Best Management
of
Minnesota Native Grasslands
for
Wildlife and Ecosystem Services

2014

(NOTE: This is a manuscript version of the document presently being prepared professionally for general publication.)

Table of Contents

Forward

This collection of best management practices grew from an intensive six-year project to learn how natural grasslands could be managed to provide services for society at the same time as they provided habitat for wildlife.

A main idea was to obtain bioenergy from grasses mowed late in the fall, after the plants had senesced and drawn nutrients from their leaves back into their roots, and after migratory wildlife had left the area. The project covered a thousand acres along the temperature gradient of western Minnesota. We were told that at the outset that the project was very ambitious, and heard that there was no way that harvesting bioenergy would also support wildlife. We learned otherwise.

With generous support from our state and federal funding agencies, we harvested, baled, and transported many thousands of tons of biomass from public and private grasslands while conducting scientific studies of the effects on wildlife, including mammals, birds, reptiles, amphibians, insects, and spiders. We also surveyed the plants that formed the habitat.

Most scientific studies look for significant effects of some treatment. But we were looking for the opposite. Here our treatments were harvesting or not, and harvesting in various patterns. We were looking for no significant effects---for methods of harvesting that on average would not harm wildlife. If such methods could be found, then simplified management and the possibility of income from harvested biomass could help increase the acreage of wildlife lands, and thereby could significantly help wildlife.

This booklet outlines what we learned and recommends practices that can be followed to manage grasslands in the Upper Midwest to promote the well-being of the resident wildlife. We offer these practices as our contribution the ongoing process of understanding how to live on our planet gracefully and harmoniously with the other species we share it with.

---CL, Saint Paul, Fall 2014

Project staff and students

Colleen Satyshur, Jacob Jungers, Joseph Schaffer, Kevin Johnson, Melissa DonCarlos, Robert Dunlap, Shelby Williams, Troy Milke

Project investigators

Clarence Lehman, David Tilman, Donald Wyse, Roger Moon, Todd Arnold

Funding agencies and supporting partners

Legislative Citizen Commision on Minnesota Resources: Environment and Natural Resources Trust Fund *(insert logo_ENRTF.jpg).*

National Fish and Wildlife Foundation *(insert logo_NFWF.gif)*

US Department of Agriculture: Natural Resource Conservation Service *(insert logo_NRCS.jpg)*

Minnesota Department of Natural Resources *(insert logo_DNR.gif)*

Long Term Ecological Research at Cedar Creek Ecosystem Science Reserve *(insert logo_LTER.jpg)*

The Nature Conservancy *(insert logo_NC.jpeg)*

College of Biological Sciences, College of Food, Agricultural and Natural Resource Sciences, University of Minnesota *(insert UMN logos here?)*

Case IH Corporation

For more information and contact information, see project website: http://www.cbs.umn.edu/wildlife

Summary of Management Practices

The body of this document explains our six-year effort at learning how to manage grasslands for both biomass production and wildlife habitat, covering experimental results, literature references, and recommendations. The present section is a quick summary of the practical ideas we learned.

In broad outline, we found that harvesting for biomass can be done in ways that will not significantly affect overall wildlife populations nor plant species diversity. To help insure this, the following practices can be observed.

General

1. Consider harvesting and removing grassland biomass as an easier, less expensive, and less dangerous alternative to prescribed fire for managing wildlife habitat.
2. Consider planting new grassland habitat for bioenergy harvests as bioenergy markets develop.
3. Leave a portion of the area unharvested each year as wildlife refuges; this portion can rotate and occupy a different part of the area in different years.
4. Employ workers trained and familiar with land stewardship, or so train them.
5. Use shape of harvested areas to an advantage, since shape did not adversely affect wildlife populations in this study. For example, let unharvested areas follow the lay of the land for aesthetic benefits. However, consider contiguous unharvested patches rather than strips for some songbird species
6. Include simple adaptive-management experiments where possible as part of each project, to learn which practices applied are most effective.
7. In analyzing harvests, use before-after statistics to detect effects of harvests.
8. Continue examining publications for new information on best management practices as technology and science on the topic progresses.

Planning and Logistics

1. Consider future expected climate conditions when choosing sites for bioenergy and wildlife.
2. Study special regulations that may apply, such as federal or state restrictions on earliest harvesting date.
3. Plan harvests after the growing season but before the snow. In Minnesota this usually means October to November.
4. Plan some catch-up harvests in spring, for not all available acres will be able to be harvested each fall.
5. Cluster harvest areas together for efficient transport.
6. Recognize that wet or rocky fields will not be fully used each year. This will affect yield calculations but unharvested areas will be additional refuges good for wildlife.

Harvest

1. Harvest at most once per year to avoid the times of most active use by wildlife and when plants are growing and flowering.
2. Abandon ideas for long straight harvesting rows, but rather harvest to follow the lay of the land and to avoid obstacles.
3. Use four-wheel drive tractors wherever possible.
4. Maintain large tire-area-to-weight ratios to help on wet fields and soft soil.
5. Allow for repairing unexpected ruts other field damage in wet conditions.
6. Favor equipment that is easy to repair. Common brands and lower-tech systems can help.
7. The previous point notwithstanding, do consider innovative ways of improving the equipment to suit the conditions for bioenergy harvest.
8. Plan for incidental equipment repair on rocky or wet fields.
9. Consider disc-bine cutting heads with multiple small spinning heads for the type of cutting that will be encountered.
10. Minimize water content in the harvest by careful timing of cutting and baling.
11. Equip tractors with tines on the front and/or rear for moving bales.
12. Outfit transportation equipment with on-board air compressors and clean all equipment before leaving an area.
13. Use GPS devices on tractors to monitor area harvested and calculate yields.

Bioenergy potential

1. Consider biomass harvest as a management tool to reduce costs over other methods such as prescribed burning.
2. Consider periodic over-planting of harvest areas with warm season grasses and legume mixtures for best biofuel production.
3. In new plantings, include sufficient early successional warm-season grasses in the seed mix for better biomass in the first years.
4. In over-plantings or new plantings, consider adding trace quantities of seed for every native species suitable for the region and conditions, in case that particular species finds its ideal habitat there and can spread to form habitat and biofuel.

Ecological considerations

1. Situate sites near wetlands for ecological benefits to waterfowl and other wetland species.
2. Keep harvested areas under eighty contiguous acres each year to accommodate flying distances of the smallest typical pollinators.
3. Do not harvest all of an area in any year, since complete harvests can lead to population reductions of some species. Be aware that some birds may decrease in abundance with harvesting while others increase, as described in the body of this document. For greatest benefit to stem-nesting bees, keep refuges intact for three consecutive years.

4. Maintain bloom abundance to provide food for pollinators by avoiding harvesting until flowering is completed for the year. However, since each field is distinct, consider methodical photography to ascertain timing and document changes in blooms.
5. Preserve nesting sites for pollinators. Some bare ground will attract ground nesting bees if it is well drained. Maintaining shrubby field borders and rotating within-field refuge areas every three years will make stems available.
6. In monitoring harvesting projects, conduct surveys before any management starts to identify potential pre-existing bias between sites, for use in later analysis.
7. Include vegetation height in analysis of any sweep net data used for monitoring, as described in the body of this document.
8. Follow general guidelines for pollinator management and monitor the fast growing pollinator research sector. For example: (www.xerces.org.)

Section 1
Background and Introduction

(banner picture here: prairie clear sky.jpg
or harvest vs not fall Harvesting09.gif)

1.1) Background: New possibilities in renewable energy
Minnesota restored prairies reliably produce resources for bioenergy that largely go untapped. The figure below conceptualizes the benefits that a restored and managed prairie field may offer.

(Foley figure.png)
Above: Ecosystem services comparing agricultural row crops (A), wholly natural systems (B), and cropland with restored and mixed ecosystem services, such as in this project (C). Water quality, carbon sequestration, and wildlife habitat are highlighted here. Others include forest production, flood and drought mitigation, and air quality control (Foley et al. 2005).

Minnesota has large areas of non-agricultural land --- from native remnant prairies to abandoned cropland that resembles reconstructed prairie. Conservation of these lands is a value held by many, and in Minnesota over 1.5 million acres---almost three percent of the state---are held in CRP (Conservation Reserve Program) alone. WMAs (Wildlife Management Areas), WPAs (Waterfowl Production Areas), and the CRP are vehicles for rejuvenating and maintaining the quality of soil, water, and habitat. They follow the prairie-forest border diagonally through the state and are relatively evenly dispersed throughout the grasslands, with the Red River Valley's fertile cropland a notable exception.
(map MN map green dots.jpg)
Above: This map shows in green land held in these three reserve programs.

CRP is a program that takes land out of crop production for 10-15 years while appropriate grasses and cover are re-planted. Participants who enroll entire fields in the program account for half of participants. They commonly rely on incomes outside of farming, while the remaining participants report farming as their primary source of income and prefer conservation techniques that allow for continued crop production (Lambert et al. 2006).

Farm managers must maintain financial sustainability of their operation but non-monetary factors of land management are important as well. Protecting open space and helping future generations are examples of common motivations for undertaking conservation plans, while tax and monetary benefits provide incentives which make them possible (Lambert et al. 2006).

Large swaths of CRP-enrolled land were up for renewal in 2012 and were not renewed, in part because of higher commodity crop prices (Rashford et al 2011). Land managers seeking incentives to support conservation-minded plans therefore can use new ways to add value to those choices. Bioenergy derived from harvested, mixed prairie grasses could be part of the solution by offering a regional fuel source, environmental services, and rural economic development.

Conditions for wildlife in Minnesota could be enhanced by proper bioenergy practices using diverse native plant communities, especially in comparison with conditions that would prevail if management steps are not taken. Without natural or managed disturbance such as fire, grazing, or mechanical biomass removal, trees can invade Minnesota grasslands and make the habitat unsuitable for prairie wildlife.

The recommendations in this report are primarily based on results from a six year project and a consolidation of our experience and understanding, supplemented with references to various studies and information from other sources. We report novel information on many aspects of grassland harvest for renewable energy. However, we could not monitor all possible species and conditions. Therefore, this is a summary of results from one research project, and implications of biomass harvest for representative plant and wildlife species. We present this information with hopes that can be a valuable resource for land managers to consider throughout Minnesota, and in neighboring regions.

1.2) Introduction to the research that lead to this document

We designed a working-scale project in western Minnesota to identify management practices that will promote (1) wildlife conservation and habitat biodiversity and (2) crop production of low input, high diversity mixed prairie plants (Tilman et al 2006). This is part of a broad effort to sustain Minnesota resources while improving the rural economy and contributing to energy independence.

A major objective of the working-scale project was to identify biomass harvesting patterns that maintain wildlife populations by leaving distinct sizes and shapes of refuges within the grassland, but doing so while harvesting the greatest sustainable amount of biomass from the sites. This project covered over 1000 acres of previously restored grasslands, which were organized into 20-acres plots located near the communities of Windom, Morris, and Crookston, MN. This study used re-established prairies that were under an existing fire and weed management strategy. We measured bioenergy potential from grassland biomass harvested in late fall from each plot, and monitored wildlife throughout the project. Wildlife surveys included birds, small mammals, and insects. Full description of project methods may be found in Williams et al (2012)

(map of sites and harves trts fig.tif)
Above: Research plots were chosen throughout western Minnesota to sample a north-to-south spectrum of temperature. The inset is the experimental harvest patterns used in the project.

This project presented an innovative way to simultaneously promote renewable bioenergy and wildlife habitat---namely, make bioenergy lands into wildlife habitat. It leveraged the powers of federal, state, academic, and non-governmental agencies to solve an urgent need of global significance.

Please see our project website (www.cbs.umn.edu/wildlife) to access other reports and information, such as working protocols for bioenergy and wildlife evaluation that we established for this project. Read on for our thoughts and recommendations on how to manage grasslands for both wildlife habitat and bioenergy production.

Section 2) Planning & Logistics

(Banner picture: Bale and Shadow.JPG)

2.1) Field selection

An important factor in the feasibility and productivity of harvesting grassland biomass is initial field selection. When selecting fields, consider characteristics such as field history and topography.

Rocks and other debris, such as abandoned fence posts, fencing, and woodpiles, are obstacles that interfere with harvesting and may cause damage equipment. Soil moisture may be a factor in most fields, especially if they do not have drainage tiles. This is one challenge in selecting appropriate non-agricultural land, which is often marginal, and considerations of harvest equipment and timing, as well as total harvest acreage should take field moisture into account. We found a number of otherwise productive wet fields difficult to completely harvest, at times impractical to drive heavy equipment on, and needing more time for the material to dry for baling. A few of our plots in northern Minnesota were located on CRP fields that were relatively flat and contained saturated soils. A two-wheel drive tractor used during the first harvest frequently got stuck and dug ruts in wet fields. This delayed harvest and sometimes broke equipment. The ruts were repaired the following spring, which interfered with other farm tasks. However, moisture conditions during harvest time varied by years. Combined with drier conditions, equipment operators learned when to drive on certain fields that were susceptible to wet conditions, therefore harvest efficiency increased throughout the duration of the study. The proportion of acres harvested of those available for harvested by not accessed was 82% in 2009 but increased to 87% in 2012. Wetland area are best excluded when computing expected harvest acreage.

(wet NW2010-harvest-ruts.png)
Above: Wet conditions during the 2010 harvest in the northwest study region. Wet ground and harvesting equipment could result in muddy ruts and lost time.

Detailed maps that include soil and elevation parameters, wetland delineation, and land cover from satellite images are becoming increasingly available (e.g. Gu et al. 2012), and LiDAR will further enhance maps and help optimize placement of bioenergy fields.

2.2) Site distribution

(map areal of plots harvest actual Timber 2011.jpg)
Above: Plots within one region are chosen to minimize travel between plots. Also shows actual area harvested from each plot in 2011.

Land must be chosen carefully on a regional scale as well as local. Generally, prairie grasslands in Minnesota are located in a wedge from the northwestern corner to much of the southwestern corner, thus these areas are best suited for bioenergy grasslands. See biomass yield section for comparison of yields between regions of the state. Factors for predicting high bioenergy yields include climatic indicators, previous performance in crop production, and clustering. The proximity of appropriate lands to each other is important when moving harvest equipment between fields and transporting the biomass to where it will eventually be consumed for energy.

Thus land managers with numerous harvest locations should consider the geographical distribution of the fields. On a large-scale basis, spreading sites out over distances greater than 4 or 5 miles requires additional planning and equipment. Also, the distribution of harvested plots within fields must considered. As plots get further away from roads into fields, removing the bales from the plots becomes more difficult and expensive.

To minimize transportation of invasive or unwanted plant species between fields, equipment should be cleaned between fields. See Equipment section for more details.

2.3) Growing degree day implications

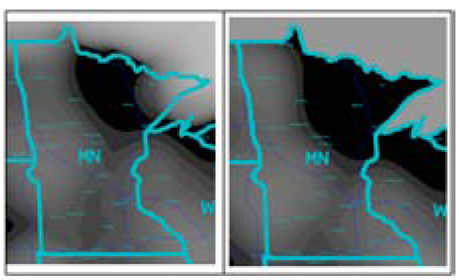
Use highres version of this picture

GDD is a measure of air temperature and is a primary predictor of the rate or timing of plant development. However the quantity of the biomass produced is influenced by soil quality, precipitation events, and nutrients, especially nitrogen. These three factors result in a difference in biomass yield between the two northern study sites and the southwest site. GDD is an indicator of plant development (Frank and Hofmann, 1989; Frank and Ries, 1990) and is one of the predictors of harvest for these prairie plants. This study is not able to correlate GDDs with the optimum harvest schedule because land manager restrictions forbid harvest at potentially peak opportunities. This confounding factor prevents using GDD as a predictor of harvest timing in this study.

Certain regions of Minnesota will respond differently because of differences in growing seasons. The northern portion of the state generally receives fewer growing-degree days (GDDs) in a season, thus less energy for biomass production---although this may be changing as number of growing degree days increases throughout Minnesota. The figure shows the movement of sample growing degree days over the previous century (www.cbs.umn.edu/climatetracker). For instance, the yellow track shows that the number of GDDs experienced west of the Twin Cities, MN in 1900 is now experienced further north, near Wadena, MN. The east-to-west movement is indicative of precipitation change -- a drying trend in the 1930s moved the track east, and has since become wetter, thus moving west, ending generally west of the 1900 point. GDDs have been hovering since 1966.

2.4) Modelling the future

Minnesota has the potential to produce biofuels decades into the future, although the specific growing areas may be on the move. Both panels of the figure on the left highlight areas that should theoretically produce high yields on bioenergy based on climatic indicators, previous performance in crop production, and clustering. The lighter areas on the first panel indicate that the tri-state area of North Dakota, South Dakota, and Minnesota could potentially generate high yields of biomass. The second panel of the figure projects climate conditions 30 years in the future, where increased areas of northwest and southwest Minnesota are included in potential biomass production areas. Planning for future biomass production should take possible climate changes into account.



Insert high-res images

Section 3) Harvest

(Banner picture: *harvester 2009.jpg)*

3.1) Harvest timing

Our harvests were initiated after the first hard frost, usually in mid- to late-October. At this time, plants were past the senescence stage. Waiting until post-senescence reduces biomass moisture content and allows the perennial plants to transfer nutrients from shoots to roots, to be used in subsequent growing seasons. To minimize impact on wildlife, harvest was delayed on DNR experimental plots until November. Consequently, there was a short window of time to harvest before the first snowfall. With variable Minnesota weather, snow can come as early as late October and terminate harvest efforts for the year. Fall weather in the harvested region can also be tricky for proper drying of biomass. Short days, cool temperatures, and snow or rain require careful planning for harvest in late autumn/early winter.

We could begin harvesting CRP plots in the northwest part of the state in mid-October, followed by selected plots in west-central areas one to two weeks later. We began harvest in southwest areas the first week of November and ended in early December. Wet conditions prevented complete fall harvests in the northwest plots in one year and harvest was completed in April of the following spring. Early heavy snow prevented a complete harvest in the southwest in another year and part of that were harvested in May of the following year.

(snow on harvest 2.JPG, birds chick.png, wet flooded.jpg)
Above: Timing the harvest to avoid wildlife nesting periods and adverse weather can be a challenge in the upper midwest.

3.2) Harvest equipment

3.2.1) Cutting

(eqp swath type cutter head.png)
Left: A disc bine cutting head consists of multiple small spinning heads and works well for the type of cutting encountered in this project.

We used standard haying and baling equipment for harvesting grassland biomass. This project served as a “proof-of-concept” demonstration that grassland biomass can harvested with common equipment. A discbine cutting head was used to harvest biomass. This consists of multiple small spinning heads that hold cutting blades, as opposed to a sickle-type cutter. After the discs cut the material, it is run through a roller-conditioner to form the windrow. The discbine head works well for cutting the various grasses and forbs encountered on the project, and allows for cutting wet or dry material. It also allows a faster ground speed if the landscape permits. The main disadvantage to running a disc-bine header is that it is expensive and time consuming to repair if damaged during harvest, as by unseen rocks or other debris. We frequently encountered rocks and obstructions on the marginal lands where our experimental plots were located.

In the first year, the disc bine head was mounted on a self-propelled swather. This was an effective setup, but had some qualities that made it suboptimal for this kind of harvest. It is a difficult machine to load for transport and requires a special trailer due to its wide wheel base. Because it is two-wheel-drive it does not handle wet ground well and can get stuck. It required a significant amount of time to move between harvest sites.

In subsequent years, the discbine cutter was mounted on a four-wheel drive tractor. This configuration is recommended because it solved many of the problems associated with the self-propelled swather---it is easily loaded, can be driven on roads, and does not get stuck as easily. It was also convenient to have a tractor available instead of the swather since it is more versatile.
(SWATHER: eqp swather 09.jpg, TRACTOR: eqp tractor with cutter.JPG
Above: Disc bine head on swather (left) and tractor (right).

3.2.2) Raking biomass

A high capacity wheel V rake was used to merge two windrows of cut biomass into one windrow and to turn the material to expedite drying. This type of rake worked well when biomass was too wet for immediate baling. Raking two windrows together sped up the baling process and reduced the number of passes the baler had to make on the field, thus reducing rutting and fuel use.
(eqp tractor with rake.JPG)
Above: A tractor raking biomass.

3.2.3) Baling biomass

(bales square and round.JPG)
Above: Both round and square bales were used. Below, Round baler (left) and square baler(right)
(eqp baler-round backlit close.JPG, eqp baler-square.jpg)

We tested two primary baling systems, round and square balers. In the first year we used a large square baler which produced 4’x 4’x 8’ bales that were tied with twine. These bales weighed about 1,000 pounds at 15% moisture. Advantages of large square bales include efficient stacking, hauling, and transport compared to round bales. Also, there is no danger of the bales rolling on slopes. The square baler was efficient to operate and handled most of the material and conditions. The one we used was a research-level bailer being evaluated for production and had three issues that could be improved. One was that is was relatively heavy in relationship to its tire size, compared with a conventional round baler. Also it was difficult to load onto a semi-trailer for transport, and it had to be protected from rain. These issues may be specific to our equipment and all can be overcome by through mechanical engineering, and square balers may be the recommended choice for the future.

In subsequent years we switched to a round baler for comparison and for utility. It produced a 4' wide by 6' high bale wrapped with a plastic net, that also weighed about 1,000 pounds. This bale size is appropriate because of the relative ease hauling them by truck to their final destinations. However, attention is necessary so that the round bales do not roll on steeper slopes. The round, net-wrapped bales can be left out in the elements without having to be covered for up to three years or more without losing significant quantity or quality of biomass. This introduces the important possibility of storing the bales in the field where land costs are low, giving farmers more control over their commodity, and allows for more time to be spent on the harvest.

3.2.4) Material handling

The best method we found for transporting bales from the field uses tractors with front and/or rear mounted bale spikes. Properly equipped, a single tractor can remove up to six bales from the field on each trip. This speeds up the process and minimizes traffic on the field. Bales can be placed in a staging area near the field for future transport or loaded directly onto trucks.

(eqp tractor with bale spikes loaded.JPG)

Above: tractor with bale spikes hauling bales.

3.2.5) Summary of equipment used in this project

Equipm ent type	Equipment details	Picture	When Used	Advantages	Disadvantages
Cutters	disc bine head	*(eqp swath type cutter head.png)*	all years, on different tractors	Works well for cutting grass and forbs, wet or dry.	As with all equipment, it can have expensive breakdowns on rocks. Check for local part availability
	two-wheel-dri ve, self-propelled, swather	*eqp swather 09.jpg*	2009, carried disc bine	Designed for biomass harvest specifically, can have high ground speed.	Difficult to load on a trailer, requires special trailer to fit wheel width. 2wd gets stuck in wet ground
	discbine mounted on a	*eqp tractor with cutter on trailer.jpg*	2010 and on	easily loaded, does not get stuck	Check fuel usage. May operate at

	four-wheel drive tractor			as quick as 2wd above. Can drive on roads. Tractor can be used for other purposes	slower speeds than 2wd above.
Racking	high capacity wheel V rake	*eqp tractor with rake.JPG*		Good for combining 2 windrows to 1 and flipping biomass for quicker drying	Adds an additional pass over field, requiring additional fuel and time.
Bailers	large square baler produced 4'x 4' x 8' twine-tied bales; 1,000 pounds at 15% moisture	*eqp baler-square.jpg*	2009 onward	Stack and transport better than round bales. Baler was efficient and handled most materials	Weight:tire size rather large, suboptimal in wet conditions. difficult to load on semi. Must be protected from rain.
	round baler produced a 4' x 6' bale wrapped with plastic net	*eqp baler-round backlit close.JPG,*	2010 onward	Round bales can be left on field for up to 3 years	Bales may roll. Harder to load on truck and transport
Material handling	tractor with rear and front mounted bale spikes	*eqp tractor with bale spikes loaded.JPG*	all	6 bales/trip in field	no major disadvantages to note

Used a different cutter also in 2012, have to look up it's name don't know much about how it worked.

3.3) Minimizing spread of invasive and unwanted plants

(eqp cleaning tractor.JPG, includes 2 of Joe Schaeffers employees)

Plots to be harvested can be located some distance apart and managed by different agencies or organizations. When moving equipment from site to site it is critical to maintain equipment in a sanitary condition, to avoid the transport of unwanted plant propagules such as weed seeds. To accomplish this, transportation equipment should be outfitted with on-board air compressors and all equipment cleaned before leaving an area. In addition to using an air compressor to blow off vegetation, was necessary to use a paint scraper to scrape off caked biomass from our equipment. This process took about half an hour each time and should be factored into harvest timing. Individual landowners will see this practice is in their best interest as well, since it protects their sites from unwanted settlers.

3.4) Personnel

Having people trained and familiar with land stewardship and harvesting equipment operation is of utmost importance. In our project, the variability of sites and differences among landowners required that harvesting personnel know what is acceptable and what is not for each field, there being more to the harvest than just getting biomass from the field. Integrity of the prairie ecosystem that supports the biomass, of the wildlife that occupy it, of the services to society it provides, and the ethics in managing it are necessary to ensure sustainable opportunities in grassland biomass harvest.

3.5) GIS and tracking harvests

Because land allocated to reserve programs and wildlife conservation tends to be marginal for agriculture, it may not be possible to harvest in long straight rows, or even to harvest all of the area. For that reason, we found it useful to track our harvest with an on-board GPS (Geographic Position Sensor). Many farm operations already use this type of equipment, and if not, handheld versions can be a good investment at relatively low costs. Recording the harvest area gave a better idea of potential bioenergy production for each place. All calculation of yield and harvested area in our study were derived from actual area taken from the GPS, which gave a more accurate output. Similar hand-held GPS devices were used in wildlife surveys, including when we walked transects for bird surveys.

Section 4) Bioenergy potential

(banner picture: Bales on semi square side.JPG…. or: Bales on semi square front.JPG, bales on semi round loading.JPG, bales on semi round diagonal.JPG)

The amount of energy that can be produced from a grassland is based on two characteristics, biomass quantity and biomass quality. Biomass quantity is often referred to as ‘biomass yield’ --- the amount of biomass that can be harvested in a given area. Biomass quality refers to the amount of energy that can be produced from one unit of biomass, such as from one ton. We measured both characteristics to learn how they will vary across Minnesota.

4.1) Biomass yield.

We assessed biomass yield northwest, west central, and southwest Minnesota. This assessment was unusual in that biomass yields were derived from production-scale harvests. Once a plot was harvested and baled, the number of bales left in the field were counted. This number was multiplied by the average weight of a bale to estimate the total amount of biomass harvested from the plot. Total plot biomass was then divided by the area that was cut to determine biomass yield.

(bales in field 1.JPG)

Above: bales produced per plot were counted

It is important to minimize water content in the bales, because (1) biomass that is wet is prone to decomposition, which decreases the energy potential of the biomass, (2) trucking wet biomass to conversion facilities is limited by weight, so damper biomass means that not as much can be moved per trip, (3) and decomposing biomass can be a fire hazard and has been known smoulder and even combust.

We measured biomass moisture content by collecting and weighing samples of cut biomass from bales, drying the same sample to remove all water, and then re-weighing the same samples to determine how much of the initial weight was actually dry biomass. This is called “dry matter determination”. Probes are available to producers that give immediate estimates of moisture content.

The timing of harvest and duration of windrow drying prior to baling affect final bale moisture content. In the south region, we consistently lowered average moisture content each year of the study, from 23% in the first year to only 10% in the last. Biomass yields reported here are on a dry-matter basis, which means that the values have been adjusted for 0% moisture content. This is common practice so that values represent actual biomass weights and do not include variability added due to moisture content.

Table X. Average biomass yield (tons per acre) from plots in three study regions in western MN from 2009 to 2012.

Region	2009	2010	2011	2012	Average

South	1.2	1.1	1.8	1.3	1.4
Central	0.7	0.7	1.0	-[1]	0.8
North	0.6	0.7	-	-	0.7

[1] Plots in this location were not harvested.

Average biomass yields in the southwest were about 60% greater than yields in the west-central and northwest (*Jungers et al 2013*). There was no difference in yields between the west-central and northwest regions. We found that fields with high biomass yields also had a greater abundance and cover of warm season grasses (C4 grasses), such as switchgrass (*Panicum virgatum L.*), big bluestem (*Andropogon gerardii* Vitman), and indiangrass (*Sorghastrum nutans (L.) Nash*). This correlation is not surprising because warm season grasses are 40% more efficient in accumulating carbon (Beadle and Long, 1985), require half of the water (Long et al. 1990), and use nitrogen more efficiently (Brown 1985) than cool season grasses (C3 grasses). Identifying fields with abundant stands of warm season grasses, or overplanting them with warm season grasses, could be a good recommended method for high biomass yield.

Other related studies have shown that a significant legume population also contributes to biomass yield (Fornara and Tilman, 2008).

4.2) Subsequent harvests.

A concern among land managers is that repeated biomass harvest could lead to decreasing yields during future harvests. We studied this by comparing the change in biomass yield in fields that were harvested every year with fields that were rested a year between harvests. Our results suggest that biomass yields do not decline with annual harvest for up to three years. It has been long known that biomass yield does not decline with annual burning (Collins et al 1998).

4.3) Biomass quality.

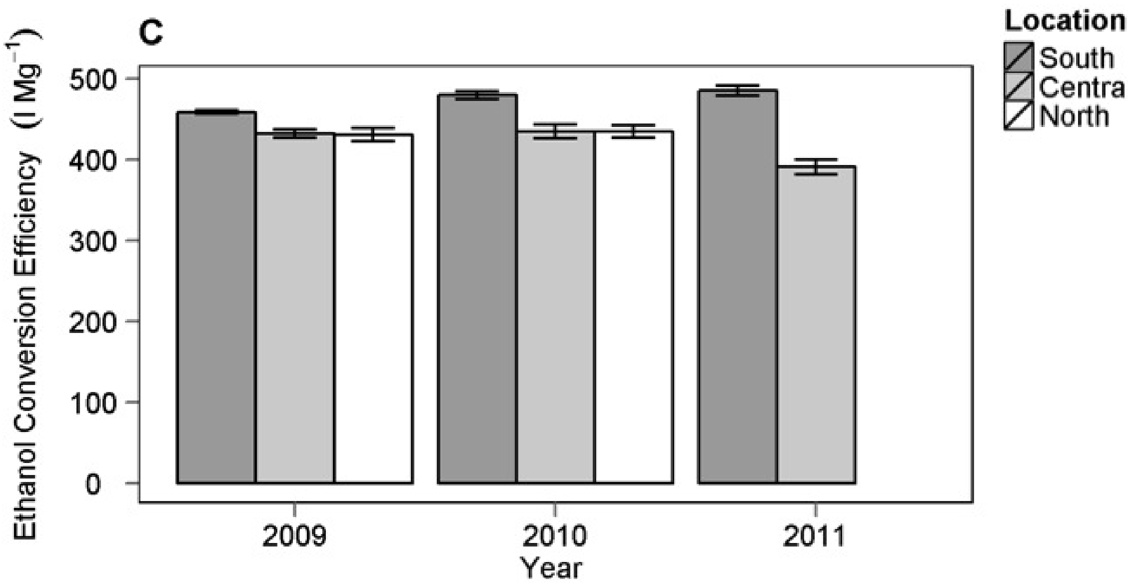
A standard metric for the quality of biomass for energy conversion is the higher heating value (HHV) of the material. HHV is used for comparing other fuel sources and is not based on conversion method (e.g. ethanol, gasification, combustion). We determine HHV by bomb calorimetry. There was little variation in HHV in our samples from the various regions, and the average value was 17.3 megajoules per kilogram (MJ/kg) and a standard deviation of 0.19)

(bale-coring.jpg, bale with horsetail.JPG)

Above: bale coring (right) and a bale with significant percentage of horsetail (left)

We also predicted how much ethanol could be produced by measuring the concentration of fermentable sugars within the biomass. The analysis estimates ethanol production if all available fermentable sugars are consumed. The result is a metric called “theoretical ethanol potential”, which is measured in liters per metric tonne (L/Mg). (Multiplying these values by 0.23 will convert the values to gallons per short ton.)

The figure below shows the average ethanol potential from biomass harvested in the south, central, and north locations during the first three years of the project (Jungers et al., 2013). Averaged across all sites and years, ethanol potential was about 450 L/Mg. Ethanol potential was greater in biomass harvested from the south, which is also likely related to the higher abundance and cover of warm season grasses there. That could be remedies in the north and central by emphasizing them in plantings. In general, however, there was little variation in ethanol potential among different regions.



With biomass yield and ethanol potential being greater in the south, it makes sense to consider that location first as a potential location for a renewable energy production facility. If we combine biomass yield and ethanol potential, we can predict how much energy can be produced per unit of land; or land ethanol yield (gallons of ethanol per acre). Approximately 150 gallons of ethanol could be produced per acre of conservation grasslands in the southwestern region of Minnesota. If we can harvest biomass from half of the available acres in conservation grasslands within an area that's profitable for biomass transportation, there is enough biomass to produce nearly 20 million gallons of cellulosic ethanol. That is enough biomass to support a production-scale cellulosic ethanol facility.

Section 5) Ecological implications

(banner picture: p39 ish flowers and indian grass.JPG)

5.1) Effects of biomass harvest on plants

Historically, natural disturbances such as fire and grazing maintained plant species composition in prairies. Without disturbance, woody plants can invade and outcompete prairie plants, which shifts the ecosystem to something other than prairie. Land managers prescribe fire, grazing, and mowing as a disturbance to maintain the prairie plant community. One goal of this project was to track how biomass harvest influenced the plant community --- for example, would harvest change plant diversity, the abundance of dominant plant species, and the abundance of non-native species.

Our results show no effects of biomass harvest on plant species composition, diversity or the relative abundance of non-native and noxious species following three years of harvest. Some changes were observed through time at each location, but these changes occurred in both harvested and unharvested plots (Jungers et al., in press). This is a good result for managers because it means that they can interrupt their normal disturbance schedule to harvest biomass from conservation grasslands without affecting the plant community. This is also a sign that the equipment cleaning protocols we implemented worked, and that non-native species and noxious weeds did not increase in plots where biomass harvesting equipment was used. It should be noted that landowners were allowed to continue their normal weed control measures, such as spot spraying thistle.

5.2) Small mammals

(smam bob trap in field.jpg, smam DSCN3049.JPG)

Trends suggest that harvesting can increase overall abundance of some small mammals if equal areas are left as a refuge. Others are reduced. Small mammals occupy a central place in the prairie food web, so these trends can be expected to have an effect up and down through the ecosystem.

Small mammals were surveyed in each region using grids of Sherman live traps. The mammals were briefly processed, marked for recapture, then released at the point of capture. Results and analyses were reported in Dunlap (2014). Almost 4500 small mammals were captured during the study, and over half were *Microtus* species. Approximately one-quarter of captures were northern short-tailed shrews (*Blarina brevicauda*), followed by fewer deer mice (*Peromyscus* spp.), short-tailed weasels (*Mustela erminea*), thirteen-lined ground squirrels (*Spermophilus tridecemlineatus*), and masked shrews (*Sorex cinereus*). We also caught fewer than ten northern grasshopper mice (*Onychomys leucogaster*), plains pocket mouse (*Perognathus flavescens*), western harvest mouse (*Reithrodontomys megalotis*), and house mouse (*Mus musculus*).

Microtus species, which may include the prairie vole (*M. ochrogaster*) and the meadow vole (*M. pennsylvanicus*) were most abundant in the northwest and least abundant in the southwest. The *Microtus* genus were the only small mammals with sufficient captures for analysis which declined with increased harvest percentage. Literature in Dunlap (2014) notes that removing grassland vegetation is generally correlated with fewer *Microtus*, thus allowing unharvested vegetation to stand in fields is supportive of greater number of *Microtus* in grasslands harvested for bioenergy. No edge effect of harvested fields was found in our study, so the pattern of harvest does not appear to affect *Microtus* species. Thus, to manage for the *Microtus* genus, harvesting that include up to 75% of standing vegetation, in either strip or block pattern, are unlikely to cause significant declines in populations. However, full harvest led to population reductions in our study. Dunlap (2014) recommends that land managers work with biofuel harvesters to retain unharvested sanctuaries where small mammals such as *Microtus* species can persist despite biomass harvest.

In contrast to *Microtus* species, the northern short-tailed shrew remained relatively constant over the course of the study and deer mice seemed to increase in abundance with increased vegetation harvest. Short tailed shrews were captured with less frequency in higher percent harvest plots. Other species of small mammals on our study plots seemed to be unaffected by amount or pattern of biomass harvest (Dunlap, 2014).

5.3) Reptiles & amphibians

(herp array.jpg, herp sal2.png, herp toad.png)

We surveyed reptiles and amphibians (herpetofauna) in four consecutive years, using catch-and-release trap arrangements that incorporated funnel and pit-fall live traps . We tested techniques for capturing herpetofauna in Minnesota grasslands and developed a method for a fenced array that works well. Frogs, toads, and garter snakes made up over 90% of species identified, with salamanders, skinks, turtles, and and other herpetofauna constituting the remainder. Approximately 2000 individual reptiles and amphibians were identified, measured, and weighed in the process. Preliminary analysis reveals an average of 28.3 individuals identified on average per array per year in the non-harvested plots and 28.7 in the fully harvested plots---not significantly different. As of this writing, effects of harvesting are being analyzed with continuation funds supplied by the University of Minnesota and will be made available in updates to this document, but the preliminary results show no adverse effects of harvesting on herpetofauna.

Proportional abundance of reptiles and amphibians identified in the southwest study area.

Rana pipiens	Northern Leopard Frog	55%
Bufo americanus	American Toad	19%
Thamnophis radix	Plains Garter Snake	11%
Thamnophis sirtalis	Common Garter Snake	6%

Ambystoma tigrinum	Tiger Salamander	4%
Pseudocris triseriata	Western Chorus Frog	3%
Eumeces septentrionalis	Prairie Skink	1%
Bufo cognatus	Great Plains Toad	<1%
Chrysemys picta	Painted Turtle	<1%

5.4) Waterfowl and Pheasants

(birds nest.png, birds ducklings.jpg)

Some conservation grasslands, such as state owned WMAs (Wildlife Management Areas) and federally owned WPAs (Waterfowl Production Areas), include the management objective of sustaining populations of waterfowl and game birds for hunting. Game bird hunting is an important economic activity for many rural communities, and hunting license fees help pay for the acquisition and management of conservation grasslands. Therefore, it is important to understand how waterfowl and pheasants respond to biomass harvest.

We focused on monitoring the nesting biology of waterfowl, since they utilize upland grasslands as nesting sites near wetlands. We searched for nests using the chain drag method (Klett et al. 1986) and monitored nest development. During sampling, pheasant nests were also found and included in the analysis. Nest searches and monitoring was conducted in spring prior to biomass harvest in the first and year following first harvest in the subsequent year, in southwestern Minnesota.

Biomass harvest can affect nesting biology in at least two way, (1) if harvested areas are less suitable for nesting, nest density would decrease, and (2) If harvested areas are less suitable for nesting but waterfowl still nest there, nest predation could increase. We found that the probability of a nest surviving is the same for nests initiated in harvested areas and unharvested areas. Nest predators in the region of this study were not more or less likely to find and consume nests in harvested areas. However, waterfowl preferred to nest in the unharvested regions. Nest density was lower in the harvested regions. It is important to note that there was a similar number of nests initiated prior to the first harvest and following harvest, but that the nests were more concentrated in the unharvested regions.

We found more nests in plots with taller grass and also in those plots that had more abundant wetlands within a 500 m radius from the plot center (Jungers et al., in review). Waterfowl preferred nesting in upland grassland sites that were near wetlands, and these nests had a better chance at surviving compared to those further from wetlands. Therefore, we recommend that some regions of upland habitat within conservation grasslands be left standing if managed for bioenergy, and that these unharvested regions be located near wetlands if possible. This selection strategy should not only help maintain waterfowl populations during harvest, but may also limit harvest inefficiencies due to wet ground.

5.5) Songbirds

(Birds path_2-4_Color KJ 1dec10.jpg)
Above: the path walked for songbird point count surveys)

Two important measures of harvest effects are total songbird abundance and number of species recorded. We surveyed plots from mid-May to late June each year to more or less coincide with the breeding period of most grassland birds. The first year of surveys in 2009 represented the pre-harvest conditions of the plots, and all years after represent the post-harvest conditions. We used area-based search methods to survey birds in our plots. We began surveys 30 minutes after sunrise, and finished by noon at the latest. We conducted two rounds of our southern plots and one round each of our west central and northwest plots. The second round in the southern plots was conducted because some species such as the dickcissel (*Spiza americana*) arrive later in the spring. Two observers independently surveyed each plot per round, and each plot was only surveyed once each round by the same observer.

We observed a total of 57 species in our plots over the five years of our study. Of these species, we identified 11 that provided us with enough data to analyze abundances. These were: sedge wren (*Cistothorus platensis*), common yellowthroat (*Geothlypis trichas*), clay-colored sparrow (*Spizella pallida*), savannah sparrow (*Passerculus sandwichensis*), grasshopper sparrow *(Ammodramus savannarum*), Le Conte's sparrow (*Ammodramus leconteii*), swamp sparrow (*Melospiza georgiana*), dickcissel (*Spiza americana*), bobolink (*Dolichonyx oryzivorus*), common grackle (*Quiscalus quiscula*), red-winged blackbird (*Agelaius phoeniceus*). Additionally, two of our common species—sedge wren and grasshopper sparrow—are designated as Partners in Flight conservation priority species, and thus the data we collected on them was of particular importance as these species have shown significant declines throughout their ranges and may be at risk of further declines without other conservation initiatives in place.

Analysis and results are presented in Dunlap (2014). In summary we found that four species—sedge wren, common yellowthroat, clay-colored sparrow, and swamp sparrow—showed declines in abundance following harvesting. Two species —grasshopper sparrow, and common grackle—actually increased in abundance following harvesting. Additionally, we found that species richness declined significantly with increasing percent of plot harvested but that the difference was very slight, 2 species or less (Dunlap, 2014). Species richness measures total number of species, without taking into account if some species are leaving, but are replaced by new species. Results became more pronounced as the number of years of fall harvest increased. Some of these results are in accord with other research on grassland birds and haying, although haying often occurs during the summer. Some birds such as grasshopper sparrows seems to prefer shorter vegetation, while others such as sedge wren and prefer taller denser vegetations.

Our results suggest that overall songbird community is amenable to fall biomass harvest as a management technique. Especially if biomass harvest provides incentives to keep grasslands from being converted to crop production. However, our study shows the importance of having initial data on songbird occupancy and of long term monitoring. If funds are limited, surveying the year following the first harvest may be omitted. In our study summer after the first harvest showed less effect of harvest than later years, possibly due to territory fidelity of birds returning from the previous year. Also if management goals prioritize any of the species negatively affected by harvest in our study, leaving at least 50 percent unharvested on 20 acre parcels is advisable. If goals include species positively affected by harvest, then higher percent harvests on 20 acre parcels may help. There was a slight preference in species richness for block over strip harvest, but not in any other group. Therefore harvest shape could be adapted to harvest logistics and landscape features, while generally leaving unharvested areas in contiguous chunks where possible.

5.6) Predator cameras

We had hoped for more information from automatic field cameras, but did not get it. There were few sightings on predator cameras, too few to be analysed statistically. We believe the concept is still sound, but either more cameras or more sampling dates should be used. Other survey methods may be more effective.

5.7) Deer surveys

Pellet count surveys were conducted in February of the second year to determine use of the bioenergy plots by deer. Although we found a trace number of deer pellets in the survey, deer did not appear to be using plots, probably because of deep snow. Deer use of bioenergy plots may need to be assessed by observation from blinds or other methods.

5.8) Arthropods & Pollinators

(Insects-sweeps-amanda.JPG)

There were three main components to our arthropod research, absolute quantitative calibration for sweepnets, arthropod biomass measured by sweepnetting, and bee abundance measured by bee bowls.

5.8.1) Quantitative sampling

(Insects Quist 2010 1.jpg)

Above: QuIST is a new technique to assess insect sweep net collections, using a small "tent" and vacuum equipment.

Because fall harvest could affect vegetation height, we designed a new process, called "Quantitative Insect Sampling Technique" (QuIST), for assessing the comprehensiveness and efficiency of sweep net collection. QuIST is an enclosed screened "tent" in which we work to capture all insects in its interior with clipping and vacuum equipment. We obtained enough information on six taxa to calculate their capture efficiency at different vegetation heights. Coleoptera (beetles) and Hymenoptera (ants wasps and bees) both appear to be captured at the same rate, no matter what the vegetation height. Vegetation height did influence capture of the other four groups Diptera (flies) Araneae (spiders), Hemiptera (true bugs, eg. aphids, stink bugs), and larvae (designated as young insects which are in the form of a caterpillar, or “grub”). These groups were captured at a increasing efficiency until vegetation height reached the diameter of the sweepnet. At this point the trend reversed and the arthropods were captured at a diminishing rate as vegetation height increased above the diameter of the net. Generally speaking, one bug in a net in tall vegetation represented a larger total population than one bug in a net from shorter vegetation.

Absolute quantitative sampling such as we did is comprehensive but labor intensive, and we do not recommend it on a regular basis. Instead, it should also be ascertained if a management practice or experimental treatment in question affects height of the vegetation. If it does then vegetation height should be measured along with any methodical sweepneting and height should be included in the analysis. Our formulae for calibrating sweepnet catch are being finalized and will be released in upcoming publication (Satyshur et al, in prep). In the mean time this table of approximate calibration amounts can be used.

Table 4: Unpublished data: Quick reference table displaying a correction coefficient which can be multiplied by number of the appropriate arthropod group in a sweepnet sample to obtain an estimate of total arthropods based on height and our best fit models. Correction coefficient is the inverse of capture efficiency.

Vegetation height(cm)	Araneae	Coleoptera	Diptera	Hemiptera	Hymenoptera	Larvae
10	141.3	72.5	17.7	71.3	116.3	110.7
20	112.6	72.5	14.1	56.8	116.3	88.2
30	106.6	72.5	13.3	53.8	116.3	83.5
40	119.7	72.5	15	60.4	116.3	93.7
50	149.6	72.5	18.7	75.5	116.3	117.2
60	179.5	72.5	22.4	90.6	116.3	140.6
70	209.4	72.5	26.2	105.7	116.3	164
80	239.3	72.5	29.9	120.7	116.3	187.4
90	269.2	72.5	33.7	135.8	116.3	210.9
100	299.2	72.5	37.4	150.9	116.3	234.3

110	329.1	72.5	41.1	166	116.3	257.7
120	359	72.5	44.9	181.1	116.3	281.2
130	388.9	72.5	48.6	196.2	116.3	304.6
140	418.8	72.5	52.4	211.3	116.3	328
150	448.7	72.5	56.1	226.4	116.3	351.5
160	478.7	72.5	59.8	241.5	116.3	374.9
170	508.6	72.5	63.6	256.6	116.3	398.3
180	538.5	72.5	67.3	271.7	116.3	421.8

5.8.2) Overall arthropod response

(insects, sorting.JPG)

Insects and spiders are an important food source for songbirds, small mammals, and other animals in grasslands. We surveyed insects and spiders in unharvested and fully harvested plot using sweep nets. Eight transects were selected from each plot and were sampled three times in each growing season, in June, July, and August. Insect samples were frozen and then sorted into taxonomic groups by laboratory specialists. June vegetation height in unharvested plots appeared to increase through subsequent years as compared to fully harvested plots. This in later months heights appeared equal between treatments. However statistical analysis did not show the June difference to be a significant difference. Therefore sward height was simply entered as a covariate in biomass analysis.

Overall insect response to harvesting was measured in biomass. Dry weights were taken from each arthropod taxa. Arthropod biomass was affected by harvest, with harvested plots displaying slightly, but significantly, higher arthropod biomass. Among taxa, this effect is significant for spiders, beetles and flies, but not for true bugs, ants bees and wasps, larvae, or grasshoppers.

5.8.3) Beneficial Insects

Certain functional groups of invertebrates---that is, groups defined by their roles in the ecosystem---are beneficial to humans. Pollinators enable seed and fruit production, and natural enemies (parasites and predators) help control certain crop pests. We counted individuals of these groups from sweepnet samples and they showed no degradation due to harvest. Pollinator numbers actually showed a slight, though significant, increase in the full harvested plots by the last year. However see the next section on bees. Natural enemies showed no significant difference between control and full harvest plots. As evidence is slight, continued study is suggested.

Sometimes grasslands harbor insect pests or insects that are vectors for plant diseases. That information is not available from our study.

5.8.4) Bees

(p38 sunflower bee-2.JPG)

There are between 300 to 400 species of bees in Minnesota, of which the managed honey bee is one and about eighteen others bumblebees. About 70% of the remaining bees nest in small tunnels in the ground and 30% nest in holes in wood or in hollowed stems. All of these feed their young nectar and pollen. Many are solitary nesters and generally depositing this food supply in their nests and then leave their young to develop on their own over the winter. The next generation emerges from their nest in the spring. Social bee species care for their young throughout the summer and may have several generations in a year all living together. Still, in most cases, only a queen survives the winter and a new colony is formed each year.

A study of bees and floral abundance was begun in the third year of the project and conducted five times a year for two years. Bees were sampled by placing an elevated ring of white, blue and yellow bowls, five meters apart, in the center of each plot. Bowls were filled partway water on one evening, and bees trapped in the water were collected the next evening.

Bee foraging distance relates to body size, and small bees would probably depend more on the floral resources in our plots and thus be more likely to be impacted by harvest one way or the other. We measured the body size of our bee specimens and using the formulas in Greenleaf et al. (2007), computed that 80 acres would cover the maximum foraging area of the smallest stem nesting-bees. The actual flight distances of these bees may be half to one-quarter of this size.

Young of stem nesting bees may spend the winter in grassland plant stems and could be removed by harvesting in the fall. Some stem nesting bee use shrubs with pithy stems such as rose, blackberry, raspberry, sumac and, by our size measurements, may also use grassland forbs with stems at least five millimeters in outer diameter---such as goldenrod or Monarda. Small stem nesting bees might be most responsive to harvesting.

Our study did not show that fall harvest affected total bee abundance in bowl traps. The more sensitive subgroups were analyzed also and while trends are suggestive of a negative impact on the small stem nesting bees, this was not verified with statistical analysis. However, relatively few small stem nesting bees were collected and at this point we do not consider the data to be conclusive. To be useful to a bee for nesting, a dead stem must persist through the two springs after its initial growing season. In the first spring, the stem is available for nesting, in the second spring the next generation of bees would emerge. Thus refuge areas that are mowed every third year cycle would provide nests.

Along with sampling bees, we measured abundance of blooming forbs in our plots. Analysis of data did not show significant difference in bloom abundance between control and full harvest.

Thus it is likely that fall harvest will have little impact though fully harvested plots did green up sooner in the spring. However, as each piece of land is different, it is well to understand the initial floral composition of a field intended for bioenergy harvest. Methods such as those used in this project for surveying plant species and counting blooms in 10-20 small squares of a field during the summer before a the first harvest would accomplish this. Photographing set points from the same angle and height on a regular schedule .This could be quicker to carry out in the field and done in each year. Then later if personal observation of review of photographs suggests that number blooms may be decreasing or increasing the photos may be useful in confirming suspicions, provided the photographs are of good quality and reliably taken.

(Bale rolling DSCN2003.JPG)

Section 6) References

Beadle, C., and S. Long. (1985). Photosynthesis - is it limiting to biomass production? Biomass 8,119-168.

Brown, R. (1985). Growth of C3 and C4 grasses under low N levels. Crop Sciences 25, 954-957.

Collins, S., A. Knapp, J. Riggs, J. Blair, and E. Steinauer. (1998). Modulation of diversity by grazing and mowing in native tallgrass prairie. Science, 280, 745-747.

Dunlap, R. (2014). Responses of Songbirds and Small Mammals to Harvests of Native Grasslands for Biofuels in Western Minnesota (Master's Thesis). Accessed 1 August, 2014 from http://conservancy.umn.edu/bitstream/11299/162823/1/Dunlap_umn_0130M_14705.pdf.

Foley, J., et al. (2005). Global consequences of land use. Science, 309, 570-574.

Fornara, D., and D. Tilman. (2008). Plant functional composition influences rates of soil carbon and nitrogen accumulation. Journal of Ecology, 96, 314-322.

Frank, A., and L. Hofmann. (1989). Relationship among grazing management, growing degree-days, and morphological development for native grasses on the northern Great Plains. J. Range Management, 42, 199-202.

Frank, A., and R. Ries. (1990). Effect of soil, water, nitrogen, and growing degree-days on morphological development of crested and western wheatgrass. J of Range Management, 43, 257-260.

Greenleaf, S. S., N. E. Williams, R. Winfree and C. Kremen. (2007). Bee foraging ranges and their relationship to body size. Oecologia, 153, 589-596.

Gu, Y., S. Boyte, B. Wylie, and L. Tieszen. (2012). Identifying grasslands suitable for cellulosic feedstock crops in the Greater Platte River Basin: dynamic modeling of ecosystem performance with 250 m eMODIS. GCB Bioenergy, 4, 96-106.

Klett, A.T., H.F. Duebbert, C.A. Faanes, and K.F. Higgins. (1986). Techniques for studying nest success of ducks in upland habitats in the Prairie Pothole Region. U.S. Fish and Wildl. Serv., Res. Pub. 158, Washington, D.C. 24 p.

Jungers, J.M., J. E. Fargione, C. C. Sheaffer, D. L. Wyse, and C. L. Lehman. (In Press). Short-term harvesting of bioenergy from conservation grasslands maintains plant biodiversity. *Global Change Biology: Bioenergy*.

Jungers, J. M., T. Arnold, and C. L. Lehman. (In Review). Effects of harvesting biomass from conservation grasslands on waterfowl nest success and density. Submitted to *American Midland Naturalist*.

Jungers, J. M., J. E. Fargione, C. C. Sheaffer, D. L. Wyse, and C. L. Lehman. (2013). Energy potential of biomass from conservation grasslands in Minnesota, USA. *PLoS One*. 8(4): e 61209.

Lambert, D., P. Sullivan, R. Claassen, and L. Foreman. (2006). Conservation-Compatible Practices and Programs. Who Participates? USDA Economic Research Service; Economic Research Report Number 14; available at http://www.ers.usda.gov/publications/err14/err14.pdf

Long, S., L. Potter, M. Bingham, and C. Stirling. (1990). An analysis of limitations to the production of C4 perennials as ligno-cellulosic biomass crops, with reference to trials in E. England. Biomass for Energy and Industry, 5th European Conference, pp 1235-1241.

Rashford, B. S., J. A. Walker, J. A., and C.T. Bastian. (2011). Economics of grassland conversion to cropland in the prairie pothole region. Conservation Biology 25:276–84.

Satyshur, C., C. L. Lehman, and R. D. Moon. (In Prep). Efficiency of sweepnet sampling arthropods in grasslands

Tilman, D., J. Hill, and C. Lehman. (2006). Carbon-negative biofuels from low-input high-diversity grassland biomass. Science 314:1598–1600.

Williams, S., J. M. Jungers, K. Johnson, C. Satyshur, M. DonCarlos, R. Dunlap, T. Mielke, J. Schaffer, D. Tilman, D. Wyse, R. Moon, T. Arnold, C. Lehman (2012). Bioenergy from reserve prairies in Minnesota: Measuring harvest and monitoring wildlife. *Proceedings from Sun Grant National Conference: Science for Biomass Feedstock Production and Utilization*, Volume 2, Chapter 5, New Orleans.

Barnes, R., C. Lehman, S. Williams, and L. Frelich. (2011). Climate Tracking: Applications of a novel technique to sustainability. Poster presented at October 2011 U of MN Sustainability Symposium.

Parr, T., and J. Way. (1988). Management of roadside vegetation : The long-term effects of cutting. J of Applied Ecology, 25, 1073-1087.

Tilman, D. (1993). Species richness of experimental productivity gradients : How important is colonization limitation? Ecology, 74, 2179-2191.