiation to directly impact biological macromolecules, including DNA, in a variety of taxa has been well documented. Third, early life stages of all taxa, and especially species in which significant metamorphosis occurs, are particularly susceptible to the damaging effect of UV-B radiation. This susceptibility is associated with the potential for greater exposure to sunlight, the potential for UV penetration through the entire embryo or early larvae, the rapid replication and differential expression of DNA, and the accelerated

production of potential UV- receptor biomacromolecules during these life stages. And fourth, other global and regional impacts not directly associated with atmospheric transmission of UV can significantly impact the UV dose received in aquatic environments (Schindler et al. 1996). Many of these impacts are associated with alteration in the flux of DOC, by far the most effective UV-attenuating component of natural waters (Williamson et al. 1996). Other impacts include subtle alterations in nutrient loads (and concomitant algal growth), loss or alteration of riparian vegetation, sedimentation, etc.

There have been a number of laboratory and field studies examining the effects of UV radiation on survival and development of amphibians. There is no question that it is possible to elicit reduced survival and a wide range of malformations in early embryonic stages exposed to UV (e.g., Worrest and Kimeldorf 1975;1976; Blaustein et al. 1994; 1995; 1997; Grant and Licht 1995; Long et al. 1995; Hays et al. 1996). Recent studies have shown that UV light can also elicit adverse developmental (specifically limb malformations) effects in later stages of metamorphosis in amphibians (Ankley et al. 1998; in review). The major question, therefore, is not whether UV light can adversely affect frogs, it is whether or not current UV intensities, or projected changes associated with global climate alterations, adversely affect amphibians. Currently at the heart of this controversy are the results of a series of manipulative studies, conducted predominantly in the field, which have yielded ambiguous or conflicting data. Specifically, Blaustein and coworkers (e.g., Blaustein et al. 1994; 1995; 1997) have published several papers suggesting that current levels of UV radiation (specifically UV-B) are sufficient to reduce survival of at least some amphibian species. By extension, these UV effects would only be expected to worsen, at least in the short-term (UNEP 1998). Other investigators, however, have not been able to replicate the results of Blaustein et al. (e.g., Grant and Licht 1995; Ovaska et al. 1997; Corn 1998). Although some of the seeming among-study contradictions may be explainable solely based on experimental design (e.g., timing and duration of exposure), the largest uncertainty in terms of comparison is due to dosimetry issues. Basically, the majority of studies conducted to date with UV and amphibians, in particular those in the field, have done so little in terms of dosimetry, either from a quantitative and qualitative perspective, that it is virtually impossible to compare them to one another, or to project the implications of their results to other settings (including future scenarios of potentially increasing UV intensities). This general shortcoming is further exacerbated by a lack of reasonable UV dosimetry data for natural amphibian habitat.

The research outlined in this report will directly address the issue of effects extrapolation in the context of UV dosimetry in two ways. First, planned laboratory and natural sunlight exposure studies, in support of the research outlined herein, will emphasize the appropriate measurement of dose. This work, although not directly supported by this IAG, should help put the data collected into a realistic context from the perspective of dose-response relationships; studies will be conducted by both the EPA (MED) and the BRD (Columbia). Second, work supported by this IAG and other research sponsored by EPA (in collaboration with the University of Minnesota), should help address the issue of UV dosimetry relative both to amphibian habitat and larval behavior.

2. UV dosimetry

The question of whether increasing reports of amphibian declines or malformations are associated with UV intensity can only be addressed at the habitat level. Regional monitoring of ozone layer depth and/or UV-B intensity, while useful in characterizing global UV fluctuation and perhaps in providing baseline intensity information, provides little habitat-specific intensity data. For example, regional monitoring data might suggest little overall increase in UV intensity, yet even small alterations in DOC concentration or character (due to local or global effects) could result in an order-of-magnitude increase in total UV dose in specific water bodies (Schindler et al. 1996). The potential for significant temporal fluctuation associated with all of the factors discussed above exacerbates the need for habitat-specific UV characterization and quantification.

The science of dose estimation for solar actinic radiation (SAR), or more specifically UV (ultraviolet radiation: UV-B = 280 nm to 320 nm, UV-A = 320 nm to 400 nm), is largely undeveloped for aquatic habitats. In general, attempts to estimate doses of UV or SAR have been based either on projections of single solar radiation measurements and/or calculations based on global location, season, time of day, etc. These estimations fall far short of accurately quantifying UV dose because several key factors, including weather, attenuation characteristics of the water column, and animal behavior, are not quantitatively considered.

The estimation of aquatic UV dose, although complex, can be considered to consist of two major components: 1) terrestrial UV dose; and 2) transmission of light within the aquatic environment. Terrestrial irradiance (the total intensity of direct and reflected radiation delivered to a horizontal surface) is influenced by geometric considerations including global location, season and the time interval considered. In addition more variable factors, including attenuation by stratospheric ozone, other atmospheric components, weather and local shading, can dramatically influence irradiance. The effects of location and time are easily modeled using trigonometric calculations that predict the angle-of-incidence of sunlight and the associated dispersion of radiation over a horizontal surface. The results of these initial calculations can be modified by more complex algorithms that estimate the effects of various atmospheric factors. However, these variable factors are much more difficult to model with confidence, particularly when very specific local habitats are considered. Historical data on terrestrial irradiance are limited to a few locations and/or very short time periods. These data, although of use in calibrating or testing irradiance models, have little direct application for the estimation of UV dose at PRIMENet sites.

The second component of UV dose estimation, transmission of light in aquatic environments, adds significant complexity to UV dose estimates for specific taxa. In addition to the factors affecting terrestrial solar transmission, the aquatic environment introduces several highly variable factors that can dramatically alter the intensity of irradiance reaching any given location or micro habitat. These factors include dissolved organic material (DOM or DOC), suspended inorganic and organic material, and shading vegetation. The wavelengths of radiation that comprise sunlight spectra are affected differentially by all of these factors. Most important for UV dose estimation

in aquatic habitats is DOC, which depending on its constituency (fulvics, humics, tannins, etc.) can vary significantly in its ability to attenuate UV radiation. Shading and reflection can increase the ratio of UV relative to visible light, and the intensity of shorter wavelengths tends to be diminished more significantly at low sun-angles. For example, at dawn and dusk UV-B is undetectable yet visible radiation can be sufficient for reading.

Finally, not all wavelengths of light are equally effective at eliciting a given response, either physiological or behavioral. For example, Setlow's DNA dose, a quantitative evaluation of the potential for DNA damage, is determined by the absorption of radiation by DNA which occurs largely in the UV-B range of terrestrial solar radiation (the DNA absorption maxima is at 254 nm and tapers steeply to essentially zero at 310 nm). Even small changes in the attenuation of UV-B by DOC or other factors can have order-of-magnitude effects on the calculated dose, depending on the spectrum of the response being considered. Hence, dose estimation should minimally include an initial quantification of the light spectra present. Also adding to this complexity is the need to characterize specific taxa as to their potential for exposure to sunlight. For example, factors influencing exposure risk will include the amount of time a species or life-stage spends in open water during high-intensity events (e.g., mid-day, mid-summer, clear-sky conditions), and any outer tissues or other materials that might shield them from radiation (e.g., shell, carapace, or constructed dwelling).

III. Experimental Design

A. Park selection

1. Criteria

From descriptions provided by park representatives, workshop attendees compiled information on the characteristics of the 14 PRIMENet sites to identify those best suited for studies relevant to: 1)Investigating habitat-specific UV levels; 2) Considering issues of amphibian decline; 3) Conducting manipulative UV effects research, and 4) Testing a geographically-comprehensive survey protocol. The criterion for UV studies was a range of UV-exposures which might be provided by the existence of an elevation, DOC, or vegetation gradient across aquatic habitats. There were two criteria identified for deciding whether amphibian declines should be addressed in the national parks. One was whether there was evidence that park amphibian populations are presently less abundant or widespread than they have been historically. The other was whether species present in the parks were in apparent decline in other non-park locations. Criteria for effects research included the presence of species of interest that metamorphose during their first summer and a gradient of UV exposure within the park. Finally, because we are interested in investigating the use of techniques that require patch-based data, the presence of species that utilize discrete wetlands as breeding habitat is critical. Additional criteria for geographically comprehensive surveys included the presence of several detectable and widespread species of wetland breeding amphibians, at least 100 potentially suitable discrete wetland breeding habitats, and the existence of GIS landscape coverages (e.g., elevation, hydrography, trails, roads, land-cover, historic amphibian occurrences) for the park. Finally, wherever present, species overlap between parks was noted.

2. Choices

Prior to the February 1999 meeting eight of the PRIMENet sites were eliminated from further consideration, based on the above criteria. Denali and Hawaii Volcanoes National Parks were eliminated due to a lack of multiple native species. Everglades National Park was eliminated due to a lack of sufficient topographical relief such that individual discrete wetlands could not be easily identified. Shenandoah and Virgin Islands National Parks were eliminated due to a lack of sufficient numbers of wetlands. Big Bend and Canyonlands National Parks were eliminated due to the regional dominance of amphibian species that are difficult to survey confidently due to their unpredictable activity patterns. Theodore Roosevelt National Park was eliminated due to a lack of basic survey data to indicate how many wetlands and what species are present.

At the meeting, representatives from Acadia, Great Smoky Mountains, Rocky Mountain, Glacier, Sequoia-Kings Canyon, and Olympic National Parks presented additional background relevant to the site selection criteria (summarized in Appendix 3). Based on these presentations and follow-up discussions, Great Smoky Mountains and Sequoia-Kings Canyon National Park were determined to be less suitable for implementation of geographically comprehensive amphibian

surveys. Great Smoky Mountains National Park was eliminated due to a marginal number of wetland habitats, and Sequoia-Kings Canyon National Park was generally considered to be less suitable due to suspected aerial loadings of anthropogenic organic chemicals that might confound effects of interest. However, the severity and extent of contamination is not established, and several representatives thought other parks may also receive similar inputs.

3. Research sites in parks of interest

Study sites within the parks will be identified using wetland maps and records of past amphibian observations to identify suitable areas. The primary concern for the survey component of the project is that at least 100 potentially suitable wetland breeding habitats can be located and sampled. In some parks this may require visiting virtually all available wetlands in the park, while elsewhere these surveys will only encompass a fraction of the available wetlands. In cases where all wetlands cannot be surveyed, parks will be subdivided based on watershed or other boundaries, and as many of these subregions as possible will be surveyed. Sampled wetlands should be distributed along gradients suspected to influence aquatic UV-dose (e.g., elevation, DOC, vegetation), and areas exhibiting an isolation gradient should be favored.

B. Species of interest

1. Criteria

We compiled basic information on all amphibian species known to occur at PRIMENet sites (Appendix 4), and species criteria varied depending on the research component under consideration. For geographically comprehensive amphibian surveys, species criteria were that discrete wetlands are the preferred breeding habitat, that some life stage is readily detectable in this habitat for much of the summer, and that species have a wide distribution within a park. Frogs and toads were noted as preferable over most salamanders, as were early breeders and species with shorter life spans because they will be less likely to skip breeding and yield spurious annual absences. Table 1 lists the pond breeding species occurring at each of the five parks still under consideration for survey work. In addition, species that are documented as declining in parks or other areas will be given priority when the suite of species to be surveyed is determined for each park. For effects research, the primary criteria for assessing potential species of interest was a life cycle conducive to manipulative experimentation and monitoring of the different life stages (i.e., metamorphoses during first summer).

Table 1. Wetland-breeding amphibians at PRIMENet sites. Asterisks indicate species noted by participants as particularly feasible for proposed survey efforts, due to relative ease and confidence of sampling. Footnotes indicate species noted as especially troublesome for reasons explained in the footnotes.

Species	Acadia	Rocky Mountain	Glacier	Sequoia-Kings Canyon	Olympic
Spotted salamander*	x				
Red-spotted newt*	x				
Four-toed salamander[1]	x				
Spring peeper*	x				
Gray treefrog*	x				
American toad*	x				
Leopard frog[2]	x				
Pickerel frog[2]	x				
Bullfrog	x			x	x
Green frog*	x				
Wood frog*	x	x			
Tiger salamander*		x			
Chorus frog*		x			
Boreal toad*		x	x	x	x
Long-toed salamanders			x		x
Columbia spotted frog			x		
Pacific treefrog*			x	x	x
Yosemite toad				x	
Mtn. yellow-legged frog*				x	
Northwestern salamander					x
Red-legged frog[3]					x
Cascades frog					x
Rough-skinned newt*					x

[1] difficult to detect in favored bog habitats
[2] hard to locate
[3] weak call makes them hard to detect at low densities

2. Target species

Target species will have to be identified on a site by site basis using the criteria discussed above, and surveys will be optimized for these species. However, information will be gathered on all amphibian species detected during surveys. Wherever possible data will be collected on species that overlap between parks, but species overlap was not identified as a critical characteristic for park selection. Species potentially of interest due to their presence at more than one park are boreal toads

(Bufo boreas) and wood frogs (Rana sylvatica). These two species are also of particular interest because their eggs and tadpoles are relatively easy to detect.

C. Survey strategy

The basic goals of the proposed surveys are: 1) To assess the logistic efficiency and diagnostic power of geographically comprehensive amphibian surveys; 2) To gain a better understanding of the doses of UV-B radiation likely to be received by embryonic and larval amphibians; 3) To determine the factors influencing aquatic UV dose, and; 4) To determine if current amphibian distributions are consistent with the negative impacts associated with elevated UV exposure. To achieve these goals we have proposed a hierarchical framework whereby some level of habitat-specific UV dosimetry will occur at all 6 PRIMENet candidate sites, while more time- and labor-intensive efforts will occur at some of the sites identified as suitable for geographically comprehensive amphibian surveys.

The workshop participants discussed time-lines for the work to be conducted under this IAG and through in-kind cooperation, extending from FY1999 through FY2000 or FY2001. Opportunities for collaboration with investigators working on related research in the parks (Appendix 5) we also identified. It was also concluded that the IAG funds should be used to support amphibian surveys and habitat-specific UV measurements in the parks, while related experimental studies would be best addressed through in-kind cooperation between interested parties. Project schedules were not discussed in detail, but some general targets were suggested. Dr. Corn suggested that retrospective spatial analyses of recent park amphibian inventories be completed before further field surveys are initiated. He suggested that the summer of FY1999 be used for park and study site selection within parks and possibly limited field surveys, while FY2000 be used for more extensive surveys integrated with UV analyses.

1. Spatial design

The primary reason for collecting geographically comprehensive survey data is that habitat isolation has been repeatedly demonstrated to influence wetland colonization and extinction, and as a result impacts occupancy patterns in amphibian systems. Thus, for each wetland a primary variable of interest must be the distance to the nearest occupied site(s). Although factors such as water quality may also influence habitat use, isolation effects must be accounted for or controlled for, less their effects obscure significant patterns of greater interest. Because standardizing isolation is difficult or impossible in most natural systems, techniques such as multiple logistic regression are used to assess the effects of isolation and other factors on habitat occupancy. Thus, it is critical that amphibian presence/absence and habitat/stressor characteristics be established for all potentially interacting wetlands within a given region. The scale at which wetlands support potentially interacting populations is difficult to establish and varies between species. However, based on published records, wetlands separated by more than 3 km are probably unlikely to exchange frequent migrants for most species. Certain landscape features, such as large lakes and mountains, may also

represent barriers to movement and constrain likely interactions.

Because national parks will often be too large to attempt surveys of all park wetlands, and some areas may be prohibitively difficult to access, it was suggested that each park be divided into multiple potential study regions based on watershed boundaries. Potentially suitable wetland breeding habitats in each of these watershed regions would be located using National Wetland Inventory (NWI) maps and aerial photographs, so that watersheds could be categorized based on number and density of wetlands, elevation, and accessibility. Because the goal of this project is to answer a research question (i.e., does aquatic UV dose have a negative effect on wetland occupancy), and not an unbiased amphibian inventory or monitoring program, site selection for this project need not be completely randomized. Areas known to be completely devoid of species of interest will be avoided, as will areas supporting too few wetland habitats to produce sufficient data return for effort invested (i.e., < 10). Watersheds identified as "reasonably accessible" and containing at least 10 wetland patches and species of interest will be targeted for surveys. These watersheds will then be divided into categories based on elevational ranges, so that sampling can be stratified among elevation categories equally. The general consensus was that, as long as each region contains at least one occupied patch and all potentially interacting regional habitat patches are surveyed, data from non-contiguous regions within a given park could be pooled with little effect. The potential impacts of data pooling in this way should be considered in greater detail.

Concern was voiced about making these survey techniques more directly relevant to unbiased monitoring efforts. One suggestion was to use a sub-sampling technique analogous to the 'point-quarter' technique utilized in vegetation surveys. Another possibility would be to randomly choose individual wetlands and then survey all wetlands within some set distance. A modeling effort would probably be best suited to evaluating the utility of various site selection and sampling schemes.

2. Amphibian survey methods

a. Retrospective analyses

In recent years, many national parks have completed extensive inventories of the amphibian populations within their boundaries (Table 2). In many cases these surveys encompassed essentially all potential wetland breeding sites within entire parks or large regions of the parks. While identical survey methods were not utilized between all parks, these data sets provide opportunities to begin to evaluate the effects of wetland isolation and other landscape features on habitat patch occupancy. We are beginning to analyze the published inventory data from Rocky Mountain National Park (Corn, et al. 1997). Amphibian inventory data will be included as layers on a GIS map of the park to facilitate spatial analysis of amphibian and landscape data. We will send out a letter of inquiry to all other parties in possession of similarly extensive amphibian inventory data from PRIMENet sites, offering to collaborate with researchers on similar analyses. To these collaborations we bring the MED's permanent GIS staff and expertise with landscape and metapopulation level analyses.

Table 2: Recent inventories of PRIMENet site amphibians

Park	Researcher(s)
Acadia	
Great Smoky	Ken Dodd, Jim Petranka
Rocky Mountain	Steve Corn
Glacier	Leo Marnell
Sequoia-Kings Canyon	Gary Fellers, Roland Knapp, David Bradford, Kathleen Matthews
Olympic	Bruce Bury and Mike Adams

b. Additional data collection:

To maximize the ability to draw reliable comparisons between parks, future surveys should utilize standardized methods and levels of effort, both within and between parks. A variety of survey techniques are utilized to survey for amphibians, but unfortunately no one technique is ideal for detecting all species. Survey techniques will be focused on those that are most useful in sampling lentic wetland habitats (e.g., lakes, ponds, marshes, swamps). The primary variable of concern for each wetland is the presence-absence determination for each of the species occurring in the park. Although we are interested in any evidence of a species' occurrence and any such data should be recorded, evidence of local breeding activity is the information of choice. Survey techniques suggested by panel members were visual surveys, calling surveys, sweep net sampling, and traps. Calling surveys were considered useful but insufficient, due to the often weak link between these observations and the presence of breeding populations. Traps were also considered potentially useful but insufficient because they passively sample only small portions of wetlands. Larval surveys utilizing a combination of visual searches and sweep net samples were generally considered the most reliable method for establishing the presence of breeding populations. Repeated sampling at a subset of sites was suggested as a means of establishing the probability of false negatives in larval surveys, and how detectability varies between species.

At some point during visits to each pond the team will also collect water samples, perform other necessary UV measurement duties (see below), and measure a variety of habitat characteristics. Because amphibians utilize aquatic and terrestrial habitats, and both may be limiting, aspects of each of these environments will need to be characterized. A suite of water quality variables will be measured including temperature, turbidity, hardness, etc. Water temperature may be among the most important habitat variables measured because it may be related to UV dose and can dramatically influence larval growth and development. If contaminants are considered an issue to be addressed at specific park(s), the team may also need to collect samples for this purpose. For each pond the exact location and dimensions should be accurately determined using a global positioning system (GPS).

3. UV dosimetry measurements

The overall goal of the initial two-year monitoring effort should be to characterize the range and variability of solar radiation flux among all wetlands selected for geographically comprehensive amphibian surveys. These data will then be used to test for correlation between estimated solar radiation dose and the presence or absence, and possibly the relative density, of amphibians among patches. In addition, the range of solar radiation flux among measurement locations will provide insight into the predictive usefulness of the Brewer spectrophotometers located at PRIMENet sites.

Two major points should be emphasized relative to this effort. First, solar radiation measurement at the selected PRIMENet sites should be guided by the amphibian survey efforts. If possible, all wetlands surveyed for amphibians should also be characterized relative to their solar radiation exposure, and then, time allowing, additional sites should be examined. Second, characterization of additional factors including animal behavior, seasonal variability in UV attenuation and shading factors would be required to confidently assess UV dose received by developing amphibians. Therefore, due to limited funding and time, these data will provide only preliminary estimates of UV dose.

Solar radiation measurements and habitat characterization will involve several procedures to be detailed in later technical documents. In general, water samples from each patch will be collected and returned to the EPA's MED Laboratory in Duluth, Minnesota for spectrophotometric quantification of spectral attenuation capacity. Field-filtered (0.45 um) water samples need to be shipped to MED within 5 days hours of collection. Mid-day, full-sun extinction data will be collected using a UV-A/UV-B broad waveband radiometer. Both the water samples and the extinction data will be collected from a central, unshaded (if possible) location within each wetland. A photographic or sketched record of wetland coverage by aquatic vegetation and algae will be generated for each patch. Gross shading (large vegetation, physical geography, etc.) will be characterized by estimating the angle of inclination at several compass points from a central location within each patch. Given sufficient time, additional efforts could include selected-patch UV-B intensity mapping and day-long extinction quantification using polysulfone dosimeters, and patch spectral attenuation and dosimetry using a portable spectrometer (this would necessitate site visits by an EPA MED scientist).

D. Manipulative studies

Given the resources needed for baseline UV dosimetry work and amphibian surveys at select PRIMENet sites, it is not envisioned that there will be support for manipulative field studies via this IAG. However, this type of experimentation could provide a critical link between field-collected UV dosimetry and presence/absence data in terms of developing causal stressor-response associations. Therefore, if further resources become available, these types of studies should be considered. The types of manipulative studies that seem reasonable fall into two broad classes: 1) Those in which a given habitat containing amphibians is systematically altered so as to change the UV dose, and; 2) Those in which subsets of animals from a given "cohort" are transplanted to multiple locations receiving differential UV exposures. Of course, studies that have attributes of both types of experiments could also be conducted. In the first case, UV dose to systems could be varied through

"natural" alterations, such as increasing or decreasing shading, or modified through the use of wavelength-specific or neutral density filters. The whole system (e.g., wetland) could be modified, or replicate experimental units within the system could be subject to UV modifications. The latter of these alternatives has been commonly utilized (e.g., Blaustein et al. 1994; 1995; 1997; Corn 1998). Transplantation studies, although potentially more complicated, could also be very useful in defining cause-effect relationships. Transplantations would be particularly attractive in parks where a natural gradient of UV intensity can be identified that is consistent with the distribution of the amphibian species under consideration. In any type of manipulative study, an important aspect of data collection would include an evaluation of animal behavior in the context of UV exposure. Further, these studies would need to be conducted with careful attention given to continual on-site solar exposure estimation.

Concurrent with the field research conducted at the National Parks there will be controlled experimentation concerning the effects of UV on amphibian survival and development at both EPA (MED) and BRD (Columbia) facilities. Although not directly supported by the EPA/NPS IAG, this work will be conducted so as to complement, to the fullest extent possible, studies at the park sites. For example, building upon the observations of Ankley et al. (1998; in review), EPA scientists will continue to investigate the effects of UV on survival and development of native North American Ranids. One emphasis of these studies will be on hindlimb dysmorphogenesis, but an important component of the work also will be evaluation of the comparative early life-stage sensitivity of several anuran species to UV light. For example, comparative studies have been/will be conducted with the northern leopard frog, green frog, mink frog and wood frog. Additional species may be added depending upon site and species selection associated with the PRIMENet studies. The point of these studies is to develop robust dose-response relationships, using both simulated (laboratory) and natural sunlight, for survival through metamorphosis and specific developmental endpoints. Dose-response data will be collected with careful attention to UV exposure characterization, such that these dose-response relationships can be directly extrapolated to field collected UV exposure data.

The natural sunlight experimentation will be conducted using the exposure facility described by Ankley et al. (in review). This system enables a large degree of flexibility with respect to sunlight dose (both from a quantitative and qualitative perspective), while maintaining a highly controlled environment in all other respects (e.g., temperature, general water quality, influence of external variables such as precipitation). Further, the system design facilitates performance of precisely replicated studies in terms of homogenous sunlight dose across a potentially large number (>40) of experimental units. Finally, real-time, continuous UV monitoring provides unique capabilities in terms of dose estimation in simulated field settings. Given these characteristics, the system provides unique opportunities, not only for dose-effects research, but for behavioral studies focused upon defining potential UV dose to amphibians as a function of key, potentially-sensitive stages of development.

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APPENDIX 1a
List of attendees

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Dr. Steven Bradbury
Dr. Steven Hedtke
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Dr. Steve Diamond
Mr. Gary Holcombe
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Ms. Sharon Batterman

APPENDIX 1b
Schedule of presentations / activities:

Research Planning for Amphibian Monitoring and Assessment at National Park Service/USEPA Index Sites

February 1-3, 1999
USEPA/ORD Mid-Continent Ecology Division
6201 Congdon Blvd.
Duluth, MN
Large Conference Room

AGENDA
Monday, February 1

1 pm Introductions and overview of agency and workshop objectives
- Welcome (Steve Hedtke)
- EPA/NPS objectives in PRIMENet amphibian/UV research (Barbara Walton)
- DOI strategy for amphibian monitoring on public lands (Bernard Shanks)
- NPS Inventory and Monitoring Program (Gary Williams)
- PRIMENet history and objectives (Kathy Tonnessen)

1:50 Overview of workshop planning history and research hypotheses
- Workshop planning history and charge to participants (Naomi Detenbeck)

2:00 Plenary presentations
- Amphibian monitoring
  - 2:00 Existing monitoring strategies (Sam Droege)
  - 2:30 Metapopulation approach (Peter Trenham)
- UV Dosimetry/Effects
  - 3:00 Early life stage effects/Dosimetry (Gary Ankley/Joe Tietge/Steve Diamond)
  - 3:45 Field study overview (Steve Corn)

4:00 - 4:15 Break

4:15 - 5:30 Overview of PRIMENet sites (approx. 10 min ea + questions)

Presented by NPS reps (collaboration w BRD researchers where appropriate)

History of amphibian monitoring/species present, background on amphibian habitat, GIS coverages available, etc.

Tuesday, February 2

Morning: Lg Conf. Room for full group discussions, Lg. conf. room + Council Room for subgroup discussions
8:00 - 9:30 Subgroups: Discussion of research hypotheses (amphibian monitoring, UV dosimetry/effects issues)
9:30-9:45 Break
9:45-10:15 Full group summaries and discussion
10:15 - 11:30 Subgroups: Discussions on integration of hypotheses
11:30 - 12 Full group summaries and discussion
12 - 1 Lunch

Tuesday, February 2

Afternoon

1:00 Discussion of experimental design issues, including site attribute requirements
Two subgroups:
Monitoring designs: populations and UV-dosimetry/effects
Manipulative studies

Wednesday, February 3rd

8 am - 12 noon

Presentations to full group from Tuesday pm subgroups
Discussion
Break-out back to subgroups for working out details in research outline

Afternoon
Lab tours for those interested

APPENDIX 2
Hypotheses for discussion:

Working Hypothesis 1:	Amphibian species are not currently present in habitats where they would be expected to occur and/or occurred historically, or are present but in diminished numbers.
Testable Hypotheses:	The distribution of occupied and unoccupied wetland breeding habitats conforms to the expectations of metapopulation theory (i.e., larger and less isolated wetlands are more commonly occupied).
	The fraction of the total wetland breeding habitats that are occupied is relatively stable over time.
	Rates of local extinction are significantly higher in more isolated and smaller wetland breeding habitats.
	Accounting for the effects of wetland isolation and size, exogenous stressors (e.g., elevated UV, anthropogenic organic compounds, introduced predators) can be shown to result in significant additional reductions in habitat occupancy or elevated turnover.
	Spatial distribution is a suitable surrogate for temporal trends in amphibian populations.
Working Hypothesis 2:	Amphibian species exhibit reduced survival and/or malformations at higher than expected or historic levels
Testable Hypotheses:	Elevated levels of aquatic UV measured in the field are associated with higher incidences of malformations.
	Early developmental stages of amphibians exhibit greater frequencies of morphological abnormalities and/or lower survivorship in wetlands where higher aquatic doses of UV are received.

APPENDIX 3

:PRIMENet site selection criteria table. Symbols indicates the presence (+) or absence (-) of characteristics considered desirable for these investigations in each park. Parks marked with +/- appeared marginal with reference to the criteria under consideration.

Criteria	ACAD	GRSM	ROMO	GLAC	SEKI	OLYM
species detectability[1]	+	+	+	+	+	+
solar radiation intense?[2]	+/-	-	++	+	+	+/-
available elevation gradients[2]	-	+/-	+	+	+	+
available DOC gradients[2]	+	+	+	+	+	+
vegetation gradients[2]	+	+	+	+	+	+
easy site access[3]	+	+	-	-	-	-
>100 wetlands in park[4]	+	-	+	+	+	+
metapopulation suitability[4]	+	+/-	+/-	+	+	+
wetland habitat mapped?[4]	+/-					
available historic data[4]	-	+	+	+	+	+
possible complications[5]	pollution, habitat disturbed?	prior logging, pollution	rain gradient, wilderness area	rain gradient, wilderness area	pollution	rain gradient, wilderness area
proximity of Brewer to amphibian habitat[6]	+	+				

[1] for metapopulation studies easily detectable species of pond breeding amphibians must be present

[2] we are interested in studying the effects of exposure to elevated UV, so high intensity solar exposure and within park exposure gradients due to elevation or DOC variation are considered favorable site characteristics

[3] because a large number of wetlands must be visited site accessibility must be a criteria considered in site selection

[4] suitability for this survey component of this research program is enhanced by large numbers of discrete wetlands, good historical amphibian distribution data, and the widespread distribution of amphibians within a park unit

[5] possible complications for surveys and UV work in each park were noted, including potential confounding effects of anthropogenic chemical stressors, habitat disturbance within or adjacent to the park, rain shadows producing dramatic variation in precipitation within certain parks, and added logistic difficulties associated with working in designated wilderness areas (i.e., no helicopters)

[6] proximity between Brewer spectrophotometers and amphibian habitats was noted because it might improve extrapolation abilities

APPENDIX 4

Table of amphibian species present in all six PRIMENet sites sending representatives to February 1999 meeting.

Amphibians Common name	Breeding general/ specific habitat	Discrete habitat patches?	Status	Duration larval stage	ACA East ⟸	GRS	ROM	GLA	SEK	OLY West ⟹
Ensatina salamander	terrestrial	no		16 WKS					x	x
Pacific tree frog	aquatic/ponds	yes		8 WKS				x	x	x
Western toad	aquatic/all	yes	decline?	8 WKS			x	x	x	x
Redlegged frog	aquatic/all	yes?	threatened	14 WKS						x
Tailed frog	aquatic/stream	no	rare	3 YRS				x		x
Pacific giant sal.	aquatic/stream	no?		2+YRS						x
Cascade frog	aquatic/all	no	declining	14 WKS						x
Northwestern sal.	aquatic/all	yes/no		12 WKS						x
Long-toed salamander	aquatic/pond	yes		12 WKS				x		x
Rough skinned newt	aquatic/pond	yes		20 WKS						x
Olympic salamander	aquatic/stream	no		3 YRS						x
Mtn yellow-legged frog	aquatic/all	no	declining	>1 YRS					x	
Blk-bellied slender sal.	terrestrial	no		?					x	
Mount Lyell sal.	terrestrial	no	decline?	?					x	
California newt	aquatic/stream	no		20 WKS					x	
Pacific slender sal.	terrestrial	no		?					x	
Yosemite toad	aquatic/pond	yes	decline	12 WKS					x	
Kern Cyn. slender sal.	terrestrial	no		?					x	
Columbia spotted frog	aquatic/pond	yes	threatened	<1 YR				x		
Tiger salamanders	aquatic/pond	yes		12 WKS			x			
Southern leopard frog	aquatic/pond	yes		<1 YR		x				
Common mudpuppy	aquatic/stream	no		5 YRS		x				
Blue Ridge Spring Sal.	aquatic/stream	no		>1 YR		x				
Cope's gray treefrog	aquatic/ponds	yes		5 WKS		x				
Jordan's Salamander	terrestrial	no		8 WKS		x				
Northern Slimy Sal.	terrestrial	no		8 WKS		x				
E. narrow-mouth toad	aquatic/pond	yes		12 WKS?		x				
S. Appalachian Sal.	terrestrial	no		8 WKS		x				
S. Red-backed Sal.	terrestrial	no		8 WKS		x				
Upland chorus frog	aquatic/pond	yes		10 WKS		x	x			
Midland Mud Sal.	aquatic/stream	no		?		x				
Black-chinned Red Sal.	aquatic/stream	no		?		x				
Southern Zigzag Sal.	terrestrial	no		8 WKS		x				
Long-tailed Sal.	egg terr/larv aq	no		>1 YRS		x				
Cave Salamander	egg terr/larv aq	yes		>1 YRS		x				
Eastern hellbender	aquatic/stream	yes	rare	5 YRS		x				
Santeetlah Dusky Sal.	egg terr/larv aq	no?		2+YRS		x				
Junaluska Salamander	egg terr/larv aq	no		>1 YRS		x				
Seepage Salamander	egg terr/larv aq	no?		2+YRS		x				
Fowler's toad	aquatic/pond	yes		8 WKS		x				

Amphibians Common name	Breeding general/ specific habitat	Discrete habitat patches?	Status	Duration larval stage	ACA East <==	GRS	ROM	GLA	SEK	OLY West ==>
Shovel-nosed Sal.	egg terr/larv aq	no?		2+YRS		x				
Green Salamander	terrestrial	yes	decline?	12 WKS		x				
Mole salamander	aquatic/pond	yes		12 WKS		x				
Marbled salamander	aquatic/pond	yes		35 WKS		x				
Imitator Salamander	egg terr/larv aq	no?		2+YRS		x				
Northern cricket frog	aquatic/pond	yes	decline?	12 WKS		x				
Seal Salamander	egg terr/larv aq	no?		2+YRS		x				
Pigmy Salamander	egg terr/larv aq	no?		2+YRS		x				
Three-lined Salamander	egg terr/larv aq	no		>1 YRS		x				
Blue Ridge 2 lined Sal.	egg terr/larv aq	no		>1 YRS		x				
Ocoee Salamander	egg terr/larv aq	no?		2+YRS		x				
Black-bellied Sal.	egg terr/larv aq	no?		2+YRS		x				
Dusky salamander	egg terr/larv aq	no?		2+YRS	x					
Eastern gray treefrog	aquatic/ponds	yes		6 WKS	x					
Bullfrog	aquatic/all	no		>1 YRS	x	x			x	x
Spotted Dusky Sal.	egg terr/larv aq	no?		2+YRS	x	x				
Red-backed sal.	terrestrial	no		8 WKS	x	x				
Spotted salamander	aquatic/pond	yes		12 WKS	x	x				
Four-toed Sal.	aquatic/ponds	yes		20 WKS	x	x				
Spring peeper	aquatic/pond	yes		12 WKS	x	x				
Green frog	aquatic/pond	yes		>1 YRS	x	x				
Pickerel frog	aquatic/pond	yes		12 WKS	x	x				
Red-spotted newt	aquatic/all	yes		12 WKS	x	x				
Wood frog	aquatic/pond	yes		9 WKS	x	x -1	x			
N. leopard frog	aquatic/pond	yes		12 WKS	x-2		x			
American toad	aquatic/pond	yes		8 WKS	x-2	x				

APPENDIX 5

Table of researchers conducting amphibian and UV related studies in PRIMENet sites in recent years

		Active in Which Parks?						
Researcher	Project	ACAD	GRSM	ROMO	GLAC	SEKI	OLYM	EPA
Malcolm Hunter	wetland alteration & amphibians	x						
Cook & Foley	NPS inventory including amphibians	x						
Ken Dodd	terrestrial salamander study/pond breeders		x					
Jim Petranka	woodfrog breeding surveys		x					
	pesticides levels in wetlands		x					
Steve Corn	amphibian monitoring and inventory			x	x			
David Cooper	Colorado River wetlands inventory			x				
B. Baker	beaver pond inventory			x				
Ed Little	characterizing UV in aquatic habitats			x	x			
Leo Marnell	amphibian inventory				x			
Roland Knapp	trout and yellow-legged frogs in the Sierra					x		
Gary Fellers	amphibian inventory and monitoring					x		
Kathleen Matthews	yellow-legged frog movements, etc.					x		
Vance Vredenburg	trout and yellow-legged frogs in the Sierra					x		
David Bradford	trout and yellow-legged frogs in the Sierra					x		
Claudette Moore	water quality monitoring					x		
Bruce Bury	Pacific northwest amphibian surveys						x	
NPS	inventory effort FY2000						x	
Ed Heithmar	contaminant studies at PRIMENet sites							x
Gary Ankley	UV effects on amphibians							x
Joe Tietge	UV effects on amphibians							x
Steve Diamond	UV dosimetry and effects research							x
Pete Trenham	amphibian metapopulation applications							x

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