

The Effects of Forestry Management on Bee Communities

A Senior Thesis

Presented to the Faculty of the Department of Biology  
Bates College

In partial fulfillment of the requirement for the  
Degree of the Bachelor of Science

By  
Celine Pichette

Lewiston, Maine  
April 2017

## Acknowledgements

Thank you to everyone who helped me throughout this process. An extra special thanks to my advisor Carla Essenberg and Kenauk Nature!

## ABSTRACT

Forestry is a multi-billion dollar industry in Canada and it is important for conservation biologists to consider the impacts of forestry practices on bee communities. The aims of this research were to study the bee abundance, bee richness, and plant-pollinator relationships found in three different forestry management practices (clear cut, strip cut and old growth). The old growth sites had the lowest number of flower-bee interactions, strip cut the second highest and clear cut with the most interactions. Clear cut sites had the highest species abundance of the three sites. Strip cut sites had second highest, and old growth had the lowest abundance. Without knowing total species richness, it is hard to discern which site type promotes the highest species richness. Our data suggests that bees proliferate in open, sunny, disturbed areas, such as the clear cut and strip cut sites; yet, species composition differ between the old growth sites (limited sunlight and floral resources) and the strip cut and clear cut sites. A challenge facing forestry is how to conserve biodiversity while meeting the demand of production.

## INTRODUCTION

Plant-pollinator networks are critical for a functioning ecosystem. Pollination is required for seed production, seed hybridisation, and it increases both fruit and seed production and quality (Corbet et al. 1991). Most flowering plants depend on animal pollinators (such as bees) to reproduce sexually; therefore without pollination by animals humans would not have food or plant products (Buchmann 1996). It is estimated that humans depend on animal pollination for about one third of the food they eat (O'Toole 1993). It has been estimated that 60-70% of flowering plants, worldwide, are dependent on insects for pollination and that bees are the principal pollinating group in most geographic areas (Richards 1986). A conservative price point placed on the annual value of pollination for crop systems in the U.S in 1997 was estimated at 40 billion dollars (Pimentel et al 1997). For global agriculture, the estimated value is 200 billion dollars (Richards 1993). Those values have most certainly increased as national and international population levels have surged since the 1990s (Roser and Ortiz-Ospina 2017). Declines in pollinator populations and diversity is a threat to ecosystems and the economy, yet the decline can be slowed through conservation efforts (Mader and the Xerces Society 2011).

One of the underlying factors causing disruptions to land and consequently pollinator declines is fragmentation. Fragmentation creates small populations from once continuous, larger ones. Issue that arise for plants from fragmentation include increased genetic drift and increased spatial isolation both of which harm pollination (Kunin 1993). Fragmentation can further reduce pollinator services if the local pollinator population decreases enough or wide-ranging pollinators avoid small, fragmented plant populations (Kearns et al. 1998). Furthermore, fragmented lands result in a loss of wild vegetation supporting pollinators, fewer nesting areas for bees, and less varied microhabitats for egg laying and larval development (Kevan 1998, O'Toole 1993). Fragmentation has largely been studied in relation to agricultural and land development, but not to forestry practices. The effects of fragmentation from forestry practices are likely to be less severe, as habitat fragmentation caused by forestry managements results in a conversion of vegetation rather than a complete loss of it.

There are different types of forestry loss. The most known method is clear cutting, which removes every tree in a designated plot of land. A more sustainable practice is strip cutting, which cuts down trees in strips, leaving buffer zones of trees in between the strips. Old growth habitats are areas where trees have never been logged. It is not known how or if bees are affected

differently by the varying types of forestry management. It has been observed that herbaceous plant species compositions remain different in recently established forests even hundreds of years after re-establishment. Younger forests which have had physical contact with older woods were significantly richer in vascular plant species than isolated newer forests, and significantly poorer than ancient forests. (Peterken and Game 1984). Peterken and Game's (1984) results suggest that the floral composition of a site which has been clear cut and naturally regrow will never resemble its older counterparts nor be as species rich, and that strip cuts should have more floral diversity due to their contact with surrounding older forests. Taki et al. (2007) found forest loss to have a significantly negative impact on bee communities and seed sets in self-incompatible plant populations, which potentially could lead to local loss of sensitive bee species and their respective plants. Non-disturbed areas are best for nesting and specialised plants; whereas disturbed areas have more sunlight and flower abundance, but not necessarily flower diversity. Generalists do better in disturbed lands, but the desired outcome is to increase specialist bee populations. Forests offer protected areas for native plants to grow and pollinators to nest and forage in (Winfree et al. 2007). Pollinators are diverse and are likely to have varied responses to the different forestry management types.

The aim of this research is to get a general biodiversity survey of hymenoptera pollinators and to study the plant-pollinator relationships found in different forestry management practices (strip cut, clear cut, and old growth). Not a lot is known about pollinators in forest contexts as most research has looked at disturbances made by monocultures and farm lands. Forestry practices are unlike farms because the biota on the land is converted rather than entirely lost. Research was undertaken at the Kenauk Institute situated on the largest private fish and game reserve in North America. The Kenauk Institute is 65,000 acres of pristine, privately owned land between Montreal and Ottawa in Montebello, Quebec. The land has been protected (and therefore never developed) through private ownerships since the King of France originally granted this land to Francois de Laval in 1675. Boasting more than 60 lakes, a pristine watershed, and a wildlife corridor the Kenauk Institute is an ideal location to study native bees and plant-pollinator networks in an undisturbed environment that has recently been introduced to logging. A select number of sites on this property were sampled to generate a snapshot of the pollinator community on the property as a whole and also within the various forestry management sites.

## METHODS

### *Location and Date*

Research was undertaken at the Kenauk Institute, privately owned land between Montreal and Ottawa in Montebello, Quebec. Kenauk is an ideal location to study bees and plant-pollinator networks due to its undisturbed environment that has recently been introduced to logging. The study started at the beginning of June and ended mid-August. It was the warmest and driest summer on record.

### *Site Descriptions*

Three different forestry management techniques (strip cut, clear cut and old growth) are present on the property and were the focus areas for sample sites. Each forestry type had 3 sample sites, for a total of nine sample sites (Figure 1). Table 1 lists the flora surrounding each sample site. The sites varied in distances from one another. All three clear cut sites were clustered approximately 500 meters from one another. Two of the three strip cut sites were 2km apart, the third was roughly 15 km north and was the most isolated of the sampling sites. The old growth sites followed a straight line where the second old growth site was in between the first and third.

### *Data Collection*

Time was standardized, not the data collection area. Each site was allocated an hour, so 60 minutes would be divided by the number of people netting that day. For example, if six people went, only ten minutes would have to be spent netting at that site. Our sampling areas were determined by flower distribution. We netted where the surrounding flower density was highest at that time, which continually changed as the summer progressed. The areas were usually no larger than 100m x 100m. All nine sample sites were visited once a week between 9:00 and 16:00. Each person netting caught bees seen on a flower, wrote down the flower on a label and placed both in a vial. The bees were all be pinned for later identification. Unknown flowers which bees were caught on were dug up, brought back and frozen to later be identified.

## *Statistical Analysis*

All statistical analysis' were computed using RStudio and graphs were made on Prism 7 software.

### Species Richness

The abundances at each site type were significantly different and therefore to directly compare species richness at each site abundance needed to be adjusted. The observation orders were randomized within each site to generate 1000 randomised data sets. The cumulative number of species at each observation (i.e. weeks 1-9) was recorded for each randomised order. This cumulative number of species was averaged across the randomised data sets. The average cumulative number of species was plotted on the y-axis versus the cumulative number of bees observed on the x-axis. I calculated cumulative number of bees observed by averaging the abundance for all observations within a site and multiplying it by the number of observations. These methods were taken from *Biological Diversity* (Magurran 2011).

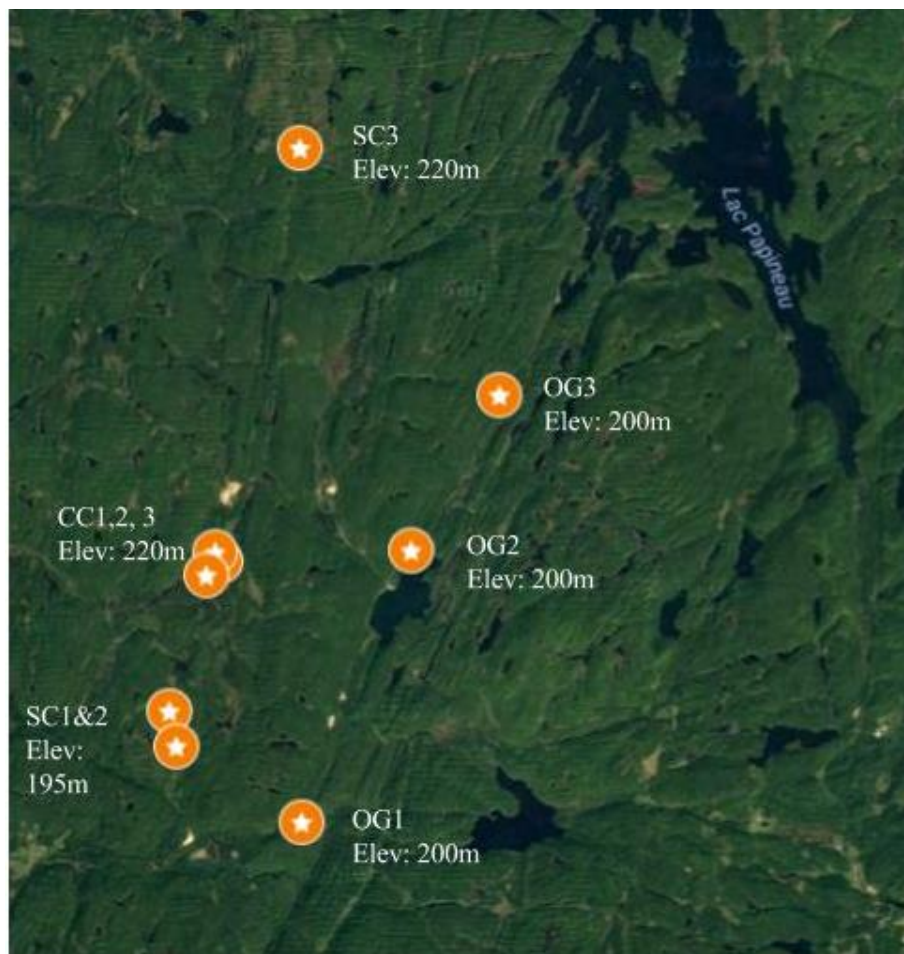
### Abundance Analyses

Several analyses were run to discern whether spatial and temporal factors required consideration. The raw data was not normally distributed, so a log transformation was used. A variogram, generated using the gstat library (Pebesma 2016), showed that there was no spatial correlation. To test for temporal correlation I compared the results the following tests using Akaike's information criterion (AIC): an ANOVA, which assumes no correlation between spatial and temporal proximity, a generalized least squares (GLS) model assuming a compound symmetry residual correlation structure in which error within each site is correlated (see Zuur et al. Ch. 6, p. 148), a generalized least square model assuming spherical (SGLS), exponential (EGLS), Gaussian (GGLS), linear (LGLS), ratio (RGLS) temporal residual correlation structure (Zuur et al. Ch. 7 pp.166-7). Both the ANOVA and the LGLS tests performed equally well and substantially better than the other models:  $AIC_{LTCS} - ANOVA = 1.8$ ; whereas  $AIC_{GTCS} - ANOVA = 8.5$ . Both models supported the same conclusions about abundance. We present the results from the LGLS test. The results assuming linear temporal residual correlation structure were used, as there was not much difference from the results of the GLS tests and the ANOVA. A natural log transformation was used to normalize the data. A likelihood ratio test was used to determine whether abundance differed across site types. A multiple comparisons Tukey test was run to give

pairwise comparisons (Hothorn et al. 2008). The gls library was used in the data transformation (Pinheiro and Bates 2016).

### Network plots

The bipartite library (Gruber 2016) was used to make bee-flower interaction plots. To make the interaction plots, all the data from site types was pooled and graphed using the plotweb function in RStudio.



**Figure 1: Location and elevation of each sampling site at Kenauk Nature, Montebello QC.** All the sites sampled at are indicated by stars. CC=Clear Cut; SC=Strip Cut; OG=Old Growth.

**Table 1: Flora surrounding each site type**



	Clear Cut	Strip Cut	Old Growth
<i>Fagus grandifolia</i>		X	X
<i>Acer rubrum</i>	X	X	
<i>Acer saccharum</i>		X	X
<i>Betula alleghaniensis</i>		X	X
<i>Achillea millefolium</i>	X	X	
<i>Prunella vulgaris</i>	X	X	
<i>Fraxinus americana</i>	X	X	X
<i>Leucanthemum vulgare</i>		X	X
<i>Pilosella aurantiaca</i>		X	
<i>Hieracium caespitosum</i>		X	
Onagraceae yellow		X	
<i>Erigeron annuus</i>		X	X
<i>Diervilla lonicera</i>	X	X	
<i>Tilia americana</i>		X	X
<i>Rubus idaeus</i>	X	X	X
<i>Fragaria vesca</i>	X	X	
<i>Quercus rubra</i>		X	X
Poaceae Plants	X	X	X
<i>Picea glauca</i>	X	X	X
<i>Polygonum scandens</i>		X	X
<i>Viburnum lantanoides</i>		X	X
<i>Cirsium arvense</i>		X	X
<i>Fraxinus americana</i>	X	X	X

## RESULTS

### *Bee Abundance per Site Type*

Clear cut sites had the highest abundance of the three sites, almost four times higher than the old growth sites (GLS, effect of site type:  $p < .0001$ ; Tukey Test clear cut versus old growth comparison:  $p < 0.001$ ; Figure 2). Strip cut had the second highest, almost two and a half times higher than old growth (Tukey Test strip cut versus old growth comparison:  $p = 0.003$ ; Figure 2).

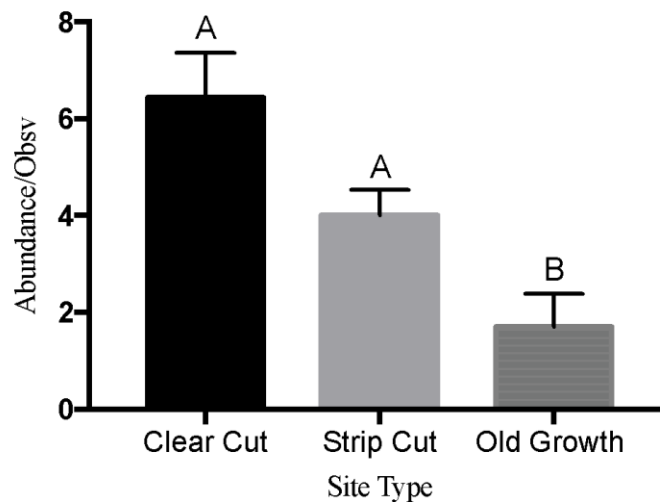


Figure 2. Average abundance (+SD) of bees caught within each forestry management type from May to August at Kenauk Nature in Montebello, QC.

### *Bee Richness*

New species were observed at the last data collection, implying that not all species were sampled (Figure 3). The species accumulation curves would level out when true species richness is attained. Two different trajectories are seen, yet there is no good evidence to indicate a difference in species richness based on management type; the old growth curves overlap with both clear cut and strip cut sites, and it is possible that, over time, all three site types may settle with similar results. Due to abundance differences at each site type in the raw species data, it would have been misleading to compare species richness; the number of species observed in both strip cut (28 bee species) and clear cut (30 bee species) sites was greater compared to bee species observed in old growth sites (15 bee species). Largely, this was because the abundance at clear cut and strip cut sites were significantly higher than the abundance collected within old growth sites. Only when true species richness is attained can species richness be compared across the

site types. True species richness would be attained when the trajectories in Figure 3 have leveled out.

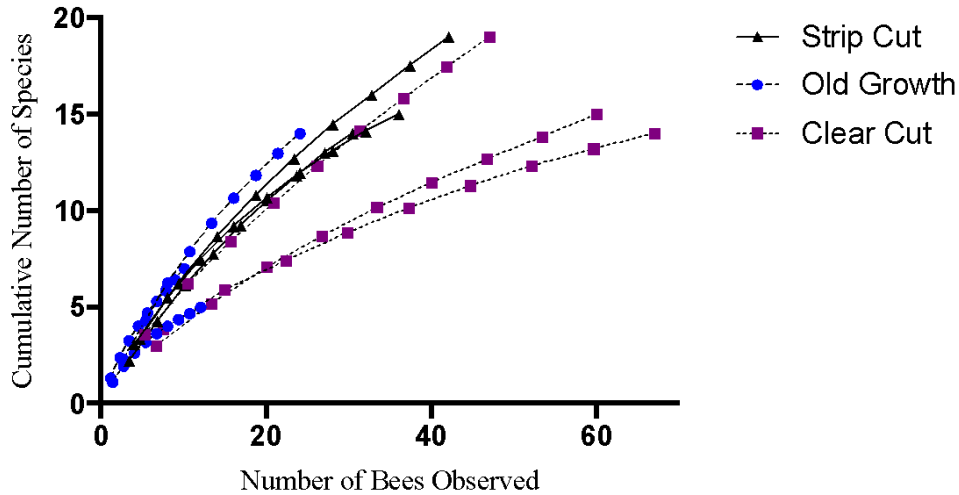


Figure 3. Cumulative number of bee species (x-axis) relative to the number of bees observed at each site type (y-axis). The data points on the graph represent the means across 1000 random permutations of the multiple species that could have been found at one day of observation at one site.  $n=9$  for each site and bees were caught over nine weeks from May-August at Keauk Nature in Montebello, QC.

### Bee-Flower Interaction Plots

There was a pronounced difference in the number of observed flower-bee interactions between the clear cut, old growth and strip cut sites. The old growth sites had the lowest number of observed links, strip cut the second highest observed number of interactions and the most flower-bee interactions were observed at the clear cut sites (Figure 4).

The largest representation of bees in both strip cut and clear cut sites is by *Bombus terminalis* and *Bombus vagans*; whereas the largest constituents of bees in the old growth sites are *Augochlora pura* and *Ceratina calcarata* (Figure 4).

Strip cut and clear cut sites had, respectively, 19 and 18 different flower species, almost twice as high as the number found in old growth sites. Old growth had eleven different flower species observed across all three sites (Figure 4).

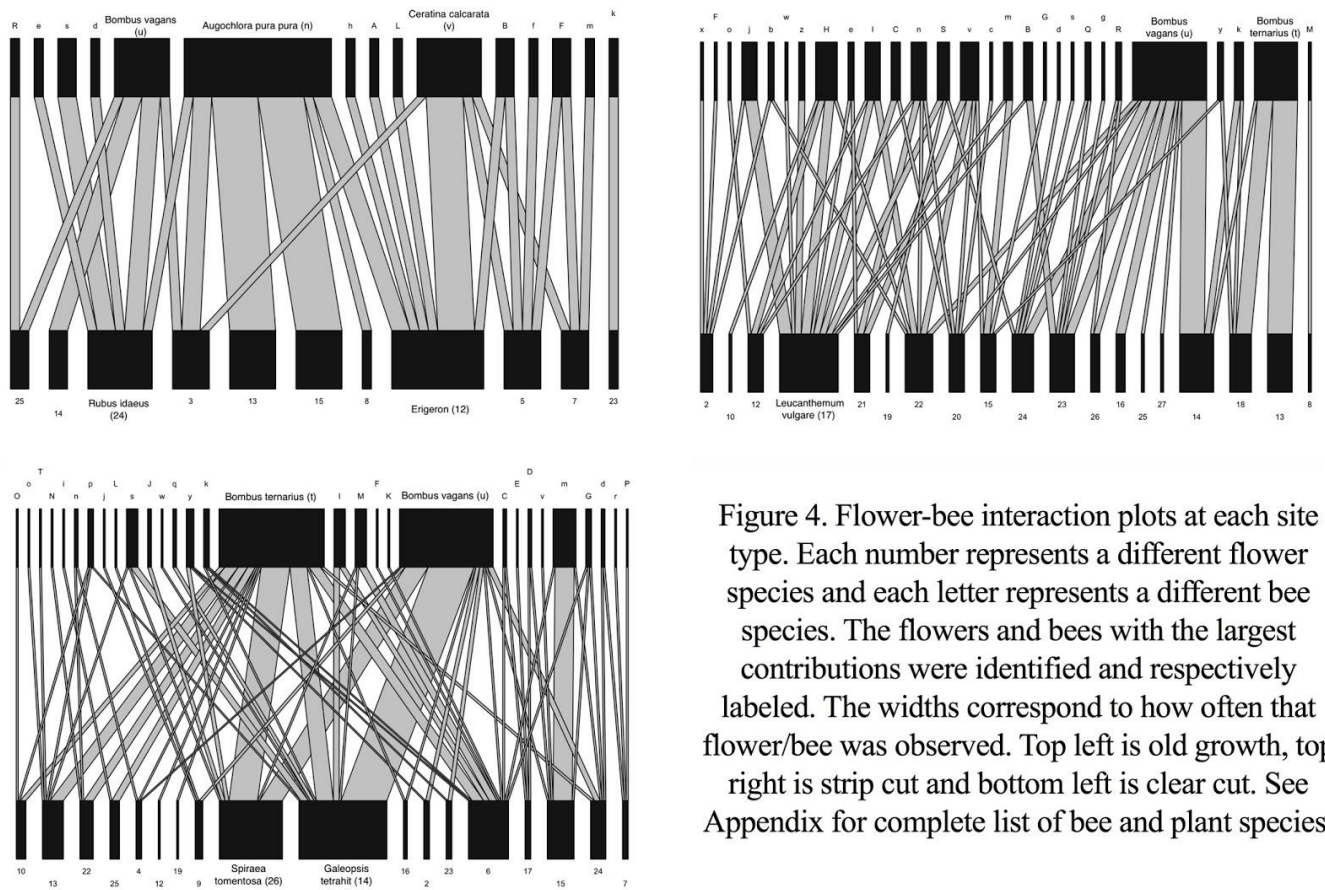


Figure 4. Flower-bee interaction plots at each site type. Each number represents a different flower species and each letter represents a different bee species. The flowers and bees with the largest contributions were identified and respectively labeled. The widths correspond to how often that flower/bee was observed. Top left is old growth, top right is strip cut and bottom left is clear cut. See Appendix for complete list of bee and plant species.

## DISCUSSION

Bees, like any organism, depend heavily on their immediate environment for survival and forestry management can therefore impart large repercussions on bee communities. Bee species' composition and abundance differed across site types. Further data collection is needed to get closer to the total species richness, and consequently better ascertain whether a site type promotes higher species richness over another.

While the most abundant bee species differed at each site type, clear cut and strip cut sites clearly possessed higher overall abundances. Forestry practices like clear cutting and strip cutting often offer open and early successional stages habitats, which generates new floral and habitat resources for bees (Yamaura et al. 2012). Other studies with similar bee abundance results in silvicultural settings include: Taki et al. (2013) observed higher abundances in early successional stages than in mature successional stages and Winfree et al. (2011) detected a negative relationship between areas of extensive forests (such as old growth sites) and species abundance. Potts et al. (2003) found that bee abundance is positively linked with habitats with abundant flowers which can partition available resources. The habitats with the greatest energy (such as pollen and nectar) are able to support the largest bee colonies. They say it is possible that the previous season's floral abundance may be a better predictor of the current season's bee abundance, so there is a chance that our abundance results are linked to last year's floral resources.

Floral richness may be an important indicator to bee composition, similar to flower abundance being an important indicator of bee abundance. The differences in bee species compositions were largely observed between the old growth sites and the strip cut and clear cut sites. Potts et al. (2003) observed that newly disturbed lands create new opportunities for plants such as flowers and that flower diversity is a defining characteristic of the surrounding bee community composition. Another factor contributing to the differences in species composition may be that some bee species depend on habitats provided during different successional stages resulting from silvicultural practices. Yamaura et al (2012) perceived early successional habitats created from active clear-cutting of forests as generating substantial positive effects on early successional species.

Forestry successional stages may also impact species richness. It is hard to predict which site types harbor higher species richness without having collected equal abundances at each site

type, yet some studies have researched trends in bee richness within various silvicultural practices. Taki et al. (2007) found that species richness was not altered by forest loss of temperate forests; whereas Winfree et al (2007) found a negative relationship between areas of extensive forests and species richness. Total species richness may be higher in a disturbed landscape as different bee species occupy the different successional stages; whereas in less-disturbed landscapes there is only a single successional stage for the bees to occupy (Chesson & Huntly 1997). Different bee species may occupy different successional stages in a disturbed landscape to distribute the competition. Competition shapes a community because only those species differing sufficiently in resource use can coexist (Chesson & Huntly 1997).

Another hypothesis which predicts total species richness to be higher in disturbed landscapes such as strip cut and clear cut is the intermediate-disturbance hypothesis. The intermediate-disturbance hypothesis predicts that species richness should increase with increasing levels of disturbance up to a point (because enough time has elapsed for a variety of species to invade but not enough time for any species to dominate), after which richness declines (Roberts & Gilliam 1995). Strip cut and clear cut sites have been exposed to more disturbance than old growth sites which have minimal natural disturbances and no anthropogenic disturbances; therefore, according to the intermediate-disturbance hypothesis, more species will inhabit the disturbed areas, increasing species richness within clear cut and strip cut sites compared to old growth sites.

A challenge facing forestry is how to conserve biodiversity while meeting the demand of production. The presiding management priority at Kenauk is conservation; consequently, silvicultural activities are implemented with close supervision and a realistic strategy to include preservation and production. According to the intermediate-disturbance hypothesis it will be important to prevent disturbances from reaching a threshold where species richness begins to decline. Future research could focus on attaining as close to the true bee species richness at each site type as is possible, so that the effects of disturbance on species richness may be better understood.

## LITERATURE CITED

- Buchmann SL. (1996). Competition between honeybees and native bees in the Sonoran Desert and global bee conservation issues. See Ref. 130a, pp. 125-42
- Gruber, B. (2016). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL <https://www.R-project.org/>)
- Chesson, P., and N. Huntly. (1997). The roles of harsh and fluctuating conditions in the dynamics of ecological communities. *The American Naturalist* 150:519-553.
- Corbet SA, Williams IH, Osborne JL. (1991). Bees and the pollination of crops and wild flowers in the European Community. *Bee World* 72:47-59
- Pebesma, E. (2016). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL <https://www.R-project.org/>.
- Pinheiro, J., and Bates, D. (2016). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL <https://www.R-project.org/>.
- Kearns, C.A., Inouye, D.W., Waser, N.M. (1998). Endangered mutualisms: the conservation of plant-pollinator interactions. *Annu. Rev. Ecol. Syst.* 29, 83–112
- Kevan PG. (1998). Pollinators in agroecosystems: their keystone role in sustainable productivity and bioindication. In *Biodiversity in Agroecosystems Role of Sustainability and Bioindication*, ed. M Paoletti. New York: Elsevier. In press
- Kunin WE. (1993). Sex and the single mustard: population density and pollinator behavior effects on seed-set. *Ecology* 74:2145-60
- Mader, E., and The Xerces Society for Invertebrate Conservation. (2011). *Attracting Native Pollinators: Protecting North America's Bees and Butterflies: The Xerces Society Guide*. Storey Publications, North Adams, MA. 384 pp.
- Magurran, A. E., & McGill, B. J. (2011). *Biological diversity: frontiers in measurement and assessment*. Oxford University Press ch.4: 40-42.
- O'Toole C. (1993). Diversity of native bees and agroecosystems. See Ref. 121a, pp. 169-96
- Peterken GF, Game M. (1984). Historical factors affecting the number and distribution of vascular plant species in the woodlands of central Lincolnshire. *Journal of Ecology* 72: 155–182.
- Pimentel D, Wilson C, McCullum C, Huang R, Dwen P, et al. (1997). Economic and environmental benefits of biodiversity. *BioScience* 47:747-57

- Potts, S., Vulliamy, B., Dafni, A., Ne'eman, G., and Willmer, P. (2003). Linking Bees and Flowers: How Do Floral Communities Structure Pollinator Communities? *Ecology* 84 (10): 2628-2642.
- Richards, A. J. (1986). Plant breeding systems. Chapman and Hall, New York, New York, USA.
- Richards KW. (1993). Non-Apis bees as crop pollinators. *Rev. Suisse Zool.* 100:807-22
- Roberts, M. R., & Gilliam, F. S. (1995). Patterns and mechanisms of plant diversity in forested ecosystems: implications for forest management. *Ecological Applications*, 5(4), 969-977.
- Roser, M. and Ortiz-Ospina, E. (2017). World Population Growth. OurWorldInData.org. Retrieved from: <https://ourworldindata.org/world-population-growth/>
- Taki, H., Kevan, PG., Ascher, JS. (2007). Landscape effects of forest loss in a pollination system. *Landscape Ecology* 22: 1575-1587
- Taki, H., Okochi, I., Okabe, K., Inoue, T., Goto, H., Matsumura, T., & Makino, S. I. (2013). Succession influences wild bees in a temperate forest landscape: the value of early successional stages in naturally regenerated and planted forests. *PloS one*, 8(2).
- Hothorn, T., Bretz., F and Westfall, P. (2008). Simultaneous Inference in General Parametric Models. *Biometrical Journal* 50(3), 346--363.
- Winfree, R., Bartomeus, I., Cariveau, D.P. (2011). Native pollinators in anthropogenic habitats. *Annual Review Ecology, Evolution, and Systematics* 42: 1–22.
- Winfree, R., Griswold, T., Kremen, C. (2007). Effect of Human Disturbance on Bee Communities in a Forested Ecosystem. *Conservation Biology* 21(1): 213–223. Retrieved from <http://www.jstor.org/stable/4124658>
- Yamaura, Y., Royle, J.A., Shimada, N., Asanuma, S., Sato, T. et al. (2012). Biodiversity of man-made open habitats in an underused country: a class of multispecies abundance models for count data. *Biodiversity and Conservation* 21: 1365– 1380.



## APPENDIX

### *Bee Species*

*b: Andrena 1*  
*c: Andrena 2*  
*d: Andrena 3*  
*e: Andrena 4*  
*f: Andrena 5*  
*g: Andrena 6*  
*h: Andrena 7*  
*i: Andrena 8*  
*j: Andrena confederata*  
*k: Anthophora terminalis*  
*l: Apis mellifera*  
*m: Augochlorella striata*  
*n: Augochlora pura pura*  
*o: Bombus affinis*  
*p: Bombus bimaculatus*  
*q: Bombus borealis*  
*r: Bombus griseollis*  
*s: Bombus impatiens*  
*t: Bombus ternarius*  
*u: Bombus vagans*  
*v: Ceratina calcarata*  
*w: Halictus confusus*  
*x: Halictus ligatus*  
*y: Halictus rubicundus*  
*z: Heriades carinata*  
*A: Hyaleus messillae cressoni*  
*B: Lasioglossum dialictus 1*  
*C: Lasioglossum dialictus 2*  
*D: Lasioglossum dialictus 3*  
*E: Lasioglossum dialictus 4*  
*F: Lasioglossum dialictus 5*  
*G: Lasioglossum stricta 1*  
*H: Megachile 1*  
*I: Megachile 2*  
*J: Megachile 3*  
*K: Megachile 4*  
*L: Megachile 6*  
*M: Megachile xanthosarus frigida*  
*N: Melissodes 1*  
*O: Melissodes 2*  
*P: Melissodes 3*  
*Q: Osmia 1*  
*R: Osmia 2*  
*S: Osmia 3*  
*T: Svastra aegis*

### *Plant Species*

*2: Achillea millefolium*  
*3: Ageratina altissima*  
*4: Anaphalis margaritacea*  
*5: Anenome canadensis*  
*6: Apocynum androsaemifolium*  
*7: Asclepias syriaca*  
*8: Cirsium arvense*  
*9: Diervilla lonicera*  
*10: Doellingeria umbellata*  
*11: Ericaceae*  
*12: Erigeron*  
*13: Euthamia graminifolia*  
*14: Galeopsis tetrahit*  
*15: Hieracium caespitosum*  
*16: Hypericum perforatum*  
*17: Leucanthemum vulgare*  
*18: Lobelia inflata*  
*19: Oenothera biennis*  
*20: Oxalis stricta*  
*21: Polygonum scandens*  
*22: Potentilla intermedia*  
*23: Prunella vulgaris*  
*24: Rubus idaeus*  
*25: Spiraea alba var. latifolia*  
*26: Spiraea tomentosa*  
*27: Verbascum Thapsus*