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NSF 06-525 09/29/06	NSF PROPOSAL NUMBER
FOR CONSIDERATION BY NSF ORGANIZATION UNIT(S) (Indicate the most specific unit known, i.e. program, division, etc.) DGE - IGERT FULL PROPOSALS	0653827

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TITLE OF PROPOSED PROJECT: **IGERT: Risk Analysis for Introduced Species and Genotypes**

REQUESTED AMOUNT	PROPOSED DURATION (1-60 MONTHS)	REQUESTED STARTING DATE	SHOW RELATED PRELIMINARY PROPOSAL NO. IF APPLICABLE
$ 3,193,585	60 months	07/01/07	0629638

CHECK APPROPRIATE BOX(ES) IF THIS PROPOSAL INCLUDES ANY OF THE ITEMS LISTED BELOW
- ☐ BEGINNING INVESTIGATOR (GPG I.A)
- ☐ DISCLOSURE OF LOBBYING ACTIVITIES (GPG II.C)
- ☐ PROPRIETARY & PRIVILEGED INFORMATION (GPG I.B, II.C.1.d)
- ☐ HISTORIC PLACES (GPG II.C.2.j)
- ☐ SMALL GRANT FOR EXPLOR. RESEARCH (SGER) (GPG II.D.1)
- ☐ VERTEBRATE ANIMALS (GPG II.D.5) IACUC App. Date ________
- ☐ HUMAN SUBJECTS (GPG II.D.6) Exemption Subsection ________ or IRB App. Date ________
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- ☐ HIGH RESOLUTION GRAPHICS/OTHER GRAPHICS WHERE EXACT COLOR REPRESENTATION IS REQUIRED FOR PROPER INTERPRETATION (GPG I.G.1)

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Electronic Signature

IGERT: Risk Analysis for Introduced Species and Genotypes

Raymond M. Newman, PI, David A. Andow, Susan M. Galatowitsch, Anne R. Kapuscinski and Ruth G. Shaw, Co-PIs, University of Minnesota

Participating Organizations: CHS, CSIRO, Embrapa, Florida A & M University, Minnesota Invasive Species Advisory Council, South African National Biodiversity Institute, U.S. Fish and Wildlife Service, U.S. Forest Service, WorldFish Center, Yokohama University and 15 other partners who have sent letters committing to collaboration.

Project Summary

Globalization is driving an unprecedented number of introductions of exotic species and new genotypes into ecosystems. Many introductions are purposeful but many are accidental. Their consequences range from highly beneficial to extremely damaging, depending upon the relative magnitudes of environmental benefits and costs and how they are evaluated. This situation has intensified the need to improve the scientific basis of decision-making on introducing new species and genotypes, how to prevent future detrimental introductions, and how to control harmful organisms already present. Our IGERT program will use Ecological Risk Analysis (ERA) as a conceptual framework for evaluating ecological effects of invasive species, genetically engineered organisms, and biological control agents from a decision-making perspective. Most ERA methods, first developed for chemical hazards, have limited applicability to introduced organisms which, unlike chemicals, reproduce and evolve. Our research will improve the science that informs decision making about biotic introductions. Our IGERT will address four focal areas of inquiry: (A) Are the regulatory processes effective at allowing or excluding new species and genotypes appropriately? (B) Can risk assessment models be improved and, if so, when is this improvement of value? (C) How can uncertainty be addressed within ERA? (D) How can risk management be improved? Students will work with leading scientists researching these issues, drawing on expertise of our faculty and partners in microbial, plant, animal, terrestrial and aquatic systems and in all phases of risk analysis (risk assessment, management and deliberation).

Approximately 29 IGERT students will participate in a curriculum that encompasses fundamental biology and ecology of introduced organisms, economic and social perspectives, and deliberation approaches. The curriculum, which emphasizes cooperative learning and links specifically to our research themes, starts with a course that exposes students to an analytic-deliberative model of ERA. Students will explore components of established risk analyses, experience common approaches to risk characterization, evaluate risk management decisions, and apply risk communication and multi-stakeholder deliberation techniques. IGERT fellows will also develop skills in quantitative modeling through a short-course on risk modeling. In the second year, students will participate in a problem-solving practicum, collaboratively researching a risk assessment dilemma in conjunction with one of our partners. In a third year practicum, students will develop cooperative learning exercises based on their work with our partners. The resulting compendium of decision cases will provide risk assessment training tools for use beyond our IGERT. The IGERT curriculum will operate as a graduate degree minor to ensure continuation of the program and its collaborations after NSF funding ends.

Our well-developed collaborations with local, state, federal and international research and management agencies offer students exceptional opportunities to apply their research efforts to current, pressing issues of ERA for introduced organisms. These partners will provide diverse opportunities for the problem-solving practicums and dissertation research projects. They will also participate in courses, annual symposia, and some will serve on our external advisory committee. **Intellectual impacts** of our IGERT will be the improvement of ERA for introduced species and genotypes and development of new genetic and ecological approaches for controlling already harmful invasive organisms. **Broader impacts** will be to advance the scientific basis of decision-making and produce a group of young scientists, with diverse cultural perspectives, who are uniquely and highly qualified to meet the special challenges posed by introduced organisms which society presently struggles to address. Further, our curricular materials, developed from real-world scenarios, will help build professional capacity worldwide for analyzing risks associated with introductions.

Key words: Biology, Environmental Sciences, Social Sciences, Risk Analysis

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For font size and page formatting specifications, see GPG section II.C.

Appendix Items:

*Proposers may select any numbering mechanism for the proposal. The entire proposal however, must be paginated. Complete both columns only if the proposal is numbered consecutively.

C (1) List of Participants

Name: ***Graduate Degree Programs***	**IGERT contribution**
Raymond M. Newman: *Conservation Biology; Ecology, Evolution & Behavior; Water Resources Science* **(PI)**	Aquatic impacts and control
David A. Andow: *Entomology; Ecology, Evolution and Behavior; Conservation Biology; Sustainable Agriculture Systems* **(Co-PI)**	Risk analysis, resistance evolution
Susan M. Galatowitsch: *Applied Plant Sci.; Conservation Biology; Ecology, Evolution & Behavior; Water Res. Sci.* **(Co-PI)**	Restoration ecology; invasive spp. biology
Anne R. Kapuscinski: *Conservation Biology; Sci, Technology & Environmental Policy; Dev. Studies & Social Change;* **(Co-PI)**	Environmental risk analysis; fish GEOs
Ruth G. Shaw: *Ecology, Evolution & Behavior; Plant Biol. Sciences* **(Co-PI)**	Evolutionary genetics
Neil O. Anderson: *Applied Plant Sciences; Conservation Biology*	Invasive plant evolution; prevention of invasion
Gary Balas: *Control Sci. & Dynamic Syst.; Aerospace Engineering*	Risk Analysis
Robert G. Haight: *Cons. Bio.; Natural Resources Sci. & Manage.*	Risk analysis models
George E. Heimpel: *Entomology; Ecology, Evolution & Behavior*	Biological control, GEOs
Frances Homans: *Applied Economics; Cons. Bio.; Water Res. Sci.*	Risk analysis economics
Terrance M. Hurley: *Applied Economics*	Risk analysis economics
William Hutchison: *Entomology*	Decision analysis; insects; biocontrol
Nicholas R. Jordan: *Applied Plant Sciences; Conservation Biology; Sustainable Agriculture Systems*	Civic engagement; invasive weed species
Jennifer Kuzma: *Science, Technology & Environmental Policy; Public Policy; Public Affairs; Urban & Regional Planning*	Science technology policy
Kristen Nelson: *Conservation Biology; Natural Resources Sci. & Manage.; Dev. Studies & Social Change*	Conflict resolution; Deliberation
Karen S. Oberhauser: *Conservation Biology; Ecology, Evolution & Behavior; Biological Science*	Nontarget GEO impacts, insects
David W. Ragsdale: *Entomology*	Biocontrol: Insects/weeds
Mike Sadowsky: *Microbiology, Immunology and Cancer Biology; Microbial Ecology; Microbial Engineering; Soil Science*	Microbial ecology, GEOs, invasive microbes
Peter W. Sorensen: *Conservation Biology; Neuroscience; Ecology, Evolution & Behavior; Water Resources Science*	Aquatic invasive control
Robert C. Venette: *Entomology; Biological Science*	Invasion biology, risk assessment, biocontrol,

Additional faculty: (Department: Name)	
Agronomy Plant Genetics: Roger Becker, Don Wyse *Applied Economics:* Steve Polasky *Ecol., Evol. Behav.*: David Tilman. Diane Larson *Center for Teaching and Learning:* Valerie Ruhe, David Langley *Entomology:* Roger Moon, Vera Krischik *Fish, Wildl. & Cons Bio:* Doug Johnson *Forest Resources*: Lee Frelich, Rebecca Montgomery, Peter Reich	*Horticultural Science:* Mary Meyer, Alan Smith *Public Health:* John Adgate, Deborah Swackhamer *Rhetoric:* Daniel Philippon *Sociology:* Rachel Schurman *Statistics:* Gary Oehlert, Galin Jones, Sanford Weisberg *Veterinary Medicine:* Will Hueston

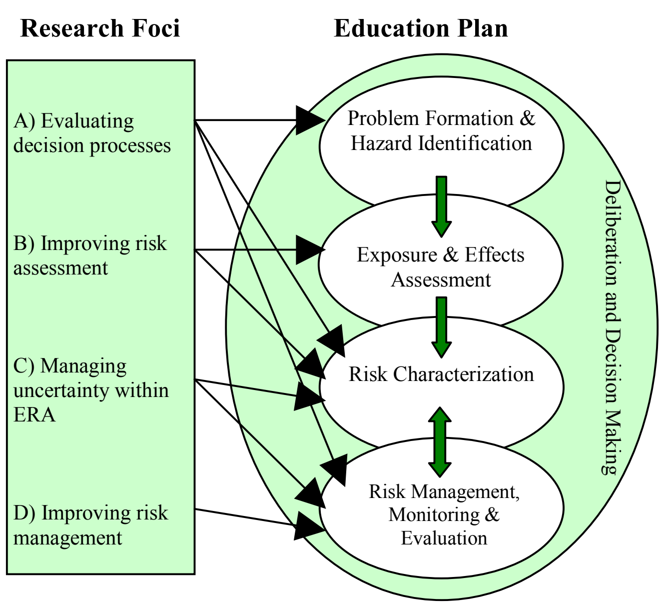
C (2) Vision, Goals and Thematic Basis

Globalization is driving an unprecedented number of introductions of exotic species and new genotypes into ecosystems. Although some of these introductions are purposeful, many are accidental. Outcomes of these introductions can range from highly beneficial to extremely damaging, with such judgments often depending upon how tradeoffs between potentially beneficial and detrimental effects are evaluated. Society desperately needs scientific leaders who excel at integrating fundamental science with consideration of societal factors in order to create better public policy and improve the scientific basis for risk analysis.

Similar ecological and evolutionary processes drive the establishment and spread of introduced species and genotypes (ISGs; Tiedje et al. 1989; Williamson 1996). These processes determine whether or not a *purposefully introduced* species becomes invasive, either as a pest within a managed system (e.g. agricultural fields, fish farms, or forests) or as a new biotic component in a natural ecosystem. They also influence whether *accidental introductions*, such as aquatic species hitchhiking on recreational and commercial vessels, remain innocuous or become highly invasive. Scientists need to understand these same processes to assess whether the purposeful introduction of *biological control agents* will effectively manage target organisms and how they may affect non-target organisms. Understanding these processes can also guide the design of genetically engineered organisms (GEOs) to reduce chances of their invasion or to help control invasive organisms via deliberate spread of detrimental genes. Comprehensive analysis of consequences of biological introductions for ecosystems and human communities requires integrating information from evolutionary and biological sciences with key areas of the social sciences.

The overarching goal of our IGERT program is to educate Ph.D. students to conduct research to improve Ecological Risk Analysis (ERA) and contribute workable solutions to policy questions and problems affecting management of introduced species and genotypes. Our IGERT program will use ERA as a conceptual framework for understanding ecological effects of invasive species, genetically engineered organisms, and biological control agents from a decision making perspective (Fig. 1). ERA was developed during the 1970s to address the environmental risks of chemical contaminants, such as pesticides, industrial wastes, and mine tailings. ERA has been supported by quantitative fate and transport models, which assess where and how long the environment is expected to be exposed to these chemical hazards. It also allows the quantitative assessment of the effects, which determines the expected harm from a given exposure to a chemical hazard. Concerns about exotic species and new genotypes arose later. However, it was quickly realized that because these organisms reproduce and evolve (Cox 2004), most quantitative methods developed for chemical hazards have limited applicability for ERA of biological introductions. Although this stimulated some development of ecological risk assessment tools (EPA 1999), in the U. S., ERA for invasive species continues to rely primarily

Fig 1. The educational plan utilizes four research foci (rectangle) that feed into improving ERA (large oval, after EPA 1999). The plan is organized around technical analysis, deliberation, and decision-making processes.



on qualitative expert judgment, while ERA for GEOs and biological control agents remains an ad hoc mixture of qualitative and quantitative methods. Thus, there is considerable room for improvement of ERA for biological introductions (Simberloff 2005).

Risk analyses have been done using two general, but often contrasting, models (NRC 1983, 1996). The 1983 model develops risk analysis as a technical process that can be divided into three interconnected parts: risk assessment, risk management and risk communication. It relies mostly on natural science information, and uses social science only to evaluate social and economic consequences of regulatory options at the end of the risk management phase. This limits multi-stakeholder input to formal public comment near the end of the decision process. This model has been modified for quantitative chemical risk assessment and, to a more limited extent, for ERA (EPA 1999). The 1996 model links scientific analysis and multi-stakeholder deliberation at key points throughout risk analysis. This allows the integration of expertise in the natural and social sciences to reach scientifically sound and broadly trusted decisions (e.g., Nelson et al. 2004). Whereas the 1983 model stresses objective features of ERA, the 1996 model emphasizes subjective ones; it measures and weighs environmental goods, representing the resolution of disparate environmental values held by different people. ***Our IGERT will utilize both of these general models to frame both our research and education components (Fig. 1), addressing the technical and deliberative demands of ERA.***

Our program will prepare students to apply scientific expertise to improve ERA of biological introductions. In our experience, ecologists, economists, and social scientists working with introduced organisms often lack adequate graduate training to apply science to solve real-world problems. Biology students typically have inadequate preparation to consider the societal and policy implications of scientific discoveries, whereas economists and social scientists often lack a fundamental understanding of ecological principles. The need to fill these training gaps is heightened by rapid developments in genetic engineering and biotechnology, concerns about invasive species and new genotypes, and increased levels of international commerce leading to increased rates of biological invasions (Mack et al. 2000).

We will address these training gaps by providing IGERT students with a program based on collaborative learning, coursework addressing the risk analysis processes and quantitative modeling, a problem-solving practicum providing experience with risk analysis problems in collaboration with national and international external partners, and a cooperative learning practicum whereby students will translate what they learned in the problem-solving practicum into teaching tools for the program and our external partners. Students will conduct research to improve the scientific basis for ERA decision making, considering how their research results can be used to improve the decision making process. They will have opportunities to conduct portions of their dissertation research off-campus with our external partners, including local as well as international institutions. Our proposed curriculum (see section C4) emphasizes collaborative learning that connects science to policy and society and focuses on establishing linkages between research and ERA decision-making.

The breadth of research expertise of our faculty and external partners (Table 1) promotes effective linkage among all phases of risk analysis (from risk assessment to management and deliberation) that pertain to the introduction of a wide range of exotic species and novel genotypes (microorganisms, plants, invertebrates and vertebrates). Our domestic and international partners offer unique educational opportunities for students; collaborations with partners will allow our students to deepen their understanding of how fundamental scientific knowledge can be brought to the interdisciplinary process of ERA.

C (3) Major Research Efforts

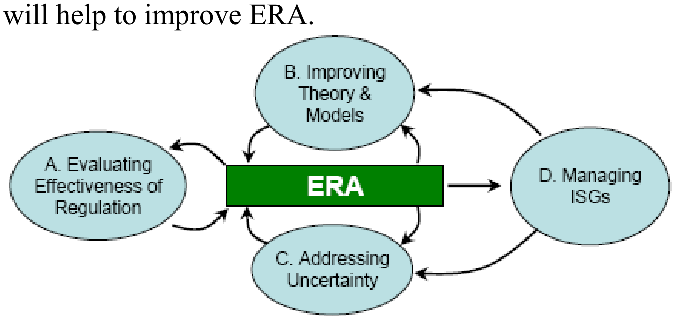
ERA leads to decisions to allow or disallow an activity, such as the deliberate introduction of an exotic species and, further, whether to require management to limit the consequences of introductions. Our research will focus on science that informs ERA in the context of the decision process that employs scientific models to assess and manage risk. Our students will conduct research to improve the scientific basis for decision-making and will examine how this scientific information filters through to improve these decisions.

Table 1. External partners who have committed to hosting IGERT students for problem solving practicums and/or dissertation research (*letters in Section H).

Organization, Location and Abbreviation	Educational Opportunities
North America	
CHS (formerly Cenex, Harvest States; MN)	See letter of support*
Center for Biological Control, Florida A&M Univ. (FAMU)	See letter of support*
General Mills (MN)	GEOs in food products
Minnesota Invasive Species Advisory Council (MISAC)	See letter of support *
Nat'l Research Council, Agric. & Natural Resour. (Wash., DC) (NRC)	ERA, policies for ISGs
United Nations, Convention on Biological Diversity (Montreal) (CBD)	Int'l ERA &ISG policy
U.S. Geological Survey (USGS)	Forest & rangeland ISGs
U.S. Fish and Wildlife Service (FWS)	See letter of support *
U.S. Forest Service (USFS)	See letter of support *
South America	
Embrapa (Brazilian Agricultural Research Corporation)	See letter of support *
Asia	
Burapha University (Chonburi, Thailand) (BU)	Fish ISGs
Chinese Academy of Agricultural Sciences (CAAS)	Biological control
Shanghai Fisheries University, Aquatic Genetic Resources Lab (SFU)	Aquatic ISGs
University of Tokyo (Tokyo and Komaba, Japan) (UT)	Plant invasion, GE crops
Yokahama Unversity (Yokahama, Japan) (YU)	See letter of support *
World Fish Center (Penang, Malaysia) (WFC)	See letter of support *
Europe	
CABI Bioscience (Delemont, CH) (CABI)	Biocontrol, plant invas.
European Biological Control Lab. of USDA (Montpelier, FR) (EBCL)	Biological control
Netherlands Institute of Ecology (Nieuwersluis, NL) (NIOO)	ERA of ISGs
Africa	
South Africa National Biodiversity Inst. (Cape Town) (SANBI)	See letter of support*
Center for Invasion Biology, Univ. of Stellenbosch (SA) (CIB)	Plant & animal invasion
Australia	
Australian Centre of Excellence for Risk Analysis (ACERA)	ERA for ISGs
CSIRO (Canberra and Hobart)	See letter of support*
Invasive Animal Coop. Research Centre (IA CRC)	ERA, biocontrol

We will improve ERA by evaluating its performance in assessing or managing specific risks. These evaluations will lead us to propose modifications to ERA associated with any of our four research themes (Fig. 2). For example, biological control of invasive purple loosestrife has succeeded in many wetlands but reed canarygrass, another invasive wetland plant, may then take over. Galatowitsch's research group developed a model based on Tilman's R* theory of plant competition (e.g., Tilman 1982) and designed experiments (Perry et al. 2004) to predict conditions that would constrain reed canarygrass growth. Management based on the experimental results verified model predictions. Another example is the risk that European corn borer will evolve resistance to transgenic Bt corn. Models

Figure 2. Organizational model for our IGERT research efforts, illustrating that our research themes are informed by an evaluation of ERA performance and that our research will help to improve ERA.



resulting from our NSF-funded biocomplexity research (Heimpel et al. 2005) and others (Gould 1998) predict that a refuge of non-Bt corn near pure Bt corn can reduce selection sufficiently to delay resistance evolution over 20 years. EPA has required the use of resistance management measures, and research to verify the models (e.g., Bourguet et al. 2003) is underway. In addition to studying such scientific aspects, we will improve ERA by integrating scientific findings with economic considerations and stakeholder deliberations within the risk assessment decision process.

Our IGERT will address four focal research themes (Fig 2). (A) Are the regulatory processes effective at allowing or excluding new species and genotypes appropriately? (B) Can risk assessment models be improved, and if so, when is this improvement of value? (C) How can uncertainty be addressed within ERA? (D) How can risk management be improved?

(A) Evaluating effectiveness of regulation using retrospective analysis

The goal in ERA of exotic species and new genotypes is to allow introductions that benefit society and pose little or no risk of environmental or economic harm, and to exclude introductions posing high risk. Yet policy and regulation vary considerably across groups of species and genotypes and among countries. Although some international treaties are beginning to standardize approaches, most notably the Convention on Biological Diversity's Cartagena Protocol on Biosafety (for GEOs), and the WTO Sanitary and Phytosanitary Agreement, the US oversight system remains a patchwork of approaches. Exotic species ERA is often based on qualitative expert opinion (Orr et al. 1993; RAM Committee 1998). ERAs are not even conducted for horticultural plants, aquarium trade, and pets (Mack et al. 2000; Reichard & White, 2001). GEO ERA relies on case-specific assessments (OSTP 1986), whereas biological control ERA considers only qualitative interpretation of host range assessments (van Driesche & Reardon 2004).

Shared characteristics of effective policies can be used to evaluate policies and regulation for ERA (O'Toole 2004; Ellefson 1992). These characteristics include clarity of intent, validity of inferences of cause and effect, and adequacy of resources to implement the policy and ensure compliance. Students will have the opportunity to advance understanding of how these characteristics and others lead to effective ERA regulation and policy formation. They may ask: how have prior policy design and implementation contributed to improvement in ERA across sectors? Have the regulatory systems strengthened decision-making? Have they been effective in excluding invasives? To what extent did they allow introductions that later became invasive?

We propose retrospective analyses to assess, for cases of *past introductions* with a well-documented history of spread, whether the application of *contemporary* regulations would have appropriately excluded harmful organisms and allowed benign organisms. Are there policies and regulations that would be more effective than contemporary ones (Table 2)? Are such policies and regulations practical and acceptable? Did science succeed in informing the cause-effect linkages in the policy? Did regulatory systems identify taxa that were invasive at the time of introduction and those that later became invasive? Should different taxa be regulated differently or can policies and regulations be unified? An interdisciplinary team of IGERT faculty and students will apply the relevant regulations to diverse, well-documented cases of deliberate and accidental introductions over the last century or longer. The breadth of our expertise allows us to compare different organismal groups, pathways of deliberate and accidental introduction, and to conduct economic analysis of alternative policies (Hurley 2005).

The analyses must include cases that exemplify the toughest challenges to decision- making. For instance, following some introductions, long lag times preceded population explosions and consequent harm, as in the cases of the Brazilian pepper tree in Florida, mitten crabs in England, purple loosestrife in N. America, and a wood-boring terrestrial isopod in California (Crooks & Soulé 1999). In some cases, the boom was followed by a steep decline of the invader (Simberloff & Gibbons 2004). For instance, recent evidence in Lake Victoria suggests that the Nile perch, implicated in the demise of numerous endemic fish species, is now declining, while certain native species are partially recovering (Balirwa et al. 2003).

Students will gain the background for conducting these analyses through a *Risk Analysis Survey Course* and semiannual IGERT symposia (see Education and Training section below). The course will offer an overview of contemporary regulation, in-depth study of some of the challenging cases, and basic tools for conducting economic and policy analysis of regulatory programs. The semiannual symposia will include focused presentations and discussions of specific regulations, comparative policy analysis, case histories of invasions and introductions, and economic analysis of policy. With this background, each student will conduct retrospective analyses as part of a practicum, as independent projects, or as a focal aspect of her/his dissertation. Our external partners offer many opportunities to develop case studies for testing and verifying the retrospective analyses.

Table 2. Possible examples for retrospective analysis of present US regulation

Group of Species or Genotypes	Introduction Pathway	Present Federal Regulation*
Crop plants	Deliberate	None
Exotic plants	Accidental	Plant Protection Act
GE plants	Deliberate	Coordinated Framework
Arthropod plant pests	Accidental	Plant Protection Act
Biological control agents	Deliberate	Plant Protection Act
Aquaculture	Deliberate	Lacey, Endangered Species Acts
Exotic fish	Accidental	National Invasive Species Act
Aquarium & pet trade	Deliberate	None
Exotic birds	Deliberate/ Accidental	Migratory Bird Treaty Act
Commodity trade	Deliberate	Plant Protection Act

*Other federal and state policies/regulations may be involved, which our analyses will consider.

(B) Improving theory and models for ecological risk assessment

ERA models for exotic species, GEOs and biological control agents are sparingly quantitative and extremely diverse in degree of sophistication. In the USA, exotic species ERA generally relies on qualitative expert opinion whereas, for GEO ERA, models are more developed but vary from somewhat qualitative food web models to more quantitative migration-selection-population dynamics models (Table 3). Strategies for model construction range from induction from empirical results (e.g., arrival and establishment models) to derivation from well-established population genetic theory. This diversity of modeling schemes poses challenges that we will address during our IGERT (Table 3).

We illustrate some of these challenges below. To prepare to strengthen and unify theory, students will gain broad exposure to the diversity of existing models in a modeling workshop, a *Risk Analysis Survey* course and a modeling course. Several problems not yet proven amenable to modeling that is useful for ERA (e.g., delayed impacts, indirect effects) will be described in

Table 3. Illustrative models for quantifying ERA

Risk or Risk component	Mathematical Biological Model
Introduction (Arrival)	Propagule pressure (Sailer 1983) International trade (e.g., McAusland & Costello 2004, Knowler and Barbier 2005, Costello & McAusland 2003)
Establishment	Intrinsic growth rate (Crawley 1986) Climate matching (Sutherst 1989)
Spread	Reaction-diffusion models (Andow et al. 1990) Spatial optimal control over space (Sharov & Liebhold, 1998)
Ecological Impact	R* (Tilman 1982; Andow 1994; Murdoch & Briggs 1996)
Gene Flow	Migration-selection (Haygood et al. 2004) Net fitness-Trojan gene (Muir & Howard 2002)
Non-target Impacts	Dose-response (Suter et al. 2000)
Resistance Risk	Migration-selection and population dynamic (Hurley 2005; Alstad & Andow 1995)

the *Survey Course* and will serve as foci for discussions during the roundtables and symposia.

Introduction (Arrival). Existing models have considered the arrival process empirically, relying on known transport pathways and assuming the probability of arrival is proportional to propagule pressure (Sailer 1983). In fact, arrival may be a non-linear function of the number of propagules and depend on aggregation. Several more rigorously quantitative models of exotic species introductions assess marine species invasions via ballast water and shipping patterns (Hayes 2002a,b; Hayes & Silwa 2003) and may guide improvement of the mostly qualitative models.

Economists have begun to investigate how best to intervene when international trade increases the risk of invasions. For example, McAusland and Costello (2004) found that the threat of new invasions depends on the past trade level with a region and the past exposure to exotic species. Identifying the relative risk of trade partners based on these aspects and then targeting specific regions can reduce inefficiencies resulting from certain market-based mechanisms, such as non-specific tariffs. Knowler and Barbier (2005) have demonstrated that taxes can produce a socially optimal level of exotic plant imports. Costello and McAusland (2003) have shown that protectionism may not mitigate invasion risks, and failure to account for agricultural damages skews the interpretation of the efficacy of these mechanisms. Students will have the opportunity to explore how these and related models may link to biological models of the introduction process so that management of ISGs can be integrated economically into broader discussions about trade policy.

Establishment. The establishment process is modeled as a function of the intrinsic growth rate, r. If $r > 0$, establishment occurs, otherwise it does not (Crawley 1986). Climate matching is currently one of the main considerations in predicting r. Students will participate in discussions of additional ecological aspects to consider improving predictions of r in the new environment. An extensive literature notes characteristics associated with invasiveness (Crawley 1986), but most of these have little predictive value. We will hold taxon-specific discussions of organismal characteristics that may help predict r in new environments, and these characteristics will be evaluated systematically through literature reviews and experiments. The taxa we will examine include soil microbes, plants, insects and fish. Characteristics that prove useful may be incorporated into existing climate-matching models. A novel element of this work will be the cross-taxon comparisons that will become possible as students progress in their research.

Spread of introduced organisms and gene flow risks. Models of both spread and gene flow are based on reaction-diffusion and migration-selection models. Spread models have been improved via more realistic population growth components, such as Allee effects (Veit and Lewis 1996), and gene flow models via inclusion of spatially restricted dispersal (Andow and Zwahlen 2006). In addition, Sharov and Liebhold (1998) have emphasized how to use spread models to "slow the spread" of an invading species in an economically optimal way. As with establishment, however, ecological factors that affect the key parameters have not been incorporated into the models. For example, the shape of the dispersal kernel, the rate of population growth at low density, and the selective advantage of a rare trait are all affected by ecological factors, but these have not been incorporated into models, thereby limiting accuracy of prediction. One specific area for student research will be gene spread models based on sexual selection. These models have been used to model gene spread in fish (Muir & Howard 2002) and may be more widely applicable.

Direct ecological impacts. One of the most challenging aspects of invasion biology is to predict the ecological effects of a new species or genotype. Following taxon-specific models (Kolar & Lodge 2002), Tilman (2004) developed a model for plant invasions based on the 'R*' rule - a species (or genotype) that can persist at the lowest level of a limiting resource will displace other species or genotypes (Tilman 1982). Consistent with this model, Fargione et al. (2003) showed that plant species most strongly inhibited the establishment and growth of invading species with similar resource requirements. This experimentally observable R* can be used to predict the effects of introduced genotypes (Andow 1994) or the efficacy of biological control agents in suppressing pests, as in the case of the California red scale (Murdoch & Briggs 1996). We will encourage students to test and extend this theory in their own research.

Minimizing direct ecological impacts via design. Our students will investigate strategies to breed non-invasive horticultural crops and farmed fish to minimize potential ecological impacts. In breeding programs, selected traits that confer market value generally constitute the basis for domestication. It may be possible to establish a 'non-invasive crop ideotype' and breed against invasiveness (Anderson et al. 2006a). Invasion models that associate species traits to ecological impacts in heterogeneous environments (e.g., Tilman 2004) could inform breeding objectives. The net fitness-Trojan gene model (Muir and Howard 2002) offers another perspective on breeding objectives. Since breeding programs are long-term, IGERT students would conduct research on the design of non-invasive horticultural crops and fish with known invasive types, using field trials to evaluate invasion risk in multiple environments (Anderson et al. 2006b).

Non-target impacts and food webs. Assessment of harm to biological diversity is typically indirect, relying on indicators of potential harm (Andow & Hilbeck 2004). The use of indicators has a long history and has proven valuable in several cases (e.g., mayflies as indicators of acidification of streams), but it has little scientific support as it is applied to invasive species, biological control agents and GEOs, for which ERA should be case-specific (Tiedje et al. 1989). Alternatives, however, have not been fully developed and validated. This gap offers rich research opportunities for IGERT students. The Andow & Hilbeck (2004) model classifies biological diversity according to ecological function (e.g., herbivory). For each function, worst-case risks in the local environment are identified (e.g., increased crop losses from enhanced herbivory), and species that are most likely causes are identified and used to assess the risk. This model allocates effort to the most serious concerns, uses financial resources efficiently and allows flexibility in developing a strategy for assessing risk. Another kind of model quantifies the probability of harm to a particular non-target species that is of special concern. For example, IGERT students could further develop the quantitative monarch butterfly model (Oberhauser et al. 2001).

The integration of quantification into decision-making. Increased quantification may not improve social deliberation and decision-making unless it is done in an iterative, deliberative process that involves diverse stakeholders. Quantification could enrich the decision-making process by informing deliberation on comparative futures, whereas quantification might be ignored if it fails to clarify cause-effect linkages. A methodology to improve social deliberation is Problem Formulation and Options Assessment (PFOA) (Nelson et al. 2004). It establishes context for societal dialogue (Fischer 2003; Hajer and Wagenaar 2003) concerning a proposal to introduce a novel species or genotype, such as farming Bt maize in East Africa. This multi-stakeholder approach to deliberation offers a rational, science-driven planning process by which stakeholders can assess their needs, evaluate the risks related to various options, and recommend to decision-makers policies to reduce societal risks and to enhance the benefits of various options. Improved quantification, in conjunction with stakeholder conceptual models, offers the greatest potential for strengthening ERA and decision-making for biological safety. In our proposed *Risk Analysis Survey* course, students will learn how such an iterative approach can be used to improve outcomes and decision-making. Some may develop multi-stakeholder modeling components within their own research program.

(C) Addressing uncertainty in risk assessments

No risk analysis can be conducted with full scientific certainty (NRC 1983, 1996). Significant uncertainty arises from poor understanding of causal mechanisms in ecological systems and from limited data to describe components of a risk assessment model. For example, population growth rates are essential to characterizing population dynamics and spread rates (components of exposure assessment), but population growth has proven exceptionally difficult to predict for species introduced into new environments. Biologists often respond to this uncertainty by calling for more data. Student research within this theme will address three interrelated questions: (1) when does increased quantification enhance the value of risk assessments; (2) do different approaches for characterizing uncertainty lead to different risk management decisions; and (3) when does increased quantification reduce conflicts over risk management decisions?

Treatments of uncertainty in risk assessment vary. Expert judgments have figured extensively in qualitative risk assessments, but usually treat uncertainty in such general terms that it has little influence on risk characterization. In quantitative risk assessments, uncertainty has often been modeled with probability distributions. Farm-to-table risk assessments for food-borne hazards, such as *Salmonella enteridis* in eggs (Baker et al. 1998) and *E. coli* 0157:H7 in beef (USDA 2001), both involving Kuzma, have pioneered methods to account for limits of knowledge about model inputs in large food and agricultural systems. More recently, Bartell and Nair (2003) studied how narrowing the range of uncertainty for parameters would improve understanding of establishment risk of the Asian longhorned beetle. Economic modeling can enhance such analyses by assessing the value of reducing parameter uncertainty, for both biological and economic parameters. To be sure, uncertainty analysis is not always warranted, nor does it always lead to better management decisions (Paté-Cornell 2002), for example, when screening indicates the risk is below levels of concern, the cost of reducing exposure is low, or characterization of the nature and extent of the hazard is inadequate to permit even a bounding estimate (Hammonds et al. 1994).

An innovative aspect of our ERA research is the application of worst-case analysis tools (bounding assessments), which have been successfully used in engineering systems to elucidate their worst-case behavior, given modeling error, uncertainty and exogenous disturbances. These techniques can directly assess sensitivity of the results to individual model uncertainty and are less data intensive than probabilistic models, yet can better inform decision makers. For example, worst-case and probabilistic analysis applied to the NASA X-38 Crew Return Vehicle (Shin et al. 2001) prior to its first test flight revealed the effects of aerodynamic and mechanical model error on the performance of the vehicle. The probabilistic analysis methods failed to identify values of aerodynamic coefficients that would cause instability, whereas the worst-case analysis techniques successfully validated the flight control system *and* identified worst-case aerodynamic coefficients. Application to ERA will require refinement of quantitative ecological models and overall performance objectives for potentially affected ecosystems. Worst-case analysis would be used in concert with probabilistic analysis to clarify the role model parameters play in the analysis of such models as resistance evolution (Alstad & Andow 1995; Gould 1998), non-target effects (Andow & Hilbeck 2004), and net-fitness for assessing gene flow (Muir and Howard 2002).

A substantial economic literature on the value of information applies to the value of resolving uncertainty in parameters. Once quantitative models are developed and performance objectives are established, we can ask questions such as: is it preferable to devote research funds to learning about the effectiveness of control techniques or about the speed of an organism's spread? The key parameters of the model can be estimated from existing scientific knowledge, and uncertainty can be incorporated via probability distributions for those parameters. We will then assess possible scenarios, each with different parameter sets, to find the optimal course of action under each scenario. Under complete uncertainty, managers are assumed to follow a course of action where the control variables take on the expected value of the various optimal strategies. If the uncertainty is completely resolved, the control can be tailored to the true state of the world. The value of information can be calculated as the difference in expected value of overall benefits when parameter values are perfectly known at the outset versus when coefficients become known. Reduced variability in the parameters also has value and can be estimated (Bartell and Nair, 2004).

The PFOA methodology (Nelson et al. 2004, see C3B) recognizes that uncertainty can result not only from lack of scientific information, but also from lack of knowledge of individual and social values. By timely presentation of the best available scientific information to all stakeholders, PFOA reduces the misinformation and misinterpretation associated with conflict-ridden issues. It provides opportunity for discussion, leading to understanding of which values stakeholders share in common and those on which they differ. It also allows scientists to learn of concerns about the limits of scientific knowledge. IGERT students will learn about the full range of approaches to address uncertainty, both quantitative and qualitative, including worst-case analysis tools, optimization models, and multi-stakeholder deliberation.

A key strength of our IGERT faculty is its breadth of experience with regulatory agencies (e.g., EPA, USDA, FWS) and risk-assessment frameworks. Research groups will link risk assessors (Adgate, Andow, Hueston, Kapuscinski, Kuzma, Ragsdale, Venette), external partners (Table 1), economists (Haight, Homans, Hurley) and biologists with specialized expertise (Galatowitsch, Heimpel, Newman, Sadowsky, Shaw, Tilman). In their retrospective analyses of risk assessments (C3A, above), students will determine whether probabilistic methods or uncertainty analyses were employed and in what form(s). Uncertainty in the model and data will be quantified, when possible, for inclusion in models. Sociologists and governance specialists (Nelson, Schurman) will help structure social science questions about uncertainty in societal discourse, governance, and decision-making. Student teams will characterize the results of the risk assessments and evaluate how the public perceived the results. Finally, students will assess the role of uncertainty analysis in affecting the choice of risk management options.

These retrospective analyses will help IGERT students define appropriate ERA approaches (quantitative or qualitative) for their own studies. Where lack of information has prevented the past use of quantitative methods, students will work with faculty to design experiments to fill information gaps. For example, Venette prepared a qualitative assessment of the risks posed by a moth species, known only to occur in Mexico and South America (Venette & Gould 2006). Even in the face of extremely limited information about this species, this analysis revealed that this pest threatens US agriculture and ecosystems and warrants quarantine. Quantitative models were needed to evaluate the efficacy of potential quarantine treatments.

(D) Managing introduced species and genotypes and post-removal strategies: development of effective and environmentally sound responses

While the previous three research foci concern strategies to prevent invasions, the fourth emphasizes responses to invasions that have already occurred. Research to improve management of invasives is germane both to species that have invaded new environments and to GEOs that have escaped the habitats into which they were released.

Management options for invasive species and genotypes range from eradication and suppression to post-removal recovery and adaptive management designs. Some control strategies have been used to selectively eradicate insect and plant species, but selective eradication is rare for vertebrates. In many instances, the need for new approaches is pressing, both because nonselective toxicants are often the only available option and more generally, because new approaches could reinforce integrated pest management (IPM) strategies. Moreover, in some systems, complications arise because removal of introduced species can have adverse consequences (Zavaleta et al. 2001). Successful management of invasives can also hinge upon cooperation of the public. For instance, in areas where boaters are more willing to clean boats between lakes, invasive aquatics such as Eurasian water milfoil spread more slowly than in other areas. Further, local eradication of the invasive Asian longhorned beetle was achieved in Chicago but not New York, which differed in a combination of factors including local policy, funding, and behavior of the public (Antipin and Dilley 2004). Such cases highlight the fact that a comprehensive approach to managing invasives incorporates human behavior as a factor in understanding management efficacy (Nelson 2005).

Research of our IGERT faculty addresses four general issues of management: (1) new techniques for controlling and removing invasive species (Sorensen, Newman, Kapuscinski, Heimpel), as well as their ecological risks and feasibility (Kapuscinski & Patronski 2005; Heimpel et al. 2004), including the impact of human behavior and choice on control potential (Nelson 2005), (2) selective control methods (e.g., pheromones and natural enemies) to minimize risk to non-target organisms (Newman 2004, Sorensen & Stacy 2004), as well as inadvertent impacts of invasive species removal on non-target organisms (e.g., mortality from control agents or transfer of poisons through food chains, Andow & Hilbeck 2004; Heimpel et al. 2004), (3) the transition from removal to recovery (Perry et al. 2004; ; Galatowitsch and Richardson 2005), and (4) adaptive management systems for invasives. Managing the risks of control measures is an essential component of ERA, and IGERT faculty study selective control from the perspective of both controlling invasives and minimizing non-target risks.

Many of our research activities concerning risk management will employ an adaptive management framework. Adaptive management involves repeated cycles of program design, implementation, and evaluation, in a deliberate 'learn-as-you-go' approach. IGERT faculty currently employ this mode of applied research (e.g. Andow & Ives 2002; Kapuscinski 2002; Newman 2004; Jordan et al. 2005; Snow et al. 2005). Andow and Ives (2002) have outlined an adaptive system for managing the evolution of resistance to GE Bt crops, but these ideas have not yet been implemented. In another context, Jordan et al. (2005) have facilitated 'learning groups' for adaptive implementation of invasive management techniques in agroecosystems. Adaptive management has also been advocated for biological control, but has been implemented only rarely (Shea et al. 2002; Kapuscinski & Patronski 2005). Our IGERT faculty and students will synergistically develop adaptive management systems for diverse situations and determine the feasibility of their implementation. Dynamic management will serve as a common framework for addressing important management questions, including: Which species or genotypes of biological control agents provide the best control? What are the implications of differing spread rates and patterns for optimal management of invasive species or genotypes? How can evolution of resistance to a novel control measure be slowed? How will human behavior and preference influence the effectiveness of the control measures and be incorporated into management adaptation? Thus, IGERT students could participate in developing best management practices that maximize efficacy while minimizing risk to non-target organisms (Heimpel et al. 2004; Brown & Walker 2004; Sorensen & Stacey 2004). Current research of our IGERT faculty on invasive species management techniques includes biological control, genetic modification and pheromone release. Examples of systems available for this kind of research within our IGERT are managing leafy spurge in Great Plains grasslands, purple loosestrife in wetlands, aquatic weeds and sea lamprey in lakes, exotic carp in rivers, and soybean aphid and European corn borer in agricultural lands.

Problems of system recovery after removal or suppression of invasives are also of mutual concern. Several of our IGERT faculty (Galatowitsch, Jordan, Larson, Newman) work on post-removal restoration of ecosystems in which invasives have disrupted food-webs or altered soil microbial and nutrient dynamics. We will predict when post-removal restoration is likely to be necessary and determine the underlying mechanisms for different responses to removal. Major issues of common interest include roles of anthropogenic disturbance and forcing factors such as eutrophication, dispersal limitation, propagule depletion, and biotic-abiotic feedbacks that may operate in community assembly after removal, as well as feedbacks between human behavior and environment. We will develop modeling approaches for identifying appropriate removal strategies and post-removal management. In particular, we will address how the rate of removal affects restoration outcomes and how landscape context affects restoration success. IGERT students will have opportunities to work with our research partners in Japan (University of Tokyo) and South Africa (Center on Invasion Biology at University of Stellenbosch) to develop models for riparian corridors following invasive species removal.

All of the concepts of risk management outlined in this section will be covered in the general survey course, both as foci of lectures and discussions and embedded within case studies. In addition, IGERT fellows will have opportunities to apply these management methods in the practicums and in their dissertation work.

The proposed interdisciplinary investigation is an exciting opportunity for both the faculty and students in the IGERT program. The fruition of this collaboration will be to expose an entire new generation of researchers to new ideas to better understand and model ERA as well as to develop strategies to limit the effect on an ecosystem of introduced species or genotypes.

C(4) Education and Training

Linking Research and Decision-Making

Our education and training program focuses on establishing linkages between research and ERA decision-making. As students develop foundational knowledge and skills in risk analysis, they will also gain practical experience in the application of risk analysis to real-world problems. In classrooms and the field, students will explore how risk analysis can reveal fundamental gaps in our knowledge and motivate new scientific questions. These educational goals will be accomplished by students' participation in: (1) a new curriculum and minor, (2) semiannual symposia and weekly roundtable discussions, (3) problem-solving practicums with our external partners, and (4) dissertation studies involving our IGERT research themes in collaboration with our external partners.

A new curriculum and minor interweaves new and existing courses at the UM to provide a broad exposure to concepts in risk analysis while ensuring a logical progression in the development of skills needed for ERA. These are unique because they capitalize on recent advances in cooperative problem-solving as a pedagogical tool to integrate research with education. The curriculum, which was developed as part of this IGERT, is poised to become a graduate minor. The minor enhances graduate majors by focusing on the concepts and research methods of ERA. In the long term, the minor will maintain the momentum of the IGERT by drawing students together from many graduate programs and will continue to promote collaborations among research groups at the UM.

Symposia and roundtable discussions will act as fora for discussion and synthesis of issues related to ERA. In roundtables, students will present proposals for dissertations and practicums , as well as results. Ethical, technical, policy, regulatory and strategic issues will also be examined. Symposia will be used to orient new student cohorts to the IGERT and focus in-depth discussions on the research themes.

The practicums will link our students with our international and national external partners and enable our students to improve their teaching skills. These practicums are structured so students will experience and learn from real-world problem situations. Student-partner collaborations will help students develop the analytic, deliberative, and communication skills necessary to advance risk analysis and their scientific careers.

IGERT dissertation research opportunities will focus on the four themes identified in the research section. These opportunities will help students develop research skills that capitalize on synergistic teamwork, as well as providing a means to connect science to ERA decision-making processes.

Cooperative Learning Approach to Introduced Species & Genotypes (ISG) Courses

Solving complex environmental problems requires collaborative, interdisciplinary teamwork (Katzenbach & Smith 1993). Our proposed IGERT curriculum therefore emphasizes cooperative, problem-centered learning to help our students develop skills as interdisciplinary problem-solvers. Cooperative learning helps students to apply course content to new situations by modeling and synthesizing information within interactive teams. Because IGERT fellows will be engaged in cooperative learning throughout the three-year curriculum, we expect this will improve their competency in multiple disciplines, foster cohesion among students, and develop their analytic-deliberative abilities. Our external partners will also play a critical role in the development of cooperative skills by hosting student teams to address real-world dilemmas.

Although over 30 years of research on cooperative learning has shown it promotes student productivity and critical thinking (e.g., Cooper et al. 1990), this approach is often neglected in university classrooms because instructors lack experience and suitable curricular materials. Some IGERT faculty use cooperative learning techniques to achieve some of their pedagogical objectives in advanced courses (e.g., Anderson, Andow, Galatowitsch, Jordan) and we believe that this instructional approach has tremendous potential for the IGERT program.

Each IGERT instructional team (Table 4) will work with the IGERT teaching specialist and teaching consultants from the University of Minnesota's Center for Teaching and Learning (CTL) to develop exercises for use in ISG courses during the inaugural year (2007-2008). The CTL, led by Langley, is nationally recognized as a leader in cooperative learning. Faculty instructional teams will convene for an all-day workshop co-organized by the CTL in May 2007 to learn about current developments in active learning, particularly cooperative learning, and to plan curricular materials. The desired outcome of the workshop is for each team to have at least one concrete cooperative learning exercise that can be further developed and researched with input/materials from selected external partners. Examples include decision controversies, jigsaws, knowledge maps, and group investigations (e.g., Danserau & Newbern 1997).

Over subsequent years of the IGERT program, we will refine these exercises based on student and instructor evaluations (see section C(6)), and will develop teaching notes to facilitate use by other instructors. Each May, we will convene a one-day Cooperative Learning Workshop to discuss how the exercises have worked in the classroom and how to improve their effectiveness. These workshops will involve both faculty and students. Our training exercises will be published in a variety of forms (e.g. peer-reviewed publications, special journal volume, book, or web sites) to aid other graduate curricula throughout the world. In addition, we anticipate that these training materials will be valuable to our external partners for continued education and professional staff training in risk analysis. An initial compilation of our IGERT training materials will be made widely available in the fourth year of this IGERT (2010-2011).

Curriculum and Minor

ISG Core Curriculum

The curriculum will be based on ERA (Fig. 1). Students will learn how scientific knowledge informs decision-making processes about potential risks and benefits of introduced species and genotypes and how decisions – made at various steps of risk assessment and management – can motivate scientific inquiry. The curriculum of the minor and this IGERT consists of 2 courses and 2 practicums, as well as roundtable discussions, workshops and symposia. Collectively, the curriculum will develop students' foundational knowledge and skills in risk analysis, provide practical experience for the successful application of risk analysis to real-world problems, inspire students to generate new hypotheses, and facilitate development of their dissertation topic and research.

To develop an effective integrated curriculum, the IGERT faculty has organized into eight interdisciplinary instructional teams (Table 4), which provide curricular coherence, expose students to many IGERT faculty members, and reduce individual teaching load. All faculty participants will be involved in curriculum planning for the first year offerings but, in any single year, less than half will lead actual classroom instruction. Each team has expertise across the natural and social sciences, both in terrestrial and aquatic systems. Teams have several members who are working together in an IGERT research theme, which will help link classroom instruction to research. We will integrate our four research themes throughout the curriculum to focus investigation on the prevailing practices of ERA (Fig. 1, see section C(3)) and to challenge students to make substantive contributions to the science supporting ERA.

Table 4. Instructional teams (*Instructor responsible for course administration).

Course or Workshop	Instructional Team
Year 1: Risk Analysis Survey Course	
Hazard Identification	Newman*, Oberhauser, Nelson, Schurman
Exposure & Effects Assessment	Andow, Larson, Balas, Jordan
Risk Characterization	Anderson, Heimpel, Kuzma, Shaw
Risk Management	Homans, Ragsdale, Sadowsky, Sorensen
Critique of Existing Risk Analysis	Venette, Kapuscinski
Year 1: Risk Analysis Modeling Workshop	Hutchison*, Haight, Hurley, Galatowitsch, Johnson
Year 1: Quantitative Modeling Course	*Students choose an existing course*
Year 2: Problem-solving Partnership Practicum	Two faculty sponsors/ student group (statistical support: Jones, Oehlert, Weisberg and Johnson)
Year 3: Cooperative Learning Practicum and Workshop	Galatowitsch*, Anderson, Jordan, Kapuscinski.

<u>First Year:</u> *Risk Analysis for Introduced Species and Genotypes* is a new course designed to expose students to the analytic-deliberative model of ERA (e.g., NRC 1996), contrasting it to scientific-technical models (e.g., NRC 1983). Students will engage in a series of cooperative learning cases to explore the fundamental components of ERA, experience common approaches to risk characterization, evaluate risk management decision processes, and use risk communication and multi-stakeholder deliberation techniques. Several of these cases will

introduce students to using models as part of risk analysis and provide needed skills to work in the research themes. During the course, students will work together in cohort teams to prepare a formal critique of an existing ERA, identify its significant shortcomings (either in data or concept), and explore how ecological theory, stakeholder deliberation models, and/or analytical methods might improve the analysis. Each cohort will present their critique to the IGERT community in a round-table discussion after the course.

Students will discover through this survey course that quantitative modeling is a particularly useful skill for researchers interested in risk analysis. Following the survey course, students will participate in a four-day *Risk Analysis Modeling Workshop* (1 cr; Jan. term between fall and spring semesters). This workshop will provide students with a comprehensive introduction to technical and conceptual aspects of model development, analysis, verification, and validation. Students will learn to formulate problems with verbal and conceptual models and analyze the models with qualitative (comparative) and quantitative (deterministic and probabilistic) methods, including sensitivity analysis to address parameter uncertainty. Students will also learn techniques for determining whether a simulation model is an informative representation of the real-world system under study. Exercises with commercial simulation software will reinforce general course concepts. Students will build on this workshop by taking one of the quantitative modeling courses (3-4 cr.) offered by other graduate programs: e.g., Applied Microeconomics (ApEc 5151), Modeling Nature and the Nature of Modeling (EEB 5963), Decision Analysis (IE 5545), Stochastic Modeling and Analysis (OMS 8672), Probability Models for Biostatistics (PubH 8429), or Population Dynamics (Ent 5045).

Second Year: *"Problem Solving" Practicum.* This is a collaborative research experience, designed and pursued by the students with guidance from a three-person faculty team. The purpose is to expose students to real-world problems in ERA and challenge them to conduct research as a team to address these problems. Our collaborative research partnerships with local, national and international research institutions and regulatory agencies will help define the real-world problems and host the student team to ground their practical experiences (Table 5). In the first year, students will identify numerous problems that could benefit from in-depth collaborative problem-solving, most of which require empirical investigations or the development of models. For the practicum, student groups will propose a research project that can be carried out within 15-weeks of intensive effort, and is linked to one of our external partners. This experience will teach students how research teams can advance the science and practice of risk analysis by capitalizing on collective skills of the team to yield publishable results. The IGERT will help fund a study visit to our partner's institution or arrange to have the partner visit the University to work with the student team (see Problem-Solving Practicum section below for additional details).

Third Year: *Cooperative Learning Practicum.* Students will participate in a practicum on cooperative learning processes that are relevant to manage deliberation in ERA and to link research and teaching in active learning. Appropriate cooperative learning techniques will be introduced, including scenario planning (Swart et al. 2004) and decision cases following the NSF Decision Case Workshop model (University of Buffalo). Students will develop a decision case based on their experience in the Problem-Solving Practicum from the previous year, focusing on decisions associated with implementation and evaluation phases of ERA. The practicum will culminate in discussion on cooperative learning and deliberation with experienced practitioners. The decision cases will be presented in the annual May Cooperative Learning Workshop (see Cooperative Learning Approach to ISG section above). After refinement, the decision cases may be used in the first-year survey course (co-taught by student authors), and will be included in a compilation of our IGERT education materials that will be made widely available as a book, CD, and on our website. We anticipate that these training materials will make a significant contribution to building international capacity in ERA, becoming one of the broader impacts of this IGERT.

ISG Minor

The free-standing minor in Risk Analysis for Introduced Species and Genotypes (ISG) was developed as part of this proposed IGERT and has received informal approval from the UM Graduate School (see section C(5)). The minor will enhance curricular oversight and control of the program, the ability to track curricular success and ensure continuation of the program and its collaborations after NSF funding ends. IGERT fellows will major in the graduate program of their choice (see list in section C(7)) and will meet the minor requirements by completing the IGERT courses and practicums, and additional relevant course(s) already offered at the University of Minnesota. For the Ph.D. minor, students will complete the previously described IGERT curriculum for a total of 13 credits. For an MS minor, students will complete the first year IGERT curriculum and two semesters of roundtable discussions. The survey course, modeling workshop, and roundtable discussions will be open to all UM graduate students, regardless of whether they are in the minor or are an IGERT fellow. The two practicums will be limited to IGERT fellows, because they directly or indirectly require significant logistical and financial support.

The major graduate programs conduct ethics training, required for all graduate students, which focus on general issues of responsible research, including intellectual property, plagiarism, bias, treatment of subordinates, regulatory compliance, and human subjects, as well as issues specific to that major. Complementary ethics training in the minor will emphasize issues or conflicts inherent to risk analysis of species and genotype introductions, and will be discussed in the core-courses and several round-table discussions each semester.

Round-table Discussions, Semiannual Symposia, and other IGERT Events

Round-table discussions will be key to sustaining the graduate learning community. They will serve as a forum for presentation of dissertation proposals, results from the practicums, and ERA-related topics, including ethical issues, novel tools and approaches for risk analysis, emerging policy and regulatory issues, new management approaches, and development of non-invasive species and genotypes. Students will be required to participate in these roundtable discussions continually throughout their graduate experience; students will enroll for credit twice (1 cr. each term). In a given semester, we plan to focus on one or two research themes to allow for a more in-depth consideration of issues. As available, we will also have external IGERT partners lead discussions. The roundtables will be convened each semester by an IGERT faculty and one advanced student. This responsibility will rotate among IGERT faculty and students.

In addition to the weekly roundtable discussions, the IGERT community will convene three annual gatherings to highlight our research efforts and accomplishments and provide additional professional training. As already mentioned, one of these will be the Cooperative Learning Workshop held in May of each year.

Recognizing the importance of communicating research results to the wider community, the other two will be research symposia focused on integrating and advancing our collective efforts in the research themes. The symposia will be organized around our four focal research themes and presentations will be structured to provide for intellectual exchange and synthesis. Members of the Notre Dame GLOBES IGERT have agreed to participate and to provide input to improve our IGERT. At each symposium, faculty, students, external partners or other invited speakers will present syntheses of recent advances in some of the research themes, and in the other themes, discussions will be organized to enable syntheses to be developed in the future. An inaugural symposium will be held in the first year to launch the IGERT and will feature some of our partners. At least one speaker each year will explicitly address ethical issues as the main focus of their presentation. We have held an annual symposium on invasion biology since 2001; this popular event is typically attended by more than 70 faculty, students, agency biologists and managers. Faculty will provide structured feedback to students presenting at the symposium. The symposia will be held in the fall before Fall Semester and during January between the semesters. After the fall symposium, IGERT researchers and their local partners will host a half day field/lab trip to introduce the incoming cohort of students to ongoing IGERT research. This is an excellent opportunity for new students to see first-hand some of the projects they will explore during their first year courses.

To foster student leadership abilities, at the beginning of our summer program for minority undergraduate students (detailed in section C(7)) we will organize tours of selected IGERT field and laboratory research and facilities. These tours will be led by advanced IGERT graduate students, with assistance from their faculty advisors; all interested IGERT faculty and students will be encouraged to attend. The tours are components of both our diversity and outreach programs. IGERT students will also be encouraged to present their research results at national and international meetings, and to enroll in seminars on presenting and publishing research results offered by several departments (e.g., Entomology, Agronomy & Plant Genetics) and the Non-equilibrium Dynamics IGERT (director, Claudia Neuhauser). Responsibility for organizing symposia, field tours and roundtable discussions, and developing cooperative learning decision cases, will give students motivation to contribute to a positive dynamic within the IGERT community and to gain first-hand experience as leaders and educators.

Problem-Solving Practicum

Students will become familiar with risk analysis dilemmas faced by many of our external partners through the cases and examples used in our survey course and modeling workshop, and the presentations at our research symposia. In the spring of the first year, student teams will develop a proposal for collaborative research to be pursued in conjunction with one of our external *research partners*, focusing on priority problems identified by the partner (Table 5). The proposed work will constitute the IGERT students' second-year practicum. The faculty engaged in each focal research theme will help identify several possible research questions for the students to consider and students will contact our research partners for additional detail. Each of our research partners has agreed to host one or two student teams for a Problem-Solving Practicum. Project opportunities will be developed to expose students to deliberative aspects of ERA, to ensure students will have experience in assessing social values and deliberative processes in ERA.

Table 5. Example practicum problems identified by our partners for each research theme. Listed partners have also agreed to host individual student visits for dissertation research.

Research Theme	Problem (Examples of Interested Partner)
A. Patterns of invasion: retrospective analysis to improve present regulation	Retrospective regulatory process changes (General Mills) Deficiencies in national / international frameworks to manage biological stressors (CSIRO, MISAC) Deficiencies in public policy to prevent unintentional transboundary ISG movement (IA CRC, SANBI) Risk assessment for 'injurious species' under the Lacey Act (FWS)
B. Improving theory & models for ecological risk assessment	Improving models for risk assessment (CSIRO, NIOO, USGS) Genetic strategies to minimize ecological impacts (IA CRC, FWS) Analysis of commodity transport paths (CHS, General Mills) Modeling transgene introgression process from GEOs to wild relatives (UT, Embrapa) Socioeconomic consequences of ISGs (YU) Decision support models to balance economic benefits and negative impacts of ISGs (WFC,ACERA)
C. Uncertainty in risk assessments	Uncertainty in risks of using GEOs (FWS, CSIRO) Fitness effects of transgenes in crop relatives (Embrapa, SANBI) Food security (CHS, General Mills) Predicting ecosystem vulnerability (BU, NIOO)
D. Management of ISGs and post-removal strategies	Comparative risk assessment processes in developing countries (WFC, SANBI) Management of ISG range expansion (UT, FAMU, BU, USFS) Evolutionary ecology of host selection for biocontrol (MISAC, FWS)

The IGERT Off-Campus Training Committee will review a short pre-proposal submitted by the student group to ensure the project is feasible, relevant, and timely. Three faculty members (including one statistician – Johnson, Jones, Oelhert or Weisberg) will be responsible for a Practicum and guide the students through proposal development and implementation the second year. We will arrange a video/teleconference with the partner (or a face-to-face meeting if they are local) to finalize details of the proposals. Final proposals must be approved by the faculty guidance team and the Off-Campus Training Committee by the end of the first year. The faculty guidance team will serve as a liaison between the IGERT Off-Campus Training Committee and the students to develop an acceptable budget. Students will spend between two and seven weeks at their partner's location, depending on the nature of their projects. Problems focused on analyzing existing data will likely entail a short residency; we consider it crucial that students obtain the partner's perspectives to gain first hand experience of their problem. When field data collection is necessary, the practicum will require a longer time in residence and additional logistical support.

The research results of the practicum will be communicated in four ways. First, the students will give a presentation to the partner at the end of their visit. Second, they will produce a report that can be developed into a publishable manuscript, guided by the faculty team. Third, they will make a presentation at a roundtable discussion at which the relevant partner will be linked via video/teleconference. Finally, they will develop a teaching decision case during the third year Cooperative Learning Practicum. We anticipate that some students will elect to expand on their practicum experience for their dissertation research.

IGERT Dissertation Research

IGERT students will form and convene their student advisory committees during their first year of graduate study. The standard graduate committee at the UM is four faculty, three from the major and one from a supporting field or the minor. In addition to the advisor (representing the major), one other member of the student's committee will be a member of the IGERT (representing the ISG minor). This committee will direct the student's research and ensure that it is linked to one of our IGERT research themes. IGERT students will develop a dissertation research proposal by the end of their third semester of study) and it will be reviewed and approved by their student advisory committee. In the dissertation proposal, students will identify how their work relates to the IGERT research themes and may influence risk analysis and decision-making. Students will present their proposal in a roundtable discussion while the proposal is being developed, so they obtain timely feedback. All UM students give a formal public dissertation defense seminar at the completion of their degree. For IGERT students, this should occur by the end of their fourth or fifth year.

Dissertation projects linked to our external partners can be readily facilitated even when the advisor does not work with the particular partner, because all partners will be interacting with us on some of the IGERT research themes and most partners have agreed to host Problem-solving Practicums. All partners listed in Table 1 have agreed to host student dissertation projects. Access to a broad research partnership network is one of the key benefits to students and faculty participating in this IGERT.

An important contributor to the success of this IGERT is the linkage of students' dissertation projects to the IGERT research themes. The advisory committee, the curriculum (especially the practicums), the roundtable discussions and the symposia are the main mechanisms to link students to the themes. In addition, an IGERT Student Progress Committee will provide oversight on dissertation research topics and the extent to which they address our IGERT research themes.

Pathways to Degrees

Typical student pathways for five of the IGERT affiliated graduate programs participating in the minor program are shown in Table 6. The ISG courses required for the minor fulfill an existing PhD requirement to take a minimum of 12 credits in a minor or supporting field. In the first two years of the PhD program, IGERT fellows will take 8-12 credits per semester, regardless of their major program, at least 2 credits less than the maximum full-time load at the University. Ph.D.

students in Applied Plant Sciences and Water Resources will often take two or three additional courses in their major field; these would be scheduled in the third year. Students will also be encouraged to enroll in Preparing Future Faculty during their third year, a program used by other University of Minnesota graduate programs that teaches students how to teach at the college level.

Table 6. Typical program schedules (first 3 yrs) for PhD students entering 5 main degree programs affiliated with this IGERT. Course credits listed in ( ). Non-credit activities are italicized.

Programs	Fall Semester	Spring Semester
First Year		
All IGERT students: ISG Courses	Risk analysis survey course (3) Round table discussions (1)	Risk Analysis Modeling Workshop (1) Quantitative modeling course (3-4) Round table discussions (1) Develop problem-solving proposal with partners
Applied Plant Sciences	Statistical Analysis (4) Intro to Plant Breeding (3) APS Seminar (1)	A plant biology course (3) Plant Breeding Principles I (3) Molecular Genetics (3)
Conservation Biology	Conservation Biology (3) CBio. Seminar (1)	Econ. & Social Dimensions Cons. Bio. (3) CBio Seminar (1)
Ecology, Evolution, & Behavior	EEB Journal Club (1) EEB Elective (3-4) Proposal Writing Seminar (1)	EEB Journal Club (1) EEB Elective (3-4)
Entomology	Insect Tax. & Phylogeny (4) Insect Ecology (3) or Insect Population Dynamics (3)	Insect Structure/Function (4) Statistical Analysis (4) Entomology Seminar (1)
Water Resources Science	Hydrology & Watershed Management (3) Environmental Chemistry (3)	Limnology (3) Water Res.: Individuals & Institutions (3) Research Ethics (0.5)
Second Year		
All IGERT students	Problem-Solving Practicum (3) fall or spring	Courses in major taken in alternate semester Round table discussions (1)
Applied Plant Sciences	[Research Methods (1)] Plant Breeding Principles II (4) APS Seminar (1)	Supervised Teaching (2) Current Topics in APS (2) Molec. & Cell. Genet. of Plant Improvmt (3)
Conservation Biology		CBio Elective (3-4) Statistical Analysis (4)
Ecology, Evolution, & Behavior		EEB Elective (3-4) EEB Journal Club (1) Written prelim exam
Entomology	Statistics Elective (4) Scientific Comm. & Ethics (1)	Entomology Elective (2-4) Entomology Seminar (1)
Water Resources Science	Water Quality: Management of a Resource (3) WRS Elective (3-4)	1 WRS Electives (3-4) Written prelim exam
Third Year		
All IGERT students	Cooperative Learning Practicum (1) Preparing Future Faculty (1)	Oral Prelim Exam Teaching Workshop
Conservation Biology	1 CBio Elective (3-4) Contemporary Problems (1) Written prelim exam	

C(5) Organization, Management, and Institutional Commitment

Organization, management, performance assessment, recruitment, mentoring and retention strategies for this IGERT build on the successful experiences of the Nanoparticle IGERT; three interdisciplinary groups, each with over 5 years history at the University, the Invasion Biology Research Consortium (IBRC), the Institute for Social, Economic, and Ecological Sustainability (ISEES), and the Center for Community Genetics (CCG); and recent ideas and experiences relayed by the Non-equilibrium Dynamics IGERT (at UM) and the GLOBES IGERT (at U. of Notre Dame). CCG activities have been supported in part by an NSF Biocomplexity grant. We will continue to interact with and learn from these groups; members of the GLOBES IGERT, most closely aligned with our IGERT, have agreed to participate in our symposia, explore collaborations and share recruiting information.

Project Director (PD). Newman will have primary responsibility for management of the program. A 50% time administrative assistant will help coordinate program activities, student affairs and administrative tasks associated with ISG minor. The assistant's salary will be funded jointly by IGERT and the University. The PD will also serve as director of the ISG minor and lead instructor of the Risk Analysis survey course.

Executive Committee (EC). The EC, chaired by the PD, will include the five co-PI's, two elected IGERT students, and five elected faculty representing the various IGERT disciplines, and will meet three times a year. The PD has successfully managed a similar-size group for the Water Resources Science Graduate program, and the Nanotechnology IGERT has been successful with a similar structure. The purpose of the EC is to provide oversight, communication and coordination. The EC will appoint an Advisory Committee and four standing subcommittees: Curriculum, Admissions, Off-Campus Training, and Student Evaluation. The chairs of these will be members of the EC. The EC will organize the annual research symposium.

Curriculum Committee (CC chair: Galatowitsch). This committee will coordinate the development, evaluation and improvement of the curriculum. All IGERT PIs, senior faculty and affiliated faculty have agreed to participate in the first Cooperative Learning Workshop in May 2007, where the syllabus and materials for the new courses will be developed. This workshop, focused on incorporating cooperative learning techniques into the curriculum, will be co-organized with the Center for Teaching and Learning. An assessor will review the Curriculum (see below), evaluate student satisfaction and outcomes and suggest curricular improvements. The Curriculum Committee will convene the annual Cooperative Learning Workshop to implement improvements to the curriculum and will coordinate the Cooperative Learning Practicum. This will obviate the need for a complex sub-committee structure to ensure development and improvement of IGERT related courses. Students will be members of this committee.

Admissions Committee (AC chair: Kapuscinski). This committee will review applications for IGERT fellowships and admission to the minor. It will coordinate with major programs to recruit and select students and will work with faculty to develop funding packages. It will recommend to the IGERT senior faculty nominations for IGERT fellowships. The admissions committee will consider the fair distribution of funds among participating programs in making its recommendations. The committee will have a representative from each of the participating graduate programs.

Off-Campus Training Committee (OCTC chair: Andow). This committee will work with our external partners to arrange Problem-Solving Practicums and dissertation opportunities that relate to the IGERT research themes, publicize these opportunities to students, and assess requests for funding for Practicums, research visits to partner labs, and dissertation research support (see Section C(9) for details on student selection). In time, students with off-campus training experience will be included on the committee.

Student Evaluation Committee (SEC chair: Shaw). This committee will assess annual progress of IGERT fellows to ensure timely progress on research related to the IGERT research themes. The committee will develop criteria for satisfactory progress that will be reviewed by the EC, modeled in part on processes in Ecology, Evolution and Behavior, and Entomology, which include reports from student meetings with their advisory committee, an annual student self review, and a written evaluation from the student's advisor.

Advisory Committee. Annually, an eight-member advisory committee chaired by the PD will provide guidance to the IGERT. The committee will evaluate the progress of the IGERT and suggest ways to improve the quality of the program. The committee will include representatives from our US partners (e.g., MISAC, USFWS, USFS), our international partners (e.g., CSIRO, NIOO, Embrapa, YU), and industry or non-governmental organizations (e.g., CHS, UN CBD). A university administrator and two senior IGERT graduate students will represent the university. Two external academic experts will also be included. We have the strong support of many external partners (see supporting letters) and their involvement will greatly enhance the perspective and relevance of our program.

Management of the ISG Minor

The faculty proposing this IGERT have developed a freestanding Graduate minor in Risk Analysis for Introduced Species and Genotypes (ISG). The minor was approved by the Graduate School Executive Committee and University Provost, and awaits final approval by the University Regents. Resources to assist faculty in developing the new courses described in the Education and Training section (C(4)), will enable the minor to be available to students fall semester 2007. Faculty participants in the ISG minor may advise IGERT fellows and will develop decision cases as appropriate for the curriculum (see Section C(4), Table 4). The minor will help ensure the continuation of the program after NSF IGERT resources end and also provide the basis for academic and curricular oversight of the program. We expect an equal number of non-IGERT fellows, including MS students, will elect the ISG minor. The ISG minor will seek funds available to interdisciplinary graduate programs at the UM to support administrative continuity after IGERT funding expires. Learning from the previous UM Nanoparticle IGERT, we have designed the ISG minor to have minimal recurring costs.

Institutional Commitment

The University of Minnesota and our colleges are providing strong support for this proposal. The Graduate School and the Vice President of Research have committed up to $170,000 for stipends to enhance recruitment of underrepresented minorities. They also provide significant fellowship and program support available to the IGERT program and students (see letter). The College of Biological Sciences and College of Food, Agricultural, and Natural Resource Sciences (CFANS) will provide $14,000/yr ($70,000 total) for operating expenses, part of the administrative assistant salary, and other expenses not covered by the proposal (see letter). The CFANS will contribute $50,000 for equipment, of which $40,000 will be used to match our NSF request of $20,000 for additional environmental chambers in the BL2 quarantine facility (see letter). We have secured space for administration, student offices, and an adjacent conference room at a convenient location for our faculty. Although most students will be housed in their advisor's department, the central office space will enhance interaction and provide superior space, especially for new students.

The University has also recently invested heavily in upgrading greenhouse and aquatics facilities and as noted in the Facilities Section upgraded facilities for Biosafety level 1 and level 2 (BL1 and BL2) containment (quarantine facility) and by the start of the IGERT will have constructed a $5M addition to the BL2 facility that can accept exotic plant and insect pathogens (BL3 quarantine), making this the third operational BL3 facility in the country. These facilities are available on campus to all IGERT faculty and students, and the MN Department of Agriculture has a Ph.D. level quarantine officer who will provide specialized training to IGERT students wishing to use these highly specialized and unique facilities which enable students to import any exotic insect, plant or microorganism for detailed study in the quarantine facility.

External Collaborations

We have developed an extensive set of 24 state, national and international external partners (Table 1) whose roles are elaborated in the Research C(3), Education C(4), and International

C(9) sections. Unfortunately, there is insufficient space to describe each of them in detail, but we have formal letters of commitment from each. The partners will assist us with Problem-Solving Practicums (Table 5) and dissertation research opportunities, and provide their perspective on key issues and approaches in risk analysis for introduced species and genotypes. The supporting letters included with this proposal provide examples of the commitments we have received. Our partners have identified research problems that they view as a high priority (e.g., Table 5), and we have a list of over 100 ideas from them. Several of our partners (e.g., Australia's Invasive Animals Cooperative Research Centre, Yokohama National University, University of Tokyo) will fund some of their students to attend our program. Many of our partners will provide material for decision cases as we develop the curriculum. In addition, we have established relationships with members of the Notre Dame GLOBES IGERT, who will participate in some symposia, explore joint research ventures and share recruiting information.

Continuation of the Program

By establishing an academic minor at the University, we have created a way for the core components of this IGERT to continue after NSF funding has expired. We expect that the success of the IGERT will carry over to continue attracting excellent students to our unique minor. The collaborations developed, both among faculty and among our external partners, will further ensure continued interactions and funding opportunities. Cost of continuing the minor is expected to be low. The cost in terms of faculty time and expense is in initial course development and we have planned and budgeted accordingly. Once developed, the faculty have agreed in principle to continued participation in the courses and the minor without release time. Administrative costs may be funded out of Graduate School funds for interdisciplinary graduate programs, so continuation is likely.

C(6) Performance Assessment

Our assessment will include formative components to guide the direction of the project and summative components to assess our effectiveness in meeting our objectives. Both formative and summative evaluations will focus on how the unique features of this project impact students, faculty, the University of Minnesota, and our partner institutions. Specifically, the assessment will target 1) student achievement in courses, research and partnerships, 2) the success of the courses and learning methods developed for the program, 3) external partner satisfaction, 4) department- and college-level knowledge of and support for the project, and 5) enhancement of faculty collaborations and faculty-partner collaborations. We will also compile statistics to assess our recruitment, retention and placement success. Tri-annual meetings of the Executive Committee will allow timely use of formative data, ensuring that we can quickly build on successes and address problems.

We will work with Dr. Valerie Ruhe of the University's Center for Teaching and Learning (CTL) on assessing impacts on stakeholders (students, external partners, UM departments, faculty) in the project. Ruhe is an assessment and evaluation specialist with expertise in assessing educational programs. Dr. Ruhe and project faculty will publish the results of their assessment findings in appropriate professional journals.

We have developed a comprehensive assessment plan that will provide multiple "lenses" on the process outcomes and impact of our work. This mixed methods approach (Greene & Caracelli 2002) will include surveys, observations, interviews, focus groups and expert panels. Ruhe will have primary responsibility for assessment objectives most closely focused on the IGERT fellows and courses (targets 1 and 2 in the list above), and will advise the Executive Committee in the development and interpretation of other assessment tools. For example, she will assess the cooperative learning features of the course modules designed for the new minor, using existing achievement and student evaluation forms developed by the CTL. The fact that these tools are already used in other University courses will allow us to compare outcomes using this new teaching approach. In addition, Ruhe or her staff will observe classes to assess the impact of this teaching approach. We will also focus on the integrated approach to science which makes this project unique at the University of Minnesota – the explicit marriage of science, economics and policy, and the growing field of risk analysis. Working with the Executive Committee, Ruhe will assess fellows' knowledge in areas outside of their specific research expertise, using tools developed in collaboration with experts in the relevant fields. We will convene focus groups during each annual forum to assess students' knowledge of risk assessment with respect to invasive and GE organisms. In addition to IGERT fellows, these focus groups will consist of faculty from the University, representatives of our external mentor group, and individuals not connected with the project but who currently advise students in related fields. We will use data from focus groups to compare our students' expertise with that of other students. An additional target of the evaluation will be our ability to recruit underrepresented groups into the program – our ability to sell this program to groups that do not traditionally choose these fields for graduate study.

In addition to assessing learning and recruitment outcomes, we will collect baseline data on the collegial interactions among representatives of the different disciplines represented in our partnership. These data will be collected before the project begins, using surveys developed with CTL personnel for this purpose. We will clarify expectations of our partners before their participation in the problem-solving partnerships, using a combination of interviews and paper surveys. This process will provide baseline data that we will use to measure our success in meeting partner expectations, as well as allow documentation of unexpected outcomes, both positive and negative, of the partnerships.

Recruitment, retention, grant-writing success and placement statistics will be collected for all students by major program and will be compared to historical and contemporary statistics for each program by project staff. We will also track progress of the Summer Undergraduate Research Program students and other non-IGERT fellow MS and PhD students who are members of the ISG minor. We will place special emphasis on tracking members of underrepresented groups when they leave our program.

As part of the summative evaluation, an independent committee will conduct an external review. The committee, composed of experts in the fields of invasive species and impacts of genetically engineered organisms, will make a 4-day site visit in year 4 and a 2-day visit in year 5 of the funding period. They will have access to all of the tools and reports generated by the CTL and program staff and will meet with students, faculty and college administrators during their site visits. One member of the committee will write a report after the visit that addresses the scientific and training success of the project.

C(7) Recruitment, Mentoring and Retention

Recruitment. To recruit a strong student group, we will develop IGERT recruitment materials, distribute targeted materials to likely student audiences, and coordinate with the participating graduate programs. To ensure diversity among the students we will use five approaches to promoting and enhancing diversity in the IGERT program. We will: 1) offer one additional year of guaranteed support to underrepresented minorities; 2) build on our connections to baccalaureate colleges with large minority populations, such as the Center for Biological Control at Florida A&M University (an HBCU) and Bemidji State University (concentration of American Indians); 3) recruit from the UM Life Sciences Summer Undergraduate Research Program, which attracts a high percentage of minority students; and 4) partner with existing Graduate School Programs, the Student Career Experience Program (USFS, USFWS), and other national recruiting resources (Committee on Institutional Cooperation, National Name Exchange) to attract a diverse pool of applicants. We aim to generate 10 additional applicants to our graduate programs each year, and to recruit at least 5 IGERT fellows from underrepresented groups. These approaches are detailed below.

We will produce recruitment brochures to circulate at major national meetings and to undergraduate colleges, especially those in and near to Minnesota. Targeted announcements will also be sent to list servers, colleagues, and professional societies. An integral part of our recruitment efforts is the creation of an IGERT website, which will be linked to participating graduate programs. We will also utilize the NSF IGERT website and our links to the GLOBES IGERT to attract students.

Ph.D. students are accepted and advised within major graduate programs, and may declare a formal minor by meeting additional course requirements. All students funded by our IGERT must enroll in the ISG minor. The participating graduate programs have committed to working with us to ensure that the IGERT gets prominent mention in their recruiting materials and websites. A representative from each graduate program will be on the IGERT admissions committee, ensuring that IGERT candidates are encouraged for admission. All participating graduate programs are committed to allocating their graduate school dissertation fellowship nominations to IGERT candidates, this will also provide great opportunities to attract outstanding students to their own programs. The Conservation Biology program has committed to using at least one of their graduate school fellowship nominations for an IGERT candidate.

The IGERT admissions committee will rank students based on the academic strength, prior research experience, letters of recommendation, and fit within the program. All students will arrive with identified advisor(s), who will commit to securing additional years of funding necessary for degree completion. We expect most students will have 2 years of IGERT fellowship and 2-3 years additional support from the major advisor, but IGERT funding is conditional on satisfactory performance. In the first year, we expect that some of the IGERT fellows will be selected from outstanding existing students who will minor in ISG. These students may be offered one or two years of IGERT funding depending on their status.

Mentoring and professional development. We have developed a comprehensive mentoring program to guide students through their graduate program. Incoming students will participate in the fall symposium and laboratory/field tour before the semester begins and take ISG coursework as a cohort in order to create a learning community. The IGERT program director will ensure that student advisory committees are formed and promptly meet. Each incoming student will also be assigned a peer mentor. We will strongly encourage IGERT students to enroll in the Preparing Future Faculty (PFF) program for training in learning theory and strategies, teaching skills, and teaching assessment. Alumni from the PFF program have significantly higher levels of job, student, and colleague satisfaction than faculty nationally. Students will also be encouraged to participate in the governance of the program (e.g. Off-campus training committees, workshop and symposium organization, etc.).

Students will participate in our unique off-campus Problem-Solving Practicum in their second year. This will allow a student to make professional contacts and determine the feasibility of continuing their dissertation research off-campus. Dissertation research grants (see C(9) International collaboration) may be awarded for longer term research overseas. Our extensive network of external partners offers over 100 possible research experiences.

Retention. We expect that most students will major in Applied Economics, Applied Plant Sciences, Conservation Biology, Ecology, Evolution & Behavior, Entomology, or Water Resources Science (see Section C(10)), but a few students may major in: Natural Resources Science & Management, Plant Biological Sciences, Scientific & Technical Communication, or Sociology. The five primary graduate programs are among the university's strongest graduate programs and collectively advise over 250 Ph.D. students. Over 90 Ph.D. students have graduated during the past three years. All programs have excellent retention rates. Three of the programs are interdisciplinary, cross-campus programs, and have extensive experience coordinating interdisciplinary programs. Most of the 40 faculty involved with the proposal participate in several graduate programs, and this will allow entering students to select the program that best matches their educational objectives. In addition to frequently meeting with their graduate dissertation committee, students will also report annually to the IGERT SEC to ensure that they are meeting program requirements, to determine if there are programmatic changes that need to be made, or if there are issues relating to their dissertation research.

Promoting and Enhancing Diversity

Our faculty and graduate programs are gender balanced, so our focus is to improve the balance of underrepresented minorities. This will be achieved as follows:

1) To enhance our recruiting efforts, the Graduate School and the VP of Research (see letter) will provide one additional year of guaranteed support, as part of a recruitment package, for up to five underrepresented minority students (up to $170,000). This is expected to be an incentive both to faculty and students – faculty to look hard for qualified students, and students to accept a stronger financial package.

2) We will build on the University's ties to baccalaureate colleges and universities with large minority populations, including Florida A&M University (FAMU), an historically black college (HBCU). This relationship has been successfully used by the UM Nanoparticle IGERT and the Non-equilibrium Dynamics IGERT to recruit students. We will specifically partner with the Center for Biological Control (CBC; see attached letter), which is a collaboration between FAMU and ARS-USDA. FAMU faculty and students will be invited to attend our semi-annual symposia, IGERT faculty and students will annually visit FAMU, and FAMU also provides an opportunity for practicum projects and dissertation research in the southeast and the Caribbean.

We will recruit American Indian students from Bemidji State University (BSU) and the University of Minnesota Duluth (UMD), which have large populations of Native Americans. The heads of the Biology programs at BSU and UMD, and the BSU Center for Environmental, Earth, and Space Studies have agreed to promote our program and will invite us to give seminars to make personal contact and recruit students. We will also pursue a longer-term strategy to recruit future graduate student from several regional tribal colleges, which are two-year institutions (e.g., Fond du Lac, La Courte Oreilles). Two former WRS graduate students are Environmental Science faculty at these two schools, and they will promote our program, invite us to their colleges, and identify students for LSSURP positions.

We will also use established professional relationships to recruit applicants. The Interdisciplinary Center for the Study of Global Change (Associate Director, Kapuscinski) partners with four HBCUs (Morehouse, Clark Atlanta, Spellman, and Morris Brown) to prepare minority undergraduates for graduate studies focused on international issues. Anderson has a research partnership with two faculty (Liedl, Chatfield) at West Virginia State University, an HBCU that offers M.S. degrees in biotechnology.

3) The LSSURP brings in outstanding undergraduates for summer research experiences from over 200 undergraduate institutions. Over the last 17 years, 528 minority students have attended our LSSURP program, and the number is annually increasing. About 30-50% of the Environmental Science students in this program have been underrepresented minorities. One of the co-PIs (Galatowitsch) was co-director of this program in the past, nearly half of the IGERT faculty has mentored minority students in the LSSURP. During the past 5 yrs, 48 LSSURP students have entered graduate school at Minnesota, of which about 30% are underrepresented minorities. LSSURP has agreed to promote our program and recruit more students with environmental interests because our IGERT will fund 4 LSSURP students per summer. LSSURP students will have an IGERT Ph.D. student as a mentor. We will hold a day-long lab and field tour for all LSSURP students in the beginning of summer, led by IGERT faculty and fellows, to expose these undergraduates to research in biological introductions.

4) We will also work with our federal partners to recruit minority students: including the Multicultural Workforce Strategic Initiatives (MWSI) program (USFS) and the SCEP (Student Career Experience Program; USFS, USFWS). These programs specifically recruit minorities for training and employment in these agencies. Through Venette (USFS, senior faculty), we will communicate with the 200+ minority students in MWSI to encourage them to begin graduate education in our IGERT as career development. The USFS can also make available funding for dissertation research in invasive species management. The USFWS-SCEP (see letter) provides the student with financial support, exposure to public service and opportunity for post-education employment that will utilize their training and experience. Since 2000, the USFWS has supported 215 biology graduate students in SCEP. All students completing degrees been hired by the USFWS, and 80% of the enrollees and 78% of the graduates have been members of minorities or women.

The Graduate School Diversity Office will aid us in searching the National Name Exchange (www.grad.washington.edu/nameexch/national/) to identify relevant and qualified prospective minority students. A recent search identified 68 students (GPA ≥ 3.0) with interests relevant to our IGERT. These students will be contacted and encouraged to apply to our IGERT. In addition, our faculty will use personal access to programs such as the American Society of Limnology and Oceanography's NSF-supported Minorities in Aquatic Sciences and the Hampton University MAST program, the Ecological Society of America's SEEDS program, the American Society for Microbiology Minority Program, and the American Fisheries Society's Hutton program to identify students to recruit.

5) As determined by the Nanoparticle IGERT, minority IGERT fellows are the most effective recruiters of underrepresented minorities. We will cover travel for minority IGERT fellows to HBCUs and colleges with large American Indian populations to give seminars on their research and discuss their experiences in our IGERT. We have budgeted Travel funds (see budget justification) to send our faculty and students to these institutions annually and bring their faculty and students to our annual symposium and other events.

C(8) Recent Traineeship Experience and Results

Our IGERT benefits from extensive collective experience with successful interdisciplinary graduate training programs that involve members our IGERT team and other university colleagues. The University of Minnesota is home to two NSF IGERTs: Nanoparticle Science and Engineering" (begun 2001) and "Non-equilibrium Dynamics Across Space and Time" (begun 2005). We have drawn from both programs in patterning some of our approaches after the most effective ones of these IGERTs. The Nanoparticle IGERT has trained 32 new PhD students and has been highly successful in promoting interactions among students and faculty from a number of departments. Faculty collaborations have at least doubled, and student cohorts have been highly interactive. The program has also been successful in recruiting for diversity, with 5 students from underrepresented groups. We have adopted a recruiting strategy found particularly effective in current IGERTs: recruitment of additional minority students by minority students within the IGERT. International collaborations have contributed substantively to the vitality of these IGERTs. A free-standing minor developed in conjunction with the Nanoparticle IGERT served as inspiration for the minor we have developed.

Several members of our IGERT team were among 10 University faculty awarded an NSF Biocomplexity Research grant (2000-2005), 'Evolution and ecology of perturbed interactions: modeling disequilibria in time and space'. This award directly funded 10 graduate students and 5 post-docs. The University supplemented this award to continue activities of the Center for Community Genetics (CCG), a graduate training program promoting interactions among scientists in a wide range of fields (math, genetics, ecology, plant biology, entomology, agronomy, plant pathology). CCG's weekly seminar offers a lively forum for discussion of ongoing research and its grants program materially supports graduate research. CCG has also hosted seminars, symposia and public lectures that bring internationally-renowned scientists to interact extensively. CCG has been very effective in fostering independence and originality of participating graduate students who have been highly successful post-degree.

Over the past decade, the Interdisciplinary Center on Global Change (Kapuscinski, Assoc. Director) has supported over 120 Ph.D. students via the Center's MacArthur fellowships for research in four interdisciplinary areas, one being environmental and social sustainability. Some of our IGERT students will participate in this on-going training program. Job placement of these graduates has been rapid and outstanding, including faculty positions at premiere institutions and leadership posts in government and public organizations. Similarly, over the last 15 years our NIGMS Biotechnology Training Grant (steering member Sadowsky), from the NIH, has funded over 100 diverse Ph.D. students, providing scientists and engineers excellent employment in academic and industrial positions.

Most recently, members of our IGERT team have been awarded a Cooperative Agreement with the USDA-Economic Research Service, funding which will support two students to focus on economic aspects of invasive species management.

C(9) International Collaboration

We will enhance the professional development of our IGERT students by engaging them in real world risk analysis dilemmas facing our international partners. Through these experiences, our students will better understand international scientific and policy issues and will become positioned to grow into leaders as they interact with established international leaders involved in introduced species or genotypes. We have developed relationships with partners worldwide. Table 1 lists our international partners, all of which have agreed to host a student for all or part of his/her dissertation research. Table 5 identifies those international partners that also have the infrastructure and staff to host a small team of students (3-5) for a short term *Problem-Solving Practicum* as described in section C(4). Criteria used to identify our partners included: (1) introduced species or genotypes are an important issue in their region, (2) disciplinary experts working on relevant issues are available to serve as hosts and mentors for student teams visiting for the Problem-Solving Practicum, and (3) the institution is willing and able to assist with logistics of student research and mentoring of students including office or lab space, access to computers and telecommunications, access to field sites, and access to data and library holdings.

Integration and Overall Benefit of International Collaboration

Sixteen international partners have sent letters committing to a significant level of collaboration (five are included in Section H). Our research partners will contribute to our *training* program by hosting teams of students involved in the problem-solving partnership practicum. Our international partners will assist student practicum teams and the advisory faculty in identifying the specific issue involving introduced species or genotypes for the team to focus upon, participate on-site with students as they conduct their research, review the final report and participate in the video/teleconference roundtable presentation. The partners will also provide information to assist development of the *Teaching Practicum* decision case, and review the draft decision-case for technical accuracy and utility. International partners can use the teaching materials developed in the teaching practicum in their own training programs. These decision cases will be presented to IGERT students and faculty at the annual IGERT Cooperative Learning workshop and many will be used in the *Risk Analysis for Introduced Species and Genotypes* survey course. For students who wish to conduct at least part of their dissertation research abroad, dissertation and research partners will assist students in selecting, designing and refining projects within the context of the partner's ongoing research program The partners will provide workspace and access to materials and study sites for the dissertation research. We will invite at least one international partner to serve on the IGERT advisory committee.

Our international partners offer students direct experience with the international dimensions of ERA of introduced species and genotypes. For example, the WorldFish Center can help students develop research to improve prediction of invasiveness of ornamental fish species exported from Southeast Asia to the United States and selectively bred tilapia escaping from aquaculture systems in Asia and Africa. The South African National Biodiversity Institute and its regional partners will provide opportunities for GEO risk assessment and invasive species management. Embrapa's Cenargen participates in the main Brazilian research network conducting experiments in support of ERA. Yokohama National University hosts a Center of Excellence for environmental risk management of biological systems and has 37 overseas partners (mostly in Asia) that our students can access. The Netherlands Institute of Ecology can provide European perspectives on invasive species and GEOs and presently collaborates with IGERT faculty. Australia's CSIRO has experience with other IGERT programs (Ecosystem Informatics, Oregon State University) along with other Australian organizations such as the Invasive Animals Cooperative Research Centre (CRC) and the Australian Centre of Excellence for Risk Analysis (ACERA). These centers and CSIRO are eager to host IGERT practicum and dissertation projects and are at the forefront of developing improved ERA models for invasive species, GEOs, and biological control organisms. They are also world leaders in developing quantitative risk analysis methods and public communication and involvement approaches required for such a bold endeavor. Students pursuing research on ecological and social aspects of controlling invaders have the chance to work with South Africa's Working for Water program

(CIB, Stellenbosch University), the world's foremost national-scale effort to clear invasive species in order to meet ecological restoration and sustainable development objectives. CABI Bioscience Switzerland Centre is one of the world leaders for exploration and introduction of biological control agents. CABI-Switzerland has cooperated with many IGERT faculty and with staff at the Minnesota Department of Natural Resources and Minnesota Department of Agriculture. All of our partners have experience advising and mentoring students, and most have mentored US students.

Selection, Preparation and Sending of US Students Abroad
We will orient all incoming IGERT students to the international research opportunities offered by our partners in the student's first academic semester in the course, *Risk Analysis for Introduced Species and Genotypes*. The IGERT office will maintain files of potential and completed opportunities for student use. Students will have opportunities for international experience during the Problem-Solving Practicum in the second year or for individual dissertation research in the following years. The Off-Campus Training committee will review and select practicums and dissertation proposals deemed suitable for funding. For practicum projects, the students will work with the Practicum Advisory Faculty and the international partner to develop a proposal; for dissertation projects, students will work with their advisors and international partners to develop a proposal.

To help students with proposal preparation, the IGERT program office will maintain a directory of our international partners and student reports from past supported travel. We anticipate funding two to three dissertation grants and one Problem-Solving Practicum annually. Any student in the ISG minor can apply for support of their dissertation research in collaboration with our partners, but preference will be given to IGERT fellows. The application process, inspired by a similar process used by the University's Center for Community Genetics (Andow, Shaw, Jordan, Heimpel), is designed to minimize the burden on our partners while ensuring the best projects are funded. The process will be as follows: (1) An individual student (dissertation support) or a group of 3-5 students (Problem-Solving Practicum support) submits a letter of intent describing the proposed international activity and relevance to the IGERT program and the student's career goals; (2) Chair of Off-campus Training Committee evaluates letters and provides the student or student group written guidance for developing a full proposal; (3) If deemed acceptable by the Chair, a full two-page proposal plus budget with justification is prepared including a letter from the major advisor (individual student) or from the Practicum Advisory Faculty (Problem-Solving Practicum groups); (4) the Off-campus Training Committee ranks awardees based on relevance of proposed work and anticipated outcomes to the IGERT program, potential relevance to host partner, the student's professional development, originality and timeliness of proposed activity, and ability to communicate in local language; (5) Students or student teams receiving top ranks will solicit formal support from international host institution; (6) Committee reviews and approves proposals; and (7) Upon return from international travel, individual students submit a two page report and make a roundtable presentation on their accomplishments, while the practicum team will produce a final report or manuscript and make a presentation to the videoconference roundtable with partners. Feedback from the international partners will be solicited so that future student travel and collaborative research can be improved.

We will encourage all IGERT students working internationally to learn basic communication skills in the local language. Students will benefit from the fact that all of our partners use English regularly in their work. The University's International Students and Scholar Services and CFANS International Programs office provide assistance in preparing overseas travel, ranging from visa applications to obtaining cultural information about countries. All our international partners are well-established, large institutions with on-site or nearby infrastructure (e.g., safe housing and medical care access) to ensure welfare of IGERT students in residence with them. One or more of our faculty have strong working relationships with each partner, which will facilitate supervision of students while they are abroad.

C(10). Recruitment and Retention History: Applied Economics Graduate Program

The Applied Economics Graduate Program is a joint program with the Department of Applied Economics in the College of Food, Agricultural, and Natural Resource Sciences; Division of Health, Policy, and Management in the School of Public Health; Humphrey Institute of Public Affairs; and Department of Human Resources and Industrial Relations in the Carlson School of Management. The program has 55 graduate faculty and 76 Ph.D. students. Since 2000, the program has graduated 40 Ph.D. students, with 11 being appointed as assistant professors at other universities. Recent graduates also hold positions in government, industry, and NGO's.

Academic Yr	Degree	Category	Apps[1]	Admit	Matr[2]	Enr F[3]	Enr P[4]	Wthdr[5]	Grad[5]	AYEN[6]	AYED[7]
2003-2004	MS	Female	17	10	2	10	4	2	4	2.5	2.3
		Male	36	22	7	11	4	2	2	2.8	2.7
		Minority	4	0	0	1	1	0	0	0	0
		Total	53	32	9	21	8	4	6	2.6	2.4
2004-2005	MS	Female	28	23	6	14	0	1	4	3.5	2.6
		Male	25	16	6	14	7	1	4	3.9	2.9
		Minority	2	1	1	2	1	0	0	0	0
		Total	54	39	12	28	7	2	8	3.7	2.8
2005-2006	MS	Female	19	17	8	12	3	0	7	4.0	3.1
		Male	23	16	4	13	6	1	5	2.0	1.8
		Minority	1	1	0	1	1	1	1	3.5	3.2
		Total	44	35	12	25	9	1	12	3.2	2.5
2003-2004	PhD	Female	11	10	2	15	3	2	7	7.1	6.0
		Male	30	24	9	29	7	3	2	5.5	5.2
		Minority	2	2	2	4	0	0	0	0	0
		Total	41	34	11	44	10	5	9	6.7	5.8
2004-2005	PhD	Female	10	4	1	11	5	0	2	6.5	6.2
		Male	33	20	4	29	9	6	4	5.4	5.1
		Minority	0	0	0	6	1	0	0	0	0
		Total	43	24	5	40	14	6	6	5.7	5.4
2005-2006	PhD	Female	18	12	4	18	7	0	0	0	0
		Male	36	23	6	33	14	3	2	6.2	5.7
		Minority	2	2	1	6	3	1	0	0	0
		Total	55	36	10	51	21	3	2	6.2	5.7

[1] Apps = No. of applicants for the academic year.
[2] Matr = No. of admitted students who enrolled or matriculated.
[3] Enr F = No. of full time (≥ 6 cr) students enrolled for fall semester.
[4] Enr P = No. of part time (< 6 cr) students enrolled for fall semester. Many advanced students who have completed coursework and thesis credits are counted as part-time under this definition.
[5] Wthdr = No. of students that withdrew; Grad = No. of students that graduated.
[6] AYEN: Average years enrolled to degree award date (2 semesters per year).
[7] AYTD: Average years elapsed from start in graduate program to degree award date.

C(10). Recruitment and Retention History: Applied Plant Sciences Graduate Program

Applied Plant Sciences is a joint graduate program between the Department of Agronomy and Plant Genetics and the Department of Horticultural Sciences comprising about 65 graduate faculty and 40 students. Since the programs inception in 1999, 58 MS. and 17 PhD students have graduated. Currently, 23 students are pursing PhD's. Our recent Ph.D. graduates hold positions in NGO's, industry and academia. Two of our recent graduates are post docs and two are in faculty positions.

Academic Yr	Degree	Category	Apps[1]	Admit	Matr[2]	Enr F[3]	Enr P[4]	Wthdr[5]	Grad[5]	AYEN[6]	AYED[7]
2003-2004	MS	Female	10	1	1	8	0	0	5	2.5	3.4
		Male	10	2	2	17	3	1	5	2.4	3.8
		Minority	0	0	0	1	1	0	1	3.0	4.2
		Total	20	3	3	25	3	1	10	2.4	3.6
2004-2005	MS	Female	6	2	2	8	0	0	6	2.1	3.6
		Male	12	4	3	11	4	0	7	2.2	3.1
		Minority	1	0	0	1	0	0	0	0	0
		Total	18	6	5	19	4	0	13	2.2	3.3
2005-2006	MS	Female	17	3	2	5	2	0	1	3.5	3.1
		Male	7	5	5	8	5	0	6	3.3	3.1
		Minority	1	1	1	2	0	0	1	3.5	3.1
		Total	24	8	7	13	7	0	7	3.4	3.1
2003-2004	PhD	Female	10	2	2	15	0	0	0	0	0
		Male	9	0	0	9	1	1	3	4.6	7.6
		Minority	2	1	1	1	0	0	0	0	0
		Total	19	2	2	24	1	1	3	4.6	7.6
2004-2005	PhD	Female	10	0	0	14	1	0	4	5.3	6.3
		Male	7	3	3	10	1	0	1	5.2	7.8
		Minority	3	0	0	1	0	0	0	0	0
		Total	17	3	3	24	2	0	5	5.3	6.6
2005-2006	PhD	Female	9	2	2	11	2	0	2	6.2	5.0
		Male	7	1	1	7	3	0	1	4.5	4.5
		Minority	0	0	0	1	0	0	0	0.0	0.0
		Total	16	3	3	18	5	0	3	5.7	4.8

[1] Apps = No. of applicants for the academic year.
[2] Matr = No. of admitted students who enrolled or matriculated.
[3] Enr F = No. of full time (≥ 6 cr) students enrolled for fall semester.
[4] Enr P = No. of part time (< 6 cr) students enrolled for fall semester. Many advanced students who have completed coursework and thesis credits are counted as part-time under this definition.
[5]Wthdr = No. of students that withdrew; Grad = No. of students that graduated.
[6]AYEN: Average years enrolled to degree award date (2 semesters per year).
[7]AYTD: Average years elapsed from start in graduate program to degree award date.

C(10). Recruitment and Retention History: Conservation Biology Graduate Program

The Conservation Biology Graduate Program is an interdisciplinary program of 107 faculty and 90 students in 17 departments from 8 colleges. Since the program's inception in 1991, 124 M.S. and 51 Ph.D. students have graduated; currently over 60 students are pursing Ph.D.s A number of our students have received NSF and Fulbright Fellowships. Almost all of our graduates are employed in the profession; Ph.D. graduates hold positions in consulting firms, NGO's, governmental agencies and academia in the U.S. and abroad. Of our recent graduates, five are in faculty positions in the US and abroad, four are with federal laboratories, three are in postdoctoral positions, and three are with NGO's. We recently graduated our first female American Indian Ph.D.

Academic Yr	Degree	Category	Apps[1]	Admit	Matr[2]	Enr F[3]	Enr P[4]	Wthdr[5]	Grad[5]	AYEN[6]	AYED[7]
2003-2004	MS	Female	30	4	4	15	2	0	7	2.0	3.5
		Male	25	10	6	11	3	1	4	1.5	2.5
		Minority	0	0	0	0	2	0	2	2.0	2.9
		Total	55	14	10	26	5	1	11	1.8	3.1
2004-2005	MS	Female	32	3	2	11	7	0	11	2.5	3.0
		Male	22	4	2	10	5	0	4	1.8	2.5
		Minority	1	0	0	0	1	0	1	2.0	2.8
		Total	54	7	4	21	12	0	15	2.3	2.9
2005-2006	MS	Female	33	2	1	8	4	1	6	3.8	3.5
		Male	22	9	6	9	4	1	3	4.2	3.9
		Minority	4	1	0	0	1	1	0	0.0	0.0
		Total	55	11	7	17	8	2	9	3.9	3.7
2003-2004	PhD	Female	19	8	4	21	13	0	5	4.7	6.5
		Male	12	6	4	14	7	0	1	4.2	3.6
		Minority	0	0	0	3	2	0	1	4.1	5.7
		Total	32	15	8	35	20	0	6	4.6	6.0
2004-2005	PhD	Female	23	12	7	29	10	1	0	0	0
		Male	16	1	0	13	11	0	3	4.7	6.1
		Minority	1	1	0	3	1	0	0	0	0
		Total	40	14	7	42	21	1	3	4.7	6.1
2005-2006	PhD	Female	21	6	3	27	11	4	4	8.1	7.3
		Male	15	2	2	16	10	2	0	0.0	0.0
		Minority	1	0	0	2	2	0	0	0.0	0.0
		Total	37	9	5	43	21	6	4	8.1	7.3

[1] Apps = No. of applicants for the academic year.
[2] Matr = No. of admitted students who enrolled or matriculated.
[3] Enr F = No. of full time (≥ 6 cr) students enrolled for fall semester.
[4] Enr P = No. of part time (< 6 cr) students enrolled for fall semester. Many advanced students who have completed coursework and thesis credits are counted as part-time under this definition.
[5]Wthdr = No. of students that withdrew; Grad = No. of students that graduated.
[6]AYEN: Average years enrolled to degree award date (2 semesters per year).
[7]AYTD: Average years elapsed from start in graduate program to degree award date.

C(10). Recruitment and Retention History: Ecology, Evolution and Behavior Graduate Program

The Ecology, Evolution and Behavior (EEB) graduate program has about 60 faculty and 50 graduate students; faculty who reside in the department of Ecology, Evolution and Behavior advise most of the students. Over the past three years we have graduated 5 M.S. and 17 Ph.D. students. A number of our students have received NSF graduate research and dissertation fellowships. Our recent graduates from the program include 1 assistant professor, 8 post docs, 1 temporary college teaching position, 1 research associate, and 1 directorship.

Academic Yr	Degree	Category	Apps[1]	Admit	Matr[2]	Enr F[3]	Enr P[4]	Wthdr[5]	Grad[5]	AYEN[6]	AYED[7]
2003-2004	MS	Female	12	0	0	0	0	0	4	2.9	4.0
		Male	8	1	1	1	0	0	0	0	0
		Minority	1	0	0	0	0	0	1	4.9	7.3
		Total	20	1	1	1	0	0	4	2.9	4.0
2004-2005	MS	Female	10	0	0	0	1	0	0	0	0
		Male	6	1	1	3	0	0	0	0	0
		Minority	0	0	0	0	0	0	0	0	0
		Total	16	1	1	3	1	0	0	0	0
2005-2006	MS	Female	9	2	2	2	1	0	1	6.5	6.1
		Male	2	0	0	2	0	0	0	0.0	0.0
		Minority	2	0	0	0	0	0	0	0.0	0.0
		Total	11	2	2	4	1	0	1	6.5	6.1
2003-2004	PhD	Female	39	7	6	20	4	1	4	4.5	6.5
		Male	36	5	3	19	1	1	2	4.6	6.3
		Minority	4	0	0	1	0	0	0	0	0
		Total	75	12	9	39	5	2	6	4.5	6.4
2004-2005	PhD	Female	45	9	4	18	4	0	2	4.2	5.8
		Male	29	6	3	15	4	0	5	4.1	6.1
		Minority	5	2	1	2	0	0	0	0	0
		Total	74	15	7	33	8	0	7	4.2	6.0
2005-2006	PhD	Female	45	9	5	23	3	0	3	6.7	6.8
		Male	22	7	4	22	0	0	1	6.5	6.5
		Minority	5	2	1	3	0	0	0	0.0	0.0
		Total	67	16	9	45	3	0	4	6.6	6.7

[1] Apps = No. of applicants for the academic year.
[2] Matr = No. of admitted students who enrolled or matriculated.
[3] Enr F = No. of full time (≥ 6 cr) students enrolled for fall semester.
[4] Enr P = No. of part time (< 6 cr) students enrolled for fall semester. Many advanced students who have completed coursework and thesis credits are counted as part-time under this definition.
[5]Wthdr = No. of students that withdrew; Grad = No. of students that graduated.
[6]AYEN: Average years enrolled to degree award date (2 semesters per year).
[7]AYTD: Average years elapsed from start in graduate program to degree award date.

C(10). Recruitment and Retention History: Entomology Graduate Program

Entomology is a graduate program comprising about 24 graduate faculty and 35 students. During the past 5 years, 17 M.S. and 22 Ph.D. students have graduated. Currently, 16 students are pursuing a M.S. and 18 students are pursuing Ph.D.s. Our students have won numerous awards, including a Best Dissertation Award from the Graduate School last year. Almost all of our graduates are employed in the profession; Ph.D. graduates hold positions in consulting firms, industry, governmental agencies and academia in the U.S. and abroad. Recent PhD graduates (2001-) are employed in government (1), post-doctoral research (8) and faculty (6) positions.

Academic Yr	Degree	Category	Apps[1]	Admit	Matr[2]	Enr F[3]	Enr P[4]	Wthdr[5]	Grad[5]	AYEN[6]	AYED[7]
2003-2004	MS	Female	7	4	2	10	1	0	3	1.7	2.4
		Male	8	3	3	3	3	0	2	3.2	5.5
		Minority	0	0	0	0	0	0	1	2.0	2.9
		Total	15	7	5	13	4	0	5	2.3	3.6
2004-2005	MS	Female	6	3	3	11	2	0	5	2.4	3.1
		Male	5	2	1	5	2	0	1	1.7	2.3
		Minority	1	1	1	0	0	0	0	0	0
		Total	11	5	4	16	4	0	6	2.3	3.0
2005-2006	MS	Female	10	6	5	9	3	0	2	3.5	3.2
		Male	2	0	0	1	3	1	1	3.5	3.6
		Minority	0	0	0	0	1	0	0	0	0
		Total	12	6	5	10	6	1	3	3.5	3.4
2003-2004	PhD	Female	1	0	0	8	2	0	2	8.7	9.9
		Male	3	1	1	10	1	2	1	3.7	4.4
		Minority	0	0	0	3	0	0	0	0	0
		Total	4	1	1	18	3	2	3	7.0	8.1
2004-2005	PhD	Female	4	1	0	7	2	0	3	3.0	4.1
		Male	6	2	1	8	2	0	4	5.8	6.0
		Minority	0	0	0	3	1	0	1	3.0	4.1
		Total	10	3	1	15	4	0	7	4.6	5.2
2005-2006	PhD	Female	1	1	1	5	3	0	1	5.0	5.0
		Male	2	1	1	7	3	0	2	9.4	14.5
		Minority	0	0	0	2	1	0	1	5.0	5.0
		Total	3	2	2	12	6	0	3	7.9	11.3

[1] Apps = No. of applicants for the academic year.
[2] Matr = No. of admitted students who enrolled or matriculated.
[3] Enr F = No. of full time (≥ 6 cr) students enrolled for fall semester.
[4] Enr P = No. of part time (< 6 cr) students enrolled for fall semester. Many advanced students who have completed coursework and thesis credits are counted as part-time under this definition.
[5] Wthdr = No. of students that withdrew; Grad = No. of students that graduated.
[6] AYEN: Average years enrolled to degree award date (2 semesters per year).
[7] AYTD: Average years elapsed from start in graduate program to degree award date.

C(10). Recruitment and Retention History: Water Resources Science Graduate Program

The Water Resources Science (WRS) Graduate Program became a degree-granting major in 1995 after approximately 10 years as a free-standing minor. This interdisciplinary program comprises over 115 faculty in 26 academic units and 11 colleges on three campuses (Duluth, Minneapolis and St. Paul). About 1/3 of our students are physically oriented, 1/3 ecologically oriented and the remainder are divided among chemistry and policy. We require Ph.D. students to first complete an M.S.; about 75% of our Ph.D. students completed M.S. degrees elsewhere and 25% have completed an M.S. in our program. Almost all of our graduates are employed in the profession; Ph.D. graduates hold positions in consulting firms, industry, governmental agencies and academia (currently 5 post docs and 3 Assistant Professors) in the U.S. and abroad.

Academic Yr	Degree	Category	Apps[1]	Admit	Matr[2]	Enr F[3]	Enr P[4]	Wthdr[5]	Grad[5]	AYEN[6]	AYED[7]
2003-2004	MS	Female	10	6	2	17	7	2	3	1.8	2.9
		Male	18	11	5	10	6	0	6	3.0	3.1
		Minority	0	0	0	0	0	0	0	0	0
		Total	29	17	7	27	13	2	9	2.6	3.0
2004-2005	MS	Female	13	7	5	10	17	2	9	3.1	4.6
		Male	17	10	7	13	3	2	4	2.7	4.0
		Minority	0	0	0	0	0	0	0	0	0
		Total	31	18	12	23	20	4	13	3.0	4.4
2005-2005	MS	Female	17	8	7	15	9	1	1	3.5	3.2
		Male	16	9	7	13	4	0	4	3.5	3.1
		Minority	1	1	1	2	0	0	0	0	0
		Total	33	17	14	28	13	1	5	3.5	3.1
2003-2004	PhD	Female	5	1	1	11	1	1	1	3.3	4.7
		Male	16	6	4	16	6	1	4	4.7	6.5
		Minority	0	0	0	1	0	0	0	0	0
		Total	21	7	5	27	7	2	5	4.4	6.1
2004-2005	PhD	Female	8	3	1	9	5	0	1	5.9	3.7
		Male	6	0	0	14	7	1	4	3.8	5.2
		Minority	0	0	0	1	0	0	1	3.0	4.3
		Total	14	3	1	23	12	1	5	4.2	4.9
2005-2006	PhD	Female	8	0	0	7	5	1	2	6.2	5.9
		Male	5	2	1	12	6	0	2	6.7	5.0
		Minority	1	0	0	0	0	0	0	0.0	0.0
		Total	13	2	1	19	11	1	4	6.5	5.5

[1] Apps = No. of applicants for the academic year.
[2] Matr = No. of admitted students who enrolled or matriculated.
[3] Enr F = No. of full time (≥ 6 cr) students enrolled for fall semester.
[4] Enr P = No. of part time (< 6 cr) students enrolled for fall semester. Many advanced students who have completed coursework and thesis credits are counted as part-time under this definition.
[5]Wthdr = No. of students that withdrew; Grad = No. of students that graduated.
[6]AYEN: Average years enrolled to degree award date (2 semesters per year).
[7]AYTD: Average years elapsed from start in graduate program to degree award date.

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