IGERT- Genetic Engineering and Society: The Case of Transgenic Pests

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SUMMARY

This IGERT will create a diverse group of interactive students, trained in technologies used for manipulation of pest genomes as well as methods needed to assess the environmental and socio-cultural appropriateness of specific products of these manipulations.

As early as this year, the world will see the first open field release of a mosquito genetically engineered for suppression of disease transmission. This release builds on decades of work in Genetic Pest Management (GPM) that began, in the 1940s, with classical genetic techniques and now includes a variety of molecular approaches. Where classical genetic techniques were restricted in application to a small set of insect species, advances in molecular genetics provide more precise methods for manipulating pest genomes and allow for application of GPM to more diverse pest taxa that affect agriculture, humans health, and biodiversity.

These developments evoke recent debates surrounding similar technological developments in agricultural crops. In that case, commercial development and sale of transgenic crops is displacing classical genetic approaches to plant breeding and cultivar deployment. Transgenic crops have been controversial enough to garner political protest and change the tenor of relations within and between associated commercial and academic scientific communities. Given this legacy, the future of GPM is likely to be determined by both social dynamics and technological advances. In addition to general public attitudes toward novel technologies and products, GPM debates will be influenced by the breadth and depth of understanding researchers and policy-makers bring to the topic. When, in the near future, broad-based societal examination of GPM takes place, PhDs trained integratively in biological and social sciences will be key facilitators who help foster more sophisticated interactions among policy makers, academicians, and members of societies where the application of GPM is being considered.

Intellectual Merit: This IGERT will produce the first graduate program in the world specifically training graduate students to understand, build, and assess impacts of transgenic organisms. This broad program integrates diverse disciplines, but maintains the focus of trainees and faculty by studying a small set of species that are targets for GPM. In each of the first years of the program, we will recruit graduate students in biological and social sciences with track records of academic breadth and excellence. Each cohort of about six students, balanced across disciplines, will work together with faculty to choose one target species as their focus, challenging students and faculty to work together and develop a common vocabulary. Through a series of required IGERT courses, including one held in Mexico, all students will receive core transdisciplinary training that will encompass molecular biology, population genetics, ethics, communication, economics, and ecology. Students specializing in the disciplines of a specific IGERT course will act as mentors to others in the class. The program, then, provides students with achievement criteria designed to ensure their integrative education is accompanied by disciplinary depth. Each student will develop a dissertation with one or more substantial chapters centered on the group target species.

Broader Impacts of this IGERT fall into the following categories: 1) expanding integrated graduate education at NCSU, 2) increasing the number of students from underrepresented groups that receive interdisciplinary education across the biological and social sciences (especially through the program's association with Historically Black Universities in North Carolina), 3) evaluating a specific novel model for transdisciplinary graduate education, 4) improving methodologies for assessing and introducing new technologies, 5) preparing Ph.D.s for careers that require interdisciplinary skills and an understanding of global issues and cultures. Successful projects within our IGERT will improve decisions regarding the development of specific GPM technologies and if/how they should be used, especially in poorer nations where many pests targeted for GPM are located. We will use existing and newly developed international partnerships to set up internships and dissertation projects in these countries.

Key words: Biology, Mathematics, Social Sciences; Evolution

TABLE OF CONTENTS

For font size and page formatting specifications, see GPG section II.B.2.

*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.

1. PARTICIPANTS

Table 1. <u>Most Critical</u> 20 Participating faculty <u>No</u> faculty with prior IGERT experience

NAME/ROLE	ROLE	DEPT. at NCSU	EXPERTISE --- (IGERT course taught)
Gould, Fred	PI	Entomology	Population genetics & ecology; courses #1, #2
Haddad, Nick	CoPI	Biology	Ecology of endangered species; course #2
Haenn, Nora	CoPI	Soc. & Anthro.	Perception of technology; courses #1, #3
Lloyd, Alun	CoPI	Mathematics	Epidemiology of infectious diseases; course #4
Kinsella, Bill	CoPI	Communication	Science, technology & society; course #3
Apperson, Charles	Part.	Entomology	Mosquito and disease management; course #2
Birkland, Tom	Part.	Public Admin.	Risk assessment & public policy; course #3
Burrack, Hannah	Part.	Entomology	Farmer education, medfly research; course #2
Cardoza, Yasmin	Part.	Entomology	Medfly research; International liaison; course #1
Dannels, Deanna	Part.	Communication	Interdisc. dynamics & team building; course 3
Dunn, Rob	Part.	Biology	Community ecology & outreach; course #3
Gilliam, James	Part.	Biology	Invasive fish species, community ecology
Gray, Denis	Part.	Psychology	Strategies for examining transdisciplinary work
Lorenzen, Marce	Part.	Entomology	Molecular genetics & gene-drive; course #2
Mackay, Trudy	Part.	Genetics	Genomics & evolution; Minority recruitment
Mahaffey, James	Part.	Genetics	Insect transgenesis & gene drive; course #2
Miller, Carolyn	Part.	English	Tech. comm.; Rhetoric of tech. & risk; course 3
Schulman, M	Part.	Sociology	Globalization, work hazard assess; course #4
Scott, Max	Part.	Genetics	Transgenesis, sex ratio alteration; course #2
Steelman, Toddi	Part.	Forestry	Multi-stakeholder policy development; course 3
<u>International Participants</u>	**ROLE**	**Institution**	**Expertise**
Ramsey, Janine; Mexico	Part.	Mexican Inst. of Health	Epidemiology of dengue and chagas disease; Course #1, Intern mentor
Reed, Floyd; Germany	Part.	Max Plank Inst.	Molecular and Evolutionary analysis of GPM; Intern mentor
Rendon, Pedro; Guatemala	Part.	USDA	Medfly sterile insect release program; Course #1, Intern mentor
Thresher, Ron; Australia	Part.	CSIRO Fisheries	Invasive fish ecology & management, transgenic methods; Intern mentor
Tripet, Frederic; England/Mali	Part.	Keele University	Genetic management of malaria vectors; Intern mentor

<u>IGERT Courses:</u>

#1. Pest Issues in Developing Nations: Biology, Culture and Infrastructure (2 Credits)
#2. Principles of Genetic Pest Management (4 Credits)
#3. New Technologies in Social and Cultural Contexts (3 Credits)
#4. Systems Thinking and Modeling (3 Credits)

<u>MOST CRITICAL EXTERNAL FACULTY</u>-**<u>Robert Cook-Deegan (Duke-Ethics), Randy Kramer (Duke Environmental Economics), Louis Jackai (North Carolina A & T – International agriculture and pest management), Jonahan Wiener (Duke-Environmental Law)</u>**

2. VISION, GOALS AND THEMATIC BACKGROUND

Vision: *Our vision is of a group of interactive students, trained in technologies used for manipulation of pest genomes as well as methods needed to assess the environmental and socio-cultural appropriateness of specific products of these manipulations.*

As early as this year, the world will see the first open field release of a genetically engineered mosquito in association with a project aimed at suppressing dengue fever. How will societies and environments react to this new technology? And, what implications will these reactions have for ongoing research and application? The history of genetically modified organisms **(GMOs)** offers ambiguous answers to these questions. Insulin, produced by genetically engineered microbes, appears to have been universally embraced. Other products, such as transgenic crops, have been controversial enough to garner political protest and change the tenor of relations within and between their associated commercial and academic scientific communities (e.g., McAfee, 2008, Waltz 2009).

The advent of Genetic Pest Management (**GPM**) offers an opportunity to learn from past experiences and train a generation of students *before* wide-scale application creates consequences for which GPM researchers, and the communities these hope to aid, are poorly prepared. The pest species linked to such engineering range from insects to rodents and from pests of large-scale agriculture to invasive pests of endangered species. Students interested in GPM and, more broadly, in the social and ecological consequences of new technologies, must be able to evaluate whether, when, and how GPM technologies might be utilized. Students must have a combined depth of training in the technological manipulation of pest genomes, the ecology of pests and their habitats, and how people in diverse socio-cultural contexts attend to the risks associated with new technologies. *Because research on transgenic pests is at the prototypical stage, our trainees will be at the forefront of these interdisciplinary evaluations.*

Specific Goal:

In the face of rapid advances in the molecular technology behind GPM, researchers and observers of this progress are concerned that examination of the ecological and social issues associated with the technology has been insufficient. Thus, The Bill and Melinda Gates Foundation, The Pew Initiative in Food Safety and the USDA have each conducted limited research and/or held symposia on ecological and socio-cultural questions related to GPM (Pew, 2004; Gates, 2010). A number of high-profile articles have also addressed this topic (e.g., Scott et al., 2002; Knols et al., 2007; Fischetti, 2008). While each of these efforts is valuable in its own way, they have been piecemeal, and an interdisciplinary framework for understanding and evaluating GPM is incipient at best (Haddad et al. 2010).

An IGERT in GPM would be the first of its kind, and would establish an axis for interdisciplinary conversations among universities, governments, and the broader GPM community. At the same time, the PIs view GPM as exemplary of new technologies of a specific kind, technologies for which intensive integration of biological and social sciences is needed for comprehensive assessments, public education, and appropriate product development to take place. In this way, GPM shares a general profile with nanotechnology, gene therapy, climate manipulation, and other technological endeavors where concerned citizens may object that "just because it can be done doesn't mean it should be done". While the IGERT training will focus on GPM, it will examine GPM in this broader context and thereby prepare trainees for careers in settings where the interaction of diverse actors (including a lay public) must take into account sophisticated methodologies and discipline-specific vocabularies. Specific goals are to:

- Develop cohorts of globally-engaged U.S. students who will conceive, develop and implement ground-breaking research to address interdisciplinary issues at the frontiers of GPM.
- Engage trainees in international research to enhance global perspective and appreciation for other cultures.
- Cultivate diversity, professionalism, and high intellectual and ethical standards among the trainees.

Background: As GPM technology advances, its potential applications are multiplying (Gould, 2008). The technology is a candidate for countering insect- and tick-vectored diseases such as malaria and Lyme disease. It could be used to mitigate the environmental damage and economic losses wrought by invasive

plants and animals such as Scotch broom and invasive fish. Additionally, the technology might be applied, especially in less affluent countries, to rodents that cause major harvest losses.

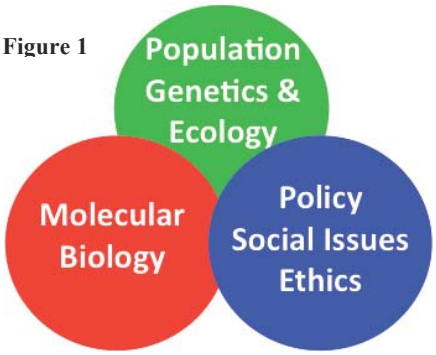
This work has its roots in the 1940s, when researchers began experimenting with directly manipulating pests' genetic systems either for population control or to replace pathogen-vectoring strains with genotypes incapable of disease transmission (Curtis, 1985). These efforts saved billions of dollars in agriculture and decreased pesticide use (e.g., see Dyck et al.'s 2005 assessment of screwworm eradication). Success in this area, however, was limited by a lack of sophisticated genetic tools and inadequate social integration of research and practice (Curtis, 1985; Gould and Schliekelman, 2004). Furthermore, only insects proved amenable to the technologies at hand.

New genetic and genomic tools are changing this scenario by offering greater precision in the manipulation of target species. The ever-increasing array of molecular genetic methods sit at the center of a major effort sponsored by the Gates Foundation (Gates, 2010), and including NCSU researchers, to manipulate mosquitoes that carry human diseases. Smaller programs currently examine insects important to agriculture (Gong et al., 2005; Schetelig et al., 2009) and involve USDA-APHIS scientists who work at the Center for Plant Health Science and Technology on the NCSU campus.

Shadowing these efforts are the controversies surrounding transgenic food crops. Disputes in that field alerted GPM researchers to the variety of reactions and depth of feeling associated with work in genetic modification (Haddad et al. 2010). It could be that public audiences, private businesses, and state authorities will espouse different positions in relation to transgenic pests than they have with transgenic crops. Unlike large-scale agriculture, where premiums on the yearly sale of seed can repay investment, most strains developed for GPM are not expected to produce large financial dividends. In transgenic crops, multi-national corporations took a lead in research. In the case of GPM, researchers predict the technology will, for the most part, be developed by academic, government and charitable institutions. These social issues, however, are far from settled, and students must be prepared to deal with them.

Ecologically, GPM presents a new set of concerns that students must contemplate. Transgenic crops were created in a way to minimize, if not preclude, their survival in natural environments. However, some transgenic pest approaches aim at long-term survival of the transgenic strain in the environment, and others may aim at eradication of species. IGERT trainees must rigorously debate the implications of specific strategies and technologies in anticipation of similar debates at local and global levels.

Figure 1



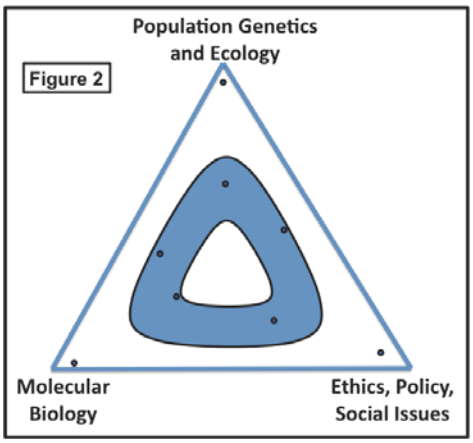
Thematic Basis and Unifying Aspects: In light of the technological, social and ecological complexities of GPM research, the proposed program resides at the intersection of the biological and social sciences. Figure 1 illustrates, in a general way, expected interactions among our IGERT trainees. The model necessarily encompasses a diverse set of disciplines. The development of a biologically successful transgenic pest method or product will depend on collaboration among researchers in molecular and whole organism aspects of biology. To assess the social appropriateness of products, research in these biological sciences will need to be integrated with innovative, cross-disciplinary research in Ethics, Policy and Social Issues (**EPSI**). Rather than expect all students to become experts in all of these disciplines, our proposed IGERT uses a practical, applied approach to establish the program's boundaries of intellectual inquiry and to unify students housed in the different doctoral programs. The program, first, focuses students and faculty on a small set of pest species which act as clear points of concentrated and collaborative effort. The program, then, provides students with achievement criteria (see pages 4 and 15) designed to ensure their integrative education is accompanied by disciplinary depth.

The program's methodology can be illustrated with the case of Lyme disease. The illness, with its tricky diagnosis and long-term complications, is well known in the U.S., especially in Northeastern states where both the disease-vectoring tick species and a secondary host, the white-footed mouse, are

prevalent. Research has shown that decreasing either the mouse or tick populations should lower human infection rates (Tsao et al., 2004). From a GPM perspective, the straightforward approach to this problem would be to use a gene-drive mechanism to force recessive lethal genes into mouse and/or tick populations that reduce the hosts' population size (see Sinkins and Gould, 2006; for purposes of illustration, we set aside the possibility of using anti-spirochete genes). Such an approach might be appealing to citizens in the affected area, but these species have roles in biological communities that must be assessed (Scheufele et al., 2007). Some gene-drive mechanisms might spread recessive lethal genes so effectively that they would cause eradication of these species (and potentially other species).

A case such as Lyme disease provides a framework for asking a series of interdisciplinary questions: Is the genetic intervention technologically and economically feasible? What are the ecological risks? What are the socio-cultural characteristics of the potential site of application? How do people conceptualize the disease itself? How do people perceive release of a "beneficial" transgenic strain of a disease-vectoring pest? What alternative interventions exist and what are their relative strengths and weakness? Recognizing that people may disagree, what interventions might be viewed as appropriate by the people living in sites of application? How would social relations be constituted across the chain of actors involved in the potential application of GPM?

Classical PhD programs recognize a tradeoff between breadth and depth, and often aim almost exclusively for depth. We recognize that no single student could develop true expertise in all areas of our program because of this tradeoff. However, the premise of this IGERT is that there is not a simple linear tradeoff, and that individual students, provided multiple paths toward achieving integrative education, will choose a path that fits their unique interests, and they will accumulate more breadth and depth than expected from the linear assumption. "The expertise triangle" in Fig. 2 generally models our students' expected educational paths and knowledge outcomes, and it contrasts these with what we consider **today's** classical graduate programs. In the triangle, an individual student's knowledge base is a single point (˙). If a student has equal knowledge of all three areas, her/his point would sit exactly at the center of the triangle. The further the point is from any corner of the triangle, the lower the student's knowledge of that area relative to others. The points placed near the corners of this expertise triangle represent the knowledge base expected of students in classical graduate programs. For example, a molecular biology program would not expect students to gain knowledge in ecology, but might require limited expertise in ethics. In some integrative programs such as "Conservation Biology," a student's knowledge point might fall somewhere along the edge of the triangle connecting Ecology and EPSI. In our program, trainees will work with mentors to design individualized education paths expected to result in a knowledge base anywhere within the shaded area. This shaded area does not include the center of the triangle; that is, the program will not expect student expertise in 3 distinct fields of study. Confident as we are that this approach will produce a high quality education that meets the needs of both science and society, the PIs have designed the program's "Performance Assessment" (page 22) to examine the tradeoff issue in detail. The breadth/depth tradeoff is a problem common to all IGERTs so our assessment should usefully inform future IGERT programs.



<u>Throughout the proposal</u>, only faculty last names are given for those listed in table 1 and for those who have provided letters. First and last names of other participating faculty are given.

Academic Infrastructure and Progress in Building the Foundation for an IGERT GPM Program:

NCSU has the academic infrastructure to provide a broad and deep knowledge base to students in our proposed IGERT because we have strong programs in the critical areas, we interact well as colleagues, and we have added faculty strength to our program beyond our university. The proposed

IGERT will allow NCSU to bring a history of interdisciplinary research and extension in Integrated Pest Management **(IPM)** to the field of GPM. It will furthermore add to these collaborations NCSUs growing strengths in risk assessment, environmental sociology, communication, and community engagement.

NCSU has been recognized for providing international leadership in the ecologically based field of IPM since the 1960s (Rabb and Guthrie, 1970). In the 1970s, NCSU faculty actively contributed to debates about the ecological and ethical issues associated with efforts to eradicate pest species using approaches that included strains altered by classical genetic methods. The strong ecological heritage in our pest management research has continued, with NCSU maintaining a reputation for innovative IPM research and high quality IPM farmer education programs in insect, weed and pathogen management. NCSU programs emphasize student training in both the academic side of pest management and in practical issues of working with farmers.

Recently, NCSU's Crop Science, Entomology and Agricultural Economics programs had major roles in development and assessment of transgenic crops. NCSU has had a distinguished program in Population and Quantitative Genetics for over 40 years and has added successful new programs in basic and applied aspects of molecular genetics. In the mid 1990s, NCSU entomologists began a collaboration with the biomathematics program to develop and analyze novel GPM strategies. In 2006, NCSU research and extension scientists from the above biological disciplines and conservation biology embarked on a GPM project under the leadership of prominent NCSU faculty (Gould, Haddad, George Kennedy, Lloyd, Mackay, Coby Schal, William Thompson). This group worked successfully with the NCSU administration to carry out the cross-departmental hiring of one senior and one junior faculty member with expertise in insect transgenesis and molecular genetics (hirings took place in 2009-2010).

Concurrently, NCSU's College of Humanities and Social Sciences (**CHASS**) began a directed effort to hire senior faculty who study risk analysis and risk communication, public perceptions of novel technologies, and the dynamics of expert-public interactions (see Birkland, 2005, 2006; Burube, 2006; Kinsella, 2004). Along with researchers in Public Administration and existing faculty in Technical Communication this group focused efforts on nanotechnology, nuclear energy and natural hazard risk analysis and communication. CHASS also developed a new interdisciplinary doctoral program in Communication, Rhetoric and Digital Media (**CRDM**). This strategic effort to implement an innovative model for graduate education consciously addresses the challenges and opportunities of interdisciplinary collaboration. Our Sociology PhD program has recently developed a core of faculty and graduate students in Environmental Sociology with international emphasis.

Discussions among these CHASS groups and faculty members in Biology and Economics led to the realization that addressing questions about GPM was a natural fit. Ongoing recruitment of other faculty in anthropology, communication, history and natural resource management to the GPM program has further enhanced these connections. Our two co-PIs from CHASS received Fulbright awards for the 2009-2010 academic year (Haenn - Mexico; Kinsella - Germany) and are now back on campus with new ideas and contacts. We have developed agreements for collaborations with faculty at Duke University to enhance our strength in Law, Environmental Economics, and Ethics of Genomics (see Cook-Degan and Kramer letters). Over the past three years we have developed a working relationship with the University of Minnesota IGERT on "Risk Analysis for Introduced Species and Genotypes" (Newman letter).

At the level of graduate training we started with a new 1-credit seminar on GPM that was held weekly in Fall 2007. In addition to students and postdocs, at least eight faculty members from four departments attended over 50% of the classes, and seven more sat in on a number of classes. A second, 1-credit seminar focusing on the selfish genetic elements underlying gene drive (Burt and Trivers, 2006) was held in Spring 2008. This more specialized seminar had 17 participants, including five faculty members from diverse departments. We also co-organized an international workshop on the population genetics and molecular biology of gene drive in December 2007, with funding and coordination from the NSF-supported National Evolutionary Synthesis Center in Durham, NC. More recently, Haddad (Biology), with help from Haenn (Anthropology), Walter Thurman (Economics) and Gould raised over $30,000 from five sources to fund an international conference, "Genetic Manipulation of Pest Species: Ecological and Social Issues," which was held at NCSU, March 4-6, 2009 (Haddad et al 2009). We had

over 70 participants with researchers from China, England, Germany, Mali, Mexico, Panama and the Philippines. Key representatives from six groups that have been critical of transgenic crops participated (e.g., Union of Concerned Scientists, Physicians for Social Responsibility, Sierra Club). Eighteen graduate students/postdocs attended, and three NCSU graduate students took notes that were used to stimulate discussions on the final day.

In the spring of 2010, our two new molecular genetics faculty members (Lorenzen & Scott) offered a journal club on molecular aspects of GPM. This fall, the 5 Co-PIs organized a journal club emphasizing social issues associated with GPM and GMOs in general. Lorenzen, Scott and Gould are now teaching a 3-credit GPM course that has drawn students from 4 departments. Four graduate students are working on GPM theses and one student recently completed her GPM-based thesis. One anthropology student is now sitting in on GPM lab meetings of an Entomology/Biomath group as part of her research. *We feel that our group has laid down a strong foundation for building the proposed IGERT program.*

Response to Previous Reviews:

We submitted full proposals to IGERT in 2008 and 2009. Reviewers for both submissions, as well as the 2010 pre-proposal, were positive about the overall project but offered substantial suggestions for change. Here, we group these suggestions in a few thematic areas. We offer quotes from previous panel summaries and explain, *in italics*, how we have used the recommendations to develop an improved proposal.

Coursework

2008: "Five courses are mandatory and there is a lack of explanation as to how these requirements will correlate to home discipline requirements. The new proposed common classes are essentially survey courses with minimal prerequisites. There is concern that the common knowledge base will be limited and too broad in nature to provide sufficient depth of information."
2009: "It is important that the faculty is not forcing trainees to take courses from outside, e.g., the disciplinary departments, but are creating courses unique to the IGERT. While these may not be as deep, the courses will be of interdisciplinary value."

Response: *In this revised proposal, we indicate the specific **learning outcomes** for each required course to demonstrate how the subject matter is integrative and will enable all trainees to achieve a **minimum requisite fluency in all aspects of GPM**. The number of IGERT courses is now four, and integrative aspects of students' education are enhanced by taking NCSU department courses in at least two disciplines. These changes were made in consultation with the directors of each participating graduate program to assure the IGERT requirements fit with home discipline PhD requirements.*

Student Research Teams

2008: "Research teams will be formed to study a particular pest from different perspectives. There is concern that although this format is collaborative, there is a lack of true integration, where students working in parallel will not learn other disciplines at an appropriate depth. Additionally, the focus on a particular target organism may limit distinctive, independent research progress, which is the hallmark of a PhD degree."
2009: "Another positive aspect is that five or six students will work in teams on a specific pest." "This is a dynamic research program and has the potential for a program working on the ground with actively engaged students. The fact that students will participate in student/faculty research groups focusing on a single target pest will provide actual training and experience in integrative research."

2010: "Focus on specific organisms utilizing at least two of the transdisciplinary areas listed was also considered a strength, providing both intensive studies, as well as a more cross-disciplinary approach. The idea of students mentoring other students with different research emphases was also considered a strength."

Response: *Our program design is guided by a recognition of the differences among multidisciplinarity and stronger models of interdisciplinarity, transdisciplinarity and integrative collaboration (cf. Weingart & Stehr, 2000; Stokols et al. 2008). We emphasize the latter approach and have revised our educational*

strategy (page 4, figure 2) to reflect this aim. We now provide each student with flexible interdisciplinary options that ensure integrative training. In order to organize multiple perspectives on a single issue (GPM), we maintain the focus of our cohort teams on specific target organisms. At the same time, instead of having each student's entire thesis focused on a single target organism, we only require that at least one substantial thesis chapter be focused in this way.

Feasibility of GPM

2009: "It is unclear whether work on transgenic pests is being driven by genuine global needs or by the faculty's perceived need. Additional outside support for the vision outlined, in the form of additional references or case studies, would be welcome." "The proposal has students building and assessing genetically modified pests, but overlooks the tremendous difficulties associated with transforming organisms as yet untamed for laboratory work. Mention is made of two recent molecular biology hires who may provide some expertise, but their CVs are not provided."

Response: *Our two new molecular biologists are now fully on board and we have other committed faculty in the Genetics Department. GPM is a new field but major progress has been made (e.g. Fu et al. 2010) with field releases of one of our target species set for 2011 or earlier. We now carefully describe the global need for the five target species selected within the proposal, and support letters provide further justification, as does the investment of more than $28,000,000 by the Gates Foundation (see page 8). We are not expecting our students to engineer a pest from start to finish, but expect their projects to contribute toward the achievement of this goal. The target species have all been cultured in the lab for genetics research, and for all but poeciliids, transgenesis methods are well developed.*

Academic Infrastructure

2008: "The panel felt that NC State cannot adequately support the sociology aspects of the proposed program due in part to a lack of faculty and long-standing graduate programs in key areas. Due to these issues, there is a lack of confidence in implementation of the sociobiological concepts. Recruitment of faculty elsewhere to effectively lead the sociology aspects of this program (e.g., risk assessment, communication, public policy) would strengthen the proposal."

2009: "The strong infrastructure and support at NCSU is evident in that they have already hired cross-disciplinary faculty in relevant areas. There are also funds for release time and curriculum development, which is positive. The tool kit has what trainees need when they complete their degree, preparing them to gather and analyze collected data. This IGERT is providing tools not typical of all fields." …"All students will take five specified courses so regardless of their discipline entering, they will get a broad education."

2010: "Even more emphasis on the importance of societal perspectives regarding transgenic organisms would strengthen the proposal even more" "Critics of transgenic research will make the case that the societal part is little more than learning PR techniques of how to manufacture consent into a position pro-industry."

Response: *This revised proposal clarifies the broader social science research within the IGERT in a separate section (pages 13-14). Two co-PIs are social science faculty. Haenn, in the Department of Sociology and Anthropology enables our IGERT to take advantage of an established program with a depth of experience in research and extension. Kinsella, a central figure in the new doctoral program in Communication, Rhetoric and Digital Media* ***(CRDM)*** *allows the IGERT program access to additional campus frameworks for integrative education. Interactions with Duke University faculty and University. of Minnesota IGERT faculty (see letters) also broaden our social science capabilities.* ***The co-PIs are by no means in agreement regarding the value of GPM,*** *and, in particular, social science faculty bring a certain skepticism to the topic. We expect that the divergent opinions found among our faculty will model, at least to some extent, the varied public reactions to GPM. We are proud of the fact that our diverse perspectives have not hindered our ability to work together on GPM projects and learn from each other.*

3. MAJOR RESEARCH EFFORTS

Here we first briefly describe the broad ethical, policy, and social issues (EPSI) context for the proposed research efforts; in subsequent sections we provide five pest-specific examples of how we will

integrate the social and biological dimensions of our research, and finally we provide more details on general social science questions to be addressed, as requested by previous reviewers.

EPSI Context: Contemporary models of global "risk society" (Beck, 1995; Adam et al., 2000) provide a useful framework for analyzing the social, cultural and policy dimensions of GPM. These models view the assessment and management of risks associated with new technologies as a fundamental social problem, analogous to the classical problem of distributing resources and social goods equitably.

Risk analysis and risk communication involve problems of social justice and equity; power relationships across diverse communities, stakeholders and sectors; and public involvement in decisions regarding technology development, deployment and regulation. Such problems require moving beyond traditional "deficit models" of public understanding of science and technology, which view stakeholders as simply in need of information and education. Social science approaches now recognize the importance of engagement with stakeholders early in the technology development and policy processes, the challenges of fostering productive dialog between experts and non-experts, and the role of local knowledge in supporting as well as supplementing science (Fischer, 2000; Kinsella, 2004). The fields of anthropology, communication, history, policy studies and sociology all contribute to this framework for our program. Policy development and commercialization of transgenic crops generally relied on a deficit model. We believe that our program will insure that GPM assessment involves a more comprehensive approach.

Pest-specific examples: Our research efforts will focus on a small number of potential pest targets for GPM. Early in their program at NCSU, each successive annual cohort-team of 5-6 students will pick one pest system as a focus for study. Each specific project will be organized using the general template in Fig. 1 (page 3), with each disciplinary area covered by students and faculty mentors specializing in that area. More detailed descriptions of the mentoring of cohort-teams and project selection will be given in later sections of the proposal (see pages 15-20).

Below, we provide five brief and provisional project sketches to demonstrate some of the relevant systems in which specific NCSU faculty members have experience and that are considered as GPM targets by the broader scientific/funding community. The student/faculty teams may ultimately pick other pest systems. We will require that at least one substantial chapter of each student's thesis will focus on issues related to the team's target species. In some cases, however, the entire dissertation will focus on the target species.

1) Mosquito Vectors of Human Diseases

Mosquitoes are vectors of several important human diseases, including malaria and dengue fever. *Because part of our IGERT team already has a long history of working on projects in this area, the mosquito/human disease system could serve as a preliminary research model from which we expand to other systems and taxa.* We have concentrated on the mosquito, *Aedes aegypti,* which transmits dengue to over 100 million people each year and heavily burdens the health care systems of developing countries (Brazil spends $1 Billion US per year, Barreto & Teixeira, 2008). We will maintain research interactions with colleagues working on *Anopheles* mosquito species that transmit malaria (see Tripet letter).

Lloyd (Biomathematics) and Gould (Entomology) received an NIH grant ($1,300,000) to work with the *Aedes*/dengue system, and their research groups (mathematical epidemiology and population genetics) have participated in two multi-organization GPM projects funded by the Gates Foundation (total $28,000,000) that includes molecular biologists, ecologists and social scientists. The goals of the projects are to develop genetic approaches for decreasing densities of *Ae. aegypti* and for replacing genotypes of *Ae. aegypti* that transmit dengue virus with transgenic genotypes that do not transmit the virus (Franz et al., 2006; Chen et al. 2007).

Our participation in the Gates projects has enabled us to hold international modeling workshops at NCSU because our expertise is valuable to all members of the Gates team. These workshops have been attended by NCSU and Duke University faculty not directly associated with the Gates project. Although Gates Foundation projects do not have specific training components, participation in interdisciplinary Gates meetings and workshops has given our faculty, postdocs, and students an understanding of factors

that contribute to success of interdisciplinary team collaborations. Future workshops will be valuable to our IGERT students.

Our molecular and population genetics research on the *Aedes*/dengue system will build on an already well-established base of work (e.g., Franz et al., 2006; Huang et al., 2007). Transgenic mosquito lines engineered for population suppression (Fu et al. 2010) are now being tested in field cages in Tapachula, Mexico, with plans for small initial field releases in 2011 (another privately developed strain may already be in the field). Strains with anti-dengue constructs and gene drive are expected to be available for release within five years (Scott et al., 2008). A novel, self-limiting, gene-drive mechanism conceptualized and analyzed at NCSU (Gould et al., 2008) is now in development by the Gates team as a risk management tool. As part of our NIH and Gates work, we have developed generic as well as highly specific simulation models that predict the fate of transgenes linked to a variety of gene-drive mechanisms (see Sinkins and Gould, 2006, for examples). The most detailed models use *Ae. aegypti* population dynamics and epidemiology data collected at the scale of individual houses in Tapachula, Mexico, and in Iquitos, Peru (Magori et al., 2009). The data from Iquitos have been collected continuously for over 10 years by our colleagues, Tom Scott and Amy Morrison (U.C. Davis; Morrison et al., 2008). These models are useful for risk analysis and optimizing efficiency of large-scale releases. We work closely with the Tapachula and Iquitos teams and have agreements for students to do internships in Tapachula (see attached Ramsey letter) and in Iquitos (No space for extra letter from Morrison).

The IGERT program will add new components to this project centered on ecology, epidemiology, evolution, and EPSI issues that are not presently addressed by members of the Tapachula Gates project or members of the Iquitos team. Four of our IGERT participants worked at the Tapachula site in January 2008 to get a feel for the research and cultural environment. As a follow up, a graduate student spent a total of 9 months in Tapachula, studying the dynamics of *Ae. aegypti* larval competition. This successful study was needed to fill gaps in our detailed simulation model and has indicated the need for further field studies. IGERT faculty Dennis Brown (Biochemistry) and Katia Koelle (Biology, Duke) are, respectively, working on molecular and population genetic aspects of dengue virus evolution. This work will be critical because a major risk issue is the likelihood of virus adaptation to different anti-pathogen genes. *Ae. aegypti* has evolved a strong commensal relationship with humans and is adapted for survival in buckets and other artificial, water-filled containers, making attention to human behavior patterns and community practices essential. For *Ae. aegypti* populations within the urban environments, ecological disruption due to GPM is not expected, but there are forest *Ae. aegypti* populations to which transgenes could spread, and this potential for spread could be examined by empirical studies of *Ae. aegypti* population structure in and surrounding Tapachula and Iquitos (for related studies-- da Costa-Ribeiro et al., 2007).

Our internship agreements in both Iquitos and Tapachula present the possibility of ecological as well as anthropological comparisons across Latin American sites. Haenn (Anthropology) has worked in southern Mexico examining the interaction of popular cultural models of the environment with the ecological models used to create and implement environmental policy. As pest management moves from the laboratory to the field, this work will be critical for understanding the norms, values and beliefs that influence perception of transgenic mosquitoes. Sarah Bowen (Sociology/Anthropology) contributes field experience examining Mexican agricultural communities in a globalization context. Student projects in this area could focus on issues ranging from analysis of non-government organization (**NGO**) involvement, to analysis of alternative approaches for transgenic insect production. In classical GPM programs for medfly and mosquitoes, rearing facilities have been large factories that produce millions of insects per week (Dowell et al., 2005). IGERT students in biology and EPSI could assess the merits and problems associated with developing cottage industries for *Ae. aegypti* rearing in Mexico. The route toward cottage production could itself include an environment/genetic educational component for local citizens and schools. This community-based approach raises practical as well as complex ethical issues that could be addressed by collaboration among our students. F. Tripet (see attached letter) who works on *Anopheles* GPM for malaria control has offered internships for students in England/Mali.

2) Mosquitoes and Endangered Bird Species

Evidence to date indicates that until the mosquito *Culex quinquefasciatus* arrived in the Hawaiian Islands, the native bird species had not been exposed to bird malaria (*Plasmodium relictum*) and are therefore typically more susceptible to malaria than invasive bird species from continental areas. A number of studies have produced strong evidence associating malaria with declining densities or complete absence of specific native bird species from low- and mid-altitude forests where *C. quinquefasciatus* thrives (e.g., Van Riper et al., 1986; Jarvi et al., 2008). Future increases in global temperatures may push native birds to even higher altitudes or to extinction (Benning et al., 2002).

Conventional control efforts for *C. quinquefasciatus* have failed, and there appears to be a general attitude that the only way in which the native bird decline will be reversed is through natural selection on the birds themselves for resistance to malaria. Kevin Gross (Biology) has participated in studies relevant to this issue (Kilpatrick et al., 2006). Transgenic approaches are suggested in the literature, but no empirical work is being done.

A typical public concern with environmental release of transgenic organisms is whether or not there will be side-effects that threaten biodiversity. In this case, the driving force behind the engineering project itself is to preserve biodiversity, offering a useful contrast for public consideration. Dannels and Kinsella (Communication/CRDM), Ed Kick (Sociology), and Steelman (Natural Resource and Environmental Policy) are positioned to work with students examining public dialog and expert-public communication challenges surrounding the implications of GMO technologies for biodiversity.

One safety issue with this system entails whether transgene-induced resistance to these bird diseases could increase *C. quinquefasciatus*-based transmission of human pathogens. Assessing such a risk would be a worthwhile project for a student focusing on molecular and epidemiological issues (Dennis Brown and Lloyd will advise). Economic estimates of the dynamic paths of costs and benefits from bird species preservation would be needed for a balanced analysis (Walter Thurman, Economics; Randy Kramer, Duke—see attached letter). Local ecological knowledge can also play a role in evaluating biodiversity risks in particular settings (see Fischer, 2000; Kinsella, 2004).

Other ecological research projects could be conducted to build more robust bird malaria epidemiology models for predicting the impacts on bird populations of different pathogen resistance transgenes and gene-drive mechanisms. Apperson (Entomology) has had many years of experience working on the ecology and management of *Culex* species. Haddad and Dunn (Biology) have expertise on the population dynamics of endangered species and communities. At our 2009 conference on "Genetic Engineering of Pests: Ecological and Social Challenges," we worked with Dr. Susan Jarvi (University of Hawaii) and set up student opportunities for investigating GPM approaches at her lab (Jarvi et al., 2008—lack space for letter). The genome of *C. quinquefasciatus* has been sequenced and transgenic strains developed.

3) Invasive Fish That Impact Endemic Fish and Insects

Invasive fish can threaten the biodiversity and functioning of fresh water ecosystems. Although one early attempt at using classical GPM to suppress lamprey populations in the Great Lakes failed, there has been renewed interest in using GPM since the advent of molecular methods (Thresher 2008). Australian researchers are in the forefront of this work (see Thresher CV) but recent evidence that Asian carp are about to enter the Great Lakes has heightened interest in the US. While invasive carp and catfish are major targets of GPM, we are focusing on invasive poeciliid fish because of their environmental impacts, the fact that they are more amenable to classical-based manipulations, and because stakeholders have divergent views of the poeciliid impacts. As the most isolated island archipelago in the world (3,860 km from closest continent) Hawaii is home to a rich assembly of endemic aquatic insects and four species of endemic goby fish species with specialized ecology (e.g. hatch in freshwater, use marine or estuarine habitats as larvae, and return to freshwater by using special adaptations for climbing waterfalls). Native fish and aquatic insect species are negatively impacted by introduced poeciliid fish such as guppies, and poeciliids are thought to be responsible for extirpations of native species, especially in headwater habitats (e.g. Englund 1999). Gilliam (Biology) and his graduate student (Ernie Hain) have been studying the ecology of goby and poeciliid fish in Hawaii for a number of years, and are interested in methods for eliminating poeciliids from target stream habitats.

Our initial target will be the guppy, *Poecilia reticulata*, which has an XY-like sex determination system that is sensitive to environmental conditions. When a female's food is augmented with hormones, her XY offspring become females. Mating of these females with normal males yields about 50% reproductive YY males or, with hormone treatment, YY females (Volff & Schartl 2001). YY males as well as YY females produce almost all male offspring when they mate with wildtype fish. At the molecular genetic level, methods for developing transgenic fish with conditional female lethality are moving ahead (Thresher et al. 2009 and Pers. Comm.). Either of these strategies could be used for population reduction (Bax and Thresher 2009).

Some native Hawaiians view the goby species (o'opu) as a cultural treasure and see threats to these fish as problematic (Titcomb, 1972). Others living on the island are not even aware of o'opu, and some perceive poeciliids as helpful for suppressing mosquitoes even though pestiferous mosquito species do not live in streams. Not all Hawaiians are opposed to GMOs, but Hawaii recently banned the planting of engineered taro plants because of the crop's cultural significance (Hawaii HR, 2009). Efforts to eliminate poeciliids in critical stream habitats may meet with mixed responses due to divergent stakeholder perceptions and priorities. Because the YY males/females approach does not involve genetic engineering it may be more widely acceptable than introducing transgenic strains.

Students under the guidance of Gilliam will continue the ecological work and will begin work on the YY system. Molecular biology students could begin work on transgenic approaches and could do internships with Thresher in Australia (see attached letter). Communication and anthropology students under the direction of Haenn, Steelman, and/or Kinsella could examine cultural and social issues related to the native o'opu. They could also analyze the relationship between attitudes to GMOs in general and those toward GPM of invasive fish. This project could easily parallel and interact with Project 2 on mosquitoes that vector bird malaria.

4) Stored Grain Beetles and Crop Losses

Tribolium and Bruchid beetles are major causes of post-harvest losses, especially in poor countries where grain is stored in poorly protected facilities/containers. Typically, only a few beetles invade locally stored grain, and the population then increases almost exponentially. In this context, any intervention that substantially lowers the beetle's reproductive potential would be useful. This IGERT project would focus on transgenic systems that drive sterility factors or other forms of genetic load into populations, with the aim of lowering the rate of beetle reproduction.

Lorenzen who was hired in July 2009 as part of the University's commitment to this area of research will lead the molecular biology aspects of the project. Work will initially focus on *Tribolium* and then be adapted for Bruchids. *Tribolium* is a useful early target for GPM because the genome of *T. castaneum* was recently sequenced (Richards et al., 2008). Additional sequencing revealed that many populations of *T. castaneum* naturally harbor a selfish genetic element called *Medea* (Lorenzen et al. 2008). This element has a predicted capacity to drive recessive deleterious genes into local *Tribolium* populations (Chen et al., 2007). It is relatively easy to engineer *Tribolium*, and a *piggyBac* transposon that results in recessive lethality has been inserted within 0.5cM of a natural *Medea* element (Marcé Lorenzen, pers comm.). This provides a tool for testing the expectation that *Medea* linked with a recessive lethal gene can lower the reproductive potential of *Tribolium*. Genetic resources for developing artificial gene-drive systems in *Tribolium* are available (Lorenzen et al., 2008). Furthermore, Mahaffey (Genetics) works with *Tribolium* genes involved in embryogenesis. These are good candidates for synthetic gene-drive mechanisms. Collaborative molecular work with Bruce Hay (Cal Tech ---lack of space for letter) will aim at producing strains with synthetic *Medea* elements that resist uncoupling.

A number of critical issues must be addressed at the population genetics and ecological levels before any transgenic strain is tested beyond a secure laboratory setting. Over and above tests to ensure that such a construct will not move into other species, there is a need to determine if diminishing reproductive rates of *T. castaneum* itself could have negative impacts in the natural environment of this beetle (Haddad, Dunn, Biology). There will also be a need to develop computer simulations and laboratory experiments to determine: 1) the rate at which the selfish *Medea* element and the linked recessive lethal allele can spread into spatially structured populations; 2) how much they will actually decrease reproduction; and 3) the

risk for genetic uncoupling of the *Medea* element from the detrimental allele (Chen et al. 2007) and potential genetic remedies (Gould, Entomology).

Because natural *Medea* elements have already spread to populations on at least five continents (Lorenzen et al., 2008), they have clearly been resistant to selective pressures for adaptation by local populations. However, in the U.S., *Medea* has not spread into southern areas of Louisiana. The hybrid zone between populations in Louisiana with and without *Medea* provides a field laboratory for studying the ecological and evolutionary dynamics of natural *Medea* elements before use of any synthetic *Medea* element begins (Haddad, Gould, and Lorenzen will lead).

Genetically engineered strains of *T. castaneum* with transgenic marker genes are currently available, enabling students in public administration and biology to collaborate with USDA-APHIS personnel at NCSU to develop formal applications for regulatory approval of transgenic marker strains that might be used in future population ecology studies. Federal regulatory approval processes for transgenic insects are only now being developed. Therefore, IGERT students would have an unprecedented opportunity to analyze the interaction of scientific and policy processes. Birkland (Public Administration), an expert on policy approaches to risk management (Birkland, 2006), will lead the advising of these students. Branda Nowell (Public Administration) contributes expertise regarding community psychology and the roles of NGOs in policy development. Kinsella (CRDM) and Steelman (Natural Resource and Environmental Policy) contribute additional expertise on public-expert collaboration in environmental policy making.

Because *Tribolium spp*. and Bruchids are primarily pests in developing countries, rigorous economic and cultural analyses of their effects on households and local economies are not available. A cooperative study by students in ecology, economics and anthropology would assess causal and possibly symbiotic relationships among pest dynamics, household farming strategies and market factors. Louis Jackai (NC A&T) has long-term experience with this issue and will assist with this effort (see attached letter).

5) Fruit Flies, Agriculture and the Global Economy

Fruit flies of the genera *Rhagoletis, Ceratitis, Bactrocera* and *Anastrepha* (not *Drosophila*), are world-wide pests of diverse fruits. The potential for establishment of medfly (*Ceratis capitata)* populations in Florida and California is considered a major threat to the citrus industry. One approach for preventing establishment of medfly has been the release of millions of males sterilized by use of radiation. Facilities for rearing and radiation treatment of medfly are located just outside Tapachula, Mexico (site of our mosquito study), and in El Pino, Guatemala (7-hour from Tapachula). These facilities are jointly operated and financed by U.S., Mexican and Guatemalan governments. They currently produce over one trillion sterile male flies per year for international use. There has been a concern at the facilities with the expense of radiation and, now, also with the potential for theft of nuclear materials.

The USDA-APHIS personnel at NCSU are collaborating with the Guatemalan government in the field-cage testing of transgenic strains of medfly that exhibit conditional lethality (Schetelig et al., 2009). Unlike other transgenic pest methods described in this proposal where the transgenes persist in the environment, the conditional lethal approach is expected to result in transgenes being eliminated after a single generation, thus reducing risk (Benedict and Robinson, 2003). USDA-APHIS and the Guatemalan government are rightly concerned about EPSI issues and want to conduct broad assessments of this technology. The medfly program affects a variety of stakeholders in Mexico and the U.S., ranging from homeowners in California cities (exposed to insecticides), to multi-national corporations, to subsistence farmers in Mexico and Guatemala. Because medfly strains with repressible sterility (tet-off system) are already available (Gong et al., 2005; Schetelig et al., 2009) and are seen to have fewer risk issues than other transgenic pest strains, medfly may become the first test case for large-scale field release of an agriculturally important transgenic pest. USDA has confirmed interest in interacting with IGERT students in their ecological and EPSI work (see attached Berger letter). Burrack and Cardoza (Entomology) have worked with medfly control programs. Kinsella (CRDM) and Miller (CRDM) have examined public risk perception, risk communication and public discourses surrounding emerging technologies. Sarah Bowen and Haenn (Sociology & Anthropology) have studied agricultural practices and EPSI issues in Mexico.

Birkland and Branda Nowell (Public Administration) and Steelman (Forestry & Natural Resources) contribute expertise on risk regulation and stakeholder engagement.

Scott (new senior Genetics faculty appointment) has developed efficient methods for transgenesis of sheep blowflies (Concha et al, 2010) and a tetracycline-repressible female lethal system in *Drosophila* (Heinrich and Scott 2000). He has begun a dialog with USDA-APHIS to obtain permission to rear specific, economically important, *Anastrepha* and *Bactrocera* species in North Carolina, with the aim of developing conditional female lethal strains. An important issue with release of males that have a single gene interfering with production of viable offspring is whether the wild population will naturally evolve resistance to the mechanism. Mackay (Genetics) is a pioneer in studying the genetics of adaptation (Falconer and Mackay, 1996) and will lead this effort, first with *Drosophila* and then with target species.

Other Pest Species:

Faculty members at NCSU have long-term experience with other agricultural pests such as Colorado potato beetles and thrips (George Kennedy, Entomology), other vectors of human diseases such as ticks (Mike Roe Entomology) and urban insect pests such as roaches and bedbugs (Schal, Entomology). Interesting GPM projects could be developed around each of these challenging pest systems.

Social Sciences Research:

Although several social science research projects were briefly described in the previous taxon-level section, we add this section in response to previous reviewer comments. Furthermore, because we now propose to only require one substantial thesis chapter be focused on the group target pest, we expect some social science theses will be broader in scope than originally planned. Here we further clarify the types of more generic research that could be conducted by IGERT students in the social sciences. The list is not meant to be exhaustive, but is indicative of the types of topics we anticipate covering. The list also reflect the expertise of NCSU faculty and our Duke University/University of Minnesota collaborators in the social sciences. This expertise centers on five broad, overlapping areas: 1) risk management and risk communication, 2) the emergence and instantiation of new technologies, 3) cultural models of the environment, 4) economic valuation, and 5) the way language both constrains and enables particular understandings of GPM issues. Cutting across these issues is a common interest in the broader contexts within which GPM projects operate, such as the political and policy terrains that shape science applications.

States and the International Order in GPM Applications (Sarah Bowen, Cook-Deegan, Haenn, Ed Kick, Schulman, Wiener): Many GPM projects will have a global impact and will be driven by global interests, heavily reliant on participating states. Given the nature of mobile organisms, a project can quickly make national boundaries irrelevant. Faculty in anthropology, ethics, law, and technical communication will work with students to explore how specific GPM projects may impinge on questions of state sovereignty, the social contract between state and citizenry, and debates regarding the international order (cf. Adam et al., 2000). While a considerable amount of social science research focuses on state activities, research on GPM and the state would constitute a new contribution to this field. For example:

1) How does a specific GPM project relate to the explicit and implicit promises that states make to citizens; promises which, in the eyes of citizens, underpin a state's legitimacy? The decision to implement or terminate a GPM project may rest on these pre-existing commitments. Because social contracts are abstract ideals, citizens may differ markedly on their application. Thus, within a given country, a GPM project may be viewed as both supporting and contradicting the same social contract. Also important are the forms of public support states receive when complying with social contracts and forms of protest that result with their contravention. One model for this research might be investigations into protected area conservation that reveals a sometimes contradictory relationship between states and the public good (Haenn, 2005).
2) While the issue of neighboring countries speaks to the bilateral quality of some GPM programs (e.g. US/Mexico medfly), others such as dengue control with *Medea* gene drive could involve a whole continent. Sites such as the World Trade Organization, United Nations working groups and multilateral frameworks (e.g., NAFTA, the African Union) have been important to delimiting the

preferences of individual countries and bolstering the position of transnational corporations and NGOs. A relatively recent review (Knols et al., 2007) called for the UN-World Health Organization to establish guidelines and/or regulate some GPM programs; however, the feasibility of such an approach has not been studied in detail. This could be a fruitful area of research for IGERT students.

Community Literacy and GPM Implementation (Sarah Bowen, Dannels, Haenn, Kinsella, Miller): GPM implementation often targets multi-cultural, multi-lingual settings, where an unevenness in formal education further contributes to knowledge structures that diverge markedly from that of policy-makers, academics and NGO staff. Faculty will work with students to investigate specific on-the-ground literacies that influence GPM work. "Literacies" here refers not only to a continuum of reading and writing abilities within the local population, but also more broadly to local knowledge, "public expertise" and "ways of knowing." The latter include the ways people in specific communities use data to create their own understandings of issues and activities (Haenn, 1999; Katz & Miller, 1996; Kinsella, 2004; Kinsella & Mullen, 2007). Through interviews with local populations, participant observation and surveys, students could determine how these literacies are learned and what influence specific types of literacies have on GPM. Students could also investigate decision-making rubrics that are embedded in local communication models. Such rubrics illuminate the processes people use to understand and evaluate different forms of pest management and could contribute to risk assessment models. Relevant questions could include:

1) What strategies are used to communicate a GPM effort to local populations and to what effect? Although communicating GPM efforts may seem a straightforward endeavor, given the diversity of literacies in any given community, people will likely re-interpret messages about GPM activities including risk. This re-interpretation may be based on the less tangible issues such as tone, trust, and past relationships with individual messengers. This re-interpretation may also be based on identity differences involving gender, class, age and ethnicity.
2) How are literacy practices related to community problem solving? Much of the proposed GPM research will examine direct connections between social groups and research, policy and implementation. However, in some cases, an indirect approach will be useful to understand the social terrain that precedes GPM. In examining local responses to a proposed GPM program, it is useful to consider existing fora for deliberation and problem-solving (Haenn, 2006; Kinsella, 2004). How do these operate and to what extent are they capable of addressing GPM issues? How do different cultures perceive, understand, construct and manage risk?

The Role of Diverse Social Sectors in Setting GPM Agendas (Birkland, Cook-Deegan, Kinsella, Branda Nowell): GPM projects have been proposed and initiated by organizations that differ considerably in structure, orientation, stakeholder constitution and motivation. Although positioned within distinct sectors (government, NGO, academic, for profit), their research, policies and operational plans do cycle across these groups such that the various sectors sometimes partake in common conversational threads. Policy "spillovers" (Kingdon, 1995) take place when policies from one sector influence actions in another sector. Using the problem of GPM as a base, this research focuses on the cycling process and the implications of cross-sector communication for GPM. EPSI faculty will work with students on questions such as:

1) Does funding from one sector have an effect on the others? For example, how might the work of The Gates Foundation influence policies and activities at NIH or USDA? Such questions engage the classic literature on policy analysis and process from many different perspectives (Kingdon, 1995; Baumgartner and Jones, 2002; Weimer and Vining, 2005).
3) Where do specific agencies, especially various NGOs, stand on GPM and alternatives? Such a study could draw on theories of the policy process to identify how coalitions form around GPM issues and why some policy ideas succeed while others fail (Kingdon, 1995).

GPM research, economic development and market economics (Birkland, Haenn, Kinsella, Kramer, Miller, Walter Thurman): Recent initiatives to develop and implement GPM technologies have used economic models strikingly different from those of initiatives with transgenic crop technologies. IGERT students will contrast the development, implementation strategies, and public reception of a specific transgenic crop developed by a multinational corporation and a GPM strain developed by university and

government researchers. Such analysis would help to explain and model the connection between the broader research on genetic modifications and market economies. Particular questions could include:

1) How does GPM research advance specific economic agendas or reveal conflicts among competing agendas? For example, transgenic crop proponents have been accused of creating economic dependence partly because transgenic crops reduce the feasibility to farm with traditional crop varieties and seed from the transgenic varieties must be purchased yearly. Do GPM technologies invite similar critiques and in what ways?
2) Given the heightened debate surrounding transgenic crops, how do development agencies balance economic and other values-based initiatives when developing technologies? To what extent, in which agency contexts and in what local conditions will non-economic values (moral obligation) override economics? (Kinsella, 2004; OECD, 2004)**.**

4. EDUCATION AND TRAINING:

Curriculum: Each student will receive a degree in an academic graduate program with a concentration in GPM (see Lomax letter). All students will take four core IGERT courses but students will customize their full curriculum in consultation with their major advisors (Table 2 gives examples of what individual curricula **could** look like). While maintaining depth and rigor, the core courses will be designed so that students from all IGERT disciplines will be able to comprehend the material. We have been gaining experience in how to do this from our past/current GPM courses (see pages 5-6). These courses are designed to make sure that all IGERT students obtain ***minimum requisite fluency in all aspects of GPM*** as defined by the course learning outcomes (below). The courses will be offered each year, so each IGERT cohort has appropriate course availability (Table 2). After the first three years of the IGERT grant, we will recruit follow-on cohorts either each year or in alternate years, depending on levels of future non-IGERT funding. We will continue to offer courses as appropriate for these students. All IGERT courses other than the summer course in Mexico and Central America will be open to non-IGERT students.

Required Courses:

Course #1. Pest Issues in Developing Nations: Biology, Culture and Infrastructure (2 credits).

This course will be taught in Mexico, Guatemala, and Honduras. The major goals of this course are: 1) team building and 2) acquiring first-hand knowledge of the environments where many of the products of GPM are targeted for use. The course will be offered to incoming students in the last week of July and the first two weeks in August before their first campus classes begin. Haenn and Gould will co-coordinate the course and will accompany students for the entire three weeks. *Other IGERT faculty will participate in the course for four to seven days*. David Auerbach (Philosophy) will develop specific readings and case studies on ethics for participants to discuss during the course. Details on the **logistics** of this course are given in the special section on *International Collaborations* (pages 26-27).

During the course we will engage with local researchers, university students/faculty, policy makers, NGOs, and citizens. We have established research and educational collaborations at each of the locations where we will stay. These collaborations range from mosquito and fruit fly GPM research programs, to anthropological studies of how biological processes are understood by citizens in rural communities. The **detailed rationale** for each of the course activities is outlined in the *International Collaborations* section.

Interactions of our students with our collaborators will range from lectures and discussions, to hands on research and interviews of local families. Contrasts between urban and rural cultures will be highlighted. Honduras is the first Central American country (2008) to permit the commercialization of transgenic corn; contrasts between Mexican, Guatemalan and Honduran policies/attitudes will be examined. Evenings will be used for formal and informal lectures and discussions within our group on culture, ethics and pest management issues.

Baseline learning outcomes: After completing the course, students will be able to:

1) Describe the challenges of communicating the concepts of genetic engineering to people in areas that are being considered for GPM programs,
2) Understand the diversity of cultural perspectives in rural and urban areas of Mexico and Central

America and describe the typical family structures in those areas,
3) Identify the existence of different scientific traditions, including the ethno-ecological frameworks employed by a lay public,
4) Recognize power relations among scholars, governments, social movements, and local communities,
5) Describe the international complexity of medfly and dengue problems and the operation of the medfly suppression program and Gates Foundation transgene-based dengue program,
6) Develop and critically examine ethical arguments for and/or against continuing these programs,
7) Write a substantive essay about each student and faculty member in the IGERT group.

Course #2. Principles of Genetic Pest Management (4 credits, Fall)

The goal of this course is to give all students an overview of the biological and social issues associated with GPM. This course is being developed based on the experience gained from the Fall 2007 and Fall 2010 courses discussed on pages 5-6, but it will be more intensive, including topics and case studies covering all of the disciplines in Fig. 1. Gould (Entomology), Scott (Genetics), Haddad (Biology) and Kinsella (Communication) will coordinate the course and attend all sessions. The expected format of the course will be two 75-minute lectures and one 75-minute discussion/lab per week. Ecological, genetic, sociological, economic and communication principles will be introduced at a level accessible by all students, but we will then move on to primary literature readings. This will be a broad and demanding course. **Graduate students/postdocs with more expertise in a specific area will hold informal tutorial sessions with others who have less background.** For some population genetics and epidemiology topics, we will have labs in which students will run our user-friendly computer simulation models (Magori et al., 2010) to obtain a better idea of the dynamics of some GPM methods.

Other faculty members will give lectures and/or lead discussions **as outlined in the last column of the table on Page 1** of the proposal. Faculty members who have been involved with the development and regulation of transgenic crops will help to contrast GPM and transgenic crop issues. This will be the first course that a cohort of IGERT students takes on campus and will assist in their selection of target research species and tentative dissertation topics. It will also expose students to the broad range of IGERT faculty.

Baseline learning outcomes: After completing the course, students will be able to:
1) Describe the molecular basis of sexual reproduction and embryogenesis,
2) Accurately explain the general population genetic concepts undergirding population suppression and strain replacement GPM approaches,
3) Describe the molecular biology concepts, transgenesis techniques and practical challenges involved in building specific engineered pest strains,
4) Discuss how the ecology of specific pests and their habitats affect their status as feasible targets for specific GPM strategies,
5) Provide detailed examples where pest population suppression could result in displacement of human populations and indirectly decrease or increase biodiversity,
6) Discuss the social, biological and policy histories of GPM and transgenic crops, and
7) Participate in debates about specific proposed GPM projects and how to assess these projects effectively.

Course #3. New Technologies in Social and Cultural Contexts (3 credits, Spring)

This course will build on background from Courses #1 and #2. It will provide all students with a framework for understanding the two-way relationships between emerging and evolving technologies and their social and cultural contexts. Social and cultural factors influence the emergence, adoption and evolution of technologies, while technologies impact society and culture in anticipated and unanticipated ways. Understanding this dynamic is crucial to successful technology management and a necessary point of engagement between biological and social science students. The course will present real-world case studies, ethnographic accounts and theoretical perspectives that introduce students to established issues and research methods for learning about "on the ground" conditions that constrain and enable technologies. Birkland (Public Administration), Haenn (Anthropology) and Kinsella (CRDM) will lead this class examining three aspects of new technology development and social integration: 1) emergence and early establishment ("instantiation"); 2) risk assessment, management, perception and communication; and 3) policy formation

and implementation processes (Birkland, 2005, 2006; Kinsella, 2004). The course will examine specific GPM examples, teaching students methods for risk assessment, risk communication and public policy development and analysis. Guest lectures on specific topics will be given by David Auerbach (Philosophy), Dannels (CRDM), Miller (CRDM) and Steelman (Natural Resources). The course will end with a two-day symposium/workshop with participation of local external faculty (e.g., Cook-Deegan (Duke), Jackai (NCA&T), Pattanayak (Research Triangle Institute), Kramer & Wiener (Duke)).

Baseline learning outcomes: After completing the course, students will be able to:

1) Understand science as a social process situated within social, cultural and policy contexts,
2) Appreciate how social and cultural factors enable and constrain scientific innovations such as GPM,
3) Recognize the broader social and political implications of scientific and technical developments,
4) Develop an ethical framework for evaluating the professional responsibilities of GPM researchers,
5) Assess technological risks of GPM from diverse social and cultural perspectives,
6) Build communication competencies for interaction with multiple publics, stakeholder groups and government officials.

Course #4. Systems Thinking and Modeling (3 credits, Fall)

The first part of the course will be largely lecture-based, led by Lloyd (Mathematics and Biomathematics) and Schulman (Sociology). Case studies will be team-taught, with guest lecturers drawn from a number of departments providing different disciplinary viewpoints (see table on page 1). The second part of the course will be a mixture of lecture and computer labs, providing both theoretical and practical, hands-on experience of the processes of model development and utilization. The course will culminate with the development of models combining processes and information from different areas. An example of an integrative capstone project would be a dynamic cost-benefit analysis of the implementation of a mosquito GPM program. The biological components of the model (targeted pests, competing species and genetic control dynamics) will be integrated with dynamic models of human behavior responding to the economic and cultural changes associated with the pest control *(Students with advanced knowledge of modeling techniques will serve as TAs and may give lectures, tutor or lead discussions).*

Baseline learning outcomes: After completing the course, students will be able to:

1) Identify the purposes and value of modeling in research,
2) Explain disciplinary terminology and methods, using experience gained through exploration of case studies from different disciplines,
3) Discuss similarities and differences among modeling approaches (e.g., qualitative/quantitative, mechanistic/statistical, analytic/simulation, strategic/tactical),
4) Utilize systems thinking theory and methodology to profile a problem area, including being able to critically evaluate system boundaries, identify system parts and evaluate system dynamics using both qualitative and computational tools and methods,
5) Formulate models at appropriate scales and complexity, appreciating that these are dependent on the questions being addressed, pre-existing knowledge of the system and the quality of available data,
6) Critique a model and its application to a given setting, explaining what factors lead to strengths or weaknesses of the model and its use,
7) Develop models to investigate the system-level operation of a process and appreciate that nonlinear interactions between simple components can lead to complex and often counter-intuitive system behavior.

IGERT Team Building and Trainee Professional Development:

Formal and Informal Team Activities: The introductory course in Mexico and Central America is specifically designed to get students and faculty from the diverse disciplines to work, travel and eat together for an extended period of time in a novel environment so that we can develop a team spirit (patterned after a 1-week summer course in Entomology). First-year students will be provided with a

† **IGERT Course**

Table 2. Typical Student Pathways through Proposed IGERT Program

Entomology (with Genetics)	Biomathematics (with Communication)	Biology (with Sociology)	Sociology (with Entomology)	CRDM (with Genetics)
Thesis Topic: *Population ecology & genetics of a naturally occurring* Medea *element in southern U.S. hybrid zones: Implications for genetic pest mgmt.*	**Thesis Topic:** *Modeling the spread of Dengue-resistant transgenic mosquitoes: The design of optimal release strategies*	**Thesis Topic:** *Balancing ecological and social factors in developing effective genetic pest management of avian malaria*	**Thesis Topic:** *Social, Economic, Environmental, and Human Capital in Community Change and Vulnerability: A Case Study of* Aedes *control in Mexico.*	**Thesis Topic:** *Scientific literacy in rural communities and consequences for science intervention: Implications for genetic pest management*
Yr. 1 summer: • Biology, Culture & Infrastructure† **Yr. 1:** • GPM Concepts & Case Studies† • Insect Biodiversity • Statistics I • New Technologies in Social and Cultural Contexts† • Insect Morphology, Physiology & Biochemistry **Yr. 2 summer:** • Exploratory thesis research • Genetics of Gene Drive (Hay) **Yr. 2:** • Systems Thinking & Modeling† • Population and Quantitative Genetics (Genetics Dept) • Statistics II • Molecular Genetics (Genetics) • Group project prep/execution **Yr. 3 summer:** • Thesis research **Yr. 3:** • Thesis research • Group project • Insect Population Ecology • Entomology Elective (special topics) • Preparing the Professoriate **Yrs. 4 & 5:** • Dissertation research, completion & defense • Group project • Elective courses and/or teaching	**Yr. 1 summer:** • Biology, Culture & Infrastructure† **Yr. 1:** • GPM Concepts & Case Studies† • Biomathematics I (Differential Equation Models) • New Technologies in Social and Cultural Contexts† • Biomathematics II (Stochastic Models) **Yr. 2 summer:** • Exploratory thesis research **Yr. 2:** • Systems Thinking & Modeling† • History & Theory of Communicatiion Technology (Communiciation Dept) • PDE Models in Biology • Stochastics or Disease Modeling Math Elective • Group project **Yr. 3 summer:** • Thesis research **Yr. 3:** • Thesis research • Group project • Qualitative Methods in Communication Research (Communication Dept) • Biomath Seminar **Yrs. 4 & 5:** • Dissertation research, completion & defense • Biomath Seminar • Group project • Elective courses and/or teaching	**Yr. 1 summer:** • Biology, Culture & Infrastructure† **Yr. 1:** • GPM Concepts & Case Studies† • Population Ecology • Statistics I • New Technologies in Social and Cultural Contexts† • Community Ecology **Yr. 2 summer:** • Exploratory thesis research • Genetics of Gene Drive (Hay) **Yr. 2:** • Systems Thinking & Modeling† • Quantitative Analysis (Sociology) • Statistics II • Conservation Ecology • Ecology Elective • Group project **Yr. 3 summer:** • Thesis research **Yr. 3:** • Thesis Research • Group project • Qualitative Methods (Sociology) • Preparing the Professoriate **Yrs. 4 & 5:** • Dissertation research, completion & defense • Group project • Elective courses and/or teaching	**Yr. 1 summer:** • Biology, Culture & Infrastructure† **Yr. 1:** • GPM Concepts & Case Studies† • Classical Theory • Quantitative Analysis • Advanced Sociology Analysis • Developing Societies • New Technologies in Social and Cultural Contexts† **Yr. 2 summer:** • Exploratory thesis research • General Entomology (Entomology Dept) **Yr. 2:** • Systems Thinking & Modeling† • Research Methods • Contemporary Theory • Sociology of Ag. development • Qualitative Methods • Theory or Methods alternative • Group project **Yr. 3 summer:** • Practicum in Integrated Pest Management (Entomology) • Thesis research **Yr. 3:** • Thesis Research • Group project **Yrs. 4 & 5:** • Dissertation research, completion & defense • Group project	**Yr. 1 summer:** • Biology, Culture & Infrastructure† **Yr. 1:** • GPM Concepts & Case Studies† • History & Theory of Communication Technology • Usability Studies for Technical Communication • New Technologies in Social and Cultural Contexts† • Qualitative Methods in Communication Research **Yr. 2 summer:** • Exploratory thesis research • Principles of Genetics (Genetics Dept) **Yr. 2:** • Systems Thinking & Modeling† • Rhetoric and Digital Media • Pedagogy and Technology • Issues in CDRM • Comm. in Networked Society • Genome Science (Genetics) • Group project **Yr. 3 summer:** • Thesis research **Yr. 3:** • Thesis Research • Group project • Directed readings for prelims • Preliminary Exams **Yrs. 4 & 5:** • Dissertation research, completion & defense • Supervised teaching • Group project

large, shared office (with carrels) to foster informal discussions. Semi-formal social gatherings will further facilitate IGERT faculty and student teambuilding. Dannels (Communication) will conduct formal team-building workshops. Our major mechanism for ensuring integrative education and research is the development of student/faculty teams working on specific target pests from diverse perspectives. We will have formal meetings within and among teams to plan and execute group projects, and to select target species (at least monthly). These meetings will alternately be held at noon (on campus) and in the evening (at a faculty home).

Research Symposium: We will host an annual IGERT Symposium at the end of spring semester at which each IGERT student will make a presentation related to *a proposed or ongoing research project* (this will follow directly after the final weekend lectures in course #3 (see page 17 top)). The audience will include IGERT and non-IGERT NCSU faculty and students, students visiting from other IGERTs, university leaders, External Advisory Board (**EAB**) members and invited internationally recognized researchers in areas of social and biological sciences relevant to GPM. These invited researchers will give plenary lectures. Roundtable discussions will be held at the end of each symposium where students can share insights from their internships and develop oral presentation skills. The EAB meeting will be held immediately following the symposium, facilitating direct student interaction with the EAB members. The symposium will be modeled on the very successful symposia held by NCSU's Keck Center for Behavioral Biology for over 10 years; several of the IGERT faculty are Keck participants (see page 25).

Professional Development: During each fall semester, the IGERT program will co-sponsor and participate in a professional development workshop with the Keck Center for Behavioral Biology, which has a long record of excellence in such events (Keck 2010). These symposia are open to and attended by a broad spectrum of students beyond the sponsoring programs. For example, last year's topic was "Publishing and Communicating Science." External participants were Orli Bahcall, Senior Editor of *Nature Genetics*, Peter Binfield, Managing Editor of *PLoS ONE*, John Rennie, Editor-in-Chief of *Scientific American* and Joe Palca, Science Correspondent for National Public Radio. Two of our students who did internships in scientific writing spoke at the workshop.

The workshop we are planning for the first year of our IGERT program is "Interdisciplinary Teamwork and Communication." Dannels, Kinsella (CRDM) and a Keck faculty member will recruit a team to help develop this workshop and invite highly regarded participants. Given the international aspects of GPM and many other NCSU programs, we will plan to have a workshop on international career opportunities and non-academic career paths. Participation by successful, innovative speakers and discussants will make these valuable to our students. Cook-Deegan (Duke) will assist with this activity. Additionally, NCSU's Graduate School provides a popular bi-weekly Professional Development Seminar series to offer graduate students training in skills to prepare them for life beyond graduate school.

Several of the IGERT faculty members have participated in the NCSU program, "Preparing the Professoriate." This program could be very beneficial for IGERT students aiming at academic careers. In one-on-one work, the student observes and discusses the mentor's teaching approach in the fall semester and then does active teaching in the spring semester. It also includes 18 group workshops during the year.

Program-wide Projects: *(This idea is still under discussion by faculty because of the time commitment)* Each year, most IGERT students would participate in a program-wide project. Typically, the fall semester will be used for planning, and the project itself will be conducted in the spring semester. For example, EPA Science Advisory Panels (SAPs) examine proposed rules and allow oral and written public comment. Student groups would examine biological and socio-cultural issues addressed in a proposed EPA ruling that is of relevance to genetic engineering (George Kennedy, John Vandenberg, and Gould have experience with these SAPs). Students will then attend the SAP in Washington, DC, where student representatives will make written and oral comments.

As a second example, each year 5,000 undergraduate students in the NCSU first-year writing program study how authors in different disciplines communicate with their readers. The Writing Program Council has accepted our proposal to use two articles about genetic engineering as a means to contrast styles of

communication by researchers and popular literature authors. It will also involve selected writing instructors/classes in a survey of student opinion about GPM before and after they work on the readings. This could become a group project involving IGERT students and faculty from all involved disciplines (Miller (English) will lead this effort). In all years, we will develop opportunities for students to conduct outreach activities that involve public communication of science.

Other Interactions: Student education and research will involve collaborations beyond IGERT faculty. In addition to our collaboration with USDA-APHIS on campus, we also have interactions with NCSU's Center for Integrated Pest Management (**CIPM**), an international hub for pest risk assessment research. Ongoing projects at the NSF-originated CIPM will be valuable to our students in their training to use sophisticated web-based tools for both risk and economic analyses of target pests. This collaboration could enable us to more efficiently target pests most appropriate for GPM. The NSF-sponsored National Evolutionary Synthesis Center in Durham, NC, has sponsored one of our workshops related to GPM, and this center is interested in developing more activities in applied evolutionary biology. Three NCSU faculty are involved in committees at this center, and we expect more interaction in the future.

We have been developing interactions with Ray Newman, David Andow and Jennifer Kuzma from the **University of Minnesota (UM) IGERT** on "Risk Analysis for Introduced Species and Genotypes" regarding potential collaborations (see attached letter). The UM IGERT focuses specifically on risk assessment, but has a broad interest in all introduced organisms. In contrast, the NCSU IGERT focuses narrowly on engineered pests, with risk analysis being only one component of the program. Because of the high level of UM expertise in risk analysis, we feel that our students and faculty could benefit from formal and informal interactions with the UM program. We have budgeted funds in our IGERT proposal for our IGERT students to attend the UM yearly symposia, and the UM students will be welcomed to the NCSU symposia. The expectation is that these visits will extend beyond the days of the symposia so that students can interact with faculty and students at UM who have expertise not available at NCSU, or could provide more diversity of viewpoints. In addition to student visits, we will invite specific UM faculty to give departmental seminars and attend symposia at NCSU. If we determine that a student's thesis could benefit from an extended stay at UM, we will arrange for an internship. Andow was one of the invited speakers for our March 2009 conference on ecological and social issues related to GPM. Two of our faculty (Gilliam, Gould) and a graduate student (Hain) participated in a UM IGERT sponsored meeting this summer on control of invasive fish with transgenic technology.

Choosing a Focal Pest System: For our program, education and research will intersect as a student cohort and the faculty work together in choosing a focal pest system. We have outlined five important pest systems where NCSU faculty expertise and external collaborations provide a solid basis for success (pages 8-12). However, as pointed out above, we are open to the possibility that over the IGERT grant period other systems will emerge as better options. **It is also possible that more than one cohort will work on a single pest system or that a student will switch cohorts.** We have rejected the educational model in which faculty make the determination of what is best for themselves and the students. Instead, we will engage in a deliberative process that makes use of formal and informal meetings (see page 19), research, and networking with external experts to build a consensus among students and faculty about which system will be both feasible and would have a substantial direct or indirect global impact. Potential projects within a system for each student will be assessed in detail before any decision is made. As the process of choosing begins, all IGERT faculty will be involved, but over the course of decision-making this group will become smaller and more focused. In some cases the process may be straightforward, but in other cases it may be quite difficult and require considerable compromise, a challenge that will face students when they move ahead in their careers. **The typical process of choosing dissertation topics at NCSU differs considerably across disciplines. The IGERT faculty members have discussed the implications of the proposed approach and concluded that they can effectively work with it**. Students applying to the program will be made aware of the process we are using. PhD research projects typically evolve as specific lines of inquiry turn out to be more and less successful. Each student's committee members will use past experience in helping her/him through this process. Because of the interactive nature of the projects, there may be the need for joint meetings of multiple student committees to insure coordination. The mentoring and retention subcommittee (page 21) will advise in this process.

5. ORGANIZATION, MANAGEMENT AND INSTITUTIONAL COMMITMENT:

General Organization and Management

The IGERT program will be primarily directed by the PI and the Executive Committee (EC), with input from participating faculty, the External Advisory Board (EAB). The EC will be composed of the PI and Co-PIs, as well as Lorenzen, Schulman, and one IGERT student. Specific members of the Executive Committee (EC) will form subcommittees. Each subcommittee will have at least two members from the executive committee and two participating faculty members who are not on the EC. The administrative assistant will be critical to the day-to-day operation of the program.

a) Project Coordination: The PI will have responsibility for general oversight, planning and budget. He will convene the EC at least four times per year and will maintain communication with NCSU administrators. He will work closely with the administrative assistant to make sure all activities are appropriately organized and carried out efficiently. He will coordinate communication with the external evaluator and the EAB. The administrative assistant will be in charge of the day-to-day organization and coordination of, 1) recruitment of students, 2) trainee dossiers and assessment data, 3) all scholarly events, 4) IGERT faculty and trainee travel arrangements, 5) international summer courses, 6) research internship logistics, 7) shared research facilities, equipment, and computers, and 8) web-based communication system and other software issues.

b) EC Activities: The EC will make sure that all activities of the program meet the goals of the IGERT program in a fair and consistent manner that encourages excellence, interdisciplinary interaction and creative approaches to meeting challenges. The EC will serve as an arbitration board if problems arise that cannot be resolved at a lower level. Half of the meetings of the EC will be preceded by a meeting of all IGERT faculty to insure that the EC has consensus input from the entire program. The subcommittees will make presentations at each meeting, with the EC making recommendations regarding any issues that the subcommittees have not been able to resolve. **We have set out a very ambitious agenda for our students and recognize that we must maintain appropriate flexibility to make changes to the program that enhance student success and morale.** A critical function of the EC will be to take in input from all possible sources and then make adjustments to the program that are most responsible and useful.

c) Subcommittee Activities:

- **Recruitment and Admissions Subcommittee** will work with the PI and the administrative assistant to recruit appropriate students. Because of the nature of our program, recruitment will require special attention (pages 23-24). This subcommittee will coordinate with academic departments and the office of minority recruitment to insure that admissions are efficient and result in balanced, diverse cohorts.
- **Mentoring and Retention Subcommittee** will work with the administrative assistant and faculty to check on the academic progress of students. A member of the committee will meet with each student at least once a semester to get feedback and make any changes deemed necessary (see *mentoring and retention* page 24-25). The subcommittee will also seek input from the external evaluator (page 22).
- **Curriculum Coordination Subcommittee** will monitor each IGERT course by sitting in on courses/discussions, reading student evaluations and speaking with students and faculty. It will make suggestions to the full EC for changes in the academic program. The curriculum committee will assist in planning the symposium and workshop each year.

d) External Advisory Board

The External Advisory Board (EAB) will comprise experts in fields related to the IGERT program. The EAB will meet once each year in conjunction with the IGERT Research Symposium, providing input on research program design, program management and evaluation. The following have volunteered to serve on the EAB: **Ray Newman (PI of the U. Minn. IGERT);** Tony James (UC Irvine, Molecular Biology, NAS member, Lead PI on Gates Foundation *Aedes*/dengue project); Paul Thompson (Mich. State Univ., Kellogg endowed professor of Agricultural, Food and Community Ethics); Norm Ellstrand (UC Riverside evolutionary genetics and transgenic crop regulation with efforts in Mexico); Michael Rodemeyer (U. Va., Science, Technology and Society program, previously with Pew agriculture initiative); R. Cook-Deegan (Duke, see attached letter); R. Kramer (Duke, see attached letter).

Institutional Commitment

Letters from Drs. Lomax, Wyer and Smith/Esbenshade attest to the fact that NCSU is providing strong backing for our IGERT proposal. As stated in the Lomax letter, NCSU is a land grant university with typical departmental structure but strong movement toward cross-departmental interactions and programs. The Graduate School has eagerly supported our plan to create a new graduate concentration in GPM, and NCSU will set up cyber-enabled communication (see Lomax letter). The Vice Chancellor for Research and Innovation has committed to providing the non-resident portion of student tuition (which will exceed the cost of education allowance) for any out-of-state IGERT student (Lomax letter). The Provost of NCSU has committed one-month release time for three social science faculty members in years 2-5 of the IGERT to develop and teach IGERT courses (total salary and fringe = $194,800, see Lomax letter).

The College of Humanities and Social Sciences (CHASS) has proven its commitment to integrated research through its recent hires of prominent faculty members whose research programs bridge the fields of social, physical, and biological sciences (see Wyer letter). The College of Agriculture and Life Sciences (CALS) has demonstrated its commitment by hiring two molecular biology faculty and one high-level technical staff member to work in the area of transgenic pest research. This is a major commitment of $240,000 yearly in direct salaries in addition to start up funds (see Smith/Esbenshade letter).

6. PERFORMANCE ASSESSMENT/ PROJECT EVALUATION

The goal stated in our "Vision Section" is to produce a group of interactive students, trained in technologies used for manipulation of pest genomes as well as methods needed to assess the environmental and socio-cultural appropriateness of specific products of these manipulations. Thus, assessments and evaluations must focus on whether we are attaining this goal. Figure 2 (page 4) provides a graphical representation of the balance of expertise we envision for our students. We must assess whether our students are achieving this balance, but as explained in "Thematic Basis" section (pages 3-4), there is a tradeoff between breadth and depth, and the extent of this tradeoff must be evaluated.

Internal assessment will be conducted on an ongoing basis by the subcommittees of the Executive Committee through processes described in "General Management" (page 21). We will take two approaches to assessment by external groups. One assessment will be by a panel of outside disciplinary experts (EAB; page 21) and the second by a program evaluation professional.

The external professional evaluation system is being designed by Evaluation Resources, LLC (Raleigh, NC) in consultation with Dr. Denis Gray (NCSU Psychology—see CV). The **evaluations will be conducted by** Dr. Pam Van Dyk of Evaluation Resources. Both Drs. Gray and Van Dyk have long-term experience in the field of research assessment (e.g., Gray 2008; Van Dyk & Gilchrist, 2010). In previous work, Dr. Gray has developed tools for assessing graduate student processes (e.g., multidisciplinarity, experiential, mentoring) and outcomes. The evaluation strategy will be based on the assumption that evaluation must go beyond accountability issues in order to aid project management, and improve project performance. Because of space constraints we can only provide a brief overview.

For each yearly cohort of students, the assessment process will begin after students have accepted offers of admission to the program but before the first course in Mexico. Students will be sent questionnaires that examine general academic and personal backgrounds and goals. More detailed questions developed in consultation with IGERT and non-IGERT faculty will examine each student's level of expertise in diverse social and biological sciences and other project-related domains including interdisciplinarity, team-work, cross-cultural perspectives. Some of the questions will be developed from baseline outcomes established for the IGERT courses. In addition to providing a "pre-program" assessment of our students, the answers to these questions will help the faculty to tailor the IGERT courses to the students' knowledge levels. In order to implement a more methodologically robust quasi-experimental design, Dr. Van Dyk will recruit **non-IGERT students** who have just accepted offers from departments participating in the IGERT. These students will be sent the same questions.

Dr. Van Dyk will track the first through third IGERT and non-IGERT cohorts during the 5-year period attainable with IGERT support. We will seek other support to continue the evaluation. The comparative assessment will entail annual questionnaires as well as personal interviews to examine

student learning strategies and knowledge. Additionally, IGERT students will evaluate the program via an annual anonymous survey-feedback questionnaire focused on educational strategies and practices.

The administrative assistant will provide Dr. Van Dyk with student transcripts, thesis proposals, and progress reports. Dr. Van Dyk will recruit non-NCSU disciplinary experts to rate the depth of student expertise in the different academic fields (and for IGERT students, thesis rigor and appropriateness). Funds for recruiting non-IGERT students and non-NCSU experts will come from an NCSU gift account to Gould. IGERT faculty will be interviewed annually to assess their perspectives on the program. Dr. Van Dyk will analyze the collected data each year and will prepare a written program evaluation. Special attention will be devoted to assessing the effectiveness of methods for recruiting and retaining IGERT students from underrepresented minority groups. Outcome and impact evaluation efforts will be aided by development of "logic models" that will explicitly show anticipated connection between program activities and intermediate changes (e.g. changes in attitudes or knowledge) and ultimate outcomes (e.g. improved job possibilities for students).

Dr. Van Dyk will provide her reports to the EAB at least 2 weeks prior to their annual meetings. At each annual meeting, four EAB experts will participate in and observe our student symposium, interview students and faculty, and prepare assessments. Two of the members of the EAB will visit in each of the five years. Two other members will visit in year 1 and 5. In years 2-4 we will invite specific experts in areas where the program faces challenges. We expect that this approach will provide continuity as well as fresh perspectives to the review. By having the outside experts participate in our symposium, we will take full advantage of our investment in their visits. We have seven volunteers for board membership (see page 21).

7. RECRUITMENT, MENTORING AND RETENTION

Recruitment: We will identify and recruit a special category of students who have a demonstrated desire to work in an interdisciplinary setting. Our experience is that some of the best undergraduate students have trouble deciding on a specific graduate school program because they enjoy multiple disciplines and are reluctant to specialize. We can offer such students a diverse academic experience while moving them into well-focused research projects and training. Because of the novel and controversial aspects of GPM, we believe that one useful recruiting tool will be having faculty present seminars at a variety of liberal arts colleges, followed by discussions with students (Gould tested this approach successfully at Swarthmore last fall). Our IGERT faculty will develop a list of faculty members at other colleges and universities, including HBCUs, across the U.S. who teach upper-level undergraduate courses relevant to our IGERT. We will develop materials about our IGERT that can be emailed to these faculty members, asking if they know of juniors or seniors who might be interested in our program. The PI and administrative assistant will follow up with personal emails to these students. Our faculty will take an updated version of our current brochure to professional meetings and any visits to other campuses in order to publicize our program. We will also make use of NCSU recruiting tools, our GPM program website (Haddad 2009), the NSF IGERT website, and websites and listservs specific to disciplines participating in the program. Our focused recruitment for each cohort should require one year of lead-time. Our correspondence with Dr. Van Hartesveldt indicates that the delay this will cause in the first cohort start date can be accommodated by rolling over funds.

Focus on Underrepresented Groups: IGERT group is creating cooperative education projects with four HBCUs in North Carolina. Lloyd and Gould have given lectures at NC A&T University (Greensboro, NC) to students in its NSF-sponsored undergraduate Biomathematics Program and have discussed approaches for cooperative programs with Drs. G. Goins and D. Clemence. Gould has followed up with visits to NC A&T administrators and other students. We have recently established a second interaction with Dr. L. Jackai at NC A&T who has extensive experience with post harvest insect pests in Africa and is now Chair of Natural Resources and Environmental Design at NC A&T (see attached letter and page 12). We have a long-term interaction with Dr. D. Swain in Library and Information Science at North Carolina Central University (Durham, NC). Dr. Swain has volunteered to help recruit social sciences students from NCCU for our program. A final interaction is with Dr. Lieceng Zhu, a molecular geneticist

at Fayetteville State University. She has already identified a candidate, Grace Chavis, who is interested in our program.

We will also recruit students from underrepresented minorities by setting up interviews with such students at elite liberal arts colleges. NCSU has a large population of underrepresented groups in its own student body, many of whom have worked in our labs, competed successfully in undergraduate research symposia and moved on to programs at Duke, Johns Hopkins and other prestigious schools. Haenn (Anthropology), who was on the faculty of Arizona State University (ASU), will lead efforts to recruit Hispanic students. Haenn will use her position as a board member of the Anthropology and Environment section of the American Anthropological Association to advertise the NCSU IGERT while working more intensively with colleagues at ASU and the University of Arizona (UofA) to recruit Hispanic students.

According to *Diverse Magazine,*(July 2010), NCSU is ranked #3 in the U.S. in minority doctorates in agriculture and related sciences, and #6 in minority doctorates in math and statistics. Despite these rankings, NCSU recognizes that it has underperformed in recruitment of underrepresented groups and has developed new programs for such recruitment. Four funded recruitment and retention programs at NCSU that could be used by our IGERT students are described in the Lomax letter of support.

We have received a $1.5 million grant from NIH for recruitment of underrepresented groups to NCSU health and behavioral sciences programs. A number of our IGERT faculty are involved with a grant from NIH for recruitment of underrepresented groups to NCSU health and behavioral sciences programs (Mackay co-PI), allowing two additional years of funding for 10 students. This will be valuable to our IGERT students when their IGERT support ends. Finally, the NCSU Diversity Program has committed two slots in their summer internship program for HBCU undergraduates to work in our IGERT labs. It has also committed four slots in its NCSU weekend visits program to HBCU students selected by our program.

Retention and Mentoring: The academic program outlined in this proposal requires substantial extra effort from our graduate students and faculty. In order to retain full participation of students and faculty, we must build a sense of group identity and purpose. The students and faculty must feel respected and appreciated for their contributions. Intellectual excitement about breaking new ground will help our group, but on the pragmatic side we will need to build a win-win situation for the students and faculty in which the extra effort put into the program has a payoff in terms of future careers and recognition by peers. In this regard, the EC will solicit input from students, faculty and advisors in making modifications that will maintain a win-win environment. *A major barrier for social sciences faculty was recently addressed by the NCSU Provost pledging teaching release time for three faculty members in years 2-5.*

Strong formal and informal mentoring is critical for retention and for making sure that each student has appropriate goals and a realistic means of achieving those goals. Students will be encouraged to choose an advisor early in their first spring semester and to create an advisory committee by the end of their first year (We will develop a mechanism so students can change advisors if projects or personal interactions make this appropriate.). Each student's advisory committee will have at least two members from the IGERT program—at least one from a college outside the student's major. This outside member will help assure that the student acquires sufficient cross-disciplinary training, and that the rest of the student's committee (some not in the IGERT) understand the utility of this broad training. Students will present a written outline of their progress to their advisory committee each year. All advisors will sign off on the progress reports. The PI will read and approve all progress outlines and will discuss any problems with the student's committee and with the EC if needed. **It will be critical for the EC to be responsive to input from faculty and students so that we develop and maintain a program with demanding but healthy workloads.**

The international course at the beginning of the students' programs will help integrate each student into our IGERT and will allow the faculty to develop a personal mentoring relationship with each student. In the spring semester of their first year, students will begin working with IGERT faculty to choose one pest system for their focus. This effort will entail considerable interaction of students and faculty and will be an opportunity to maintain and build group identity with a goal of presenting the choices made at the

student symposium late in the spring semester. If students and faculty in a cohort find it difficult to make a choice of a system, the symposium could serve to provide extra input to the cohort. The annual symposia and annual IGERT projects will help to unify the individual cohorts into a larger team.

***Mentoring and Retention of Underrepresented Groups*:** Students from underrepresented groups can face special challenges in graduate school. We expect the undergraduate internships set up at NCSU to at least help alleviate the culture shock experienced by some of these students. Many of our faculty members have served as graduate advisors for underrepresented minority students. IGERT faculty members who are themselves from underrepresented groups will be of special help as mentors. Beyond our IGERT program's specific attention to preparing and bringing students from underrepresented groups into our teams, NCSU has active programs for retention of these students through the Provost's Office of Diversity and African American Affairs. We will draw on their programs and services.

Student Placement: The field of GPM is expected to grow over the next five years, resulting in demand for our graduates in academic, government, non-profit, and industry sectors. The cross-disciplinary training and interactions experienced by our graduates will also prepare them for positions in other fields that require skilled communication between biological and social science disciplines and between these disciplines and the public.

The interactive nature of our program, along with visits from internationally recognized experts in diverse disciplines, is expected to raise the profile of our program and students. Student attendance of professional meetings along with faculty mentors will enable further networking. Professional development workshops will help to prepare students for the world beyond graduate school. As outlined in the accompanying charts, our graduates have gone on to work in an impressive array of academic, industry and government positions. We expect the proposed IGERT to enhance this record.

The yearly student progress report will have one section titled "future vision" in which students will write a paragraph about how they currently see their professional career after graduate school. This will be valuable for discussions by the dissertation committee, and it will also be useful to the PI and EC in directing program activities. As students approach graduation, their committee members will reach out to the rest of the NCSU faculty as well as their colleagues at other universities, government, and the private sector in helping IGERT students search for external employment opportunities.

8. RECENT TRAINEESHIP EXPERIENCE:

Many of the participating IGERT faculty members have had experience in NSF, NIH and USDA training programs as well as a Keck Foundation research/training program. We have also participated in many recruitment and summer programs for underrepresented groups.

Other experience with graduate training programs: The W. M. Keck Center for Behavioral Biology is now entering its 12th year as a graduate and postdoctoral training program. The faculty and students in the Behavioral Biology program range from molecular biologists to behavioral ecologists. The program began with no outside support. It later obtained a grant of $800,000 from the Keck Foundation that ended over six years ago. The program is still thriving with a variety of sources of support, and it is considered a model for interdisciplinary training at NCSU. Four of our IGERT faculty (Gould, Mackay, Coby Schal, John Vandenbergh) were founding members of the Behavioral Biology Executive Committee. That program sponsors a yearly student symposium (about 24 presentations per year) and a professional development workshop (attendance of about 60). During the fall and spring semesters, monthly evening discussions are held at the home of two of the faculty (attendance of about 25). Three to four seminars are sponsored by the program each semester and are held in the seminar slots of Entomology, Genetics and Biology. Many of the students and postdocs move between labs, and co-advising is common. This fall we are having an alumni reunion symposium for members who have gone on to careers in Government, Industry, and Academia.

Previous IGERT support: NC State received funding for an IGERT in Functional Genomics and Bioinformatics from 2000-2005. Long-term impacts of this IGERT included establishment of an interdisciplinary functional genomics/bioinformatics graduate program at NCSU that now has 32 faculty and 40 graduate students. The funding and clout resulting from the Genomics IGERT were major factors leading to hiring key faculty members who have helped expand the graduate program.

INTERNATIONAL COLLABORATIONS:

This IGERT project will leverage strong collaborations with international partners to provide each IGERT student with an appreciation of other cultures in addition to an understanding of the global nature of GPM and its societal impacts. Each first-year IGERT trainee will participate in a 3-week summer course to be held in Mexico and Central America. In addition, IGERT trainees will be encouraged to plan a research internship of more than three months with a foreign collaborator. Many of the general logistics for the groups and individual students have already been arranged, with local collaborators acting as facilitators (see attached letters). Our budget includes a $200,000 request to include air travel, housing, per diem and ground transportation (buses) for the extensive international experiences for students. International health insurance will be provided through NCSU's Study Abroad Program, covering both medical treatment and repatriation in the event of an emergency.

Three-week International Summer Course: Pest Issues in Developing Nations: Biology, Culture and Infrastructure: This course will include 8 days in Mexico, 5 days in Guatemala, and 7 days in Honduras. As described in the education section of the proposal, this course has two main goals: 1) team building and 2) acquiring first-hand knowledge of the biological and cultural environments in which many of the products of GPM will be utilized. The two goals are equally important. We have chosen sites in Mexico and Central America instead of other parts of the world based on 1) relatively easy travel logistics and low costs, 2) availability of two of the world's most advanced, in-country, research programs focused on GPM, 3) ongoing regional issues related to transgenic crops, 4) previous collaborations of our faculty with the institutions involved, and 5) previous work by our faculty in this region. We intend to use the same sites for this course each year to build a good working relationship with our hosts and to continually improve local logistics. Each group of about six students will be accompanied at all times by at least three faculty members. Below we describe some, but not all of our logistics and activities.

In Tapachula, Mexico, we have ongoing collaborations with the Gates project, which has permanent personnel conducting research (A. James - PI of Gates project and will be a member of our IGERT EAB), and with the Mexican government's Centro Regional de Investigación en Salud Pública (CRISP - see Ramsey letter & CV). Working with CRISP, our students will help with lab and field investigations involving insect-vectored diseases including dengue, malaria and chagas. CRISP has permits from the Mexican government to do surveys of household mosquito abundance and has included our students in the past. Local households where we sample mosquitoes have welcomed our visits, giving us the chance to speak with many people about their lives and issues related to dengue (IRB approved). We believe that IGERT students will profit from spending three days doing surveys in different areas of the city.

The Gates Foundation dengue research program has built 12 large field cages ~10km from Tapachula to house experiments with transgenic mosquitoes. Our students will be able to visit the field cages, hear lectures and have discussions with Gates research scientists (two from NCSU). We will also spend one day at the MuscaMed rearing facility that produces radiation-induced sterile fruit flies, and is located about an hour from Tapachula. We have toured their facility and had evening discussions with two of their key researchers. Students and faculty will be housed at the Hotel Don Miguel, which is located within walking distance of CRISP, has good basic accommodations and has a conference room suitable for evening lectures and discussions. We will encourage IGERT students to take intensive Spanish classes prior to the beginning of their first IGERT year to facilitate their interactions with local populations. However, we have good translation capability so this will not be necessary for every student.

Our major goal in El Pino, Guatemala, will be observing and understanding the transgenic medfly research conducted at this facility (see APHIS letter and Rendon CV). We will interview workers at the plant about their knowledge of the radiation and transgenesis processes. Rendon will assist us in meeting and interviewing other members of the local rural community. In Guatemala City, our goal will be to meet with policy makers to gain insight on their views of GPM. Allan Hruska (FAO; 20 years agriculture work in Latin America, NCSU-PhD) will be our liaison in Guatemala City (no room for letter). He will assist in arranging interviews with urban citizens. Gould will be in Tapachula for research studies in July 2011 and will visit El Pino and Guatemala City to finalize arrangements.

The goals of our visits in Honduras are to: 1) Interview agricultural researchers, students, and policy makers who differ in attitudes toward transgenic corn that is now being commercialized in Honduras, 2) interact with researchers working on other pest-related agricultural problems, and 3) visit subsistence and commercial farms. We will visit Zamorano University and Universidad Nacional Autonoma de Honduras (UNAH). Zamorano is a private university that draws students from all of Latin America. UNAH is a smaller but growing public university that recently signed a research agreement with Monsanto. NCSU has formal agreements with both institutions that were pioneered by Dr. Y. Cardoza (Entomology), who will be responsible for logistics for our visit. Dr. Cardoza, a graduate of Zamorano, visited Zamorano in October, 2008, and Dr. John Sabella from UNAH visited NCSU in 2008.

International Internships: To meet our goal of producing globally engaged scientists, capable of performing in an international research environment, we will provide IGERT students with an opportunity for internship experience with one of our international collaborators (examples below). Although not every student will do an international internship, each of the interns will report on their experience at our research symposia and will use their experience to enhance their team's project.

CRISP/Gates - Tapachula, Mexico: We have agreements with both CRISP and the Gates Group to host international interns (see Ramsey letter). Some biological and social science projects that could be conducted in Tapachula have been outlined in the research section of this proposal. Interns will either live with a local family or in a small apartment. One of our graduate students, Rachael Katz-Walsh, spent 9 months in Tapachula doing thesis research and just returned in August 2010. She had taken Spanish prior to her first trip, but also found an instructor in Tapachula. We would expect the same for future interns.

El Pino, Guatemala - The research and production facility in El Pino is run collaboratively by the Guatemalan government and the USDA. We have an agreement with the USDA-APHIS group at NCSU (see attached letter) to have interns work at the El Pino site. As indicated in the letter, we are encouraged to have students work on biological, economic and community engagement studies. Gould will visit El Pino in July 2011 to determine the best logistical arrangements for interns.

Iquitos, Peru - Tom Scott has been the director of an *Aedes*/dengue research project in Iquitos for over 10 years. He has been a Co-PI on an NIH grant with Gould and Lloyd for 6 years and visits NCSU at least once a year. He and Morrison have a research lab in Iquitos where Dr. Morrison is stationed permanently. We have written consent for interns to work with them (letters not included due to NSF limit).

CSIRO (Commonwealth Scientific & Industrial Research Organization) Australia – Dr. Ron Thresher and his research group are at the cutting edge of research on development and use of transgenic fish for control of invasive fish. Their work emphasizes fish ecology as well as community engagement. Dr. Thresher is also interested in the potential for new work of CSIRO on pest insects. He indicates in his letter that he would welcome students to work on ecology, molecular biology, or social aspects of genetic management of fish populations and would also connect students with researchers working on insects.

Keele University, UK, and Bamako, Mali - Drs. Tripet, Hurd and Eggleston are leaders in molecular and ecological research on *Anopheles* mosquitoes that vector malaria. They have been awarded a Wellcome Trust Grant to continue their work in Mali. As indicated in Dr. Tripet's letter, it would be best for internships to begin at Keele and then travel to Malaria Research Training Center in Mali with their research group. Research collaborations and accommodations in Bamako (Mali) are considered to be the best in West Africa. The research projects will focus on ecological issues, but may use molecular tools.

Germany –Three programs have offered to work with interns who could gain experience ranging from molecular to social aspects of GPM: Dr. F. Reed's group at *Max Plank Institute for Evolutionary Biology* (see letter and CV) is doing some of the most creative work on gene drive systems at the molecular and mathematical level. Prof. Armin Grunwald, director of the *Karlsruhe Institute for Technology Assessment and Systems Analysis Unit* is engaged in two interdisciplinary projects on the ethical, legal, and social impacts of synthetic biology. Prof. Ortwin Renn, Director of the *Interdisciplinary Research Unit for Risk Governance and Sustainable Technology Development, University of Stuttgart*, is widely recognized throughout the European Community and the US for his extensive experience as a policy consultant at the federal and state levels in Germany.