

**Project Title**

Effects of Stand-Replacing Wildfire on Ecosystem Carbon Pools in Lake States Jack Pine Forests

**JFSP Project Number**

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## **I. Abstract**

A key barrier to resolving uncertainty about the effects of fire on ecosystem C balance is the fact that fire effects on ecosystem C budgets are manifested over decadal time scales, meaning that we are largely forced to draw inferences using space-for-time substitution, or chronosequence, studies. Whereas chronosequences allow us to study processes occurring over long time scales, they are almost never re-sampled to verify the temporal trajectory of response variables, raising questions about the validity of chronosequence estimates of post-fire C dynamics. We re-sampled a well-studied fire chronosequence of jack pine (*Pinus banksiana*) forests in Michigan, providing a unique opportunity to both determine the accuracy of chronosequence estimates of post-fire C fluxes for this forest type, as well as elucidate variability in rates of C loss and recovery following wildfire. In addition, we conducted stable-isotope analysis of deep soil C profiles to gain a better understanding of the response of mineral soil C to stand-replacing wildfire and used retrospective, tree-ring analysis to identify potential changes in tree growth over the past 50 years. Finally, we integrated these results into a spatial modeling framework to estimate the effects of alternative management practices and changing disturbances regimes on landscape carbon balance. We are currently in the process of preparing manuscripts for peer-reviewed publications addressing chronosequence C budgets and deep-soil C response to disturbance. We are also developing a Technical Report for land managers addressing the implications of changing rotation length and disturbance regimes on landscape C balance.

## **II. Background and Purpose**

The role of forests in the global carbon (C) cycle is of growing concern to scientists and policymakers, with forest management activities being seen as a potential tool for mitigating anthropogenic emissions of carbon dioxide (CO<sub>2</sub>) from fossil fuel burning (Schultze et al. 2000; Martess 2009). In addition, the frequency and intensity of disturbances (notably wildfires, prescribed burns and fuel treatments) across space and time has an overwhelming influence on the cumulative C balance of a National Forest, or equivalent land unit (Chen et al. 2004). As a consequence, state and federal forestland managers are increasingly faced with the problem of understanding how current wildfire regimes and forest management practices affect landscape-scale carbon balance, and how management could be altered to enhance net C sequestration. However, considerable uncertainty remains about the effects of fire and forest management on total ecosystem C balance. A key barrier to resolving this uncertainty is the fact that fire effects on ecosystem C budgets are manifested over decadal time scales, meaning that we are largely forced to draw inferences using space-for-time substitution, or chronosequence, studies that quantify patterns of C stocks or cycling across sites spanning a range of time since disturbance. Whereas chronosequences allow us to study processes occurring over long time scales, they are susceptible to misinterpretation, if factors other than stand age vary among sites (Yanai et al. 2000; Johnson and Myanmashi 2008). We re-sampled a well-studied fire chronosequence of jack pine (*Pinus banksiana*) forests (Rothstein et al. 2004; Yermakov and Rothstein 2006; Spaulding and Rothstein 2009) with the following objectives:

Objective 1. Use re-measurement chronosequence sites to test the accuracy of chronosequence estimates of post-fire C fluxes.

Objective 2. Understand mechanisms underlying variability in post-fire ecosystem C flux.

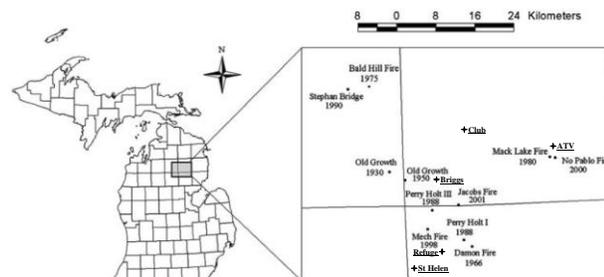
Objective 3. Use  $^{13}\text{C}$  natural abundance measures to assess the potential for post-fire C losses from mineral soil horizons

Objective 4. Quantify the consequences of alternative management practices for landscape-scale carbon storage and cycling in jack pine forests

### III. Study Description and Location

This study took place in the Highplains district of northern Lower Michigan (Fig. 1). The landscape of this region is primarily composed of broad outwash plains dominated by acidic, excessively drained sandy soils which support forests dominated by jack pine (*Pinus banksiana*; Comer et al. 1995). Jack pine forests of this region were historically maintained by frequent (ca. 60 y), stand-replacing wildfires (Cleland et al. 2004). Wildfires are still quite common, but clearcut harvesting now dominates the disturbance regime of this landscape. Jack pine forests of this region are intensively managed, because young stands provide the only significant breeding habitat for a federally-endangered songbird, the Kirtland's warbler (*Dendroica kirtlandii*; Walkinshaw 1983). Thus, state and federal land managers in Michigan and throughout the Lake States must balance the potentially conflicting demands of managing for natural ecosystem processes in a fire-prone landscape, maintaining and expanding essential habitat for an endangered species, minimizing the risk of wildfire damage to human structures, maximizing the economic return from forest management, and maintaining the long-term productivity of sensitive soils.

In 2002 we developed and sampled a chronosequence of 11 wildfire-regenerated jack pine stands that burned in 2001, 2000, 1998, 1995, 1990, 1988, 1980, 1975, 1966, 1950, and 1930 ( Fig. 1). At each site, we sampled the amount of C stored in overstory and understory vegetation, dead wood, organic horizons and the top 10 cm of mineral soil. We sampled a single soil pit at each site to estimate C stored in mineral soils between 10 and 100 cm. Carbon inventories and chronofunctions describing changes in C stocks as a function of time since stand-replacing wildfire were developed and published in the Canadian Journal of Forest Research (Rothstein et al. 2004). We initiated a second study in 2005 aimed at comparing forest structure, ecosystem C stocks and soil fertility between fire-origin and harvest-origin stands. Stands ages for this comparative chronosequence study were selected with the goal of achieving replication ( $n = 3$ ) within three age classes representing distinct periods of stand development: establishment (3-6 years), exponential growth (12-17 years) and maturity (40-70 years). This study resulted in one



**Figure 1.** Locations of study sites in the northern Lower Peninsula of Michigan. Original 2002 sites noted with circles, 2005 sites noted with crosses and underlined text. Adapted from Yermakov and Rothstein (2006).

publication on forest structure (Spaulding and Rothstein 2009) and another on soil C and soil fertility (Rothstein and Spaulding 2010).

For the current project we relocated and resampled all of the 2002 and 2005 study sites that remained undisturbed. We were able to relocate plot locations for the 2005 study sites, but had to set up new plots for the 2002 study sites. During the summer of 2010 we visited each site and measured diameter at breast height and total tree height of all standing trees, live and dead. We measured every piece of coarse woody debris (CWD) greater than 5 cm in diameter at each plot. We sampled understory vegetation, and surface organic horizons using a sample frame, and we collected mineral soil cores to a depth of 80 cm. We used allometric equations to convert tree and snag measurements to estimates of biomass C. In the summer of 2011 we collected CWD samples which we used to determine density of various decay classes to convert field

CWD

measurements to C pools. Samples of organic horizons were weighed, composited, subsampled and analyzed for C concentration on a COSTECH ECS 4010 elemental analyzer. Soil cores were separated into 0-15, 15-30 and 30-80 cm samples, air-dried, picked free of roots and rocks, weighed sieved, subsampled, pulverized and analyzed for C concentration using the elemental analyzer.

**Table 1.** Chronosequence stands utilized in this study. Age refers to age in 2010, x's indicate that that stand was sampled for ecosystem C budgets in 2002, 2005 or 2010.

Name	Age	2002 Sampling	2005 Sampling	2010 Sampling
HVRP <sup>1</sup>	0.2			x
Jacobs	9	x		x
No Pablo	10	x	x	x
ATV	11		x	x
Mech	12	x	x	x
Perry Holt (III)	15	x		x
Stephan Bridge	20	x		x
Perry Holt (I)	22	x	x	x
Refuge	22		x	x
St Helen	23		x	x
Mack Lake	30	x		x
Bald Hill	35	x		x
Damon	44	x	x	x
Briggs <sup>2</sup>	60	x	x	x
Club	65		x	x

<sup>1</sup>This site burned in a stand-replacing fire in May 2010 and was sampled in July of that same year.

<sup>2</sup>Sampling in 2005 was done on the same fire as for the 2002 chronosequence, but in a different location.

In 2011 we revisited all of the sites to collect increment cores for tree ring analysis. All sites with ages greater than 12 years were sampled in 2011. This age was chosen to allow trees a few years of additional growth beyond breast height before they were sampled. Eight plots per site were re-located using GPS coordinates collected during 2010 sampling. At each plot, two dominant trees were chosen for increment boring. By choosing dominant trees, we hoped to eliminate as much of the effect of competition on ring width as possible. The youngest sites (ATV, Mech) regenerated sparsely and have fewer cores than the older sites. Two cores were taken from each tree to help account for within tree variation. The second core was taken perpendicular to the first, just above or below. After fieldwork was completed, cores were

oven-dried and mounted. Cores were then sanded down to 400 grit sandpaper. Images of the cores were then obtained using a scanner set to 1200 dots per inch. Using the program CooRecorder, ring widths were recorded by manually clicking ring boundaries. Cores were crossdated and a master chronology developed using the program COFECHA.

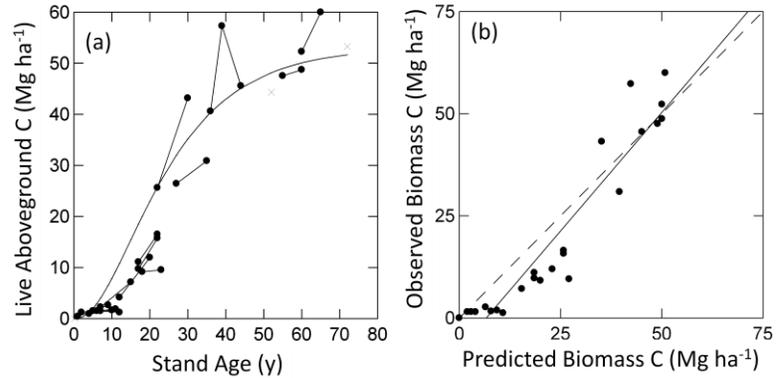
In 2011 we collected additional 80-cm cores at a subset of sites representing the nadir of ecosystem C (Jacobs, No Pablo, ATV and Mech) and peak C (Damon, Briggs, Club). These cores were collected with a custom-designed corer with openings at 10-cm increments. After carefully removing approximately 1 cm of the exterior portion of the core, a clean subsample of soil was taken at 10-cm increments for detailed analysis of depth gradients of  $^{13}\text{C}$  natural abundance. Samples were brought back to the lab where they were dried and carefully picked through to remove all visible roots or root fragments. This step was particularly critical because live roots will have a unique  $^{13}\text{C}$  signature that would confound investigation of  $^{13}\text{C}$  patterns of soil organic C. Once picked free of roots these samples were pulverized, weighed and submitted for  $^{13}\text{C}$  analysis at the University of California, Davis Stable Isotope Facility.

To assess landscape-scale patterns of C storage and potential response to changes in management and disturbance we applied the LANDIS-II spatially-explicit ecosystem model to our study region. This involved accessing, merging and clipping USDA-Forest Service and Michigan-Department of Natural Resources (MDNR) stand inventory shapefiles. The resulting shapefile was converted to raster format to provide input stand data for simulation modeling. The resulting landscape for modeling was 68,350 ha of jack pine forests on national and state forest lands, which encompassed approximately 760,000 individual 30 x 30 meter cells. Scenarios investigated in LANDIS-II included: i) business as usual (50 year harvest rotation period and contemporary fire return interval of 787 years from Cleland et al. 2004); ii) continuation of current management with an increase in fire frequency (50 year harvest rotation period and return interval of 350 years; iii) management intensification with no change in fire frequency (30 year harvest rotation period and contemporary fire return interval of 787 years); and iv) a pre-European reference disturbance scenario (no harvesting and pre-settlement fire return interval of 59 years as estimated by Cleland et al. 2004). Scenarios were run for 100 years at 10-year time steps and model output on disturbance and stand age distribution were coupled to ecosystem C stock chronofunction from Objective 1 to generate estimates of stand carbon density and total landscape C stocks.

#### **IV. Key Findings**

Objective 1. Use re-measurement chronosequence sites to test the accuracy of chronosequence estimates of post-fire C fluxes. Figure 2 shows living aboveground biomass C as a function of age since stand-replacing wildfire. The solid line shows the original chronofunction for living aboveground C developed by Rothstein et al. (2004). Resampled stands are shown circles with lines connecting individual sample dates. Stands sampled only one time are indicated with an X symbol. Overall our original chronosequence well described pattern of C accumulation over time following wildfire in this ecosystem. Unlike resampling of the famous Covington Forest floor chronosequence (Yanai et al. 2006) we find no systematic bias in comparing changes in C stocks – trends over time within individual stands generally followed the changes predicted from the chronofunction with a few exceptions. Two patterns emerge from this raw data. First there is substantial variability in changes observed in older

stands over time, with no apparent systematic pattern. In contrast, for the younger stands, aboveground biomass increases as expected but our original chronofunction appears to systematically overestimate aboveground biomass growth for stands younger than 30 years. This result is demonstrated quantitatively in Figure 2 b. where we regress observed aboveground biomass C against that predicted for each stand. These data show that our original chronofunction explains nearly 90% of the variation in aboveground biomass C ( $r^2 = 0.896$ ); however the slope (0.772) is significantly lower than 1 ( $P < 0.001$ ) due to the overprediction for younger stands.

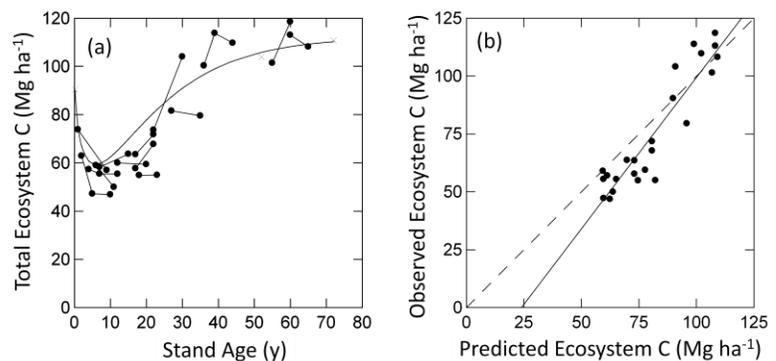


**Figure 2.** Predicted and observed changes in aboveground biomass C. Panel (a) shows results for individual stands superimposed over the original chronofunction reported in Rothstein et al. 2004. Stands with repeated sampling are represented by filled circles and connected by lines. Stands sampled only a single time are represented with x's. Observed total aboveground biomass C is regressed against predicted in panel (b), with the 1:1 line represented by the dashed line.

Patterns for total ecosystem C (Figure 3) were similar to aboveground biomass C. Overall our original chronofunction for total ecosystem C matches well the pattern of C accumulation shown by resampling stands. In particular, the early decline in ecosystem C stocks, the stabilization and increase from ages 10–40 years and the slowing of ecosystem C accumulation late in stand development were well captured with a few exceptions in individual stands (Fig. 2a). Comparing predicted ecosystem C stocks vs those observed from resampled sites provides similar results as for aboveground biomass (Fig 2b). In this case our original chronofunction explains 85% of the variation in total ecosystem C ( $r^2 = 0.854$ ) and, again, the slope (0.653) is significantly lower than 1 ( $P < 0.001$ ) indicating systematic overprediction for younger stands.

Objective 2. Understand mechanisms underlying variability in post-fire ecosystem C flux.

Results from Objective 1 clearly showed that our original chronofunctions captured well the basic pattern of ecosystem C loss and recovery following wildfire in this ecosystem, but that we were consistently overestimating the C gain by stands younger than approximately 40 years. In order



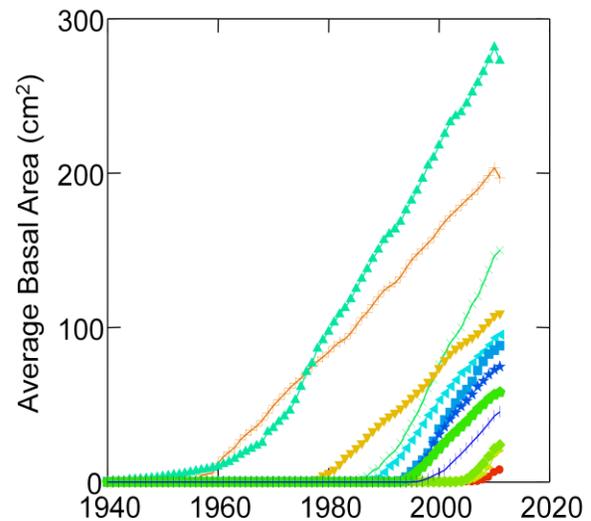
**Figure 3.** Predicted and observed changes in total ecosystem C. Panel a shows results for individual stands superimposed over the original chronofunction reported in Rothstein et al. 2004. Stands with repeated sampling are represented by filled circles and connected by lines. Stands sampled only a single time are represented with x's. Observed total ecosystem C is regressed against predicted in panel (b), with the 1:1 line represented by the dashed line.

to understand mechanisms underlying this variability we regressed the residuals of our predicted vs. observed relationships against two factors we know to influence ecosystem C pools in these systems: stem density and soil texture (Rothstein et al. 2004). Our approach here was to understand if one of these underlying variables could explain the degree to which individual stands were under- or over-predicted by our original chronofunction. Stem density had no relationship to the residuals of either aboveground biomass C or total ecosystem C. In contrast, soil silt + clay content was positively correlated with residual variation for both aboveground C ( $r^2 = 0.214$ ;  $P = 0.026$ ) and total ecosystem C ( $r^2 = 0.314$ ;  $P = 0.005$ ). Thus our over-prediction of both aboveground and total ecosystem C tended to be greater for stands on coarser-textured soils compared to finer-textured soils; however, the amount of residual variation explained by texture was low for both (20-30%).

Another possibility is that long-term changes in climate over the 60+ years of this chronosequence may explain the systematic overestimation of C gain by younger stands. We are taking two novel approaches to address this possibility. First, we intend to reanalyze all of our chronosequence data using a Bayesian, resampling approach that will allow us to generate estimates of expected annual biomass change with uncertainty (e.g. McMahon et al. 2010). Resulting confidence limits for expected C gain will allow us to statistically evaluate deviation of individual stands and relationships with stand age and underlying site factors. Second, we collected increment cores from 2 dominant trees in each plot across our chronosequence for all stands greater than 15 years in 2011. After fieldwork was completed, cores were oven-dried, mounted, sanded and scanned. Using the program CooRecorder, ring widths were recorded and then a master chronology was built with cross-dating using the program COFECHA. Currently we are working on detrending our ring widths in the program ARSTAN in order to evaluate climatic relationships with tree growth over the 50+ years of our chronosequence. This will allow us to test the hypothesis that long term changes in climate resulting in reduced rates of tree growth explain the underperformance of current growth relative to expectations generated from space-for-time substitution. Raw data for temporal changes in average basal area of dominant trees over the entire chronosequence are presented in Figure 4.

### Objective 3. Use $^{13}\text{C}$ natural abundance measures to assess the potential for post-fire C losses from mineral soil horizons

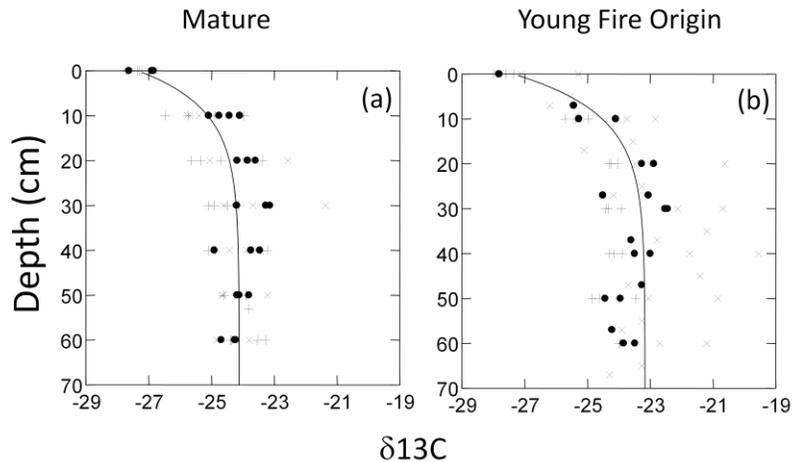
It is notoriously difficult to detect changes in mineral soil C pools over time, and across treatments, due to the large pool of very stable C present in soils and the high degree of spatial and depth variability within sites (e.g. Homann et al. 2008). The natural abundance of the stable isotope  $^{13}\text{C}$  in soil organic C has been proposed as a sensitive indicator of C loss from



**Figure 4.** Temporal patterns of tree growth reconstructed for all chronosequence stands originating in 1999 or earlier. Data are average basal areas for dominant trees reconstructed from increment cores.

mineral soil profiles where changes in bulk soil C cannot be detected (Wynn et al. 2006; Diocion and Keller 2008). Briefly, under equilibrium conditions, kinetic fractionation against  $^{13}\text{C}$  results in a characteristic trend of increasing enrichment of soil C (Wynn et al. 2006). Enhanced decomposition and reduced litter inputs following disturbance can shift this gradient such that losses of soil C that are undetectable by conventional methods can

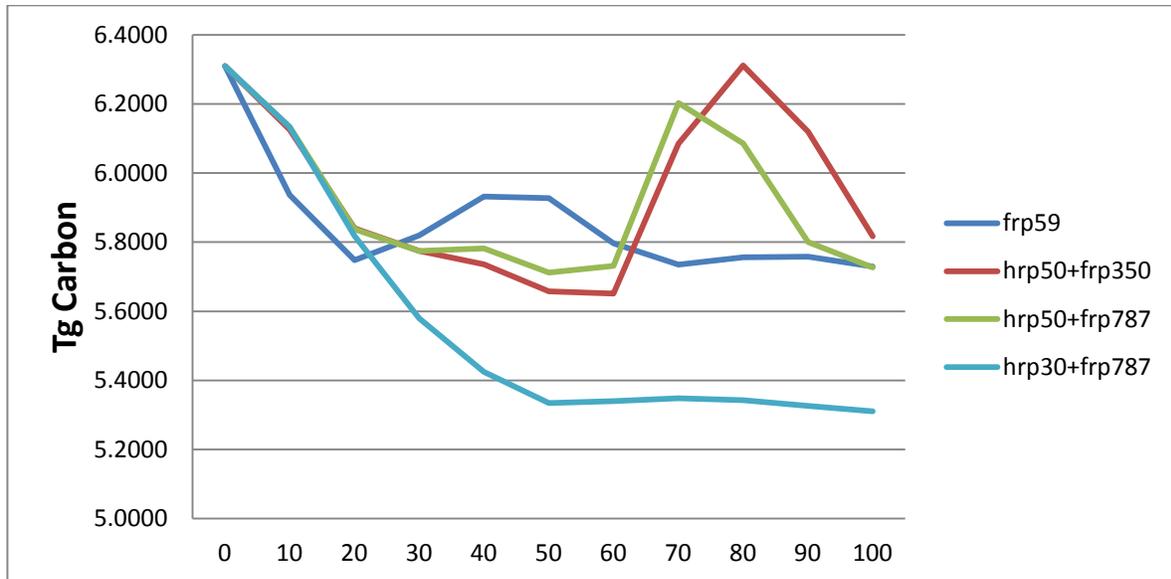
be identified through isotopic analysis (Diocion and Keller 2008). For this study, we collected soil samples at 10-cm increments (from 0 – 60 cm) from three mature jack pine stands (aged 50-60 years) and from three young stands (aged 10-13 years). The age range for the young stands was selected to correspond to the nadir of ecosystem C based on our chronosequence work (e.g. Fig 3a). These samples were carefully picked free of roots and root fragments, pulverized, encapsulated and analyzed for  $\delta^{13}\text{C}$  using isotope-ratio mass spectrometry (IRMS). We fit depth profiles of  $^{13}\text{C}$  natural abundance to the equation  $\delta^{13}\text{C}(z) = \delta^{13}\text{C}(s) + k(1 - e^{-z/z\delta})$ , where  $\delta^{13}\text{C}(z) = \delta^{13}\text{C}$  at depth  $z$ ,  $\delta^{13}\text{C}(s) = \delta^{13}\text{C}$  at the surface,  $z\delta$  is the e-folding depth and  $k$  is an empirical constant describing the magnitude of isotopic shift from surface to the maximum depth (Diocion and Keller 2008). Our expectation was that losses of mineral soil C due to decomposition post disturbance would be indicated by greater values for  $k$  in younger stands indicative of enhanced decomposition and reduction of inputs of new C in the decade following stand-replacing wildfire. We did indeed observe a trend towards greater enrichment of mineral soil C in the young stands (mean  $k = 4.23$ ) compared to the mature stands (mean  $k = 3.271$  (Fig. 5); however, due to a high degree of variability among young stands this difference was not statistically significant ( $P = 0.096$ ). We resubmitted approximately 15% of our original samples that were approaching the detection limit for IRMS in the hopes that we could reduce variability with larger samples. We received these data in mid-January 2013. Our plan is to reanalyze our depth profiles using these new data and incorporate into a manuscript for submission in Spring of 2013.



**Figure 5.** Depth distributions of  $^{13}\text{C}$  natural abundance of soil organic carbon for mature stands (a) and young stands (b). Lines represent best fit of data for each age class to the model:  $\delta^{13}\text{C}(z) = \delta^{13}\text{C}(s) + k(1 - e^{-z/z\delta})$ , where  $\delta^{13}\text{C}(z) = \delta^{13}\text{C}$  at depth  $z$ ,  $\delta^{13}\text{C}(s) = \delta^{13}\text{C}$  at the surface,  $z\delta$  is the e-folding depth and  $k$  is an empirical constant describing the magnitude of isotopic shift from surface to the maximum depth. Different symbols indicate different stands within each age class.

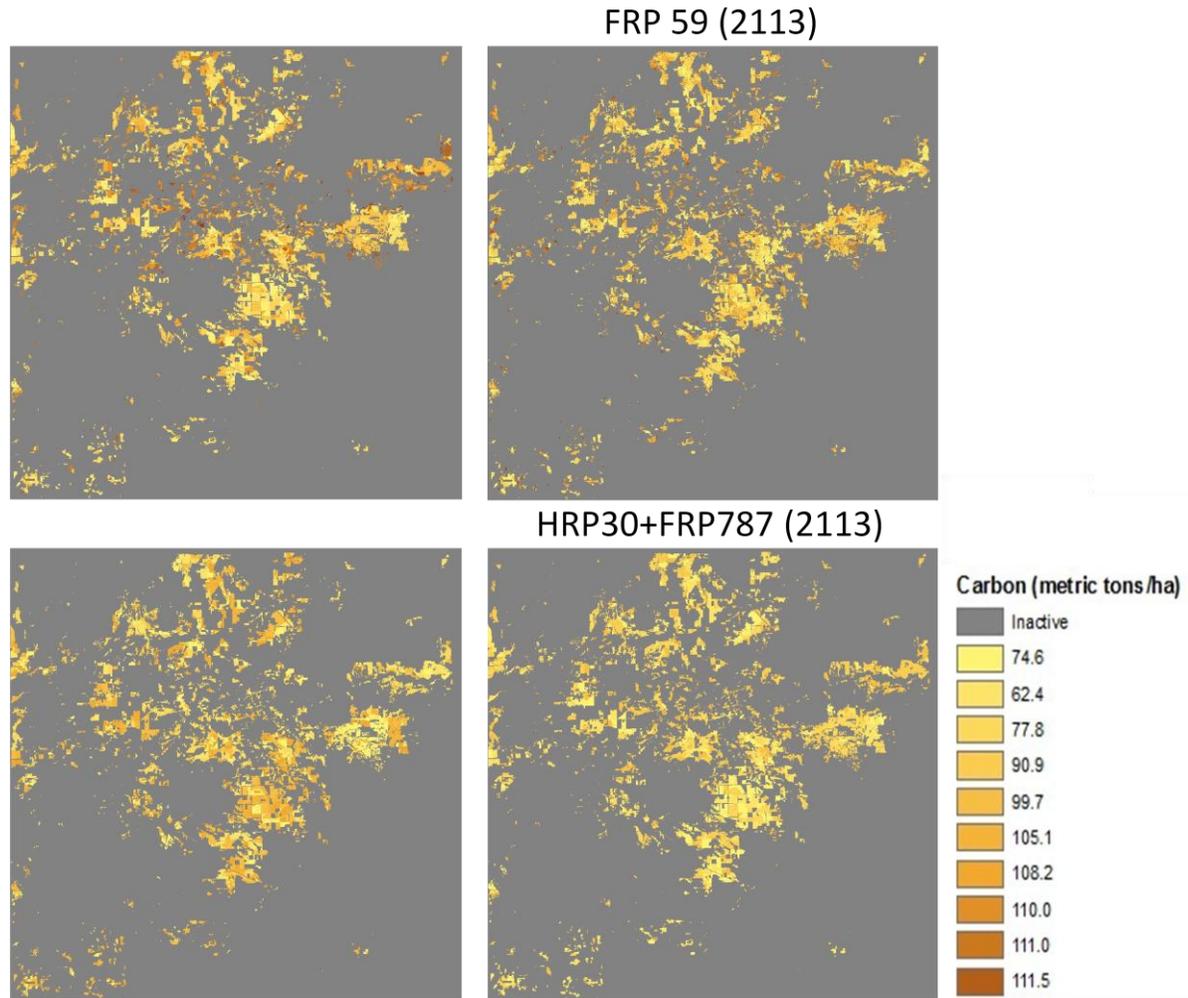
Objective 4. Quantify the consequences of alternative management practices for landscape-scale carbon storage and cycling in jack pine forests

At the landscape-scale jack pine forests of this region store approximately 6.3 Tg, or 6.3 million metric tons, of C. Results from our simulation modeling clearly show that this level of landscape-scale C storage is outside the range of natural variation and likely results from the legacy of fire suppression and limited harvesting during the mid-19<sup>th</sup> century. Under every scenario – including a return to pre-settlement disturbance regimes – landscape C storage drops rapidly during the first 20-40 years of simulation (Fig. 6, Fig. 7). Our modeling work also suggests that a 50-y harvest rotation period creates landscape-scale C dynamics that are generally congruent with those we would expect from the pre-settlement disturbance regime.



**Figure 6.** Changes in landscape C storage in jack pine forests projected for the Highplains district of northern Lower Michigan under varying disturbance scenarios: frp 59 = no harvesting and pre-settlement fire return interval; hrp50+frp350 = current management and a doubling of fire frequency relative to current conditions; hrp50+frp787 = current management and current fire frequency; and hrp30+frp787 = intensification of management with no change in fire frequency.

However, we need to extend our modeling runs to evaluate this further as landscape C storage had clearly had not equilibrated by the end of our 100-y simulations. Regardless, under current management, we would expect this landscape to function as a net source of C to the atmosphere over the next few decades. Finally, our simulation modeling indicates that intensification of management, to increase Kirtland’s warbler habitat and/or greater biomass energy production, clearly pushes this landscape outside of the range of natural variability for C storage.



**Figure 7.** Patterns of C density of jack pine stands across the Kirtland’s Warbler Management Area in northern Lower Michigan for: 1) present day condition, 2) after 100 years simulation of no harvesting and pre-settlement fire return interval (FRP 59); 3) after 100 years simulation of current management and current fire regime (HRP50+FRP787); and 4) after 100 years simulation of intensified harvesting and current fire regime (HRP30+FRP787).

## Management Implications

### Predictability of stand C storage.

The original chronofunctions developed by Rothstein et al. (2004) have been demonstrated to describe well the changes in ecosystem C storage for jack pine on outwash soils in this region. The revised chronofunctions we are producing in this project, that utilize additional stands and resampling of older stands, will allow land managers to develop credible estimates of landscape-scale C storage and to predict changes in C storage in response to changes in stand age distribution. This is particularly important for the jack pine ecosystems of northern Lower Michigan where managers are beginning to grapple with a transition in management goals from a narrow focus on creating habitat for the endangered Kirtland’s Warbler to an approach that encompasses a suite of ecosystem attributes including processes such as C cycling.

Chronofunctions for C storage will allow managers to easily evaluate potential tradeoffs or synergies between C storage and Kirtland's Warbler habitat.

#### Long-term trends in jack pine growth under a changing climate.

Our tree ring analysis will provide important information on the climatic drivers of jack pine growth in this region. Because jack pine occurs here at the southern limit of its range, and provides critical habitat for an endangered species only in the Lake States, there is great concern that future climate change will result in declines of both jack pine and Kirtland's Warbler in northern Lower Michigan (Botkin et al. 1991). Results from our analysis of climate relationships with tree growth over the period 1960-2011 will aid in our understanding of potential responses of this ecosystem to future climate change.

#### Process Modeling of Landscape C Dynamics

We are using the wealth of field data on ecosystem C pools and forest growth rates to calibrate the landscape ecosystem model LANDIS-II for our study region. We are using LANDIS-II with the CENTURY extension that includes cycling processes of C and N. Because LANDIS-II can incorporate natural disturbance, harvesting and changes in climatic parameters, this will provide a powerful tool with which to project changes in jack pine stand dynamics and landscape C sequestration under varying management scenarios and potential future climate scenarios. For example, we are working now to define the potential tradeoffs between management for Kirtland's Warbler habitat vs management for maximizing C sequestration. An example of this can be seen in Figure X, where accelerated harvesting to increase the amount of warbler habitat on the landscape results in a significant decline in equilibrium C storage across the landscape.

#### **Relationship to other recent findings and ongoing work on this topic**

Members of this research team are involved in the following efforts that build from this project:

1. In 2012 PI Rothstein began serving as the chair of a new science advisory committee advising the interagency Kirtland's Warbler Management Team (USDA-Forest Service, US Fish and Wildlife Service, MI-DNR, etc) on issues related to a potential delisting of the species and strategies for applying an ecosystem management approach to managing critical habitat. Results from this project, especially the development of a locally-calibrated landscape disturbance model, will greatly aid these efforts.
2. Technician Michael Cook is leading efforts to apply the LANDIS-II model to Lake States jack pine as part of a future MS thesis. Work on this project laid the groundwork for this effort. In the future he will incorporate more complex future scenarios of changing management and changing climate. His goal is to produce output that is relevant to the Kirtland's Warbler Management Team's stated goal of moving to an ecosystem-management approach to managing jack pine habitat.
3. PI Rothstein is involved in several projects investigating the sustainable production of wood-based bioenergy in the Lake States Region. The understanding of jack pine growth and biomass accumulation gained in this project can inform evaluation of the potential of this landscape to produce biomass energy in a sustainable manner.

## VII. Future work needed

We have completed all of the field work, lab work and initial data analysis for this project we still have work to do in terms of final data analysis and synthesis. Specifically, we are working on the following products to be completed during the next 3-6 months:

1. A manuscript submitted to a peer-reviewed journal dealing with changes in aboveground biomass C dynamics incorporating data from both chronosequence resampling and tree-ring analysis.
2. A manuscript submitted to a peer-reviewed journal dealing with changes in belowground C based on <sup>13</sup>C work.
3. A General Technical Report and accompanying seminar detailing the response of stand and landscape C stocks to forest management alternatives. This report is currently in preparation and the seminar is scheduled to be delivered to the interagency Kirtland's Warbler Recovery Team on March 13, 2013.

Over the next 6-18 months, we will continue to refine the LANDIS-II landscape ecosystem model for this ecosystem type and produce at least one peer-reviewed article dealing with projections of landscape C change under varying management, disturbance and future climate scenarios.

## VIII. Deliverables Cross-Walk Table

Deliverable	Status
<i>From Original Proposal</i>	
Updates to KW Recovery Team	Completed for 2011 and 2012, scheduled for March 2013
Master's Thesis (Chumack)	Ms Chumack completed all of the fieldwork and labwork for this project; however, she has had a great deal of difficulty with data analysis and writing. This deliverable likely will not be achieved
General Technical Report for Land Managers	In Progress, expected first draft March 2013, Final Draft May 2013. Technician Cook has completed scenario analysis. PI Rothstein will write the initial draft and seek feedback from other PI's and land managers on additional scenarios to incorporate for the final draft.
Seminar	First presentation scheduled for KW Recovery Team Meeting March 2013. Additional presentations will be scheduled for summer 2013.
Refereed Publication Chronosequence	In Progress. PI Rothstein is taking on data analysis and lead writing responsibilities with the goal of submitting a manuscript incorporating chronosequence data plus tree ring data by June 2013
Refereed Publication 13C	Dr. Razavi-Toosi has been working on this aspect of the project. He will incorporate recently re-run IRMS samples, reanalyze data and begin writing a manuscript with the goal of submission by June 2013.

<i>Additional Deliverables</i>	
Refereed Publication Landscape Ecosystem Modelling	Technician Cook will utilize primary field data on soils and ecosystems generated in this project to calibrate the CENTURY extension for the LANDIS-II model. This will allow us to simulate ecosystem C and N dynamics across real landscapes. He is developing a modeling project investigating interactions of management, disturbance and projected climate change on future ecosystem dynamics for the study region. The goal is to submit a peer-reviewed manuscript by August 2014.

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