PROJECT DESCRIPTION

1. LIST OF PARTICIPANTS

Agricultural and Resource Economics
James E. Wilen (3)
Anthropology
Monique Borgerhoff Mulder***** (3)
Richard McElreath*
Bruce Winterhalder* (3)
Civil and Environmental Engineering
Jay R. Lund (3)
Deborah A. Niemeier*
(Director, *John Muir Inst. of the Environment*)
Environmental Science and Policy
Edwin R. Grosholz (3)
Alan Hastings (3)
Mark N. Lubell* (3)
Pete Richerson*
Paul Sabatier
Mark W. Schwartz (3)
Andrew Sih*
Evolution and Ecology
Richard Grosberg (2,3)
Eric Sanford*
Thomas W. Schoener*
H. Bradley Shaffer (3)
John J. Stachowicz
Maureen L. Stanton
Sharon Y Strauss (1,3)
Donald R. Strong
Michael Turelli*
Susan L. Williams (3)
History
Louis S. Warren
Land, Air and Water Res.
James Richards
School of Law
Holly D. Doremus (2,3)

(1) PI; (2) Co-PI;
(3) Biosketch included

Philosophy and Ethics
James R. Griesemer (2,3)
Roberta Millstein* (3)
Gerald Dworkin* (3)
Plant Sciences
Allison Berry*
Paul L. Gepts (3)
Kevin J. Rice (2,3)
Truman P. Young
Mary Cadenasso* (3)
Plant Pathology
Pamela C. Ronald
Sociology
Thomas D. Beamish*
Patrick Carroll*
Joseph P. Dumit*
Wildlife, Fish, and Cons. Biol.
Timothy M. Caro*
Peter B. Moyle (3)

**** new trainers***

NON-UC DAVIS FACULTY TRAINERS:

California Department of Food and Agriculture
Dr. Steven Schoenig (invasives control, management, and policy)
California Department of Fish and Game
*Dr. Brenda Johnson (habitat conservation and planning; adaptive management)
The Nature Conservancy
Dr. John Randall, Director, Global Invasive Species Initiative (invasive weed policy, biodiversity conservation)
UC Cooperative Extension
Dr. Joseph DiTomaso, Director, Weed Control Program (invasives mgt and outreach)
UC Wildlife Health Center
*David Bunn (Environmental policy)
US Geological Survey
*Dr. Robert Klinger (climate change, fire ecology, plant-animal interactions)
Centro de Investigación Científica de Yucatán, Mexico
*Drs. Patricia Colunga, Daniel Zizumbo Villarreal
Institute for Applied Ecology, Canberra, Australia
*Dr. Arthur Georges
International Livestock Research Institute, CGIAR, Nairobi, Kenya
*Dr. Mohammed Said (land use, biodiversity conservation, human resource management)
Grupo de Ecologia Terrestre y Dpto. Genetica, Granada, Spain
*Drs. Rafael Morales Baquero, Juan Pedro Martinez Camacho
The Mountain Institute, Peru
*Dr. Jorge Recharte (sustainable development, conservation of mountain regions)
Universidad Autónoma de Aguascalientes
*Dr. José de Jesús Luna-Ruiz (ecological genetics, agroecology)

PROJECT DESCRIPTION

2. VISIONS, GOALS, AND THEMATIC BASIS

GOALS: Successful stewardship of species, resources, and ecosystems depends on understanding the biological consequences of rapid, human-mediated change, the limitations and uncertainties in this understanding, and the roles of human behavior and social institutions in environmental decision-making. Research emphases in our REACH IGERT will blend the expertise of faculty and non-faculty trainers to examine (a) biological responses to rapid environmental change, (b) human adaptation and decision-making in a changing world, and (c) the dynamic interplay that links information, institutions, and policy. **The REACH IGERT will train graduate students proficient in both the science and social structures that enable effective decision-making under the unique challenges posed by rapid environmental change**.

WHY RENEW? Our Biological Invasions (BioInv) IGERT established a highly successful program that trained a diverse group of students in natural and social science approaches addressing the complex problems associated with biological invasions (see section 8 below for our accomplishments). ***Our new REACH IGERT (REsponding to RApid Environmental CHange) substantially broadens the scope of the BioInv IGERT to encompass the larger suite of environmental problems (e.g. climate change, habitat loss, fragmentation) arising from human-caused rapid environmental change, as well as expanded training in human environmental decision-making.*** The value-added elements of our REACH IGERT will include (1) an expanded set of theoretical and empirical tools from both the natural and social sciences; (2) international internships that provide global perspectives on environmental problems; (3) Bridge RAships that foster multidisciplinary faculty-student collaborations; (4) institutional longevity through the joint sponsorship of a REACH Visiting Scholar with the John Muir Institute of the Environment; (5) innovative assessment approaches that evaluate the actual and perceived impacts of IGERT student products on institutional change, diverse stakeholders, and students; (6) expanded recruitment activities through a faculty and student exchange program with two universities that have NSF Undergraduate Mentoring In Environmental Biology (UMEB) programs: Howard University (a historically black university) and California State University, Fullerton (a Hispanic-serving institution); (7) establishment of a UC Davis SEEDS chapter (mentoring under-represented minorities in ecology) of the Ecological Society of America (ESA) through our IGERT; and (8) linkage of our minority recruitment efforts with the Alliance for Graduate Education and the Professoriate (AGEP) program at UC Davis.

Our REACH IGERT will provide trainees with new resources that augment those developed during our BioInv IGERT. REACH IGERT trainers have expertise in ecology (physiological to landscape scales), evolution, and genetics (**Berry, Cadenasso, Gepts, Grosberg, Grosholz, Hastings, Moyle, Rice, Richards, Ronald, Sanford, Schoener, Schwartz, Shaffer, Stachowicz, Stanton, Strong, Strauss, Turelli, Williams**); animal and human behavior (**Borgerhoff Mulder, Caro, McElreath, Richerson, Sih**); environmental law and policy (**Doremus, Sabatier**); environmental economics (**Wilen**); environmental engineering and adaptive management (**Lund, Niemeier, Lubell**); philosophy, distributive justice, and ethics (**Cadenasso, Dworkin, Griesemer, Millstein**); and social science at the interface of natural science (**Beamish, Carroll, Dumit, Richerson, Warren, Winterhalder**). In addition, with 33 UC Natural Reserves located in alpine, marine, riparian, estuarine, forest, coastal scrub, and desert habitats, UC Davis can provide IGERT students with protected research sites in which to study organisms and ecosystems affected by environmental change. Museum collections at UC Davis and nearby California Academy of Sciences and UC Berkeley, plus long-term databases at many UC Reserves, provide an unmatched historical context to rapid environmental change. REACH IGERT trainees will be able to capitalize and expand on BioInv IGERT-established ties to state legislators, NGOs (e.g., The Nature Conservancy), and state and federal agencies (e.g.,

US Geological Survey, and CA Departments of Food and Agriculture, and Fish and Game). These ties allow students to develop and implement policy relevant to rapid, human-caused environmental change. California faces especially challenging environmental problems and has been an influential laboratory for the development of innovative policy solutions. Thus, IGERT students working in California ecosystems with local policymakers will have the opportunity to address problems of national and global significance.

RESPONSE TO PREVIOUS REVIEWS: In two pre-proposals and one full proposal REACH was generally well received, as indicated by the Panel Summaries: "This pre-proposal is compelling, well-detailed and of high relevance to the IGERT mission. The institution has a solid track record from its previous IGERT, and this new pre-proposal links and leverages from this initial success, while providing an entirely new and innovative expanded research and educational program." Because in all versions of this proposal our major focus has been enthusiastically embraced, we retain our research and training emphases from the previous proposals while addressing the main concerns of the panels. From the previous full proposal (E, V, V) and latest pre-proposal reviews (E, E, E), the panels encouraged us to include (1) targeted training in distributive justice/environmental ethics; (2) a more thorough explanation of management, peer-mentoring, and the international component; and, finally, (3) additional disciplines in the proposal; specifically, in three sets of reviews, four areas were identified by different reviewers and panels (see below).

In response to the last panel, we have added substantial training in environmental ethics and distributive justice, as we agree that these disciplines are fundamental components of environmental decision-making. We have also more fully expanded details on the management, peer mentoring, and international elements of the program.

A key challenge with our REACH proposal remains doing full justice to the reviews that recommended we include more disciplinary breadth. The discipline-focused comments partly reflect the number (≤20) of biosketches allowed in the proposal. Because of these limits, it was not possible to convey the full range of expertise covered by our trainers. Additionally, analysis of rapid, human-caused environmental potentially spans a large number of disciplines in the natural and social sciences-- more than is possible to include and still retain a coherent intellectual focus and training program.

The central goal of our REACH IGERT is to prepare trainees to be conversant in both organismal and human responses to rapid environmental change. **We have therefore assembled a group of trainers with broad disciplinary and multidisciplinary expertise in our focal areas of organismal and human adaptation to rapid environmental change.** In some cases, the expertise of our primary trainers actually does cover gaps noted in prior reviews. For example, trainers Cadenasso, Young, and Schwartz have worked extensively on landscape-level ecological questions, an area identified as missing in our previous submission. In the case of climatology, trainers Lund, Schwartz, and Sanford incorporate predictions from climate-change models in their research. We do not include a climatologist as a core trainer because we feel that climatology, like hydrology (another suggested area for disciplinary expansion), are secondary to the main training emphases of human decision-making and organismal adaptation.

That said, **we recognize the need for input from these, and many other disciplines in understanding and responding to rapid environmental change.** *Our experience from the BioInv IGERT tells us that targeted inclusion of colleagues for specific portions of training provides the optimal balance of focus and cohesion of the training program with needed expertise in key areas.* For example, we enlisted our colleague Mark Lubell, an expert on collaborative management approaches to environmental problems, when a BioInv IGERT student project focused on conflicts between state agencies and local communities. (Lubell is

now a core trainer in the REACH IGERT.) Similarly, if a course element (a case study or project) were to explore decision-making with regard to water regulation, we would draft one of our colleagues who is a hydrologist (e.g., Jeff Mount) as a guest trainer for that component. More generally, on a campus whose strength lies in applied environmental sciences, we can draw on literally hundreds of faculty, extension agents, and organized research units across the full range of areas directly pertinent to rapid, human-caused environmental change. **Because IGERT trainers direct several of these centers and research units, they are already integrally connected to our program.** These programs include: **Long-Term Research on Agricultural Systems** (LTRAS: a 100-year-old experiment examining rapid evolutionary change in agricultural settings), the **Center for Watershed Sciences** (restoration of ecological function in rivers, streams and estuaries; sustainable management of regulated river systems; floodplain restoration and management), the **Tahoe Environmental Research Center** (research, education, and engagement at Lake Tahoe; physics, chemistry, and ecology of inland waters and their contributing watersheds), the **Public Service Research Program** (regional and community environmental engagement; public understanding of science and the environment; place-based research and education), the **Road Ecology Center** (ecological informatics; wildlife impacts of road noise; invasive species and roads), the **Environmental Justice Project** (environmental justice and equity; environmental benefits and pollution burdens related to race, class, and gender; the environment, communities, justice, and health in the Central Valley and California), the **Information Center for the Environment** (geographic patterns and ecological processes in biodiversity, water, and land use; impacts of urban growth and infrastructure development; environmental informatics), and the **Center for Natural Resources Policy Analysis** (payments for ecosystem services; management of marine ecosystems; applied policy analysis using bioeconomic models).

3. MAJOR RESEARCH EFFORTS (trainers in **boldface**)

A. BIOLOGICAL RESPONSES TO RAPID ENVIRONMENTAL CHANGE. Human activities often have multiple unanticipated effects on the capacity of organisms to adapt to changing environments. Aside from causing both novel forms and increased intensities of "natural" selection, humans have profoundly altered patterns of species dispersal and gene flow through activities that include habitat fragmentation, habitat loss, and the introduction of invasive species. Global climate change intensifies these impacts by concurrently driving changes in community composition and range shifts (Davis and Zabinski 1992; Iverson *et al*. 2004, 2005). Thus, all of the major factors known to influence phenotypic and genetic responses of species are being profoundly affected by human activities.

The impacts of human activities on individuals, populations, communities, and ecosystems have traditionally been considered to be in the domain of applied ecology. It is now clear, however, that humans are also causing rapid changes in the genetic composition of populations (e.g., Hendry 2001; Conover and Munch 2002). Thus, the ecological and evolutionary consequences of human-caused environmental change are inextricably linked. The convergence of ecological and evolutionary responses of species is being approached from several different perspectives. For example, the ecological process of human "predation" leads to rapid evolution in life-history traits of harvested species (including age and size at first reproduction, migratory behavior, and longevity). Similarly, habitat fragmentation, by reducing connectivity and population size, has both ecological and evolutionary consequences. In ecological terms, these reductions increase the likelihood of local extinction through demographic stochasticity; in evolutionary terms, they enhance the impacts of genetic drift and change patterns of gene flow. Thus, humans must consider protecting both the ecological integrity of species and their capacity to evolve in the face of rapid environmental change.

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Our REACH IGERT will combine expertise in ecology, behavior, and evolution to examine organismal responses to rapid environmental change. Traditionally, the biotic effects of rapid environmental change have been studied primarily from an ecological perspective. Indeed, the research of many of our trainers emphasizes ecological facets of environmental change across multiple spatial and temporal scales (e.g., **Cadenasso, Caro, Young, Moyle, Sanford, Schoener, Schwartz, Strong, Williams, Stachowicz**). *Yet, it is increasingly apparent that an evolutionary perspective is central to understanding organismal adaptation to environmental change* (Kinnison and Hairston 2007; Parmesan 2006), *and this evolutionary perspective is a unique strength of our program.* The research projects emphasized in this proposal therefore highlight how integrating ecological and evolutionary perspectives can improve our understanding of problems that have conventionally been approached as primarily ecological.

Combining molecular and ecological genetic approaches to the study of biotic responses to environmental change offers novel ways to conserve biodiversity in the face of contemporary and future environmental challenges. Phenotypic and genotypic selection analyses provide one framework for understanding the patterns and strength of selection on traits under human-modified conditions (**Grosberg**, **Rice**, **Stanton, Strauss, Turelli**). In addition, several faculty trainers are using genomic tools to identify genes underlying adaptive variation, and to track the roles of these genes in adaptation to rapidly changing environments (**Gepts, Grosberg, Rice, Ronald, Shaffer, Stanton**). Basic genomic resources, including expressed sequence tag (EST) and bacterial artificial chromosome (BAC) libraries, provide the opportunity to follow how invasions, hybridization events and local adaptation cause changes at the genomic level. In addition, genomic approaches can be used to identify portions of the genome involved in rapid evolutionary responses. These molecular tools can also be used to assess the contributions of gene flow (affected by habitat connectivity and dispersal behavior) versus *in situ* acquisition of genetic variation through mutation, recombination, and epigenetic processes to these adaptive responses. This information makes it possible to estimate the rate and magnitude of evolutionary responses as organisms are challenged with novel physiological and ecological conditions at unprecedented rates of change.

Current research projects of our trainers exemplify the importance of evolutionary processes in rapid, human-caused environmental change.

i. <u>Rapid Evolutionary Response of Plant Species to Elevated CO_2</u>. Human activities are causing levels of CO_2 in the atmosphere to rise at geologically unprecedented rates. Across the world, **F**ree **A**ir **C**O_2 **E**nrichment (FACE) experiments have been used to study the effects of increased atmospheric CO_2 on ecological processes. The FACE program has primarily focused on ecological and physiological responses of plant communities to elevated CO_2, and on potential shifts in productivity, nutrient cycling, and species composition. To date, few studies have examined the potential for rapid *evolutionary* change within species at these sites. Current studies of the invasive annual grass (*Bromus madritensis* ssp. *rubens*) at the Nevada Desert Research Center FACE site indicate that this species has evolved rapidly to simulated global change (BioInv IGERT student Grossman and **Rice**). In less than a decade, populations of this weed exposed to elevated CO_2 have evolved increased photosynthetic and water-use efficiency compared to populations at ambient CO_2 levels (unpubl. data). Ongoing studies are characterizing the fitness consequences of these physiological changes, their effects on competitive outcomes within communities, and whether patterns of plasticity have also evolved under elevated CO_2.

ii. <u>Hybridization and "Genetic Pollution</u>." Conservation policy in the U.S has focused on the protection of "species" that have tacitly been assumed to be stable entities; however, rapid

evolutionary change poses important challenges to such a concept of species. Consider the case of human alteration of gene flow through the introduction of exotic species or non-local genotypes that hybridize with native taxa (Wares ***et al*.** 2005). For example, construction of dams and hatchery operations can promote hybridization between ecologically differentiated forms of the same fish species (**Moyle**). Similarly, hybridization can occur between the native marsh grass (*Spartina foliosa*) and an invasive congener (*S. alterniflora;* Daehler & **Strong** 1997). Hybridization between endangered and invasive taxa represents an especially difficult problem because it raises important questions about the goals of conservation. For example, the endangered California tiger salamander (*Ambystoma californiense*) hybridizes with its non-native relative, *A. tigrinum*, which was brought to California as bait by enterprising fishermen about 50 years ago (Riley et al. 2003). California tiger salamanders are now listed under the Endangered Species Act, and hybridization with this non-native congener has converted 20% of the entire species into a massive hybrid swarm (Fitzpatrick & **Shaffer**, 2007a). Recent advances in developing genomic resources for the tiger salamander (Voss ***et al****.* 2001) have resulted in a collaborative, genome-wide approach to the analysis of this invasion. This case raises important questions about the targets of conservation (genetic diversity, native integrity, ecological functionality). Recent results (Fitzpatrick and **Shaffer 2007**b) indicate that within the early larval stage, the fitness of highly admixed salamanders is greater than either of the pure parental types, suggesting that late-generation hybrids have higher fitness than their native parents; at the landscape level, introduced genes seem to be favored in permanent water bodies like human-made cattle and agricultural ponds (Fitzpatrick & **Shaffer**, 2007a, b). These results raise important ethical issues for conservation, as well as practical issues concerning our ability to eliminate non-native genes that are favored by natural selection.

The impacts of "genetic pollution" from the introduction of genes from crops (traditionally bred or transgenic) into the environment (**Gepts, Ronald**) include the creation of weedy hybrids (Ellstrand *et al*. 1999) and the loss of culturally and agriculturally important land races (*e.g.* Zapotec maize: S. Ortiz-García *et al*. 2005, González 2001). Crop biodiversity is both a resource for indigenous people and the raw material for genetic improvement of crops. Mexico is one of the richest centers of crop diversity in the world and the center of origin of maize, beans, peppers, and cocoa wild progenitors. Asymmetric gene flow from domesticated to wild populations of crops can lead to a displacement of the native genetic diversity in wild populations, as in common bean (*Phaseolus vulgaris*) in Mexico (Papa & **Gepts** 2003; Papa ***et al*.** 2005). Patterns of gene flow therefore must be considered a target of management.

iii. <u>Evolution, Dispersal and Ecological Reserve Design</u>. Just as ecological and evolutionary attributes co-determine the success of species *in situ*, both must also inform our strategies to limit or ameliorate the effects of rapid environmental change.

No-take marine protected areas (MPAs) have the potential to conserve marine biodiversity and sustain marine fisheries. The ability of no-take MPAs to achieve these goals fundamentally depends on connectivity among protected areas to facilitate the exchange of individuals and genes from protected areas into regions where harvest is permitted (**Hastings**). Rapid evolutionary responses to local protection may, however, counteract efforts to promote connectivity and exchange (Dawson, **Grosberg**, & Botsford 2006). Just as selective harvesting of the largest and oldest individuals in fish populations has led to the rapid evolution of early maturation at progressively smaller sizes and reduced yield (*e.g*., Hendry 2001; Conover and Munch 2002), commercial and recreational harvesting pressures outside of MPAs could rapidly select for decreased dispersal and localized recruitment in organisms experiencing protection (Baskett et al. 2007). These evolutionary changes are likely to occur over short time scales, and may have profound effects on the management of marine populations by reducing needed exchange of individuals and genes between reserves and fishing areas. Thus, the very

establishment of MPAs, unless designed with these evolutionary consequences in mind, may quickly reduce their effectiveness as sources of harvestable individuals. Such responses to no-take MPAs illustrate the potential for feedbacks between policy decisions and organismal responses to those decisions.

Climate change is already causing many populations to shift their ranges poleward, but a discontinuous and human-dominated landscape can thwart such dispersal (**Schwartz** *et al.* 2001). Models of reserve design are just beginning to incorporate the dynamism of climatic change through the creation of networks of connected reserves that facilitate the natural movements of species and genes to follow suitable climatic envelopes. Fragmented land ownership, however, can block the creation of corridors, and some species may not use corridors effectively even when they are in place. In such cases, "assisted migration" through human transport of species into climatically suitable conditions reduces the risks of migration across human-dominated landscapes. Assisted migration for species "trapped" by climatic warming is currently being employed for *Torreya taxifolia* in the southeastern United States (Barlow & Martin 2005). It is, however, biologically controversial (**Schwartz** 2005, McLachlan *et al.* in review). Moving species into new habitats may compromise ecosystem and community integrity of the recipient site. Moreover, pre-existing patterns of gene flow, spatial scales of adaptation, and past and current selective regimes should inform the choice of source populations for the creation of new or restored populations. The importance of evolutionary processes in ecological restoration are just beginning to be recognized; the resilience and sustainability of any restoration project in the face of environmental change may critically depend on the capacity of restored populations to evolve in response to novel selective challenges (Harris *et al.* 2006, **Rice** & Emery 2003).

In each of these circumstances, our evaluation of potential policy choices must begin with careful evaluation of conservation goals for all species, and must include consideration of environmental values and fairness to affected human populations. In addition, effective policy decisions minimally require integrating scientific understanding with careful evaluation of the goals of environmental management. The goals and processes of environmental management are further complicated by the feedback between policy and the trajectory of the environmental problem. Additionally, the rapidity of environmental change presents novel challenges because all of these decisions must be made in the face of unprecedented levels of scientific uncertainty. How do individuals and institutions respond when action must be taken against a background of incomplete and developing scientific understanding (**Winterhalder** 2006)? Our previous collaborative studies in the BioInv IGERT highlighted the importance of understanding how and why humans make the decisions they do, and the role of the flow of information through human institutions, in models of environmental decision-making (**Doremus** 2007).

B. HUMAN ADAPTATION AND DECISION-MAKING IN A CHANGING WORLD. The social sciences provide the critical link that integrates scientific information into the development and implementation of effective environmental policy. The REACH IGERT expands theoretical and empirical training in the social sciences by including trainers who study complex interactions among scientists, government agencies, organizations, and stakeholder groups (**Beamish, Lubell, Sabatier**); relations between science, society, and ethics (**Carroll**, **Dumit, Cadenasso, Dworkin, Millstein**); human behavioral ecology (**Borgerhoff Mulder, McElreath, Richerson, Winterhalder**); environmental economics (**Wilen**); and environmental history and philosophy (**Griesemer**, **Warren**).

Many of the evolutionary and ecological theories and concepts that have improved our understanding of the response of natural systems to rapid environmental change are now focusing on the question of human decision-making. One distinctive and critical aspect of human adaptation to the environment is how quickly, through social learning, human societies

can evolve locally specialized, highly complex adaptations (**Richerson** & Boyd 2000; trainers **Borgerhoff Mulder**, **McElreath**, **Richerson**, **Winterhalder**). Social learning has allowed humans to adjust to past climate change, as well as to invade and dominate nearly every biome on the planet. The study of the processes by which human individuals and organizations — be they families, villages, nation states, or multi-national entities — make decisions is the key to understanding how humans effectively respond to and prepare for environmental change.

Models of optimal foraging, rational choice, decision-making under uncertainty, combinatorial games, common-pool resources, and multiple inheritance transmission pathways bear on problems associated with rapid environmental change. For example, game theory, first developed in the context of economic analyses and animal behavior, is now being applied to environmental decision-making through experimental studies of human choices under varying levels of uncertainty in payoffs (Camerer & Fehr 2004, **McElreath**, **Lubell**). Game theory can be used to explore how social institutions affect human patterns of resource harvesting. For instance, in a game where conservation is modeled as an acceptance of short-term costs for longer-term benefits, East African pastoralists develop conservation rules (and punish rule-breakers) only in situations where there is marked heterogeneity in livestock holdings; that is, the cost-benefit threshold for conservation changes with the wealth of the decision-maker (Ruttan & **Borgerhoff Mulder** 1999).

i. Environmental Economics. Environmental economics explores how changing incentives and valuation can alter human behaviors. Economic insights into the behavioral basis for environmental decision-making have stimulated a shift in policy strategies away from coercive command-and-control approaches toward market-driven strategies that alter economic incentives (e.g., recycling deposits and emissions markets) or that improve the information available to market participants (**Wilen**, 2006; **Doremus** 2003). Over the past several decades, environmental economics has begun to define and measure the values associated with non-marketed ecosystem services, so that those values can be incorporated into resource policy. A classic example is the recent debate over whether to establish networks of marine reserves for habitat and biodiversity benefits at the potential expense of commercial and recreational fishing (Sanchirico & **Wilen** 2005, Sanchirico, **Hastings**, ***et al.*** 2006). Non-market valuation can also be used to quantify the loss of ecosystem services provided by marine reserves that are degraded by rapid environmental change. If the decision to create or maintain reserves is resolved by cost-benefit analysis (the traditional economic tool), then the outcome will likely depend on whether non-market values are included in the calculations.

ii. Ecological Rationality. Several competing theoretical approaches have been advanced to explain human decision-making under uncertainty. Conventional models of bounded rationality predict that human decision-making is suboptimal (Tversky & Kahneman 1974, 1992). Recently, those have been challenged by new models of ecological rationality, which claim that decision-making heuristics match key features of our evolutionary environments (Rhode *et al*. 1999; Landa & Wang 2001; Ostrom 1990; **Winterhalder** 2006). For instance, Gigerenzer *et al*. (1999) showed that people sometimes make better decisions when they ignore some information. This result surprised many psychologists, because classic decision theory suggests that using more information always improves average outcomes. Likewise, the apparently poor decision to accept a low, but immediate, return over a better long-term return may be consistent with ecological rationality in an environment in which resources are patchily distributed (Stephens *et al*. 2004). In each case, consideration of the ecological context in which humans evolved improves our understanding and prediction of human decision-making.

iii. Cooperation and Collaboration. The biological, social, and political challenges of rapid environmental change are increasingly being addressed by encouraging cooperation among multiple stakeholders. Collaborative environmental management efforts have been most studied in the context of watershed management. These efforts rely on the assumption that resource-use decisions are interdependent and, therefore, successful human responses to environmental changes require cooperation. Recent research on collaborative management has shown that cooperation is more likely when stakeholders (1) agree on the identity, severity, and causes of environmental problems, (2) have a high degree of trust in each other, (3) regard the policy process as fair, and (4) believe that their participation in policy makes a difference (**Lubell** 2004, **Sabatier *et al***. 2005). In the final analysis, discussion about how to mitigate and control adverse environmental impacts of human actions requires understanding the physical, biological, and social processes that drive the problem.

C. DYNAMIC INTERPLAY THAT LINKS INFORMATION, INSTITUTIONS, AND POLICY. To accommodate uncertainty, new information, and contested values, solutions to problems posed by rapid environmental change must be flexible and dynamic. Our trainers' collective expertise in natural sciences, social sciences, law, and policy will allow us to explore the feedback networks that link scientific information, individual choices, policy decisions, and biological and environmental responses.

i. Adaptive Management. Since the late 1970s, the concept of adaptive management has been promoted as one way to improve decision making with incomplete environmental knowledge (Walters 1986; Walters & Holling 1990). Adaptive management rests on the principle that decisions made under conditions of high uncertainty about their impact on resources should generate information that can be used to improve future decisions (National Research Council 2004). Recognition that managed systems may be rapidly changing, and that management choices themselves may change those systems, strengthens the case for adaptive management.

In principle, adaptive management has many potential benefits. In practice, however, a host of scientific, social, and institutional barriers make it difficult to implement. First, managed systems are typically highly complex and poorly understood. Second, from an experimental perspective, replication may be impossible, and relevant variables may be difficult to control or manipulate. Third, management decisions occur in a contentious political environment in which organized interest groups attempt to secure their favored outcomes. Managers and stakeholders may resist experimentation, monitoring, and changes to the management *status quo*. Fourth, adaptive management is expensive, requiring ongoing monitoring and assessment of both outcomes and compliance. Stable, long-term funding is difficult to obtain. Fifth, adaptive management must continually incorporate new ecological and evolutionary theory relevant to understanding the managed system. Finally, policymakers, managers, and scientists often do not fully understand the constraints under which each must operate.

Despite these challenges, adaptive management approaches are increasingly being employed at ecosystem scales and are even legally mandated in some settings. REACH IGERT non-faculty trainer Dr. **Brenda Johnson**, from the CA Department of Fish and Game, together with colleagues at the US Fish and Wildlife Service, has developed a number of Natural Community Conservation Plans (NCCP) based on adaptive management principles for several southern California ecosystems (Atkinson *et al*. 2004). Johnson is eager to collaborate with and mentor REACH IGERT trainees to refine these approaches. Other REACH trainers (**Moyle, Doremus, Lund**), in conjunction with the Watershed Sciences Center in the John Muir Institute for the Environment at UC Davis, are studying re-licensing of hydropower plants in California. By law, license durations must run for 30-50 years — a time span over which there can be

dramatic changes in water availability, population densities, and genetic structure of affected species. License renewals provide a crucial window of opportunity to introduce adaptive management practices to ensure that operations respond to ongoing environmental change. **Doremus**, **Lubell**, **Moyle**, and other UC Davis faculty are working with the California Hydropower Coalition to identify and overcome barriers to an adaptive licensing process. Hydrologist **Lund** and ecologist **Moyle,** with a geologist, an engineer, and environmental economists, recently produced a visionary analysis of options for managing California's river delta (**Lund *et al.*** 2007).

ii. Information Flow. Natural resource management decisions heavily depend on the supply of scientific information; nevertheless, little attention has been paid to the processes through which that information is supplied. Our previous empirical studies, based on a series of group projects in the BioInv IGERT, highlighted the importance of information flow through human institutions in environmental decision-making. Current regulatory systems often discourage the pursuit of new information relevant to regulatory choices, and fail in the timely distribution, assimilation, and response to new information as it becomes available. The rapidity of human-caused environmental change further complicates environmental decision-making and information exchange. Trainers **Doremus** and **Griesemer** study patterns of information flow and obstruction of flow (**Doremus** 2007, Star and **Griesemer** 1989). In the case of rapid environmental change, technical documents such as habitat conservation plans, draft regulations, and reports of scientific findings with policy implications must be effectively exchanged among diverse constituencies (scientific, legal, policy, media). The difficulties of such exchange are illustrated by Cox et al. (2007), who find that fishing gear modifications intended to reduce bycatch in commercial fisheries may work well under experimental conditions used by scientists, but function poorly in the very different circumstances and culture of real-world fishermen. These authors advocate improved communication and information flow between scientific and fishing communities as necessary elements of effective bycatch reduction. Because lack of information is often cited as a limiting factor in environmental policy (**Doremus** 2007), the study of patterns of information flow reveals areas where more effective communication benefits decision-making processes.

RESEARCH SYNOPSIS: Solutions to environmental problems require new networks of collaboration and collective action that transcend differences among individuals, disciplines, and institutions. Our trainers' collective expertise in natural sciences, social sciences, law, and policy will allow us to explore the abilities of both **organisms** and **human decision-making organizations** to adapt to rapid environmental change. Through the activities described below, our REACH IGERT will train citizen-scientists proficient in the multidisciplinary perspectives needed to address the complex relationships between humans and environmental problems that are often further complicated by the speed of rapid environmental change.

4. EDUCATION AND TRAINING

OVERVIEW: The research described in the previous section epitomizes the need for broad training of environmental scientists. Over 20 years ago, UC Davis recognized that traditional departments no longer served the growing need for multidisciplinary graduate training and developed a system of cross-departmental graduate groups. Graduate groups are designed to facilitate multi- and interdisciplinary training, and to encourage dissertation research that crosses traditional departmental boundaries. For this reason, rather than establish a new Ph.D. program in our previous IGERT, we augmented the curriculum of trainees admitted to cross-departmental graduate groups with additional IGERT training. We plan to use the same approach in the REACH IGERT. Trainees will be expected to meet the requirements of their

"home" graduate group (including essential coursework and the passage of comprehensive or qualifying exams) in addition to completing requirements of our IGERT (outlined below).

The REACH IGERT curriculum includes formalized training structures that bridge biological and social approaches to environmental problem-solving. Specifically, through a **core course**, **multi-disciplinary collaborative research project**, and **internships** in the public and private sectors, our trainees will emerge with an understanding of how biological, social, and legal perspectives collectively inform strategies for responding to rapid environmental change. Full-time support for two years from the IGERT program frees trainees from TA and RA duties for their first two years of graduate school, and thus provides them sufficient time to complete these dual curricula. In addition, by fulfilling the research component of the IGERT, students will have completed one chapter of their dissertation. Trainees will complete all mandatory IGERT requirements before the third year, allowing students to focus on their dissertation research in years 3-5. Our BioInv IGERT students are completing their degrees in time periods comparable to those of students in standard UC Davis Ph.D. programs (see section 4.E below). In addition, the REACH IGERT will provide optional, multidisciplinary training opportunities to advanced graduate students through **Bridge RAships** and **Chancellor's Teaching Fellowships**.

A. ADMISSION INTO THE REACH IGERT PROGRAM. Student essays, coupled with academic record, GRE scores, and letters of recommendation, serve as the basis for admission to the REACH IGERT. In the BioInv IGERT, we developed a successful dual admissions policy in which students applied simultaneously to a UC Davis graduate group and to the IGERT program. For the REACH IGERT, students will write an essay that describes their interest in multidisciplinary approaches to rapid environmental change and any pertinent background that might make them especially suitable for the REACH program. Our 100% retention rate in our BioInv IGERT program (see Sections 7.C and 8 below) shows that we have learned to identify students with diverse backgrounds who succeed in multidisciplinary training programs.

Student applications will be evaluated by an admissions committee, consisting of a trainee, a PI/Co-PI, our academic coordinator, a trainer from natural sciences, and a trainer from social sciences. As with our past IGERT, we will continue to work closely with the admissions committees for each graduate group to admit jointly the best candidates to the REACH IGERT and the graduate groups. Because our students have historically been of high quality, and because we can offer students full support for two years, graduate groups have enthusiastically supported concurrent admission of our students.

B. REACH IGERT CURRICULUM. During the BioInv IGERT, we modified the structure of our curriculum based on feedback from students and trainers and have arrived at a balance of course organization and research training that efficiently fulfills the training goals of the IGERT program. We therefore build on this past experience and keep the fundamental training structure of our BioInv IGERT;, however, we have modified course content to include our new foci of interest. We have also added several completely new training components (noted with ***boldface italics*** *i*n the text) that will expand the impacts of the curriculum.

i. <u>Year 1: First-Year Core Course</u>. This three-quarter course introduces students to the range of disciplines, and their theoretical and empirical foundations, that contribute to the response to rapid environmental change. Our core course is essential to preparing students for the capstone of our training program, the year-long collaborative project (year 2), and our faculty are committed to its development.

Lecturers in the core course will cover modules in organismal adaptation, environmental economics, environmental history, environmental sociology, environmental ethics and justice, decision-making under uncertainty, law, and policy. Lectures, readings, and weekly discussions

will guide students through diverse research methodologies and the theoretical underpinnings of disciplines that contribute to the study and management of environmental change. Constructs from ecology and social sciences will be integrated throughout the course.

Students will use ***case studies*** viewed through many lenses to examine environmental change from natural and social science perspectives. The course will be framed by an initial discussion, co-led by several trainers, of an exemplar case study that illuminates natural science, social science, policy, and ethical angles of a common problem. An example might be the design of marine reserves, which would draw on the expertise of trainers Grosberg, Moyle, Wilen, Hastings, and Doremus. In-depth presentation of research questions and methods from both the natural and social sciences will follow, grounded in additional case studies. Other UC Davis trainers and non-faculty trainers from the public, private, and non-profit sectors will present guest lectures and lead discussions in their areas of expertise. Through discussions, mini-projects, and essays, students will synthesize material across multiple disciplines. Trainers **Millstein** (a philosopher of biology who teaches environmental ethics), **Cadenasso** (urban ecology and environmental justice), and **Dworkin** (bioethics, law, and autonomy) will lead one section of the core dedicated solely to ***training in environmental ethics***, and ***distributive and environmental justice***.

The format of the first quarter will be primarily lecture/discussion, but the second and third quarters will integrate material and links between science and policy through a series of hands-on, small-group projects and interactions with policymakers. Projects will include preparing a legislative briefing statement, writing an op-ed piece and essays for a general audience, and completing a student-designed mini-group project. Formal course material will be augmented with workshops on public communication (e.g., how to speak to the media, and how to work with legislators), offered in cooperation with staff from the UC Davis News Service and Office of Governmental Relations.

In a separate reading seminar in the spring quarter of Year 1, trainees will work as a group and with a faculty mentor to develop ideas for their year-long 2nd-Year Project.

ii. <u>Year 2: The 2nd-Year Collaborative Project</u>. Students will work together to design and execute a year-long, multidisciplinary research collaboration centered on a specific problem within the broad area of response to rapid environmental change. The second-year project has been the crown jewel of the BioInv IGERT: each student learns to develop a multidisciplinary research project as a member of a group, implement a research plan, and produce a product that has major impact. We have found that allowing students to select their project topics, with support from faculty mentors, fully engages them in the identification of a problem of mutual interest and promotes collaboration. Ultimately, this process gives students complete "ownership" of the project and pride in their accomplishments. The primary faculty mentor participates for the duration of the project and provides advice and assistance in locating and recruiting resources, both human and material.

The group project culminates in tangible products that are disseminated to the public and in a symposium-workshop organized by the trainees. In the BioInv IGERT, these symposia brought together diverse participants and created dialogue across disciplines and stakeholders. Topics have engaged participants from multiple disciplines in the natural and social sciences, from both academic and non-academic communities. During a 2005 symposium that examined how species invade via the horticultural and aquarium trades, an industry representative commented that, in his thirty years of experience, our symposium was the first time that academics had asked for his input and created a forum for dialogue between researchers, agencies, and trade groups. Previous workshops have focused on (1) the pivotal roles of multiple stakeholders (especially members of impacted communities) in developing and implementing protocols for the control of invasive species (attended by citizens and former

mayor of Portola, CA, CA Dept. of Fish and Game staff, and academic experts on invasive fish and collaborative management); (2) self-regulation in the private sector and the role of the horticultural and aquarium trades as sources of invasive species (attended by academic researchers, staff from non-governmental organizations, and pet-industry lobbyists); (3) factors impeding control of invasive yellow star thistle in ranching communities and the role of cooperation across private, state, and federal landowners (attended by representatives from state and federal agencies, cooperative extension agents, and ranchers); and (4) the role of scientists in writing environmental education curricula (attended by educators and academics). **Symposia are open to the campus community, and therefore increase the impact of student projects and multidisciplinary IGERT approaches across campus***.* Another desirable and unexpected impact of the symposia has been invitations extended by symposium participants to our IGERT students; these invitations solicit IGERT students to present the results of their project at meetings of state agencies and non-governmental organizations.

Student products have included an acclaimed film (*Fear and Fishing in Lake Davis: A Tale About People, Government, and the Fish That Came Between Them*; reviewed in *Biological Invasions*) that has been shown in over 10 college or university classrooms across the country, at CA Dept of Fish and Game, and at several environmental film festivals; papers on the role of aquarium and horticulture industries as sources of invaders (Burt *et al*., 2007; Chang *et al*. in review); practical impediments that hamper control of yellow star thistle in rangelands (Aslan *et al*. in review); and a complete high school environmental studies curriculum (Mata *et al*. in prep) Because of the great success of the collaborative project and the accompanying workshops/symposia, the 2nd-year group project will continue to be a key training element of the REACH IGERT.

iii. <u>Non-Academic and International Internships</u>. Broadly based approaches to solving the environmental problems that result from human-caused rapid environmental change require the training of scientists who can collaborate with colleagues outside academia and across international boundaries. The BioInv IGERT internship program provided all of our trainees with experiential learning in government agencies, the private sector, and/or non-governmental organizations (e.g., a science writing internship at the local newspaper, internships on invasive weeds at the California Department of Food and Agriculture). Local and regional leaders in non-academic settings have been eager to direct our students in these internships. Valerie Vartanian of The Nature Conservancy wrote: “Having [your trainee] work on this project for the Voluntary Codes of Conduct program has been incredibly helpful. He did a wonderful job …The information we gather from [his] survey will add to the overall program by providing better insight as to how the public views invasive plants in general and if they are supportive of businesses tackling this issue.” Because of the success of this internship program, we will require all trainees in the REACH IGERT to complete a quarter-long internship, typically in the summer of the first year or during the second year of the program, with either an international organization or a domestic non-academic organization. **The proposed REACH IGERT expands our ties with international collaborators and *provides new internship opportunities in Kenya, Mexico, Peru, Australia, and Spain*.** In each case, we have identified a mentor for our interns abroad (listed in non-UC Davis faculty trainers, above), with commitments of housing or logistic support (see Section 9 for full information). These organizations will also provide similar support to IGERT students wishing to conduct dissertation research under their auspices. **Previous reviewers asked whether international internships would primarily depend on pre-existing ties of faculty trainers.** While ties can be very useful for developing internships, our students have been extremely successful in creating their own internship opportunities as well. Current trainee Kari Veblen forged our first ties with the International Livestock Research Institute (ILRI) in Kenya for her internship; ILRI is now a formal REACH partner. **We have**

proven success in forging relationships with both national and international mentors for our internships; our students come with pre-paid stipends to conduct work that is mutually beneficial to both the host and the student. The current international collaborators facilitate the logistics of working overseas, but students are not limited to these collaborators or institutions. A key feature of our IGERT is the freedom we give our trainees to create tailored internship and project opportunities**.** In evaluations, our students routinely comment that such independence makes these experiences particularly rewarding. Internship proposals are developed by the trainee and the sponsor, and must be approved by the Internship Committee.

iv. Responsible Conduct of Research. All REACH trainees will take a quarter-long seminar on scientific ethics and responsible conduct of research. **This course, originally developed and offered through our BioInv IGERT, now satisfies the requirements of several training grants and graduate programs, and will be cross-listed through Graduate Studies**. Cross-listing this course as a Graduate Studies offering will increase its availability to non-IGERT students. Topics include the examination of normative assumptions, scientific honesty, credibility, and misconduct; publication practices; student-mentor relationships; funding and conflicts of interest; communication and peer review; human-subjects policies for social sciences; and the responsible use of scientific information to guide public policy.

v. Career Development. We have implemented activities both within and outside our curriculum specifically to enhance the professional development of REACH IGERT trainees. During the core course, students will present project results orally and will receive feedback from the trainers teaching the course; students giving talks at the Fall Conference (see below) will practice their presentations, with written comments, in sessions facilitated by the project mentor and Academic Coordinator. In addition, UC Davis' Office of Graduate Studies offers a rich array of workshops in career development on topics such as "Demystifying the Qualifying Exam," "Proposal Writing," "Writing a Curriculum Vitae," and "Transferable Skills." Similarly, UC Davis' Teaching Resources Center offers workshops for graduate students at all levels and special year-long programs for advanced students. Our REACH IGERT has arranged for staff from Graduate Studies and the Teaching Resources Center to speak at our Fall Conference about these distinctive programs.

vi. Presentation of Results at Professional Meetings. Travel to national and international meetings is essential preparation for professional careers, and compels students to present their research results and to network with other scientists. Every IGERT trainee will be funded to present his/her research results at a national or international meeting. In a new element**, *the REACH IGERT also will fund one trainee per project to attend a conference where she/he will present results of their 2nd-year collaborative project*.**

D. OTHER NEW TRAINING OPPORTUNITIES PROVIDED BY THE REACH IGERT

i. Bridge RAships to Foster Multidisciplinary Collaboration. A growing number of graduate student research projects require the input and collaboration of multiple faculty and non-faculty mentors. These research projects are proving to be a highly effective means to foster novel collaborations among faculty and reinforce the culture of multidisciplinarity. ***A value-added innovation in the REACH IGERT will be one- and two-quarter Bridge RAships for advanced graduate students conducting research with two or more trainers from different disciplines.*** These RAships are intended for trainees who have completed the IGERT curriculum and will serve two vitally important components of the IGERT mission. First, the RAships will provide advanced graduate students with opportunities to work closely with, and

"bridge," trainers from different disciplines. Second, and equally important, they will serve to catalyze collaboration and institutionalize a culture of multidisciplinary research within the faculty. An exemplar RAship might include an analysis of the appropriate role of genetic, ecological, and other evidence in identification of subspecies or distinct population segments for protection under the Endangered Species Act. This is an area of significant current policy controversy, illustrated by recent litigation over the legal treatment of the sage grouse and Preble's meadow jumping mouse. Our REACH IGERT can bring together a trainee with trainers in both policy (e.g., Doremus) and ecology/genetics (e.g., Shaffer) to address this question.

These Bridge RAships will entail the preparation of a mini-proposal on a topic of interest to the student and trainers. The RAship will require regular, joint meetings of at least two trainers from different disciplines and the graduate student. We expect that faculty participation will be high because these RAships are funded by IGERT and they provide exciting research opportunities.

Bridge RAships will be open to advanced BioInv and REACH IGERT trainees, as well as to IGERT associates (*i.e.,* students who have taken the IGERT multidisciplinary core course, but who are not lGERT-funded trainees). RAships will be awarded competitively based on the quality of the mini-proposal and on the multi-disciplinary nature of the project. We are very excited by this REACH innovation because we feel **the Bridge RA will act as a catalyst for lasting change at UC Davis by fostering multidisciplinary research among faculty***.* Faculty trained in individual disciplines are often reluctant to participate in cross-disciplinary research efforts. We feel this Bridge RA program will play a major role in opening faculty to broader collaborative efforts. Bridge RAs will present their results at the Fall Conference (see below).

ii. <u>Training in Teaching</u>. While many students have TAships, few graduate students are able to experience the challenge of serving as the primary instructor in a course. In cooperation with the UC Davis Teaching Resources Center (TRC), ***we will be able to fund advanced trainees each year for a quarter-long Chancellor's Teaching Fellowship***. These prestigious fellowships partner highly motivated graduate students with faculty mentors to teach a regularly scheduled undergraduate course. TRC staff will help guide the students in pedagogy and development as teachers. These fellowships will be awarded on a competitive basis to IGERT trainees in their third through fifth years, upon approval from their faculty advisor.

iii. <u>Fall Conference</u>.. We will begin each academic year with a Fall Conference, as we have in our BioInv IGERT. This conference consists of an in-house meeting, attended by all trainees, undergraduates, faculty trainers, and non-faculty trainers. New to REACH, ***the conference will feature a guest speaker working in multidisciplinary research****.* The primary goal of the conference is to highlight the activities of the IGERT over the past year. It is an enjoyable and informal gathering that helps develop community among trainers and students. In addition, the Fall Conference allows new students entering the program to meet all the trainers and trainees, and to hear about IGERT activities. The PI will present a brief overview of previous and future activities of the REACH IGERT; students will do presentations on ongoing research and internship experiences. Finally, there is a longer presentation on the second-year collaborative project that is about to be undertaken. Because the full suite of faculty and students from multiple disciplines attends the conference, the latter presentation allows students developing a project to receive diverse perspectives and feedback from students and faculty, and to establish new collaborations. In years 3-5, there will also be a presentation by the cohort that just finished their collaborative project. This presentation will focus on lessons learned in the process of carrying out their project. Such presentations are invaluable to younger students and to faculty in learning about pitfalls and valuable practices in conducting a large collaborative project.

Beginning in year three, the Fall conference will be two days long, and will include an open discussion of the program evaluations. Moreover, the second day will consist primarily of a symposium or workshop planned and hosted by the cohort finishing their collaborative project in that year (see 2nd-year Collaborative Project, above). In the BioInv IGERT, we only began combining the Fall Conference and the 2nd-year Symposium/workshop in our last two years; this practice has been an effective way to build synergism between these two IGERT activities. One reviewer of the full proposal remarked that the Fall Conference seemed too ambitious; however, we have used this model to great success in the BioInv IGERT.

iv. Developing Community. Building strong relationships within cohorts is critical for successful multidisciplinary collaboration. In our previous IGERT we used traditional mechanisms, such as common coursework and projects, formal cohort activities, informal lunches, and potluck dinners, to develop community. We will expand these activities in the REACH IGERT. Because of the structure of the core course, students will interact frequently and will develop group camaraderie through in-class discussions and, of course, the 2nd-year collaborative project. In addition, the UC Davis campus has provided the REACH IGERT with dedicated space in a central location that will be available to students for meetings and informal coffees. To maintain community with our alumni, we will continue our current practice of writing an annual newsletter that describes IGERT events, trainee and trainer accomplishments, and alumni activities. We also plan to establish an IGERT blog where alumni and current students can contribute thoughts. The Fall Conference also provides the opportunity for all persons involved with IGERT to interact informally. Finally, as described in the mentoring section, all IGERT trainees will have peer mentors, and will mentor other students.

E. SUMMARY OF TRAINEE EXPECTATIONS AND STUDENT SUPPORT. Trainees will enter our IGERT as 1st-year graduate students and should complete required elements of the IGERT program before their 3rd year of graduate school. Beyond the second year, trainees will devote the bulk of their time to their dissertation research with support from internal and external fellowships, RAships, and TAships; however, we expect all IGERT students to attend every IGERT Fall Conference while they are on campus and to mentor new IGERT trainees. As in the BioInv IGERT, as part of their acceptance into the program, REACH trainees will sign a contract that outlines these expectations. A similar contract will be signed by each trainee's major professor, acknowledging that the student will undertake the IGERT curriculum for the first two years and that the major professor will attend each Fall Conference. We have found that such contracts clarify and reinforce the obligations of both students and faculty advisors to the IGERT mission.

We anticipate supporting **four cohorts of 5-7 trainees** for two years each, and providing a total of **20 quarters of Bridge RAships** and **13 Chancellor's Teaching Fellowships** for advanced IGERT trainees and associates over the course of the REACH IGERT.

i. Timeline. We present a training timeline on the next page.

Year 1, fall-spring	IGERT core course
Year 1, spring	Develop collaborative project
Year 1, summer	Dissertation research project
Year 2	Conduct collaborative project though IGERT, complete home program requirements started in year 1, continue dissertation research
Year 3, Fall Conference	Presentation of collaborative project results by cohort just starting their 3rd year
Other requirements to be completed before year 3, flexible scheduling	1 quarter internship, 1 quarter seminar on responsible conduct of research
Additional optional training opportunities for advanced students (Year 3 and beyond)	career development workshops, Bridge RAship, Chancellor's Teaching fellowships

ii. Typical Trainee Pathways. Based on our current IGERT, we expect that our REACH trainees will make good progress through their doctoral programs without substantially affecting time-to-degree. Trainees in the BioInv IGERT, on average, pass their qualifying examination during their 7th enrolled quarter of graduate study. This mean time to advancement to candidacy is the same as that for non-IGERT graduate students in the Population Biology (7th enrolled quarter) and Ecology (8th enrolled quarter) graduate groups. The three trainees below began IGERT participation when they entered graduate study (in different graduate programs), were funded by IGERT for two years, and had the following paths:

MAJOR	POPULATION BIOLOGY	ECOLOGY	AGRICULTURAL & RESOURCE ECONOMICS
Entered IGERT	September 2002	September 2003	September 2004
Completed IGERT requirements	April 2005	September 2006	expected December 2007
Advanced to candidacy	March 2005	March 2006	September 2006
Expected graduation	June 2008	June 2008	June 2008

iii. Other Student Participants in REACH – Graduate and Undergraduate Program Associates. In the BioInv IGERT, we found that many non-IGERT graduate students were interested in the multidisciplinary study of environmental problems and wished to participate in the activities of the training program. As before, we will admit qualified non-IGERT students to the training program as unfunded "associates" who can take part in the core course, seminars, and other activities, as desired. In particular, associates who have participated in the core course will also be eligible to develop Bridge RAships. *Training these additional students greatly expands the impact of our IGERT across campus, and promotes cross-disciplinary training culture as a valuable approach to environmental problem-solving*.

In 2007, PI Strauss, together with two undergraduates, initiated a chapter of ESA's SEEDS program at UC Davis to promote environmental research careers to underrepresented minority undergraduates. We will work with academic development programs and SEEDS participants at UC Davis to include underrepresented juniors and seniors in the REACH program as undergraduate associates. As associates, these students will have opportunities to participate in ongoing research of REACH trainees and faculty, and also in career development activities sponsored by REACH and the NSF-funded Undergraduate Biology and Mathematics (CLIMB) program at UC Davis. A recent report on African-American students in ecology showed that involvement in an authentic research experience as an undergraduate increased the likelihood

of choosing a career in environmental sciences (Armstrong *et al*. 2007). The 12 undergraduates funded by the BioInv IGERT have gone on to pursue careers in science (4 in graduate programs, including 2 NSF predoctoral fellows, 2 in science education intending to go to graduate school, 2 in scientific research, and 2 in professional school; of these 12 students there were 3 Hispanics, 1 Native American, 1 Pacific Islander, 2 disabled, and 8 women). We anticipate continued success in broadening minority undergraduate participation in environmental science. We recognize that IGERT no longer funds undergraduate training, so undergraduates will be supported with REUs on faculty grants and by partnerships with other UC Davis undergraduate research programs (e.g., CLIMB, BUSP, McNair Scholars).

5. ORGANIZATION, MANAGEMENT, AND INSTITUTIONAL COMMITMENT

A. ORGANIZATION AND MANAGEMENT. OVERVIEW: The REACH IGERT will be primarily directed by the PI, a Steering Committee, and the Academic Coordinator, with guidance from an External Advisory Board. Three other committees are central to IGERT administration: the Recruitment and Admissions Committee, the Mentoring Committee, and the Curriculum Committee.

i. Project Coordination. The day-to-day activities of the IGERT are coordinated by the PI and the Academic Coordinator. Sharon Strauss (PI) will direct the IGERT, with responsibility for general oversight, convening the steering committee, communicating with administrators, recruiting trainers to mentor collaborative projects and the core courses, and coordinating with the External Advisory Board. In addition, our current IGERT has taught us that a dedicated manager with academic credentials to implement and coordinate program activities is crucial to our success. Dr. Carole Hom, the Academic Coordinator (AC) of the previous BioInv IGERT and the REACH IGERT, has academic training and administrative experience in interdisciplinary training programs (see Hom biosketch). She will be intellectually engaged with all aspects of the REACH IGERT. In addition to interactions with trainees, she will work with the PIs, IGERT committees, and faculty in planning courses, internships, and student projects. She will also coordinate visits by personnel involved in assessment and recruitment and serve on UC Davis' Steering Committee for the Responsible Conduct of Research campus curriculum.

ii. Steering Committee. The Steering Committee will consist of PI Strauss, co-PIs Grosberg, Doremus, Rice, and Griesemer, Coordinator Hom, two trainers (one each from social and natural sciences), and one trainee. Trainer and trainee representatives will serve one year; trainee reps will be appointed after advancement to candidacy. The Steering Committee will meet quarterly to share information and make decisions on curriculum, recruitment and retention, budget, student projects and internships, and other aspects of IGERT operations.

iii. Recruitment and Admissions Committee. (Co-PI Rice, chair; three trainers)**.** The REACH Recruitment and Admissions Committee will work with the Academic Coordinator, graduate groups, PI, and UC Davis' Office of Graduate Studies to recruit students (see recruitment strategies for underrepresented minorities in Section 7 below). The committee will review applications each year and recommend students for admission to the program. Final acceptance to the IGERT will be made after PI Strauss and AC Hom coordinate admissions with disciplinary graduate groups. This structure has functioned well in our previous IGERT: because of their excellence, over half of our IGERT trainees garnered additional fellowship support for their degrees (NSF, EPA, or intramural fellowships), and our trainees are diverse — 17% underrepresented minorities and 65% women.

iv. Mentoring and Retention Committee (Co-PI Doremus, chair; two trainers)**.** Responsibility for mentoring trainees within the REACH IGERT will be shared by research advisors, faculty leaders of the second-year projects, senior trainees, and the Academic Coordinator. One member of the Mentoring and Retention Committee will meet quarterly with each first-year trainee to discuss his/her experience in the IGERT core courses; committee members will also help students by providing suggestions for appropriate faculty to serve on the trainee's dissertation committee. Peer mentoring pairs a "big brother" or "big sister" IGERT trainee who has already been through the core with new IGERT students. These senior students provide informal advice, peer support, and community to new IGERT students.

v. Curriculum and Internship Committee. (Co-PI Griesemer, two faculty trainers, non-faculty trainers). This committee will plan curriculum, cultivate relationships with internship sponsors, and approve trainee internship proposals. Suggestions from non-faculty trainers in government agencies, non-governmental organizations, or the private sector will provide students with opportunities and ideas for internships. The final choice of internships, however, is up to the student. These strategies have worked well to create rewarding internships in the BioInv IGERT.

vi. External Advisory Board. New to this IGERT, we have established an ***External Advisory Board of accomplished experts in areas directly pertinent to the REACH IGERT*****. Dr. Margaret Palmer** (Entomology, University of Maryland; Member Science Advisory Board, National Center for Earth Surface Dynamics; Member, Board of Chesapeake Bay Recovery Partnership), **Dr. Daniel Simberloff** (Gore Hunger Professor of Environmental Science, University of Tennessee; Member National Science Board), **Dr. Sheila Jasanoff** (Pforzheimer Professor of Science and Technology Studies, Kennedy School of Government, Harvard University; Board of Directors of the American Association for the Advancement of Science; and **Dr. Mark Brunson** (Professor of Environment and Society, Utah State University: social aspects of management of ecosystems, management, connections between biophysical and socio-demographic changes) have all agreed to serve. Palmer and Simberloff are natural scientists (aquatic and terrestrial, respectively) with added expertise in science and policy; Jasanoff is a social scientist with expertise in the role of science and technology in the law, politics, and public policy, with a particular focus on the challenges of globalization; and Brunson is a social scientist, trained in both ecology and psychology, who works at the interface of society and environmental management. The advisory board will visit our IGERT twice: during the Fall Conference in 2010 (after two years of the REACH IGERT), and again in the next year, when they can evaluate our response to their suggestions. The board will receive annual information on all our activities, evaluations, and progress.

B. INSTITUTIONAL COMMITMENT: Because of the success of our previous IGERT, we have been able to garner substantial institutional support. **The Academic Coordinating Council of Deans will support Hom's appointment 25% time for five years** and will provide one non-resident fellowship per year for five years (see supporting letter). Additionally, the Dean of Graduate Studies will provide a total of 12 non-resident tuition fellowships over the course of the IGERT and teaching buy-out funds for faculty members to develop new coursework for the REACH IGERT. ***Also, new in this IGERT, the John Muir Institute for the Environment will fund one-quarter of teaching releases for five years to faculty who teach our multidisciplinary core courses.*** The Center for Population Biology will provide staff support for accounting and grant administration. The College of Biological Sciences will provide a common meeting room for IGERT activities.

C. COLLABORATING WITH OTHER UC DAVIS IGERT PROGRAMS: We anticipate working closely

with the UC Davis "Collaborative Research and Education in Agricultural Technologies and Engineering (CREATE)" IGERT in seminars on responsible conduct of research, public communications and working with the media, career development, preparation for international research, and recruiting. In particular, both the CREATE and REACH IGERTs include partnerships with historically black universities (Tuskegee and Howard Universities, respectively) and campuses in the California State University system. We will partner with the CREATE IGERT in recruiting activities (described more fully in Section 7.A).

6. PERFORMANCE ASSESSMENT/PROJECT EVALUATION

Applying the experience from our BioInv IGERT, we propose a program evaluation that utilizes internal personnel, an external evaluation consultant, and an External Advisory Board of content experts (see above). ***The latter two are new to our proposed IGERT***. The external consultant, Kristin Kusmierek, brings a background in higher education administration and research, and considerable evaluation experience with other IGERTs. She will design our evaluation plan, guide its execution, and collect data on participant observation data. Coordinator Hom will help implement the student interview data entry on-site. Kusmierek will provide written reports each year, with a longer, more detailed evaluation in year 3 and at the end of the IGERT. Also in years 3 and 4, an external advisory board of content experts will provide complementary feedback on intellectual content and activities. After each evaluation is received, the Steering Committee will meet and decide how to implement changes. Evaluation results also will also be discussed with trainers and trainees at the annual Fall Conference.

The program evaluation will explore the impact of our various educational and research components, our administrative elements and effectiveness, and our outreach efforts, using both formative and summative approaches. Evaluation activities include:

a. **Entrance interviews with trainees and a non-trainee control group**, conducted by Hom and Kusmierek, reporting student backgrounds, expectations, intentions, and perspectives on interdisciplinary work.
b. **Exit interviews with trainees and non-trainees** upon completion or departure from the program, conducted by Kusmierek, that explore response to the overall program experience, collaborative research projects, perceived interdisciplinary advances, and impacts on students' educational and professional experiences.
c. **Interviews with program faculty**, conducted by Kusmierek and emphasizing perceptions of program progress, mentoring, student progress, development of collaborative networks, perceptions of institutional change, and advances in interdisciplinarity.
d. **Course evaluations for course and workshop components** that are not already served by institutional mechanisms (UC Davis courses already have mandatory evaluations by students).
e. **Focus group interviews**, conducted by Kusmierek in Years 3 and 5. Separate focus groups will be arranged for students, faculty, and partners.
f. **Assessment of activities and products**. ***A new feature of the REACH IGERT will be assessment of the impacts of our products, including the second-year collaborative projects, internships, faculty exchanges, and international partnerships.*** Interviews/surveys will be conducted by Kusmierek and partners, emphasizing impacts and perceptions of impacts (intended or unintended) of products on students, partner organizations, and targeted constituencies. Students will also be interviewed to record their perceptions of overall product impact, perceived impacts on educational and professional experiences, as well as perceived impacts on partners and other constituencies. To evaluate collaborative projects, we will document products (e.g., student-produced brochures, white papers, symposia, training manuals, publications for academic and

practitioner audiences) and interview students, partners, and key constituents targeted by collaborative projects.

g. **Interviews with key university partners and leaders**. New to this IGERT, *we will investigate through interviews with university administrators and partners, institutionalization and longevity of multidisciplinary training at UC Davis, and potential impacts on the broader academic and research community.*

h. **Post-program tracking of student participants** to capture collaborative endeavors, advancement in and completion of degree program, and career path.

i. **Interviews with program staff to review administrative elements**, including recruitment, program data management, and organizational efficiency and effectiveness. Kusmierek will collaborate with us to ensure we have a collection of data that reflects both the status of the program and its participants, and their activities and outcomes.

j. **Review of course materials**, including electronic and print materials, by the external consultant to assess use and perceived effectiveness.

Kusmierek will provide an annual report that will be sent to the Steering Committee and disseminated to trainees, trainers, and the External Advisory Board. A more lengthy evaluation will be conducted in year three, with a final assessment in year five.

7. RECRUITMENT, MENTORING, AND RETENTION

A. RECRUITMENT AND BROADENING PARTICIPATION. We will continue to expand the recruiting techniques that have resulted in representation of 17% under-represented minorities and 65% women in our BioInv IGERT program. These percentages exceed the number of minorities earning doctorates in our primary fields of Environmental Life Sciences and Sociology (4% and 10%, respectively; NSF 2006). Our BioInv IGERT includes 9% Asian-American trainees in addition to the 17% minority trainees; Asian Americans, while not technically an under-represented minority across the sciences as a whole, are poorly represented in environmental sciences [in 2000, 2.4% of Ecological Society of America members were Asian-American, compared to 3.6% of the US population in the same year, and ca. 10% of STEM workforce; (Ortega et al 2006)]. Thus, our BioInv IGERT has 25% non-white students, including students who are African American, Hispanic, Pacific Islander, and Asian American, in a field that is more than 90% white (Ortega et al 2006). In addition, the diversity of our program is enhanced by having one trainee who is physically disabled.

Our recruitment efforts include sending IGERT participants to graduate fairs and national conferences of organizations such as the Society for Advancement of Chicanos and Native Americans in Science, Historically Black Colleges and Universities-Undergraduate Program, and the California Louis Stokes Alliance for Minority Participation in Science, Engineering, and Mathematics; providing travel assistance for attending professional society programs that mentor students from under-represented groups (e.g., the SEEDS program of the Ecological Society of America); and working closely with UC Davis' recruiting staff and the staff of the Institute for Broadening Participation (see letter of support). UC Davis' Summer Research Program and REU site at Bodega Marine Laboratory further promotes a diverse pool of students to establish relationships with potential graduate mentors from our IGERT. Campus-level programs include partnerships with several Hispanic- and African-American-serving institutions. ***Our new value-added activities will include a student/faculty exchange with a Hispanic-serving campus, California State University, Fullerton (CSUF), as well as with Howard University****,* a Historically Black University. Both institutions are sites of NSF-funded Undergraduate Mentoring in Environmental Biology (UMEB) programs. Together, we will develop a student-faculty exchange program. (1) Each year, a faculty member from UC Davis and an IGERT student will visit CSUF and Howard to give a research seminar, participate in

discussion groups, and talk about graduate study at UC Davis. (2) We will build on those connections with a reciprocal summer visit to UC Davis by a CSUF/Howard faculty member and several students, who will learn about and participate in research of UC Davis faculty. For example, groups of CSUF UMEB students and a faculty advisor visited UC Davis in Fall 2006 for a campus tour and meetings with faculty and graduate school representatives, and we have continued contact with several of those students. We have included a letter of support from faculty members William Hoese (CSUF) and Mary McKenna (Howard).

In addition, new to the REACH IGERT, ***UC Davis' Office of Graduate Studies has agreed to reserve two slots in the campus AGEP-funded bridge program for students from under-represented groups admitted to our IGERT.*** This pre-enrollment program includes a mentored research experience, seminars on strategies for success in graduate school, faculty research presentations, and training for faculty on effective mentoring. We believe that the CSUF and Howard partnerships will build a critical mass of students interested in graduate study in fields related to our IGERT and thus will broaden participation at UC Davis. Additionally, because our student group is currently diverse and well-mentored, with 100% retention, trainees should feel comfortable in our IGERT community.

B. MENTORING. Mentorship at multiple levels is one of the most effective ways to retain students and to provide them with leadership skills. Our web of mentorship involving faculty and non-faculty trainers, academic coordinator, and peers has resulted in **100% retention in the BioInv IGERT.** Given this success, we will continue to form mentoring teams, consisting of the trainee's research advisor, his/her guidance committee, an IGERT peer, and the Academic Coordinator, for each trainee. Trainees in our IGERT enter graduate study with an identified research advisor in the home graduate group. This faculty member works with our Academic Coordinator to familiarize the student with UC Davis, the student's graduate program, and the IGERT. Our trainees' guidance committees include faculty trainers from at least two different areas of the REACH IGERT and provide students with access to faculty expertise outside the home discipline. The guidance committee helps the student design an individualized curriculum based on the student's primary research areas, and suggests internship possibilities that complement fundamental academic training with applied experience. Peer mentoring entails a Big Brother or Sister senior IGERT student who meets informally with a new trainee on a quarterly basis and offers support and advice from a student's perspective.

Mentoring students from under-represented groups will also entail linking them with groups on campus that can provide them with additional social-support networks. These include: Mixed Student Union, ACE - African & African Americans Cultivating Education, BRIDGE - Filipino Outreach & Retention Program, GAAAP - Graduate Academic Achievement & Advocacy Program, NE'UE - Natives Empowered through Unity and Education, and Chicano/a Latino/a Holistic Student Support Program.

At the campus level, UC Davis provides professional development programs for graduate students that include workshops on grant writing, interviewing for positions, and innovations in teaching. In addition to campus-level postings, Coordinator Hom specifically advertises these programs to trainees and encourages their participation.

C. RETENTION. The BioInv IGERT has a superb record in retention. All 24 trainees supported for two years are making satisfactory progress toward their doctoral degrees. We also supported 27 short-term trainees on one-quarter traineeships. Of these, only one student left UC Davis (for medical/personal reasons); the others completed their degrees and are working in postdoctoral positions, have accepted faculty offers at liberal arts colleges or research universities, or have gained positions with non-governmental organizations, federal agencies, or similar institutions.

In the REACH IGERT, we intend to continue the practices that led to this strong record. UC Davis' excellent programs, supportive atmosphere, and superb students, coupled with the close-knit IGERT community and the mentoring program, create a synergy that leads to high retention. On the institutional level, UC Davis has a well-deserved reputation for excellent teaching and graduate mentoring, thus creating an affirming climate for graduate study.

We use several mechanisms to maximize student retention. First, Academic Coordinator Hom maintains close contact with our trainees. She attends all sessions of the core course and other IGERT seminars, and thus develops a strong relationship with new trainees. Because of her high level of participation and day-to-day contact with students in their first year, she has firsthand knowledge of individual trainees' performance in IGERT courses. Second, the Academic Coordinator and a member of the Mentoring and Retention Committee meet with students at critical transitions during their IGERT program: at entrance, after one quarter, at the end of the first year, and after completing the IGERT program. Third, peer mentoring provides both formal and informal support throughout graduate study. Last, but not least, our IGERT provides an excellent blend of structure and intellectual freedom for our trainees. Our trainees have the freedom to design a group project and internship that meets their interests, yet they have the support and structure of the faculty mentor, meetings with the Academic Coordinator and oversight by the Internship and Curriculum Committees to make them feel safe within this sometimes intimidating, multidisciplinary adventure. Because of the intellectual freedom provided by our IGERT program, students are able to tailor their activities to their own interests. Our BioInv IGERT students comment on the fact that they seem much happier in our program than students in other IGERTs in which the projects or internships are more prescribed.

D. FACULTY DIVERSITY. Of the 40 faculty in the REACH IGERT, 10 (25%) are women and one is an Asian-American male. The Academic Coordinator of the IGERT is an Asian-American woman. One female trainee commented, "It has been particularly inspiring for me to work with strong women scientists through the IGERT — it has redirected my future interests toward academia as a career."

8. RECENT TRAINEESHIP EXPERIENCE AND RESULTS FROM PRIOR NSF SUPPORT

A. TRAINEE SUCCESS AND TRAINER COLLABORATIONS: The BioInv IGERT (1 Oct 2001 to 30 Sep 2007) has resulted in **26 trainee-authored peer-reviewed scientific publications** (most recently, **Burt** *et al*. 2007, **Byrnes** *et al.* 2007), **50 trainee conference presentations**, and high-impact faculty publications on invasions (e.g., Grosholz 2005, Hastings *et al*. 2005, Hughes and Stachowicz 2005, Strauss *et al*. 2006, Lodge *et al.* 2006). All trainees supported by our IGERT are making satisfactory progress toward the Ph.D. All but one of our one-quarter trainees completed Ph.D.s or are making satisfactory progress. Alumni have accepted positions with non-governmental organizations, two have faculty positions at research universities, and others are in postdoctoral positions (including a fellow of the American Association for the Advancement of Science). All four postdoctoral fellows, funded 50% by NSF and 50% by institutional funds, have accepted faculty positions, some in interdisciplinary programs. All indicated that the interdisciplinary experience afforded by our IGERT was critical to their success in the job market. Four undergraduate alumni are in graduate programs, with two supported by NSF predoctoral fellowships, and four others intend to pursue doctoral study after 1-2 years in the scientific workforce.

B. INTERDISCIPLINARY PROJECTS AND OUTREACH: Interdisciplinary collaborative projects have been a hallmark of our program. The projects, designed and executed by students, address cross-disciplinary aspects of biological invasions. The 2002 cohort examined the biological and

social impacts of an invasive predatory fish in a reservoir, the poisoning of the reservoir by a state agency to kill the fish, and subsequent community backlash. The students wrote and filmed an environmental documentary ("*Fear and Fishing in Lake Davis: A Tale About People, Government, and the Fish That Came Between Them*") that has been shown in theaters and classrooms across the US, and at the CA Dept of Fish and Game (DVD available at cost from UC Davis). In addition, the students were invited to lecture about their film to an upper-division environmental problem-solving class at UC Berkeley in 2006 and 2007. The professor in the course commented, "The Lake Davis story is classic and fills an important need … for showing what happens when there is no appropriate communication among all the stakeholders." The 2003 cohort studied retailers in the horticultural and aquarium trades and examined their attitudes and actions toward preventing the introduction of invasive species (**Burt** *et al.* 2007; **Chang** *et al.* in review). After the student-run symposium on that project, trainees were asked to present their results at several state-wide invasive species agency meetings. Burt *et al.* (2007; published open source) was enthusiastically embraced by USDA and posted on the USDA National Agricultural Library website. The 2004 cohort studied cattle ranchers' attitudes toward yellow star thistle and practical impediments hampering its control (Aslan *et al*. in review); the 2005 cohort collaborated with K-12 teachers and a non-governmental organization to write a high school environmental studies curriculum that will be used by schools from urban and rural districts in 2007-2008. Additional outreach efforts include a widely emulated brochure on alternatives to invasive plants (*Don't Plant a Pest*), a primer on government relations for citizen-scientists, and an extensive revision of invasive species entries in Wikipedia.

C. DEMOGRAPHICS: We will continue and augment the recruiting techniques that have resulted in 17% representation of minorities and 65% women in our current program. This percentage exceeds the number of minorities earning doctorates in our primary fields of Environmental Life Sciences and Sociology (4% and 10%, respectively; NSF 2006). Our BioInv IGERT also includes an additional 8% Asian-American trainees; Asian Americans, while well-represented across the sciences as a whole, are much less common in environmental sciences.

In addition to students funded on two-year traineeships, we also have supported 27 students on one-quarter-long traineeships to conduct interdisciplinary research or to organize interdisciplinary symposia that addressed some aspect of biological invasions.

D. EXPERIENCE WITH OTHER INTERDISCIPLINARY TRAINING GRANTS: In addition to the BioInv IGERT, several key personnel have considerable experience with other interdisciplinary traineeships. PI Strauss recently was invited to participate as an advisor in the inaugural symposium of a new IGERT at the University of Minnesota on risk analysis for introduced species. Co-PI Grosberg served in 2005 as an external reviewer for a mathematical biology IGERT at Colorado State University. Grosberg is also the PI of an NSF Undergraduate Biology and Mathematics training grant at UC Davis. Finally, the BioInv IGERT, along with the IGERT Coordinating Council (ICC) at Davis helped host an all-UC IGERT meeting at UC Davis at which best practices and pitfalls were discussed.

E. INSTITUTIONAL CHANGE: The UC Davis BioInv IGERT has established a reputation among agencies, non-governmental organizations, and colleagues across the US for training students who conduct top-quality research, are well-versed in its policy implications, and are skilled in communicating research results. As a result, agency staff and faculty colleagues approach our IGERT with suggestions for internships, student projects, and symposia. In addition, one of our trainers is leading an effort involving all campuses of the University of California to form a center for the study of marine invasions.

Every activity sponsored by our IGERT has had substantial participation by non-IGERT students. These include core courses, symposia, and seminars on collaboration and the responsible conduct of research for environmental scientists. The latter has been approved to satisfy a program requirement of UC Davis' graduate group in environmental toxicology.

UC Davis, as a campus, is committed to multi-disciplinary study at the graduate level. Most graduate education occurs within graduate groups that cross traditional departmental boundaries. We must develop a culture that rewards and recognizes multi-authored, collaborative research if multi-disciplinary research is to be fostered and, accordingly, have advocated for a "Designated Emphasis in Multidisciplinary Studies" that would allow an add-on certificate to a disciplinary Ph.D. degree to recognize the additional work interdisciplinary students undertake. This Designated Emphasis will provide institutional recognition that the recipient has completed a formal program of multidisciplinary training. We have also asked that students who have co-authored papers as members of collaborative teams be allowed to use this publication as a dissertation chapter.

A widely recognized problem associated with multidisciplinary training programs is the additional teaching responsibility shouldered by participating faculty. UC Davis deans have offered their support of our IGERT via teaching releases for faculty heavily involved in IGERT activities and collaborations (Law: Doremus; Biology: Schoener, Strauss; Social Sciences: Warren). ***The current IGERT also includes institutional funds for teaching buy-outs for faculty to participate in our IGERT curriculum from both Graduate Studies and from UC Davis' John Muir Institute of the Environment*** (letter of support included).

Our BioInv IGERT has been key in promoting institutional change at UC Davis. We have played a leading role in the IGERT Coordinating Council, consisting of the Graduate Dean and PIs of all campus IGERTs. Under the aegis of the ICC, UC Davis hosted a conference of all UC IGERTs to discuss interdisciplinary research and share challenges and solutions to common problems. The ICC also held a UC Davis IGERT research conference, and encouraged the administration to implement a program for training graduate students in the responsible conduct of research (initiated in Fall 2005) and to form an office for assessment that will have a research function, as well as serving training grants. New to REACH, we have added the support of JMIE to interdisciplinary training on campus. Faculty in the REACH IGERT will work closely with faculty from the newly-funded CREATE IGERT at UC Davis to maximize our collective effectiveness in training, professional development, and recruiting.

F. VALUE-ADDED GOALS OF THE REACH IGERT: We have accomplished much, yet many of these changes require more time to become fully institutionalized: the impact of our IGERT will be maximized by another five years of funding. The REACH IGERT program builds on what we have learned from the BioInv IGERT. We have retained its successful attributes – educational program, recruitment activities, administrative structure, management team, and several aspects of assessment. Thus, we have in place an effective infrastructure that allows us to minimize inefficiencies at start-up. We are experienced in recruiting high quality students who thrive in multidisciplinary programs, and in mentoring them to attain their career goals. To these important foundations, we have added **(1) new training and research emphases; (2) expanded recruitment activities; (3) a program that fosters more extensive multi-disciplinary research; (4) new models for assessment; and (5) opportunities for international collaboration.** These have been described in each section of this proposal, and have been highlighted as novel, value-added components. These new components and emphases of the REACH IGERT encompass a greater range of environmental problems, disciplines, and problem-solving approaches than in our BioInv IGERT. The REACH IGERT will equip the next generation of natural and social scientists and policy makers with the skills to address the broad and diverse challenges stemming from rapid environmental change.

9. INTERNATIONAL COLLABORATION

A. INTERNATIONAL RESOURCES. Human-caused changes to the environment generated in one location often create impacts felt around the globe (e.g., atmospheric emissions). Working with people in other countries is, and will continue to be, a prerequisite for addressing rapid, human-caused environmental change (e.g., Kyoto Protocol). Even when impacts are primarily local, knowledge of how different cultures and nations approach universal, human-caused environmental problems will promote more effective resolution of these problems.

One of the innovations of the REACH IGERT is the opportunity for trainees to conduct their required internship or dissertation research at foreign institutions. The REACH IGERT will pay for student stipends, airfare, and housing costs (if needed), to allow trainees to work for at least a quarter at a foreign institution whose mission includes addressing rapid, human-caused changes to the environment. Each participating institution has formally agreed to partner with us and host our students for internships and research projects, and is providing, at minimum, support for logistics and permits, and in many cases, housing. In most cases, UC Davis faculty trainers in the REACH IGERT have personal connections with these institutions, and most have ongoing research partnerships with them. Close contacts between UC Davis advisors and international mentors mean that students have mentors both at home and abroad. International institutions that have agreed to host our students for research projects or internships, include the Universidad de Granada (Spain), Programo Andino (Peru), International Livestock Research Institute (ILRI; Kenya), and the Institute of Applied Ecology (Canberra, Australia). We have attached letters of support, with additional letters on file. In addition, in keeping with our philosophy of ownership, students can create their own international collaborations as long as they have sufficient mentorship and written support from the foreign institution.

B. SELECTION AND PREPARATION FOR INTERNATIONAL RESEARCH. While the freedom we give trainees to create tailored internships makes these experiences particularly rewarding, we also recognize the need for structure and extra preparation to ensure success in a foreign country. Trainees will write a proposal that details the proposed objectives and activities with their internship partner. In addition to describing scientific or policy objectives, the proposal must include a discussion of the environmental problem in the context of the specific international setting (Rodriguez *et al*. 2007). Trainees may propose internship sponsors other than those included in this proposal; in such cases, we will explore with the sponsor the resources available to the student and ask for a formal letter of sponsorship detailing the commitments made to each student. The Curriculum and Internship Committee will review proposals and suggest modifications, if needed, prior to approval.

All trainees selected to participate in an international internship or research experience will be required to attend a preparatory workshop. Although designed for IGERT students, this workshop will be open to all UC Davis graduate students. It will be developed by REACH trainers from graduate programs that include Anthropology and International Agricultural Development, and in collaboration with the UC Davis CREATE IGERT and staff from UC Davis' Education Abroad Program, Office of University Outreach and International Programs, and Graduate Studies. Topics will include basic traveler's information, obtaining permits for research and permission to import/export materials, approval of protocols for research with vertebrate animals or human subjects in an international setting, and considerations in working with local collaborators and communities in foreign cultures.

C. PRIOR GRADUATE STUDENT EXPERIENCE IN INTERNATIONAL RESEARCH. We know the proposed international collaborations are feasible and rewarding: a current BioInv IGERT trainee recently completed an internship with Dr. Robin Reid at the ILRI in Kenya. Several of our current BioInv

IGERT trainees have dissertation research abroad (Kenya, Mexico, Australia, India, the Bahamas). In some cases, these projects are an extension of a faculty member's research program; in others, the project was developed independently by the student. One trainee's research in Mexico addresses human land-use patterns, gene flow, and conservation of teosinte, the wild relative of maize. Another trainee studies the cultural (religious, caste, and village-based) and ecological drivers of fire as a landscape-management tool in southern India. A third trainee studies the origin and development of wildlife "hotspots" derived from abandoned traditional cattle corrals in Kenya, and the roles of wild and domestic large herbivores as dispersers and mediators of competition and facilitation in the plant community. These students have described their work at BioInv IGERT fall conferences; thus all trainees have benefitted. Based on these successful international experiences of our current BioInv IGERT trainees, we are confident that we can succeed in providing a mentored international experience.

10. RECRUITMENT AND RETENTION HISTORY

The following page summarizes data on recruitment and retention history, and employers of graduates for students in the BioInv IGERT (Oct 2001-present). As stipulated by NSF program directors in the 31 July 2007 Webinar, information on other graduate programs was not included because this proposal is for a renewal of an existing IGERT.

Ethnic and gender diversity in the BioInv IGERT are proportionately higher than that of graduate programs from which our IGERT draws. All trainees on two-year fellowships are making satisfactory degree progress and are still enrolled in the IGERT program. None have withdrawn.

Short-term fellows in the BioInv IGERT were students funded for one quarter to conduct an interdisciplinary research or outreach project. Because they entered as advanced students, they were not required to participate in the full IGERT curriculum. Totals in the "other" category may not be equal to the sum of entries for women plus minorities because some minority applicants and trainees are also women.

BioInv IGERT Trainees	Short-term	2002 cohort	2003 cohort	2004 cohort	2005 cohort
Total Applicants	59	23	29	27	25
Women	35	12	21	15	19
Minorities: African American	1	0	1	0	1
Native American	0	0	0	1	0
Hispanic	1	1	1	1	1
Pacific Islander	0	1	0	0	0
Disabled	0	0	1	0	0
Other	21	10	7	12	6
Total Accepted	27	6	8	6	6
Women	18	4	5	2	6
Minorities: African American	0	0	1	0	1
Native American	0	0	0	0	0
Hispanic	1	0	0	1	1
Pacific Islander	0	1	0	0	0
Disabled	0	0	1	0	0
Other	8	2	2	3	0
Total Matriculated	27	6	8	6	4
Women	18	4	5	4	4
Minorities: African American	0	0	1	0	0
Native American	0	0	0	0	0
Hispanic	1	0	0	1	1
Pacific Islander	0	1	0	0	0
Disabled	0	0	1	0	0
Other	8	2	2	3	0
Total Withdrawals	1	0	0	0	0
Total PhDs awarded	24	0	0	0	0
Total Currently Enrolled	2	6	8	6	4
Women	18	4	9	13	17
Minorities: African American	0	0	1	1	1
Native American	0	0	0	0	0
Hispanic	1	0	1	1	2
Pacific Islander	0	1	1	1	1
Disabled	0	0	1	1	1

Alumni: number of short term trainees	**Faculty, research university**	**Faculty, liberal arts college**	**Faculty, other college/compreh. university**	**Faculty, community college**	**Research postdoc**	**Research staff, university**	**Research staff, agency**	**Cooperative extension**	**Presid Mgt/AAAS Congres/Dipl. Fellow**	**Private sector**	**Exec/Staff, nonprofit**	**Pursuing other advanced degree**	**Not available**
women	2	0	0	0	4	1	1	0	2	0	3	0	2
men	1	1	1	0	1	2	0	0	0	0	1	2	0

PROJECT DESCRIPTION