REQUIRED FORMAT FOR TITLE PAGE OF PROPOSAL

University Proposal #10 FOR PASSHE OFFICE USE ONLY: FPDC proposal #

Project Title: The effects of timber harvest on understory plant reproduction and pollination in south central Pennsylvania

RFP Category: 1-A Total Grant Amount Requested from FPDC: $7,919

Discipline: Biology Sub-Discipline: Ecology

Project Director (name, position, department, university, telephone number, and e-mail address):
Heather Sahli, Assistant Professor, Department of Biology, Shippensburg University, 717-477-1580, hfsahli@ship.edu

Faculty Status (see definitions below):
☐ Tenured ☒ Probationary ☐ Non-Tenure Track

Other Participants (names, departments, e-mail addresses):
N/A

IRB Status: ☐ Approved (IRB #) ☐ Pending ☒ N/A

ABSTRACT (one paragraph of approximately 150 words in non-technical language):
Timber harvest is a regular disturbance in many of Pennsylvania's forests. Michaux State Forest, which comprise more than 85,000 acres in south central Pennsylvania, actively manages forests for timber production. The effec of timber harvest on understory plants and animals has been little studied in this region of Pennsylvania. Furthermore, as most plants are dependent on insect pollinators for reproduction, disruption of pollinator habitat during timber harvest may have a resulting affect on plant reproduction. I propose to examine the effects of timb harvest on pollination of understory plant communities by comparing pollinator communities, limits to plant reproduction, and flower abundance and diversity in un-logged control sites and logged sites. This research will provide me with a better understanding of the plant and pollinator communities in Pennsylvania, allowing me to develop future research projects involving undergraduate and graduate students. Results from this work will alsc be included in curriculum development in my plant and ecology focused courses.

Endorsement: _____ 15 FEB 2010
Chair, University Faculty Professional Development Committee Date

Endorsement: _____ 15 Feb 2010
University President Date

Faculty Status Definitions:
Probationary Non-Tenured Faculty - a faculty member who is appointed to a tenure track position and who has not been granted tenure.
Non-Tenure Track Faculty - a faculty member who is appointed to service in a position in which service will not be credited toward tenure, f example Temporary Part-Time or Temporary Full-Time or Regular Part-Time faculty.

3. Project Narrative

Background and Significance

Past land-use history can have an impact on plant communities. Logging has taken place throughout much of the northeastern United States and logging is still common throughout most forested regions of Pennsylvania. State Forests comprise a large part of the remaining forest in the United States, thus much of the remaining forest diversity is found in these state lands. In Pennsylvania, the Bureau of Forestry alone owns 2.1 million acres of forest, which is roughly 15% of the forested land in the state (McWilliams et al. 2007). However, since these lands are also heavily logged, it is essential to understand how such logging practices affect the remaining forest community. Current logging practices in south central Pennsylvania focus on maximizing timber in an environmentally sensitive manner. However, little attention has been paid to the non-timber plant community comprised mostly of the shrubs and herbaceous plants in the understory. Understanding the effects of logging on understory species is important for managing forests not only for sustainable timber production, but for biodiversity as well. In general, selective logging is expected to cause an initial increase in species diversity by allowing early succession species to colonize (Thomas et al. 1999), although many of these new colonizers may be invasive weedy species, which can negatively impact the native forest community (Battles et al. 2001).

Plants are heavily dependent on animals for reproduction with roughly 80% of flowering plant species depending on animals for pollination (Tepedino 1979). Therefore, in order to manage for understory plant species, it is also important to manage for animal pollinators as well. Many insect pollinators as well as hummingbirds rely on forested habitats. A recent study found that crop plants in agricultural areas surrounded by woodlots had higher rates of reproduction than those landscapes devoid of forests (Kremen et al. 2002). This suggests that forests play an important role in maintaining pollinator diversity. However, we still know relatively little about habitat requirements of many native pollinators and there have been few studies examining the effects of forest management practices such as logging on pollinator communities in temperate forests. The few studies examining the effects of logging on bee diversity or pollination to date have found no effect of logging alone on pollinator visitation rates (Totland et al. 2006), increased exotic pollinators with increasing habitat disturbance (Morales and Aizen 2002), and increases in bees with logging (Cartar 2005; Romey et al. 2007). However, few of these studies examined how changes in pollinator communities affected plant reproduction. There have still been too few studies of this type to determine what effects logging has on reproductive success of understory plant species. Logging may increase pollinator abundance or diversity by increasing floral resources due to increasing light in the understory, or by providing warmer soil for ground-nesting species. However, logging may have a negative impact on pollinator populations if soil moisture is altered, nest sites are destroyed, or host plants die due to increased light and draught conditions. It is difficult to predict what effect logging will have on pollinator communities and plant reproduction in south central Pennsylvania.

In this study we will examine the effects of logging on plant and pollinator communities and the resulting impact this has on plant reproduction. Results from this study will have applied significance in helping to shape our understanding of how to effectively manage forests for increased plant and pollinator diversity. My previous research has focused on adaptation of flowers to pollinators and quantifying plant-pollinator interactions in a variety of native habitats in the Hawaiian islands. Being new to Pennsylvania, I do not have a good understanding of the pollinator species in this area and the factors affecting plant and pollinator communities in this region. Thus, I have experience with the general methods for conducting this work, but this proposed research will provide new information on the effects of timber harvest on pollination and will provide me with the necessary background to continue to develop a research program at Shippensburg University.

Goals and Objectives

This is my first year at Shippensburg University and in Pennsylvania. As such, this research will greatly aid in my long-term professional goals by allowing me to start a local research

program and to later build on findings from this first study. I strongly believe that this work will lead to many future studies and will result in smaller projects that students can work on with me in the upcoming years. This project will also fund an undergraduate student to collaborate on the project, providing me with the additional experience of mentoring a student and providing the student with experience conducting research. I also teach a course in Field Botany/Plant Taxonomy that entails field trips to different sites every week. This work will allow me to gain a better understanding of the plant communities in Pennsylvania, which will greatly aid in the teaching of this course. I will be able to include additional sites in field trips for this course and will be able to teach more about the factors affecting plant communities in this region.

Specific Objectives:
1. Quantify floral abundance and diversity of logged and un-logged sites in south central Pennsylvania.
2. Quantify pollinators to several plant species in south central Pennsylvania.
3. Determine the effects of logging on pollinator distributions.
4. Quantify the effects of logging on plant reproductive success.
5. Target future research projects suitable for undergraduate and graduate students.
6. Develop curriculum for Field Botany and Plant Taxonomy that includes knowledge gained from this work.
7. Publish findings from this study in peer reviewed journals and present results at the national meetings for the Ecological Society of America

Description of Project

Study sites: All study sites will be located in Michaux State Forest. Michaux State Forest is over 85,000 acres and comprises diverse habitats such as wetlands, uplands, and ridge-tops which range across an elevation gradient. Since there is such considerable variation within Michaux State Forest, all attempts will be made to select sites that are at the same elevation and that have similar plant communities. Additionally, we will pair control and logged sites so as to minimize any difference among control and treatment sites due to soil composition, slope, temperature, etc. Choosing paired un-logged and logged sites that do not differ in these environmental variables will ensure that any differences we find in pollination and reproduction are due to the effects of logging rather than environmental differences across sites. We will have a total of 14 sites: seven sites that have not been logged in the past 100 yrs (control sites) and seven sites logged 15-20 yrs ago. The forest service has detailed maps of each site that has been logged, the date of the logging, and the type of logging that was done. These maps will be used to select paired logged and un-logged sites. Control sites will be selected at a distance of at least 1km from the nearest logged sites so we may adequately characterize the effects of logging on pollinator communities. Preliminary examination of state forest maps indicates that we will be able to find seven control sites that are at least 1km from the nearest logged site.

Floral abundance and Diversity: To determine how logging affects abundance and diversity of nectar and pollen resources, we will quantify the number of floral units open within each of the 14 sites. We will use a stratified random sample of 15 circular 25m^2 plots at each site, counting the number of flowering individuals and the number of open floral units for each species in each circular plot. Circular plots will be randomly located along evenly spaced transects at each site. Quantification of floral resources will be done three times throughout the field season, during late May/early June, late June, and late July. This will allow us to test whether any differences we find in pollinator communities are related to differences in abundance and diversity of floral rewards, and how logging affects flower abundance and diversity of the understory plant community.

Pollinator and Plant Reproduction Monitoring: Several techniques will be used to monitor pollinators and plant reproduction. To determine how logging affects pollinator assemblages, we will use video cameras to record visitation rates and visitor composition to flowering species in the community. I have experience using video cameras to conduct pollinator observations and it is possible to get clear video footage documenting the number of visits to flowers during a time period as well as identification of the floral visitor to at least the family or genus level. Using video cameras will allow us to collect pollinator observation data while we are simultaneously conducting our floral abundance surveys. Direct pollinator observations will also be carried out for a total of at least 10 hours of observation (video and human observation combined) at each site. Pan traps, consisting of red, yellow, white, and blue plastic bowls filled with a solution of soapy water, will also be set out to catch pollinators. These traps are widely used as a method for quantifying pollinator communities, as insects are attracted to the brightly colored bowls and fly into the solution (Aizen and Feinsinger 1994, Wilson et al. 2008). Fifteen trap locations (with one of each bowl color at each trap location) will be regularly dispersed throughout each site during seven days of the study period to characterize the potential flower-visiting insect community at each site. All insects collected from traps will be identified and stored at Shippensburg University, and will serve as a reference collection for identifying insects in the video footage as well as a reference collection for future studies. Pollinator diversity will be calculated as species richness (the total number of pollinator species in a site) and using the Shannon-Wiener diversity index, which takes into account species richness as well as the abundance of each species (Magurran 1988). Pollinator abundance and diversity in pan traps will be compared using an ANOVA with logging, bowl color, and paired sites (random factor) included as independent variables. Abundance and diversity of animals visiting flowers will be analyzed using an ANOVA with logging and paired sites (random factor) as dependent variables.

Non-metric multidimensional scaling (NMS) will be used for ordinating both insect and floral diversity using PC-ORD (McCune and Mefford 1999). Ordination will be used to plot communities of plants and insects for each site to analyze whether floral communities and pollinator communities at logged sites are more similar to each other than those at un-logged sites.

We will determine how differences in pollinator communities across logged and un-logged sites affects plant reproduction in two ways. Using our pollinator observations, we can compare how many animal-visits flowers get across sites to determine if logging reduces, increases, or has no affect on rates of visitation to flowers. While visitation rates may sometimes be related to plant reproduction, plant reproduction may be limited more by resources rather than by the amount of pollen they receive (Knight et al. 2006). In other words, increasing the number of visits to a flower, and thus increasing the amount of pollen brought to the flower, may not necessarily increase the number of seeds a plant produces if the plant does not have enough nutrients to produce a large quantity of seeds. Therefore, we will use hand pollinations to test to what extent plant reproduction at different sites is limited by the amount of pollen they receive (i.e., pollinator visitation; Kearns and Inouye 1993; Knight et al. 2006). We will select two plant species to work with at each site, choosing those plant species that are present at both the logged and the paired un-logged site. Common plant species found in both un-logged and logged sites that we may use for hand pollinations are mountain laurel (*Kalmia latifolia*, flowers May-early June), one of several blueberry species (*Vaccinium*, flowers in May) or huckleberry species (*Gaylussacia*, flowers in May), or teaberry (*Gaultheria procumbens*, flowers in July). Species will be chosen based on whether there are enough flowering individuals present in each population, and attempts will be made to use the same species for each of the 14 sites. Fifteen individuals dispersed throughout each site will be tagged. We will collect pollen from several other individuals in the population, and will use this collected pollen to hand-pollinate all open flowers on one flowering branch on each of the 15 tagged plants. A different flowering branch

on the same plant will be tagged and left alone. For small plants with few flowers, such as teaberry, a more appropriate method is to hand pollinate all flowers on a plant, and compare seed production to plants that have not been given supplemental pollen. Thus, in this case, 30 plants will be chosen and half will be given supplemental pollen (Knight et al. 2006).

After fruits have matured, we will harvest the control and hand-pollinated branch on each of the tagged plants and count the number of fruits matured and the number of seeds produced per flower on each branch. The difference between the number of fruits and seeds produced on control branches versus those that were hand-pollinated will be compared. If branches that received supplemental pollen produce more seeds than those that were naturally pollinated, this indicates that plant reproduction is limited by pollinator visitation. If there is no significant difference between treatments, this indicates that plant reproduction is not limited by pollinator availability. We will use several paired t-tests to determine if plants at each site are pollen limited. To test whether plants at logged sites are more pollen limited than plants at un-logged sites, we will obtain the average seed difference between pollen supplemented branches and naturally pollinated branches for each site, which is the mean pollen limitation at each site. Mean pollen limitation will be compared across logged and un-logged sites using an ANOVA, again with logging treatment and paired site (random variable) as dependent variables.

I will hire an undergraduate student to help me with all aspects of the fieldwork and the analysis. I have experience training undergraduate students with no prior experience to conduct all of the field techniques described above.

Timeline:

Quantification of floral abundance and pollinator observations will begin in late May. Pollinator observations and pollinator collecting will take place from late May to late July. Hand pollinations will be conducted when large numbers of flowers are blooming on the species chosen, likely from late May-July. Mature fruits will be collected during August-September and seeds counted during November-February.

Expected Outcomes This work will aid in my professional development by providing me with the opportunity to get my research started at Shippensburg University. Establishing a local research program and getting students involved in this research is essential for my continued success at Shippensburg University. This research will allow me to work with local agencies such as the Forest Service and the Pennsylvania Natural Heritage Program, which will pave the way for future collaborations. I foresee great potential for this work to lead to future studies in my lab that will be conducive for both undergraduate and graduate students. Other projects that may result from this work are examining the mechanisms behind any differences found during this study, effects of invasive species on native plant communities, competition among plants for pollinators, and the effects of logging on genetic diversity of native plant species. Depending on results from this work, I may collect similar data from additional sites during the summer of 2011 if an increased sample size is necessary. In the future I also expect to examine successional changes in forest re-generation after logging by quantifying changes in plant communities across a number of sites logged during different years. By providing me with the resources needed to establish a research program, this grant will allow me to attract more undergraduate and graduate students to conduct independent research with me in the future. Results from this work will be incorporated into the curriculum of my Field Botany/Plant Taxonomy course, as well as my non-majors course, Introduction to Ecology.

I fully intend to publish findings from this research in peer-reviewed journals such as *Oecologia* (an ecological journal) and *Forest Ecology and Management*. I also expect to present findings from this research at both local meetings for the Pennsylvania Academy of Science and the Commonwealth of Pennsylvania University Biologists, and regional meetings such as the Ecological Society of America's annual meeting. All students working on this project will be

expected to take part in presenting at these meetings and will be included on manuscripts resulting from this work. This research will provide me with a better understanding of the local plant and pollinator communities and the factors affecting the distribution and abundance of these species. This work will also provide information on the pollinators of a variety of plant species in the forests on South Mountain, about which little is known. This research will be done in cooperation with managers of Michaux State Forest, who will be able to use results from this work for future management plans.

4. Assurance of compliance with university research requirements - N/A
5. Project Budget -

BUDGET SUMMARY

Project Budget	Proposed Grant	University Contribution	Other Revenue Sources	Totals
Salaries/Stipends	$4000			
Student Wages	$2175			
Benefits	XXXXXX	$888		
Supplies	$47			
Equipment	$1057			
Travel	$640			
TOTALS	**7919***	**$888**		**$8807**

Budget Notes

Salaries/Stipends: Two months of summer salary for June and July during which time I will be carrying out the fieldwork for this project.

Student Wages: One undergraduate student will be hired to collaborate and help with the fieldwork, including conducting pollinator observations, pan trapping, and hand pollinations. The student will work for a total of 10 weeks during May-July, working 30 hrs/week @ $7.25/hr. I will advertise and interview for this position, looking for a Shippensburg student majoring in Biology.

Benefits: $720 (18% of salary) + $168 (7.7% of student wages)
Travel: Roundtrip, we will travel approximately 32 miles per day to reach our field sites. We will visit sites four days/week for 10 weeks for a total of 40 days. This equals 1280 miles total. The current mileage rate is $0.50 per mile, which totals $640.

Supplies: Flagging tape (5 rolls @ 2.10 ea=$10.50), lab tape (2 packs @$13.10 ea)=$26.20, paint brushes (for pollination=$10)

Equipment: Two camcorders for conducting pollinator observations @ $250 each=$500. Sony VCTR640 Light Weight Tripod (2@ $29 each=$58). Two camcorder long-life batteries ($100). Mini-dv cassettes=$20; 2 meter tapes ($40 ea)=$80. Software: $299 PC-ORD, an ordination software package

Curriculum Vitae

HEATHER F. SAHLI
Department of Biology, Shippensburg University, Shippensburg, PA 17257
Phone: 717-477-1580 email: hfsahli@ship.edu

EDUCATION

MICHIGAN STATE UNIVERSITY	Ph.D. in Plant Biology (Ecology)	2006
COLLEGE OF WILLIAM AND MARY	B.S. in Biology and B.A. in English	2000

PROFESSIONAL EXPERIENCE

Assistant Professor: Biology Department, Shippensburg University,		2009-Present
Postdoctoral Researcher: University of Hawaii-Manoa	Pollination Webs	2007-2009
Instructor: University of Hawai'i-Hilo,		Fall 2006
Instructor: Michigan State University		Fall 2005

Mentored NSF sponsored REU students Katie Szekely (2003), Steve Howe (2004), Allison Lale (2005) and MSU undergraduate student Lisa Robertson (2004); University of Hawai'i-Hilo Keaholoa interns 'Alohi Gronquist (2007) and Pohai Patterson (2008); NSF REU students Jonathan Koch (2007), Chandra Legdesog (2008), and Lan Truong (2008)

TEACHING EXPERIENCE/COURSES TAUGHT

Evolution, Introductory Biology Laboratory (majors and non-majors), Field Botany/Plant Taxonomy, Introduction to Ecology (non-majors), Basic Biology, Problems of the Environment

AREA OF RESEARCH SPECIALIZATION

Plant Ecology and Evolution: plant pollinator interactions, population genetics, floral adaptations, plant reproductive success

RESEARCH GRANTS

2007-2008 Hawai'i EPSCoR Research Enhancement Activities Program. ($24,000)
Quantification of floral traits across native Hawaiian plants for future studies on the evolution and ecology of pollination in Hawai'i. Heather Sahli (PI) and Don Drake

2006-2007 Hawai'i EPSCoR Research Enhancement Activities Program. ($24,960)
Development of microsatellite (SSR) markers for ecological and evolutionary studies of the model tree species, Metrosideros polymorpha. Heather Sahli (PI) and Elizabeth Stacy

2005 Dissertation Completion Grant, Michigan State University ($4,000)

2004-2007 NSF, Dissertation Improvement Grant ($12,000)

PUBLICATIONS (peer-reviewed)

Conner, J.K., **H.F. Sahli,** and K. Karoly. 2009. Tests of adaptation: functional studies of pollen removal and estimates of natural selection on anther position in wild radish. *Annals of Botany* 103: 1547-1556.

Sahli, H.F., J.K. Conner, F.H. Shaw, S. Howe*, and A. Lale*. 2008. Adaptive differentiation of quantitative traits in the globally distributed weed, wild radish (*Raphanus raphanistrum*). *Genetics* 180: 945-955

Crawford, N.G., C. Hagen, **H.F. Sahli,** E. Stacy, and T. C. Glenn. 2008. Fifteen polymorphic microsatellite loci from *Metrosideros polymorpha* (Myrtaceae: Myrtales), a model species for ecology and evolution. *Molecular Ecology Resources* 8: 308-310.

Sahli, H.F. and J.K. Conner. 2007. Visitation, effectiveness, and efficiency of 15 genera of visitors to wild radish, *Raphanus raphanistrum* (Brassicaceae). *American Journal of Botany* 94: 203-209

Sahli, H.F. and J.K. Conner. 2006. Characterizing ecological generalization in plant-pollination systems. *Oecologia* 148: 365-372

Strauss, S. Y., **H. Sahli**, and J.K. Conner. 2005. Toward a more trait-centered approach to diffuse (co)evolution. *New Phytologist* 165: 81-90.

Sahli, H.F. and S. Ware. 2000. Oviposition sites and emergence habitats of 13-year periodical cicadas (Brood XIX) in Eastern Virginia. 2000. *Virginia Journal of Science* 51: 187-194

In Review:

Conner, J.K., K. Karoly, C. Stewart, V. Koelling, **H.F. Sahli,** A. Monfils, L. Prather, and F.H. Shaw. Rapid independent trait evolution despite a strong pleiotropic genetic correlation. *American Naturalist.*

Sahli, H.F. and J.K. Conner. Testing for trade-offs and non-additive selection: Floral adaptation to multiple pollinators through male and female fitness. In revision for *Evolution*

Book Contracts:

Sahli, H.F. and D.E. Powless. *Wildflowers of the Great Lakes Region*. University of Michigan Press.

* denotes undergraduate students

PAPERS PRESENTED

Sahli, H.F., D. Drake, A. Taylor, T. Fukami, and E. Stacy. 2008. Changes in pollination along an elevation gradient. Ecological Society of America (ESA) Annual Meeting

Koch, J.B.* and H.F. Sahli. 2008. Pollination webs in Hawaiian ecosystems across elevation and succession. ESA Annual Meeting.

Sahli, H.F., D. Drake, A. Taylor, T. Fukami, and E. Stacy. 2008. Changes in pollination along an elevation gradient. Hawaii Conservation Conference

Sahli, H.F., D. Drake, A. Taylor, T. Fukami, and E. Stacy. 2007. Characterizing plant-pollinator interaction webs in the Hawaiian islands. National NSF EPSCoR, Annual Meeting

Sahli, H.F. 2007. The importance of day and night pollinators to the reproduction and evolution of dame's rocket (*Hesperis matronalis*). ESA Annual Meeting

Sahli, H.F., D. Drake, A. Taylor, T. Fukami, and E. Stacy. 2007. Hawaiian pollination webs: Quantifying connections between Hawai'i's plants and pollinators. Hawai'i Conservation Conference

Sahli, H.F., J.K. Conner, S. Howe*, and F. Shaw. 2005. Population differentiation at a global scale: Examining adaptation of wild radish through comparisons of F_{ST} and Q_{ST}. Society for the Study of Evolution (SSE) Annual Meeting

Sahli, H.F. and J.K. Conner. 2004. Floral evolution in wild radish (*Raphanus raphanistrum*) in the presence of multiple agents of selection. SSE Annual Meeting

Sahli, H.F. and J.K. Conner. 2003. Is a Jack-of-all-Trades a Master of None? A study of adaptation to different pollinators of wild radish (*Raphanus raphanistrum*). SSE Annual Meeting

7. References

Aizen, M.A., and P. Feinsinger. 1994. Habitat fragmentation, native insect pollinators, and feral honeybees in Argentine 'Chaco Serrano'. Ecological Applications 4: 378-392.

Knight, T.M., J.A. Steets, and T.L. Ashman. 2006. A quantitative synthesis of pollen suplementation experiments highlights the contribution of resource reallocation to estimates of pollen limitation. American Journal of Botany 93: 271-277.

Battles, J. J., A. J. Shlisky, R. H. Barrett, R. C. Heald, and B. H. Allen-Diaz. 2001. The effects of forest management on plant species diversity in a Sierran conifer forest. For. Ecol. Manage. 146:211-222.

Cartar, R.V. 2005. Short-term effects of experimental boreal forest logging disturbance on bumble bees, bumble-bee pollinated flowers and the bee-flower match. Biodiversity and Conservation 14: 1895-1907.

Kearns, C.A. and D.W. Inouye. 1993. Techniques for pollination biologists. University Press of Colorado, Niwot, CO.

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Magurran, A. 1988. Ecological diversity and its measurement. Croom-Helm Limited, London.

McCune, B., and M. J. Mefford. 1999. PC-ORD. Multivariate analysis of ecological data. 4. MjM Software Design.

McWilliams, W. H., S. P. Cassell, C. L. Alerich, B. J. Butler, M. L. Hoppus, S. B. Horsley, A. J. Lister, T. W. Lister, R. S. Morin, C. H. Perry, J. A. Westfall, E. H. Wharton, and C. W. Woodall. 2007. Pennsylvania's Forest 2004. USDA Forest Service, Newtown Square, PA.

Morales, C. L., and M. A. Aizen. 2002. Does invasion of exotic plants promote invasion of exotic flower visitors? A case study from the temperate forests of the southern Andes. Biol. Invasions 4:87-100.

Romey, W. L., J. S. Ascher, D. A. Powell, and M. Yanek. 2007. Impacts of logging on midsummer diversity of native bees (Apoidea) in a northern hardwood forest. J. Kans. Entomol. Soc. 80:327-338.

Tepedino, V. J. 1979. The importance of bees and other insect pollinators in maintaining floral species composition. Great Basin Naturalist Memoirs 3:139-150.

Thomas, S. C., C. B. Halpern, D. A. Falk, D. A. Liguori, and K. A. Austin. 1999. Plant diversity in managed forests: understory responses to thinning and fertilization. Ecological Applications 9:864-879.

Totland, Ø., A. Nielsen, A. L. Bjerknes, and M. Ohlson. 2006. Effects of an exotic plant and habitat disturbance on pollinator visitation and reproduction in a boreal forest herb. Am. J. Bot. 93:868-873.

Wilson, J.S., T. Griswold, and O.J. Messinger. 2008. Sampling bee communities (Hymenoptera: Apiformes) in a desert landscape: are pan traps sufficient? J. of the Kansas Entomol. Soc. 81: 288-300.

8. Previous FPDC grants and outcomes: N/A

9. Letters of endorsement: N/A

10. Any other contract documents: N/A