CALFED BAY-DELTA PROGRAM

CALFED SCIENCE FELLOWS PROGRAM

In cooperation with the

California Sea Grant College Program

FELLOWSHIP APPLICATION COVER PAGE

APPLICANT TYPE ☐ Postdoctoral Researcher ☒ Ph.D. Graduate Student

PROJECT NUMBER ______________________

PROJECT TITLE Addressing Stakeholder Concerns: Pests and Pest Control in the Sacramento River Conservation Area

FINANCIAL SUMMARY

First Year CALFED Funds Requested:	$43,052
Total CALFED Funds Requested:	$129,239
Duration:	36 Months
Proposed Start/Completion Dates:	9/1/05 to 8/31/08

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Will animal subjects be used? ☒ Yes ☐ No

APPROVAL DATI 5/1/05 PROTOCOL #: Gilb03.01 PENDING: ______________

Does this application involve any recombinant DNA technology or research? ☐ Yes ☒ No

PROPOSED RESEARCH

INTRODUCTION

Restoration of terrestrial riparian ecosystems is a crucial goal for improving water quality, fisheries habitat, and terrestrial wildlife habitat (Castelle et al. 1994). In addition to providing critical breeding and migratory habitat for a host of important flora and fauna, terrestrial riparian corridors play important roles in moderating stream temperature and reducing sediments and nutrients emanating from upland agriculture (Altier et al. 2001). In particular, restoration of the Sacramento River terrestrial riparian habitat is essential for improving water quality and restoring species and ecosystem services in the Bay-Delta region (RJHV 2000). At the same time, management of the Sacramento River ecosystem is also highly contested because of its economic potential for urban, agricultural and recreational uses. Views on agricultural use of the Sacramento River are particularly polarized, with, on the one hand, concern about the potentially harmful impacts from pesticides and fertilizers used in conventional agriculture, and, on the other hand, the exceptionally high agricultural value of the region's fertile land and abundant water.

These concerns call into question the optimal extent and pattern of riparian restoration projects and impact the chances of restoration success. For example, along the Sacramento River, the area designated for restoration was decreased in 2002 due to landowner concerns (Evans 2002). However, those in opposition to restoration of riparian habitat often may not account for potential positive effects of restoration projects on ecosystem properties that are important to agriculture, including increased pest control, improved pollination services, and improved water quality (Kremen et al. 2004). More specific accounting of the costs and benefits of riparian restoration for neighboring agriculture may significantly reduce conflict and alter the patterns and extent of restoration efforts.

My research focuses on this contested interface between agricultural and riparian habitat in the Sacramento River watershed, particularly on the effects of riparian habitat on pests and pest control in nearby agricultural systems. The movement of pests from restored riparian forest tracts into nearby agricultural lands is a major focus of concern for farmers in the Sacramento River region. At the same time the movements of pest predators from restored habitat could benefit agricultural production and reduce pesticide requirements**. My first objective is to use extensive fieldwork and existing data to answer the following questions concerning the interactions between riparian restoration areas and adjacent farmlands**:

1) What are the quantities and distribution patterns of serious agricultural pests, including weeds, insects and mammals, from riparian forest into farmlands?

2) Does crop production benefit from elevated densities of pest enemies, including both arthropod and avian predators, that move from riparian forest areas into nearby farmlands? If so, how far does this beneficial effect of riparian forest sites extend into farmlands?

My second major objective is to use my empirical results to inform stakeholders in the region, so that their perceptions of the costs and benefits of restoration are better grounded with real information. As one aspect of this work, I will use my data in a strategic, interactive decision-making model developed in collaboration with ecological economists, in order to determine the best strategies for focusing investment and management in restoration.

In fulfilling these two objectives, my research will provide critical information on how to manage scarce resources for optimum restoration outcomes in the context of landowner motivations and perspectives. Using a scientific approach to evaluate the strength of perceived problems and possible benefits of agricultural success associated with restoration.

I will focus my work on what is arguably the most important crop grown within riparian areas– walnuts – and to a suite of its most important pests and predators. My goal is to share my findings with the agricultural and restoration communities, fostering better understanding of the impacts of restoration and focusing management priorities. Specifically, the CALFED Call for Proposals is soliciting studies that will "help improve existing approaches or develop new ones for substantiating cause-and-effect relationships between multiple CALFED actions and specific program goals". Without support from stakeholders and the community for terrestrial riparian habitat, many of the Ecosystem Restoration Program goals are not possible. In particular, it is critical to have community support for upstream terrestrial restoration in order to achieve recovery of species, native and harvestable (Goal 1 and 3), to rehabilitate natural processes in the Bay-Delta and its watershed (Goal 2), to restore and protect functional habitats, and to improve and maintain water and sediment quality (Goal 6). My research will use strong science and a strategic modeling approach to determine how to adapt riparian habitat management for stakeholder support and ecosystem restoration success.

LAND USE IN THE SACRAMENTO VALLEY

I am conducting this work in the upper Sacramento River landscape, where the mobility of both pests and insectivorous arthropods and birds create significant ecological links between riparian forests and adjacent farms (Lundberg and Moberg 2003). The Sacramento River was historically surrounded by a riparian corridor ten miles wide. However, conversion of the riparian forest to orchard and row crop agriculture has occurred since 1850, and currently only about 2% of the original riparian habitat remains (Katibah 1984). Further, the river has been leveed for flood control and irrigation since the late 1800s and controlled by Shasta Dam since the 1940s. Nonetheless, the riparian habitat along the Sacramento River still contains some of the last viable habitat for several threatened and endangered animals and provides critical breeding, overwintering and migration areas for many birds (Golet et al. 2001, Gaines 1977).

In 1986, the California state legislature passed Senate Bill 1086, creating the Sacramento River Conservation Area. Through this legislation, The Nature Conservancy, River Partners, and other organizations are purchasing properties from willing sellers within the 2.5-year floodplain along 160 km of river between Red Bluff and Colusa. At this time, approximately 2000 hectares have been planted with a mix of riparian species. This type of large-scale restoration creates a "replicated experimental design" to investigate ecological questions regarding the effects of restoration (Holl and Crone 2004). However, as described above, many conflicts have arisen based on uncertainties about the effects of restoration on pest control in nearby agricultural lands.

I will be conducting my research in walnut orchards in the Sacramento River Conservation Area. The Sacramento and San Joaquin Valley account for more than 99% of the total production of walnuts for the United States and half of the world's export trade of walnuts is grown in California. Walnuts are the ninth most significant export commodity in California and cover over 80,000 hectares. This crop is often associated with riparian zones, as walnut trees are able to withstand periodic flooding (Ramos 1985). Because they are the dominant crop within the riparian zone and one of the most abundant crops in the Sacramento River Conservation Area, understanding the effects of riparian restoration on walnut orchards is particularly important.

ECOSYSTEM SERVICES AND PEST IMPACTS OF TERRESTRIAL RIPARIAN HABITAT

To date, there has been limited research on how adjacent natural areas affect farmland. What little research has been conducted has largely focused on small-scale buffer strips of non-crop vegetation (Bugg and Pickett 1998, Nicholls et al. 2001). There is little understanding of the effects of large natural areas or mosaics of differing habitats on pests and pest predators. In most natural landscapes, both predators and prey can move between nearby communities, influencing both the donor (where the prey/predator comes from) and recipient habitats (Polis et al. 1997). As with such interchange in natural landscapes (Sabo and Power 2002), movements of species across the interface of restored or remnant riparian forest and agricultural areas could have cascading effects on all levels of the food webs in both habitats. These effects could include changes in the populations of predators or herbivores that could then have cascading effects on other trophic levels and thus on crop success.

Within the agricultural landscape of the Sacramento River watershed, these movements and subsequent cascading effects on crop growth could have both positive (increased pest predators) or negative (increased agricultural pests) effects. In a survey conducted in the Sacramento River

Conservation Area, over 60% of farmer respondents agreed that one agricultural benefit due to increased terrestrial restoration could be an increase in pest predators (Buckley 2004). Recent research has demonstrated that agriculture receives important "ecosystem services" such as pollination services from natural areas; such services could be incentives for restoring and conserving natural habitat (Kremen et al. 2004, Daily and Ellison 2002, Ricketts 2004). However, extremely little is known about the ecology of these services (Palmer et al. 2004). In some situations, generalist predators can effectively suppress populations of agricultural pests (Kirk et al. 1996, Marc et al. 1999, DeBach 1949) and increased diversity of plant species in agricultural systems can increase impacts of predators on lower trophic levels (Symondson et al. 2002). However, these results have not been linked with sources of these generalist predators, such as adjacent natural habitats, and no research has investigated how patch size of natural habitat or distance from crops affects such pest control services.

While recognizing possible benefits of riparian restoration, many farmers perceive the restoration of natural habitat as having mostly negative effects on crops (Wolf 2002). These concerns include restoration areas acting as a source for weed propagules, providing habitat and protection for insect pest species, and increasing the damage to crops due to increased mammal populations (Wolf 2002). Confirming this concern, research has shown that vegetative buffers or natural vegetation surrounding agricultural habitat can sometimes act as a "safe harbor" for herbivores depending on the age of the habitat and the species composition (Denys and Tscharntke 2002). However, as with positive effects of nearby natural areas, little or no research has investigated the effects of distance and size of natural habitat patches on these possible negative impacts. In a survey of farmers on the Sacramento River, over 60% believed that there is an increase in invertebrate, weed, and mammal pests due to riparian habitat restoration (Buckley 2004). In the absence of empirical data, answers to the questions and concerns of farmers about how the restoration of wild areas near their farms will affect production on their lands can only be addressed with guesses.

OUTLINE OF RESEARCH OBJECTIVES, QUESTIONS, AND HYPOTHESES

Objective 1: Empirical study of pest and pest-predator distribution. My research focuses on the spatial distribution of walnut pests and their predators, and how restoration of riparian habitat will affect their distributions and abundances (Ramos 1985, Buckley 2004) (see Conceptual Model). Here, I present how two general questions about the proximity of restoration areas to agricultural lands translate into specific hypotheses that can be addressed using adjacent walnut orchards and riparian forest. I have designed this study to allow data collection that will produce both general inferences about the biological communities that cross the agricultural-forest boundary, and also targets particular pests and concerns of most importance for farmers in this system.

Question 1: What are the quantities and distribution patterns of serious agricultural pests, including weeds, insects and mammals, from riparian forest into farmlands?

Insect Pests. Walnuts harbor a moderately diverse community of herbivorous insects, so that sampling and quantifying the insect community is feasible. Among the several possible herbivorous insects, walnuts are most threatened by three major insect pest species: codling moth (*Cydia pomonella*), navel orangeworm (*Amyelois transitella*), and walnut husk fly (*Rhagoletis completa*) (Ramos 1985). Codling moth overwinter as full-grown diapausing larvae under loose scales of bark. Adults emerge during leaf-out of the walnut tree and then develop through four generations before the next overwintering period (Ramos 1985). Summer larvae feed and complete their development inside the walnut. Walnuts that have been infested with codling moth are unmarketable because of feeding damage to the nut. Codling moth is not only a major pest in walnut, but also infests apples, pears and plums (Ramos 1985). Navel orange worm overwinters as larvae inside leftover nuts on the tree and on the ground. Pupation begins in March, with peak emergence of the adult moths in late April to mid-May. Adult moths lay their eggs singly on the leftover nuts, codling moth infested nuts or diseased nuts. Navel orange worm will goes through two generations during the summer with the second generation larvae sometimes infesting the new crop of nuts as the husks begin to split. Navel orange worm also infests almonds, and because almonds are harvested earlier than walnuts, it is possible that there are movements from almonds to walnuts during the second generation. Nuts infested with navel orange worm are unmarketable because the larvae feed on the nut and produce webbing and frass (Bentley et al. 2005). Walnut husk fly overwinter as pupae in the soil and emerge as adults from June to August. When the adults emerge, they mate and lay eggs on the surface of the walnut husk within several days after emergence. Eggs hatch and maggots feed on the husk for 3-5 weeks before dropping into the ground, burrow several inches and pupate. Walnuts that have been damaged by walnut husk fly can be unmarketable for nuts sold in the shell because of stains on the nutshell (Ramos 1985).

The spatial distribution of walnut husk fly could be affected by the distribution of its alternate host, California walnut (*Juglans californica*), found in remnant riparian forest (Bentley et al. 2005, Hunt et al. 2003a, 2003b, 2003c). Since codling moth and navel orange worm are unlikely to be using California walnut as an alternate host, it is unlikely that restored or remnant habitat would harbor these species (Welter pers comm.). Given the diversity of walnut-feeding insects and also the disproportionate importance of these three pests, I will focus on three hypotheses regarding the effects of nearby riparian restoration sites:

> *Hypothesis 1A: The abundance and diversity of herbivorous insects will be greater in walnut orchards closer to restored or remnant riparian forest*
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> *Hypothesis 1B: Proximity to restored or remnant riparian forest will not affect abundance of codling moth or navel orange worm.*
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> *Hypothesis 1C: The abundance of walnut husk fly will be greater in walnut orchards closer to remnant riparian forest, but not closer to restored riparian forest.*

Weed Pests. Restored or remnant riparian habitat may contain seed propagules of weed species of concern for farmers. In a survey of farmers within the Sacramento River Conservation area, weeds from riparian areas were considered an issue by over 70% of farmers surveyed. Plant surveys in the remnant forest on the Sacramento River demonstrate that many non-native species that are considered problem weeds are present in the riparian forest (Hunt et al. 2003a, 2003b, 2003c). Within the restored riparian forest, non-native species are not planted, but often colonize these areas (Efseaff et al. 2003). Restoration organizations are looking for methods to reduce the number of non-native species that colonize the restored areas, and are planting native perennial grasses in order to try to outcompete the invasive species of particular concern to both restorationists and farmers (Efseaff et al. 2003). Previous research has demonstrated that native grasses planted on roadsides can reduce the invasive weeds in adjacent habitat (Bugg et al. 1997). Perennial native grasses, once given a chance to establish, could also outcompete invasive species (Efseaff et al. 2003). However, although there is extensive research on the movement of invasive species from agriculture to restored habitat (Fox et al. 1997), there has been little research focused on investigating movements of weeds from natural habitat to agricultural areas.

> *Hypothesis 1D: The abundance of weed species of concern will be greater on walnut orchards closer to remnant and restored riparian forest.*

Mammalian Pests. Several mammal species have been observed in the riparian habitat that could be of concern to farmers. Mammals were the concern for over 80% of farmers surveyed in the Sacramento River Conservation area (Buckley 2004). Ground squirrels (*Spermophilus beecheyi*) are considered to be one of the biggest pests to walnut farmers because of the possibility that they will eat the nuts from the trees (Salmon et al. 2005, Langridge pers obs.). Farmers also are concerned about voles (*Microtus californicus*)that girdle trees and gophers (*Thomomys spp.*) that eat roots of walnut trees thus making them more susceptible to disease (Salmon et al. 2005.). However, farmers have also voiced concern regarding the presence generally of burrowing mammals due to the instability of the soil with an extensive burrow network (Wolf 2002). Research has demonstrated that mammals will use non-crop habitat as a refuge from which crops can be recolonized (White et al. 1997, Horskins et al. 1998).

> *Hypothesis 1E: The abundance of burrowing mammal species will be greater on walnut orchards closer to remnant and restored riparian forest.*

Question 2: Does crop production benefit from elevated densities of pest enemies, including both arthropod and avian predators, that move from riparian forest areas into nearby farmlands? If so, how far does this beneficial effect of riparian forest sites extend into farmlands?

Spatial Distribution of Arthropod Predators: Proximity to riparian habitat could also increase the numbers of generalist natural enemies of pest species, including some species of spiders (Dondale et al. 1979), insects (MacLellan 1962), mites (MacLellan 1972), and birds (MacLellan 1959, Mols and Viser 2000). Top-down control usually focuses on "keystone" species and their strong effects on community dynamics (Power et al. 1996). In the four decades since the classic work on insect outbreaks by Holling (1965), most studies have disregarded the importance of generalist predators in biological control. However, it is increasingly clear that assemblages or guilds of generalist predators can effectively suppress populations of pest species in agricultural settings (Marc et al. 1999, Symondon et al. 2002). Many studies have demonstrated that the presence of generalist arthropod predators can lead to reduced herbivore damage on crop plants (Riechert and Bishop 1990, Carter and Rypstra 1995, Symondson et al. 2002).

> *Hypothesis 2A: The abundance and diversity of arthropod predators will be greater on walnut orchards closer to restored or remnant riparian forest.*

Impact of Avian Predators on Herbivores: Birds are mobile links between restored/remnant riparian habitat and agricultural areas (Lundberg and Moberg 2003). Due to their mobility, birds can move to high-density food patches, and are capable of complex prey-switching and specialization behaviors (McFarlane 1976, Kirk et al. 1996). Research has demonstrated that birds can suppress insect populations (Holmes et al. 1979, Marquis and Whelan 1994), and consequently increase plant growth (Marquis and Whelan 1994, Hooks et al. 2003). Further, birds have also been demonstrated to have top-down effects on pests in agricultural systems (Kirk et al. 1996), including effects on codling moth, one of the main pests in walnut crops in the Sacramento River area (Solomon et al. 1976, Solomon et al. 1979, Wearing and McCarthy 1992). Research has also demonstrated that birds can suppress insect pests that are not affected by other natural enemies (Jones et al. 2005).

Within the Sacramento River watershed, research has demonstrated that bird populations increase with restoration activities (Gardali et al. 2004). Abundance and diversity of bird populations along the Sacramento River Conservation Area have also been shown to be similar to remnant riparian forest bird populations within three years of restoration implementation (SRP 2002). Therefore, restoration activities could have benefits for farmers due to increased bird populations that forage within the agricultural areas.

> *Hypothesis 2B: Avian predators will have a stronger impact on herbivorous insects on walnut farms closer to remnant and restored riparian forest.*

Avian Impacts on Codling Moth: I am also investigating the impact of birds on overwintering codling moth. Birds should be significant natural enemies on both the larval and adult stages of the codling moth in these systems. Overwintering larvae in particular are vulnerable to avian predation, due to their availability as prey as full-grown diapausing larvae under loose scales of bark. Several studies have shown the importance of birds in consuming overwintering codling moth larvae in apple orchards

(Solomon and Glen 1979, Wearing and McCarthy 1992). However, none have determined how distance to non-agricultural habitat could affect these impacts.

Hypothesis 2C: Avian predators will have a stronger impact on codling moth overwintering larvae on walnut farms close to remnant and restored riparian forest.

Objective 2: Dissemination of results and development of strategies for cooperation through a decision-making model and associated actions. Landscapes are not only connected ecologically, but also linked socially. This connection between adjacent landscape elements often leads to tensions between groups with interests in either or both landscape elements. Different stakeholders within watersheds can have very different goals for the land use in the region (Leach et al. 2002, Adams 2003). Often, riparian zones have been converted to agriculture because of the flat, fertile soil associated with this zone, with concomitant loss of other natural riparian features and functions. Within the past twenty years, watershed issues such as decreased water quality and negatively impacted wildlife populations have led to both small- and large-scale restoration efforts, converting agricultural lands to more natural habitats (Berger and Bolte 2004, Leach et al. 2002). However, the goals of these restoration projects often are in conflict, or are perceived to be in conflict, with the current agricultural land use. For farmers, these perceptions include negative views of natural disturbance regimes such as flooding and fire, loss of access to the best soils close to the river, and an increase in crop damage due to an increase in pests crossing into crop land from riparian habitat (Wolf 2002, Buckley 2004). My research will include identifying actions to increase cooperation between stakeholders through reduction of pest problems or dissemination and encouragement of pest-predator effects. I am also collaborating with ecological economists to use a strategic approach to restoration in order to determine the best approach to non-cooperative outcomes for restoration.

APPROACH

Study Sites and Experimental Design: Because my research questions are focused on the spatial patterning of ecological interactions, I have designed my field work to allow statistical testing at two different scales: A) within each orchard, to probe for relatively short-scale effects of distance to riparian forest; B) across orchards, looking for large-scale effects of the influence of the size and average distance to nearby restoration sites. A further benefit of my design is to allow comparative analyses of very different taxonomic groups across the same gradients and in response to the same factors. In other words, to give a united sense of how weeds, birds, and pests are influenced by riparian restoration, I need a single sampling plan for all these groups, while also recognizing that different methods may be required to understand patterns and relationships for each.

The first challenge to this design was identifying a sufficient number of farms on which I could be granted permission to work and that were arrayed to allow large-scale comparisons of restoration effects. I have now secured permission to work on 27 farms that range from adjacent up to eight kilometers from restored riparian habitat, and up to three kilometers from remnant riparian forests (Figure 2). Together, these allow for strong statistical tests of the large-scale effects of landscape alteration through restoration programs.

At the within-farm scale, I will use the same sampling plan on each farm, a 300m x 300m area within which I will conduct surveys for pests and pest predators. With this design, I will be able to investigate spatial data on both a large- (among farms) and small- (within farms) scale, since different taxa will respond to scale differently. In insect, mammal, and weed surveys I will collect data at 16 points within each farm's 9-ha grid, seven points at the interface between the farm and the adjacent habitat and nine points at different distances from the edge within the farm habitat (Figure 1). This will yield a total of 189 edge and 243 interior sample sites over all farms. In bird surveys I will collect data at 9 points, three on the edge and six in the interior, yielding a total of 81 edge and 162 interior sample points. Sampling will be repeated at least one to four times per year over 2 years, with the number of sampling periods varying with the taxonomic group. On a subset of 12 intensively-sampled farms, I will conduct additional surveys and pest-predator interaction experiments, using 72 edge (36 treatments and 36 control) and 72 interior (36 treatment and 36 control) sampling points. These 12 farms include four farms each that are: adjacent to remnant forest; adjacent to restored forest; and far from any forest.

I will map all farm sites using GPS in order to use GIS methods to determine how distance and size of restored habitat affects spatial distribution of pests. I will use currently available GIS data and aerial photos to determine associated habitat sizes and classifications and land use. I have conducted preliminary work on all of the methods described below and the time necessary to complete the tasks has been calculated. For example, in the bird exclosures described below, I am able to complete exclosure placement in four hours on one farm site, therefore I am able to put up all of the exclosures within six days. For the malaise trapping described below, each trap captures approximately 100 insects, which take approximately 10 person hours to complete, once familiar with the main morphospecies, therefore all of the sites take 240 person hours. These calculations have assured my mentors and me that while it is ambitious, my project plan is feasible.

Specific Hypotheses and Methods: With the overall framework just described, I now present the particular field methods that I will use to address each hypothesis. Since the analytical methods that I will use are similar for these hypotheses, I group the description of these statistical tests together after presenting the field methods. Finally, I discuss the ways in which I will address my second objective, using the information I gather as well as existing information to address the conflicts in the agricultural and conservation communities involved with the Sacramento River riparian system.

Hypothesis 1A: The abundance and diversity of herbivorous insects will be greater in walnut orchards closer to restored or remnant riparian forest

I will use malaise traps to determine the abundance and diversity of mobile arthropods at the 12 sites (Townes 1972). I will place non-directional malaise traps in the center of the 9-hectare orchard plot and in the adjacent habitat (remnant, restored or other agriculture), and will place bi-directional malaise traps on the edge between the two habitats in order to determine directional movement cross this interface (Jeanneret and Charmillot 1995). All individuals will be sorted to morphospecies, identified to family and classified to ecological guild. I will also note abundance of known walnut pests from the UC Davis IPM Webpage (Bentley et al 2005). For those individuals captured in the bi-directional malaise traps, immigrant or emigrant individuals will be identified by difference in capture rate toward and away from riparian habitat. These data will provide an estimate of rates of boundary crossing. I will also look at similarity between immigrants and emigrant morphospecies and feeding guilds at the edge. I will also use the arthropods collected from the exclosure sampling described under Hypothesis 2A below to determine more sedentary herbivorous insect diversity and abundance.

Hypothesis 1B: Proximity to restored or remnant riparian forest will not affect abundance of codling moth or navel orange worm.

At each sampling site in each farm, I will use tree banding to survey for codling moth overwintering larvae (Judd et al. 1997). Eight-cm wide strips of corrugated cardboard will be placed approximately 0.5-m off the ground around sixteen trees on each farm before diapause (between end of September and end of October,). Bands will be checked once monthly for number of codling moth larvae and any evidence of predation. Navel orange worm surveys will be conducted by collecting nuts left over after harvest. A minimum of 10 nuts and maximum of 40 nuts (depending on availability) will be collected from each tree at the 16 grid points. These nuts will be checked for presence of navel orange worm and number of navel orange worm in each nut. I will also get a complete count of number of nuts left on each tree as a co-variate. Number of leftover nuts is one cause of navel orange worm abundance (Bentley et al. 2005) and how many nuts are left in trees differs with each farm plot depending on the management (Langridge pers obs.). Nuts will be collected and examined in February over a two-week period. Preliminary data collected last February showed no relationship between distance to riparian forest and navel orange worm abundance.

Hypothesis 1C: The abundance of walnut husk fly will be greater in walnut orchards closer to remnant riparian forest, but not closer to restored riparian forest.

I will conduct surveys of walnut husk fly using sticky traps placed at each sampling point on the 27 farms (Henneman and Papaj 1999). Surveys will be conducted over a two-week period in July during the period when the adult flies have emerged. Traps will be examined for number of walnut husk fly. Six traps will also be placed in the adjacent habitat to determine use of the adjacent habitat.

Hypothesis 1D: The abundance of weed species of concern will be greater on walnut orchards closer to remnant and restored riparian forest.

I have collected plant cover and species diversity data and am currently conducting seed bank studies to investigate the spatial distribution of weeds. Above ground surveys were conducted by collecting 1-m^2 diversity and abundance data at each of the 16 points on all the 27 farms. At each of these points, I also collected a soil sample which I am currently using for a germination study. Preliminary results from above-ground surveys showed no effect of distance to remnant or restored riparian habitat. However, these surveys are highly affected by herbicide and mowing, which differs in timing and extent on each farm. Further research will be conducted on weed distribution depending on results from the seed bank study.

Hypothesis 1E: The abundance of burrowing mammal species will be greater on walnut orchards closer to remnant and restored riparian forest.

I will conduct small mammal surveys using two methods. First, in order to get a relative density of burrowing mammals among farm sites I will conduct burrow surveys on the 27 farms on three 300m transects that run from the edge into the farm on each farm. Surveyors will walk the transects and record any burrows observed within 2.5m on each side of the transect (VanHorne et al. 1997). I will measure, photograph, check for current activity through presence of tracks, scat or spider webs, and record GPS points at all burrows in the transect. Secondly, I will use tracking boards to record mammalian tracks the 12 intensively-sampled farms (Fisher and Merriam 2000). Boards will be set out at the same 16 points on this subset of farms and left for three days. Experienced mammal researchers will determine the identity of all tracks. I will use mammal data collected through the Nature Conservancy to determine how mammal distributions in the walnut farms compare to activity in the remnant and restored riparian forest.

Hypothesis 2A: The abundance and diversity of arthropod predators will be greater on walnut orchards closer to restored or remnant riparian forest.

I will use malaise traps to determine the abundance and diversity of mobile predatory arthropods at the 12 intensively-sampled farms. These methods were described under Hypothesis 1A above. I will use the arthropods captured from these surveys to determine for the orchard, edge and riparian habitat, the ratio of herbivores to predators and numbers of known natural enemies. I will also use the arthropods collected from the exclosure sampling described under Hypothesis 2B below to determine more sedentary predatory arthropod diversity and abundance.

Hypothesis 2B: Avian predators will have a stronger impact on herbivorous insects on walnut farms closer to remnant and restored riparian forest.

I will characterize the interaction between birds and insects in the farms using a combination of bird surveys, foraging observations, and experimental bird exclosures. This work will occur on the 12 intensively-sampled farms. I am conducting bird surveys using a version of the point count methodology described by Ralph et al (1995) and Reynolds et al. (1980), recording all birds detected in a 50m radius over an 8-minute survey period at nine points on each grid, each point 150m apart. I will also conduct foraging observations of the birds, utilizing the methodology of Remson and Robinson (1990). Preliminary observations demonstrate that birds move from the adjacent remnant and restored forest and capture both flying and sedentary herbivorous insects.

To experimentally determine the effect of birds on insect populations I will use branch exclosures (Figure 2), each of which is 1-m^2 in cross section by 1.5-m long will exclude birds from the foliage and branches. The exclosure will be made of a pvc pipe frame covered with monofilament netting with holes small enough so that birds can not enter, but large enough to allow passage to Lepidopteran species (Marquis and Whelen 1994). These type of exclosures have been shown to not attract arthropods or significantly reduce light (VanBael et al. 2003). Exclosures will be placed on three trees at the edge of the habitat interface and three trees in the center of the 9-ha block, for a total of 72 exclosures and 72 control branches. Control branches will be paired with these treatments by similar size, height and direction of the branch. Exclosures will be placed before bud break in mid-March and will be removed before the first pesticide spray in mid-June. I will measure insect abundance and diversity, ratio of herbivore to predator, and leaf damage at each exclosure.

Hypothesis 2C: Avian predators will have a stronger impact on codling moth overwintering larvae on walnut farms close to remnant and restored riparian forest.

I would expect that birds have a strong predatory effect on codling moth, due to the ability of birds to find and extract overwintering codling moth larvae. I will conduct feeding experiments with overwintering codling moths in order to determine how predation on this pest varies over space. In order to experimentally investigate the effect of birds on codling moth, I will place larvae at different distances from the edge of the riparian-agriculture interface. On each tree I will place nine larvae, three exposed, three caged (excluding birds), and three screened (excluding other natural predators) (Baumgartner 1999, Solomon and Glenn 1979). I have access to larvae through University of California, Berkeley.

Analytical Methods

Large-Scale Effects. To characterize the area surrounding the farm plots at different scales, I will measure the proportional area of different habitats within radii of 0.1, 0.5, 1.2, and 4km (c.f. Kremen et al. 2004). Proportional areas of riparian, river, road, almond, walnut, prune, row crop, urban and other specific habitats will be calculated using the GIS data available through the TNC on land use, habitat type and restoration age, among other variables. For arthropod analyses, I will also measure the insecticide use within the same radii. This will give me an idea of toxicity level within the area that could affect abundance of insects (Kremen et al. 2004).

I will use multiple regression on mean results from each farm to look for effects of distance to remnant and restored areas, at the same time accounting for effects of important covariates. For example, to look at abundance of birds associated with each farm to six predictor variables: distance to remnant forest, size of closest remnant patch, distance to restored forest, size of nearest restored patch, size of walnut trees, and age of restoration:

$$\text{Bird abundance} = ß_0 + ß_1(\text{remnant distance}) + ß_2(\text{size remnant}) + ß_3(\text{restored distance}) + ß_4(\text{restored size}) + ß_5(\text{walnut size}) + ß_6(\text{age restoration}) + \varepsilon_I$$

In addition, I will example these farm-level data for evidence of both geographic gradients in pest and predator numbers (Cliff and Ord 1981, Legendre 1993) that could obscure effects of riparian forests, and also autocorrelation in pest and predator numbers that could complicate interpretation of simpler statistical tests (Cliff and Ord 1981). If I do find evidence of spatial autocorrelation in farm-level data, I will use spatially-corrected versions of regression and ANOVA tests to include these effects in my analyses (Griffith 1978, 1987, Legendre 1993, Doak, unpublished results).

Within-farm effects. I will use a similar combination of parametric and spatial statistics examine the within site effects of distance to forest edge on pest abundance and predator effects. I will begin these analyses with the assumption that substantial spatial autocorrelation is likely to exist between sampling points within each farm. Thus, I will begin by estimating Moran's I values for different with-farm lag distance classes. These analyses will use only data from farms far from restoration sites, to allow autocorrelation estimates that do not include within-site restoration effects. If I find substantial autocorrelation, I will then use these results to spatially correct my data from farms that are adjacent to restored or remnant forest areas in tests of distance effects. I will also use gradient analysis methods to test for the influence of distances from forest habitats on pest and predator populations and their interactions

I will also use spatial analyses to contrast the patchiness of pest and predator numbers close to and far from riparian forest areas. Semi-variograms and partial autocorrelation results for all sample points that are at different distances from the forest edge will allow comparisons of the patterning of variance near to and far from riparian sites. I will also use spatial cross-correlation methods to examine the patterns of co-occurrence of predators and parasitoids and their prey species (Griffith 2003).

Objective 2: Dissemination of results and development of strategies for cooperation through a decision-making model and associated actions.

Data on perceptions of the agricultural community regarding positive and negative impacts of restoration were collected previously by Buckley (2004). I will present results from my research to the local community through the Sacramento River Conservation Area forum, Walnut Board meetings and articles, and other agricultural forums. At these meetings, I will conduct interviews and will ask for quantitative evaluations of how restoration impacts their farms. This data collection will be done in a similar structure to Buckley (2004) in order to combine the perceptions before and after results were presented. This information will be compiled with previous data collected by Buckley (2004) on perceptions before availability of such data of the agricultural community in the Sacramento River Conservation Area, in order to determine how the research may have changed perceptions. I have also conducted interviews of the farm owners and managers of the 27 farms where I am conducting research. I will follow-up these initial interviews with presentation of the results to the farmers and discussion of any changes in perceptions. These data will be incorporated into a strategic game theory model developed by M. Buckley.

I will also use the results from the research, the information collected from the surveys, and the game theory model to determine actions that could be taken to reduce negative impacts on farms. For example, adding bird or bat boxes to reduce both mammal and insect pest impacts. Although this research is conducted on walnut farms, many of the same issues could be applied to other crops as well.

OUTPUT AND ANTICIPATED PRODUCTS

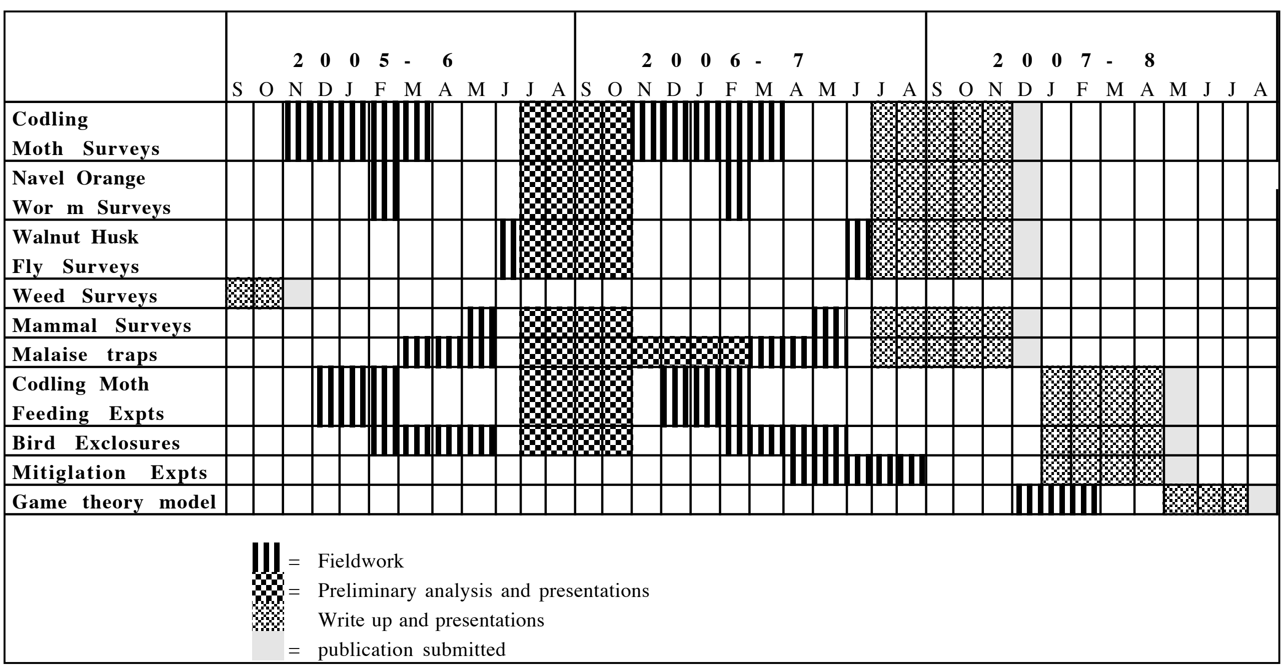
In order to disseminate information from my research, I will present findings at many conferences, including CALFED Science Conference, Society for Ecological Restoration Conference, and Ecological Society for America conference, among others. I will also use the Sacramento River Conservation Forum as a way to communicate findings within the local community. This forum was specifically designed as a way to communicate and facilitate information of concern to the local community. This work will also generate several peer-reviewed publications, including publications submitted to Ecological Applications and/or Journal of Applied Ecology for the international ecological community, Restoration Ecology and/or Conservation Biology for the conservation and restoration practitioners, and California Agriculture for the agriculture community. I will also publish findings through newsletters such as the Walnut Board notes and the UC Extension newsletter.

This fellowship will benefit me through funding, community support, and further research support. The three-year fellowship will allow me to conduct research on a scale that will fulfill the needs of the stakeholder concerns. Only completing part of the stated research will leave some areas of interest to the environmental or agricultural communities without a strong scientific basis for next steps in managing competing perceptions of restoration. This fellowship will also give me the resources necessary to communicate my findings to the many stakeholders interested in the outcomes of the research including the Bay-Delta scientific community, the agricultural community, the environmental community, the international scientific community, and local communities associated with the Sacramento River Conservation area.

My research mentor will benefit from my fellowship through a connection to the CALFED scientific community. Further, although Dr. Doak has been involved in many applied conservation projects, this is an opportunity to be involved in research that takes a larger landscape approach. Through this fellowship, he will be able to lend his expertise in spatial analysis, food web studies and conservation modeling. The community mentors will gain much needed information that they can use to focus their efforts and funds. Further, through my research, they will have a scientific basis for actions that take into account community and stakeholder concerns. Many stakeholders want their concerns to be addressed, but community mentors in both the restoration and agricultural communities often have neither the time nor resources to conduct this research. By working with mentors in both sectors and having the time to conduct solid research, I will be able to cross this divide and produce results that are strong and unbiased.

The goal of the Ecosystem Restoration Program is to “protect and restore functional habitats, including aquatic, upland and riparian, to allow species to thrive”. Negative perceptions have led to the reduction of some restoration programs and the use of funds to quell concerns, without a scientific basis to focus efforts and funds. This research directly leads to the protection and restoration of riparian habitat through a better understanding of the scientific basis for the perceptions of stakeholders within the Sacramento River Conservation Area.

<u>TIMELINE</u>



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