FORSight Resources LLC

Forest Management Scheduling Models for Manchester, Wee Tee and Sand Hills State Forests

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Executive Summary

In 2002, the South Carolina Forestry Commission (SCFC, hereafter) published the "Long Range Plan South Carolina Forestry Commission's State Forests". This publication guides the management of the State Forests into the 21st century. Included in this document is a call for effective use of technology to enhance the management strategies on the State Forest. This includes the centralization of data, improved use of GIS, and utilization of forest planning models. In 2005 the SCFC implemented webFRIS™, a decision support system for forestry which facilitates centralization of data and improved utilization of GIS. However, forest planning models had yet to be implemented.

FORSight Resources, LLC (FORSight, hereafter) was contracted by SCFC to develop strategic and tactical harvest schedules for Manchester, Wee Tee and Sand Hills State Forests. As part of the modeling process, FORSight conducted a rigorous screening and cleaning of the data received from SCFC. The forest database was checked for missing data, data that fall outside biologically reasonable bounds, and data that were suspect or may have produced incorrect results. The analysis of the Sand Hills dataset revealed several sources of error that were subsequently corrected.

Prior to the beginning of the modeling effort, SCFC staff had identified a set of management regimes for both even-aged and uneven-aged management on the State Forests of South Carolina. After some deliberation about suitable growth and yield models and their ability to adequately project the desired regimes, a total of nine management regimes were chosen for inclusion in the harvest scheduling models.

For the purpose of generating existing and future yields for candidate management regimes, stratification of the land base by biological parameters was performed. Growth and yield models were chosen based on cover type appropriateness and their ability to model required management regimes. A variety of stand-based growth and yield models were used in developing current and future yield estimates. The stratified current forest inventory data was projected forward to best meet the needs of the harvest schedule planning horizon and the management regimes. Regeneration yields were grown for 120 years or 100 years for longleaf and loblolly pines, respectively.

FORSight used the Remsoft Spatial Planning Suite (Remsoft, 2007) to develop the forest planning models, with Spatial Woodstock as the strategic planning model and Stanley as the tactical planning model. It was decided that Sand Hills (SHSF) would be modeled on its own, and Manchester and Wee Tee would be modeled together in a separate model (MAWT). To facilitate comprehension and interpretation of results, FORSight attempted to make the two models as similar as possible, with common action and output keywords, and similar stratification schemes wherever possible.

The SCFC's primary goal for the State Forests is to provide a range of amenities for the citizens of South Carolina in an economically efficient manner. State Forests are to cover their own operational costs and, where possible, generate revenues to the State and the counties where they are located. Therefore, a discounted cash flow model that maximizes the discounted net revenue over the planning horizon was the appropriate model formulation, using the 5% (real) rate provided by SCFC. SCFC provided FORSight with documents detailing the assumptions, parameters, and management regimes/silvicultural treatments to be included in the SHSF and MAWT model formulations.

Regime	Description	Forest where implemented
0	No mid-rotation thinning (HW, other pines)	MAWT, SHSF
1	Modified two-age management (loblolly, longleaf)	MAWT*, SHSF
2	Extended plantation rotation for sawtimber production (loblolly, longleaf)	MAWT
3	Group selection (loblolly, longleaf)	MAWT*, SHSF
4	Extended natural rotation for sawtimber production	MAWT
5	Individual tree selection for RCW	-
6	Plantation economic rotation (loblolly, longleaf)	MAWT
7	Individual tree selection economic	-
8	Natural economic rotation (loblolly)	MAWT
9	Intensive plantation (loblolly)	MAWT
10	Shelterwood natural rotation (loblolly, longleaf)	MAWT

** only implemented in RCW partitions on MAWT*

No suitable growth and yield models were available that could adequately simulate individual tree selection (ITS) without resorting to tree-based versus stand-based growth models. Since the stand-based models were considered more robust overall, it seemed reasonable to drop the ITS regimes from consideration in the planning models.

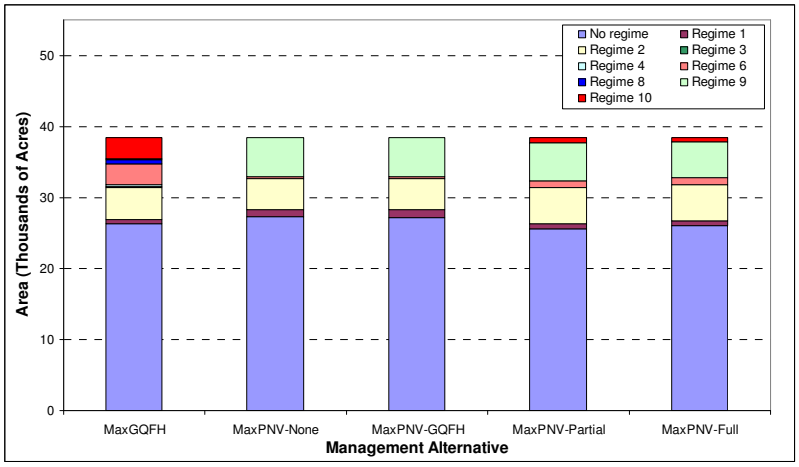
Both models include outputs standard to most harvest scheduling models: volume by product, revenue by product, acres harvested or treated, etc. Special outputs were developed to estimate foraging habitat for Red-cockaded Woodpeckers (RCW) on SHSF and MAWT. These foraging habitat estimates were used to constrain the model solution to demonstrate progress toward the recovery standard over the planning horizon.

Sensitivity Analysis

FORSight conducted a sensitivity analysis of the planning models to ensure biological and economic consistency. Five harvest schedule alternatives were analyzed by FORSight to test MAWT model.

Alternative Label	Description
MaxFH	Maximize foraging habitat (FH) within the five RCW clusters subject to no stand mortality and mandatory regeneration following final harvest.
MaxPNV-none	Maximize discounted net revenue subject to no stand mortality and mandatory regeneration following final harvest.
MaxPNV-FH	Same as MaxPNV-none plus constraints requiring minimum FH levels of 75 acres in RCW clusters 1,2,3,5 beginning in period 2 and 38 acres of FH in cluster 4 beginning in period 3
MaxPNV-partial	Same as MaxPNV-FH plus constraints setting a floor on net revenue and a ceiling on manpower required for prescribed burning and timber marking/cruising.
MaxPNV-full	Same as MaxPNV-partial plus constraints limiting net revenue and volume by product to fluctuations no greater than 20% period-to-period, and a nondeclining constraint on natural pine regeneration.

Net revenue and discounted net revenue are substantially lower with alternative MaxFH than with the other four alternatives because the objective focuses management almost exclusively on the RCW clusters, which comprise only about 10% of the total area. Over the first fifty years, alternatives MaxPNV-None and MaxPNV-FH exceed the manpower ceiling values nine times, at times by more than twice the limit. Forcing the fourth and fifth alternatives below these levels means less area can be treated, and the reduction in treatment area in turn results in the lower net revenues.

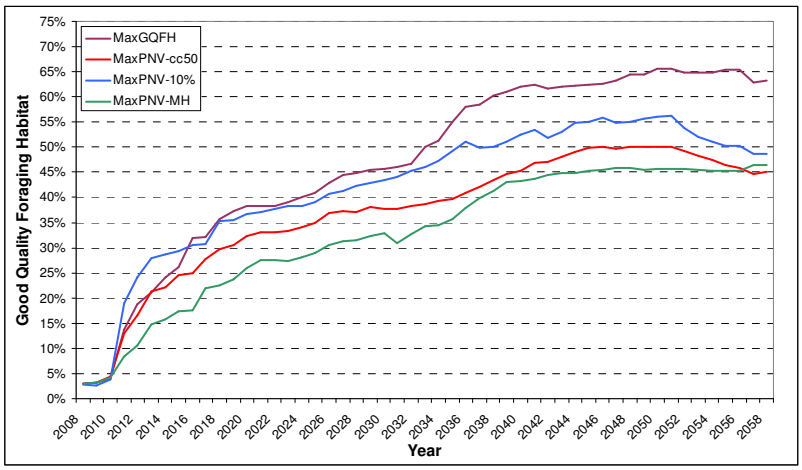


Manchester/Wee Tee area managed under each regime at year 2058, by alternative.

All alternatives transition towards a 3-way split in pine management among *final harvest only, extended rotation for sawtimber production* and the other regimes. Alternative MaxFH manages a majority of the remaining one-third under *optimum economic rotation* and *shelterwood rotation for natural stands.* The remaining four alternatives manage the remaining one-third primarily under *intensive plantation management*, but a small area is still managed under *optimum economic rotation* and *shelterwood rotation for natural stands.* The stand conditions promoted by these two regimes provide better RCW habitat, helping explain the higher habitat score and FH values for alternatives MaxFH, MaxPNV-FH, MaxPNV-Partial, and MaxPNV-Full.

Sensitivity analyses on four harvest schedule alternatives were performed by FORSight to test the SHSF model.

Alternative Label	Description
MaxGQFH	Maximize good quality foraging habitat (FH) within all RCW clusters.
MaxPNV-cc50	Maximize present net value subject to maximum clearcut harvest area fluctuations of +/- 50 acres between consecutive planning periods.
MaxPNV-10%	Maximize present net value subject to maximum net revenue fluctuations of +/- 10% between consecutive planning periods.
MaxPNV-MH	Maximize present net value subject to maximum personnel hours for prescribed burning of 2000 hours/year and for timber marking/cruising of 2500 hours/year.



Sand Hills Proportion of GQFH by management alternative (2008-2058).

As one might expect, the alternative MaxPNV-10% provides the highest discounted net revenues and MaxGQFH, the lowest. With respect to foraging habitat, alternatives MaxGQFH and MaxPNV-10% provide the highest average GQFH and habitat scores over both periods. Alternative MaxPNV-MH indicates that the model is sensitive to the number of personnel hours available for timber management. In the case of foraging habitat, a shift to group selection requires a substantial investment of time for marking trees, without which the improvements in foraging habitat are foregone. Similarly, capping the number of personnel hours limits the amount of timber harvesting that can be performed, which in turn limits harvest revenues.

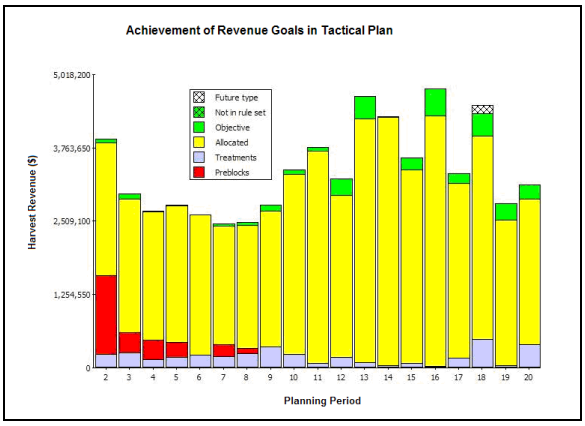
Preferred Alternatives for Manchester/Wee Tee and Sand Hills State Forests

Initial runs of the MAWT model showed high levels of hardwood harvesting in Tract 7 of MSF, an area that is considered well-stocked with high recreation values. Alternatively, the hardwood resource on WTSF is considered low-quality and had been targeted for aggressive harvesting to replace those stands with higher-quality hardwoods. To address these issues, the operability limits for hardwood harvests were altered to favor harvest of hardwoods on WTSF and disfavor those harvests on MSF. An upper limit was placed on hardwood clearcut harvesting of 600 acres/year. With these additional constraints, the resulting strategic harvest schedule yielded discounted net revenues of $57,964,392 over the first 50 years.

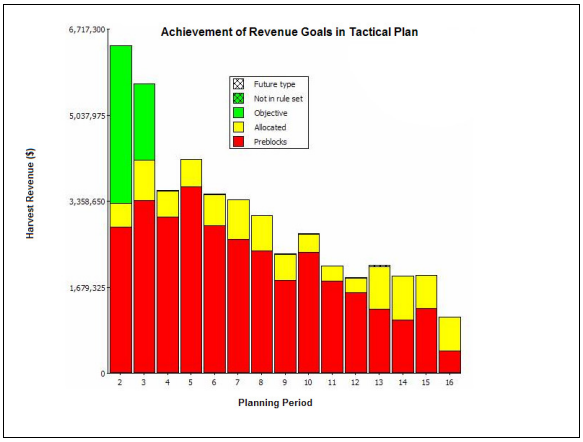
The SHSF model had a planning horizon of 176 years, 75 years longer than the planning horizon for MAWT. The rationale for the longer planning horizon was the longer rotations used in longleaf pine for RCW management: a planning horizon of 101 years would not have constituted a full rotation for the youngest stands on forest. Constraints were placed on each RCW partition on SHSF requiring at least 50% of the acres both within, and beyond, ¼ mile of the cluster center to be good quality foraging habitat (GQFH). Since this goal is clearly infeasible at the present time in most of the clusters, the model was formulated using goal programming, with penalties applied to underachievement of these goals. The objective is to devise a management schedule that minimizes the shortfalls in GQFH over time. With constraints on personnel hours, revenue fluctuations and a floor on harvest revenue of $1million per year, the strategic harvest schedule yielded discounted net revenues of $51,778,892 over the planning horizon.

Tactical harvest schedules of no less than 10 years were developed for MAWT and SHSF using Stanley. The Stanley tool attempts to allocate strategic harvest schedules to forest stands, while imposing spatial restrictions on harvesting that cannot be addressed in the strategic harvest schedule. Such restrictions include minimum and maximum harvest block sizes and green-up intervals (the minimum time that must elapse before harvesting adjacent or nearby harvest blocks). Once the blocks have been identified and scheduled by Stanley, the resulting block harvest schedule is incorporated back into the Woodstock strategic model as pre-planned activities to determine the impact of spatial restrictions on long-term management. The rationale for this step is to see if the tactical plan imposes limitations on long-term management goals. A significant change in harvest revenues predicted in the future, or severe violations of the manpower constraints would indicate a problem with the spatial plan.

In both cases, the tactical block harvest schedules were quite consistent with the original strategic harvest schedules. Initial periods of the tactical schedules suffered shortfalls in harvest volume and revenue relative to the original strategic harvest schedule, due to spatial restrictions; in SHSF, the shortfalls are significant. However, over the long-run, the discounted cash-flows are not significantly lower in the tactical harvest schedules, and the minimum revenue thresholds established in the strategic harvest schedules are not violated. MAWT exhibits more shortfalls in revenue in later periods whereas the shortfalls are most pronounced early in the planning horizon for SHSF.

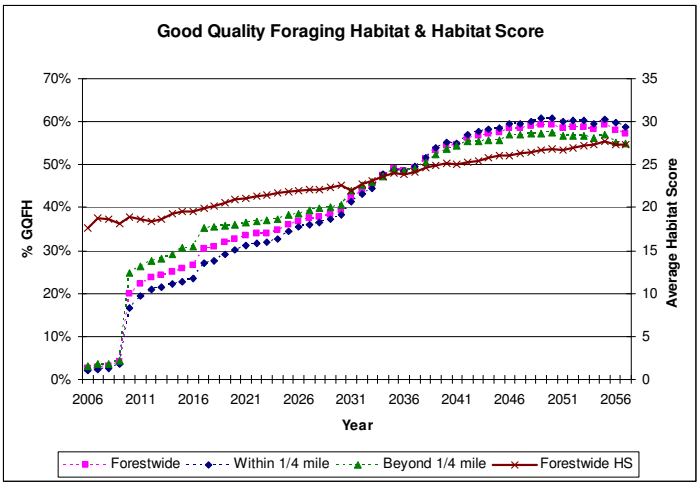


Achievement of strategic revenue targets in the MAWT spatially-feasible harvest schedule.



Achievement of strategic revenue targets in the SHSF spatially-feasible harvest schedule.

One of the goals for SHSF is to demonstrate progress toward the recovery standard for RCW. Initially there is a low preponderance of GQFH across the forest, but there is steady improvement over the first fifty years.



Sand Hills GQFH proportion & average habitat score (HS) (50 years).

Within 5 years, the proportion of GQFH has increased from less than 5% to over 20%; by 2018, it has increased to 30%.

Conclusions

This project represents a number of firsts with regard to the South Carolina Forestry Commission, RCW management and FORSight Resources' forest planning capabilities. For SCFC, the MAWT and SHSF planning models represent the first, comprehensive forest planning exercises attempted, using the updated RCW recovery guidelines and explicit management objectives in a formal planning model. In the past, forest management was largely stand-based, implementing silvicultural treatments that would benefit individual stands, but without consideration of the forest-wide context. As the first exercise, the learning curve has been somewhat steep and long, but SCFC staff has gained new understanding of the processes involved with planning of this type, and are confident that future planning efforts will proceed smoothly.

To our knowledge, no other public land management agency has attempted active timber management of lands that have been encumbered by RCW Recovery Guidelines. Most federal lands managers have essentially withdrawn such lands from the productive land base, with the result that RCW recovery is the predominant management emphasis. SCFC staff instead undertook a detailed analysis of silvicultural regimes to determine those that are compatible with both timber production and RCW. This planning exercise should serve as a model for other management agencies in the region, demonstrating that careful planning can not only co-exist with RCW recovery but help to facilitate it.

For FORSight Resources, this project has yielded several significant achievements. In order to predict foraging habitat in future stands, a growth model for longleaf pine had to be developed from various published sources and with significant professional judgment from both FORSight biometrics experts and SCFC staff. The result is the Longleaf Pine Growth Simulator. In addition, the Virginia Tech FASTLOB model was extended to allow more thinning opportunities to meet the needs of extended rotations of loblolly pine.

In terms of objectives, SCFC was interested in increasing revenues to the state coffers while simultaneously meeting RCW habitat requirements. Both the MAWT and SHSF models demonstrated that these seemingly comflicting objectives can be achieved, significantly increasing revenues and not only maintaining, but improving foraging habitat conditions over time. SCFC has invested significant time and financial resources in updating and revamping their forest management strategies, and the successful conclusion of the planning process justifies those efforts.

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1 Introduction

In 2002, the South Carolina Forestry Commission (SCFC) published "Long Range Plan South Carolina Forestry Commission's State Forests". This publication guides the management of the State Forests into the 21st century. Included in this document is a call for effective use of technology to enhance the management strategies on the State Forest. This includes the centralization of data, improved use of GIS, and utilization of forest planning models. In 2005 the SCFC implemented webFRIS™, a decision support system for forestry which facilitates centralization of data and improved utilization of GIS. However, forest planning models had yet to be implemented.

FORSight Resources, LLC (FORSight) was contracted to develop forest planning models for the SCFC that fulfill the recommendations outlined in the SCFC's "Long Range Plan South Carolina Forestry Commission's State Forests" publication. This ambitious project involved several phases, including the compilation and auditing of existing forest (GIS and tabular) data; the formulation of a stratification schema that is effective for this forest planning model; the compilation of suitable growth and yield projections for the stratified forest types; the development of strategic forest planning models; sensitivity analysis to ensure strategic planning model validity; the development of tactical harvest schedules that comply with harvest spatial restrictions; and finally, the compilation of this report detailing model development and results.

1.1 Manchester State Forest

Manchester State Forest (MSF) encompasses over 26,000 acres of productive forest land, divided into eight tracts (Figure 1). The majority of the land base is dominated by pine types (61%) with hardwoods comprising 32% of the forest and unstocked clearcut areas and cultivated fields making up the remaining 7%. Loblolly pine is the dominant pine type with nearly 6,000 acres in plantations, followed by longleaf pine at just over 5,000 acres. Swamp bottomland hardwood is the dominant hardwood type, with 4,155 productive acres located almost exclusively in Tract 7. Upland hardwood, bottomland hardwood and oak stands are also found in MSF. The forest cover breakdown is presented in Figure 2. While there are currently 5 RCW partitions located in MSF, these partitions are managed according to Private Land Guidelines[1].

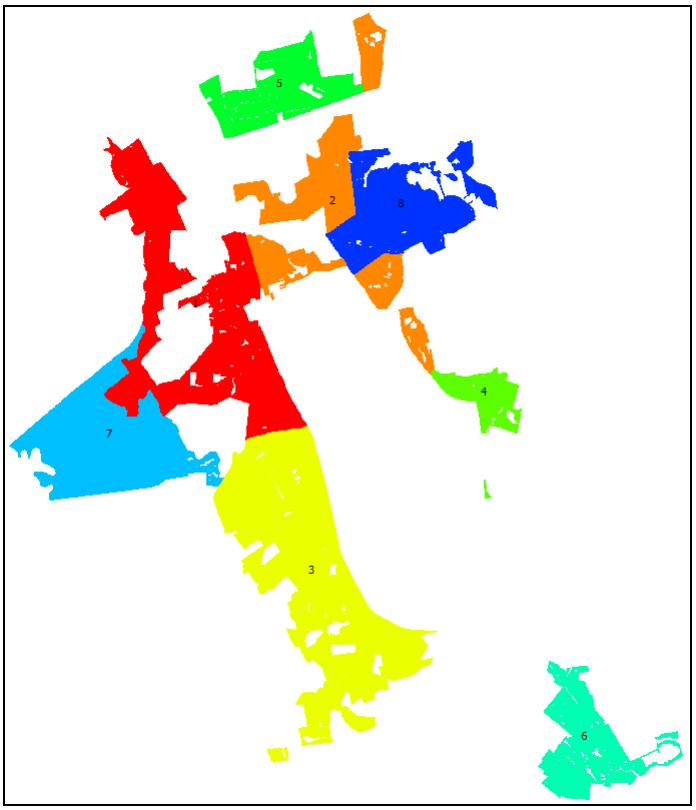

Figure 1. Manchester State Forest with tracts displayed.

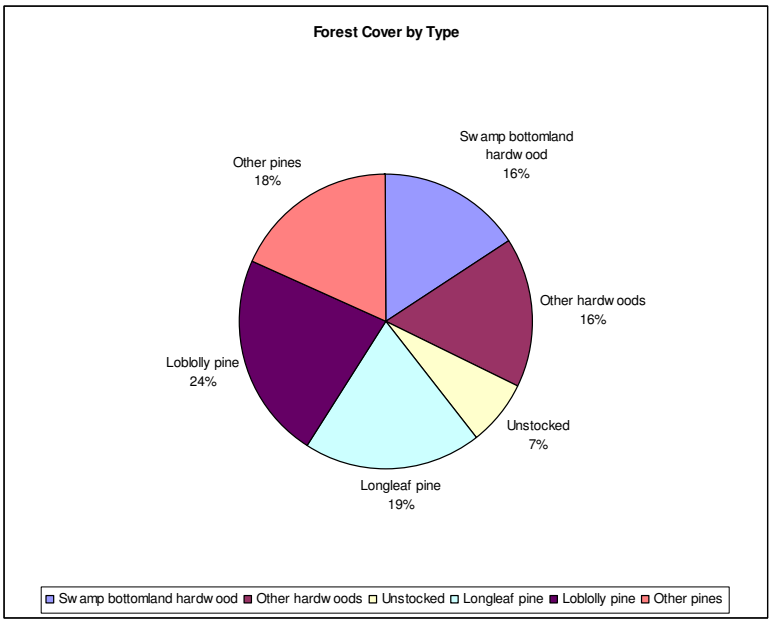

Figure 2. Forest cover breakdown for Manchester State Forest.

Stand ages range up to 206 years but the majority of the pine stands are 70 years or younger. There is a large cohort of swamp bottomland hardwood (about 4,000 acres) near 50 years of age, but most of the hardwoods are distributed in age classes of fewer than 500 acres per 5-year class. The age class distribution is given in Figure 3.

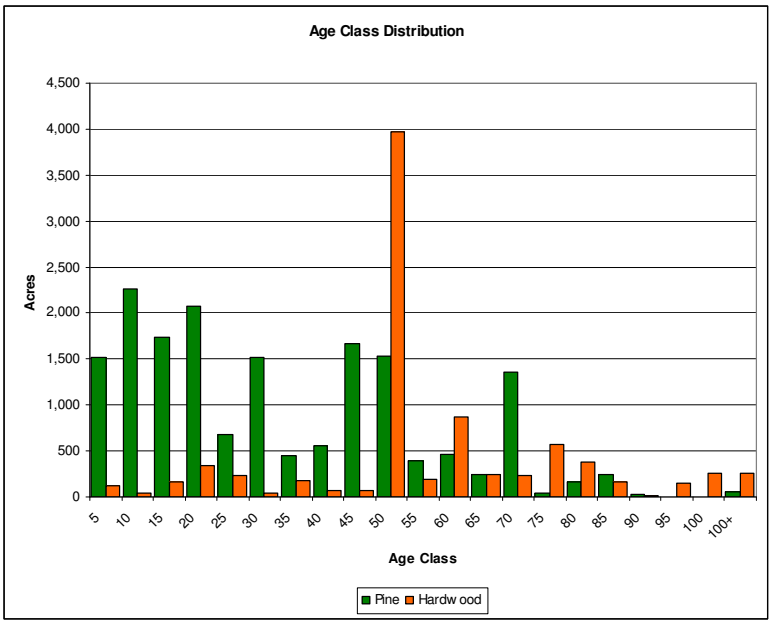

Figure 3. Age class distribution of Manchester State Forest.

1.2 Wee Tee State Forest

There are just over 12,000 acres of productive forest land on Wee Tee State Forest (WTSF), of which 94% is swamp bottomland hardwood. Most of this forest has been selectively harvested numerous times in the past with the result that most of the stands are of lower quality (relative to the swamp bottomland hardwoods found in MSF). The forest is contiguous rather than divided into tracts. Figure 4 shows the WTSF boundaries and cover types. There are no RCW clusters in WTSF.

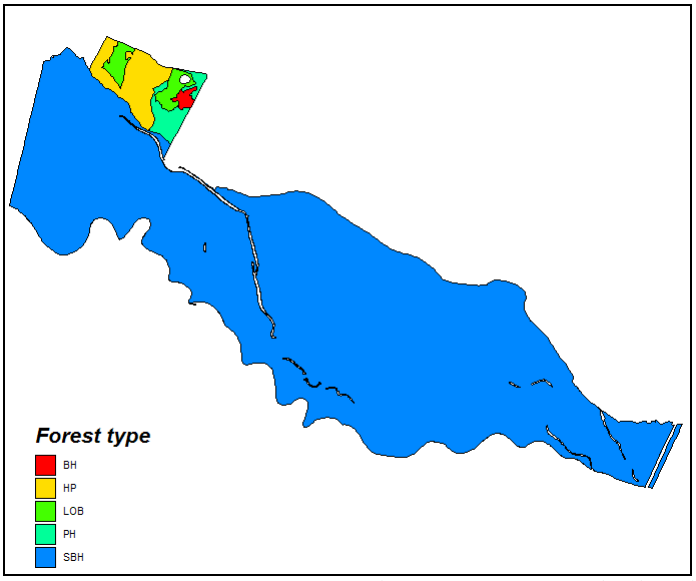

Figure 4. Wee Tee State Forest with forest cover types displayed.

The age-class distribution shows a single, 10,300 acre cohort at age 30 . The complete age-class distribution is shown in Figure 5.

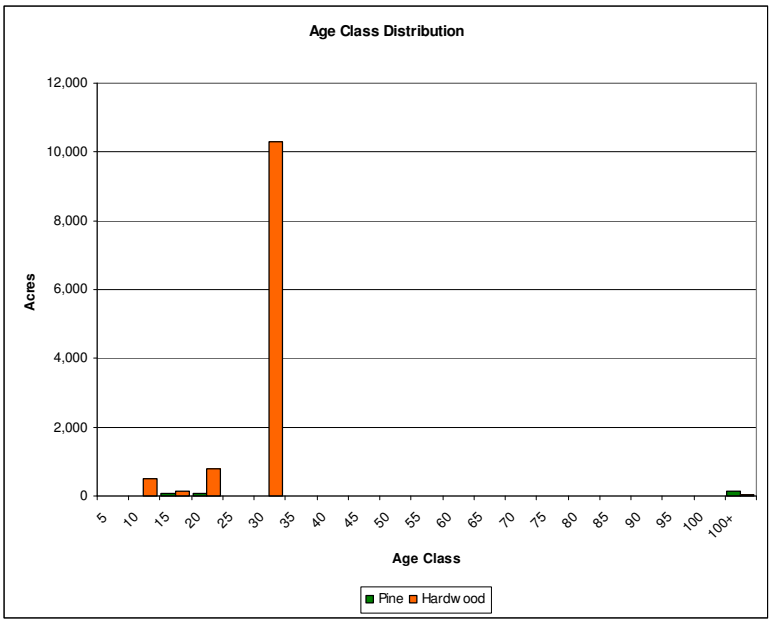

Figure 5. Age class distribution of Wee Tee State Forest.

1.3 Sand Hills State Forest

Sand Hills State Forest (SHSF) is divided into twelve tracts (Figure 6) and encompasses over 46,800 acres of forest land, of which 45,983 are productive.

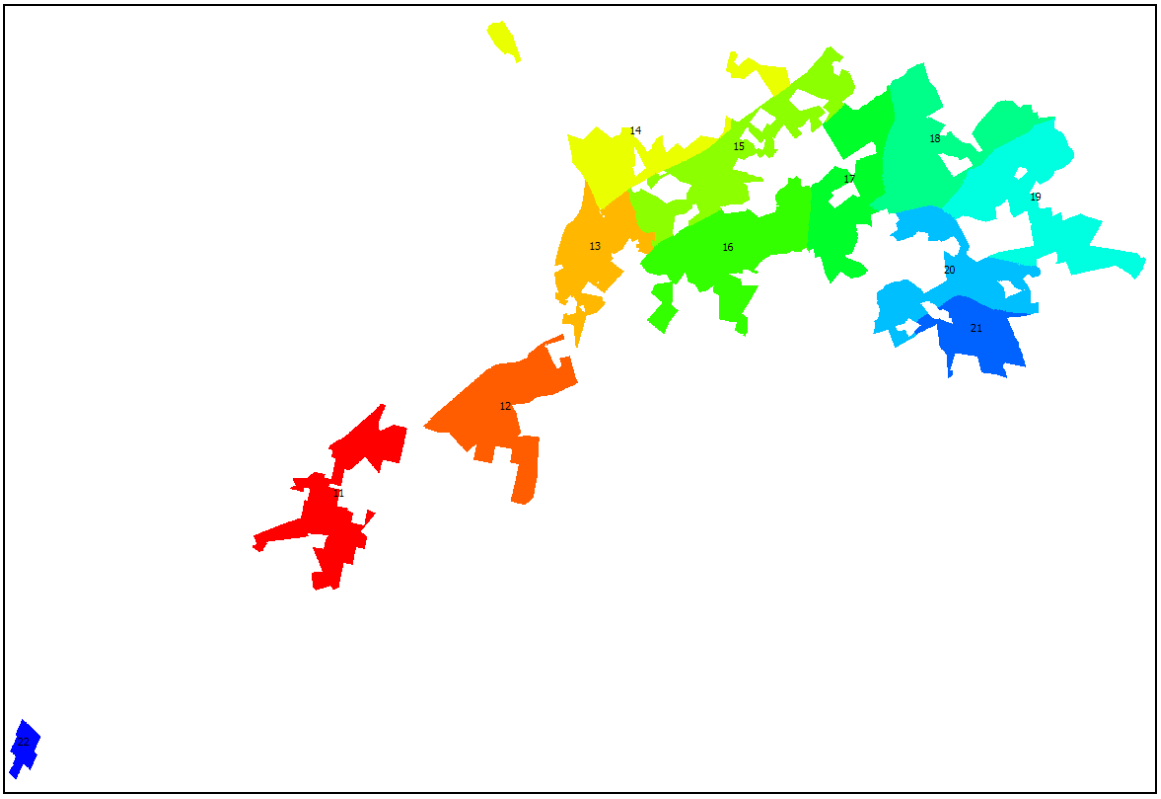

Figure 6. Sand Hills State Forest with tracts displayed.

The majority of the land base is dominated by pine types (94%) with hardwoods comprising just 6% of the forest (Figure 7). Longleaf pine is the dominant pine type, with nearly 19,000 acres in pure longleaf stands,

followed by nearly 18,000 acres of mixed natural pine stands that are predominantly longleaf pine. Most of the hardwoods are bottomland hardwoods.

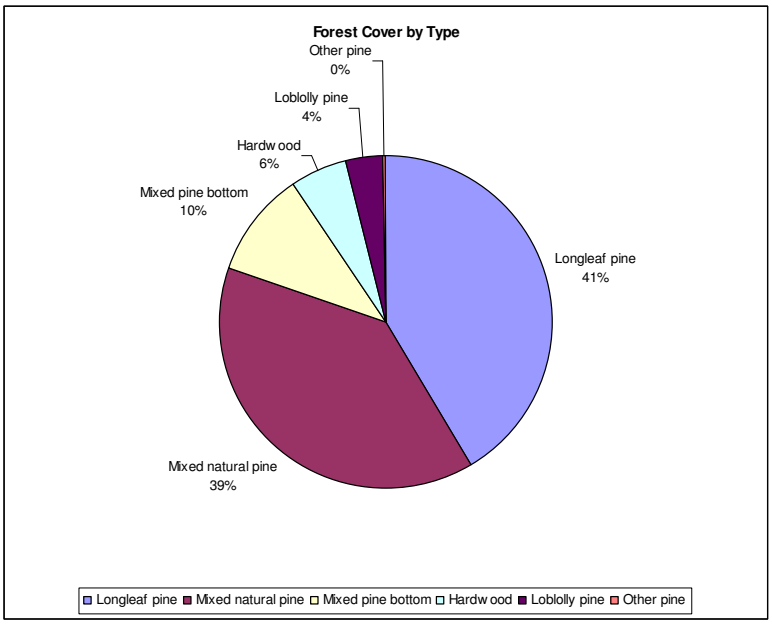

Figure 7. Forest cover breakdown for Sand Hills State Forest.

Forest stand ages range up to 76 years with the majority of the pine stands at exactly 76 years of age (Figure 8).

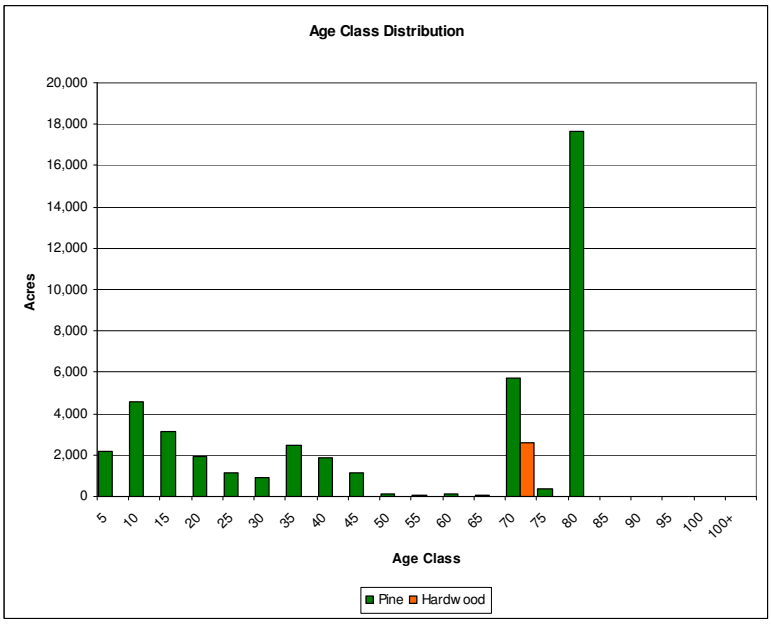

Figure 8. Age class distribution of Wee Tee State Forest.

This unique age-class distribution is the result of an afforestation effort when SHSF came into being. During the years 1935-1939 the federal government purchased the lands that now comprise SHSF from local landowners as a relief measure under the Resettlement Administration. These landowners were resettled on more fertile land elsewhere, and the depleted farm lands were planted. The land was managed as a state forest by the S.C. Forestry Commission under an agreement with the U.S. Department of Interior from 1939 until 1991 when title was transferred to the state.

As part of the transfer agreement, South Carolina agreed to continue managing SHSF according to the Draft Recovery Guidelines specified in the Recovery Plan for the Red-Cockaded Woodpecker (US FWS, 2003). As a result, the primary goal of management for SHSF is to maintain and increase good quality foraging habitat (GQFH) for RCW. To that end, SHSF has been partitioned according to existing and expected future clusters as shown in Figure 9.

Unlike most government-owned forest land encumbered by RCW Recovery Guidelines, SCFC policy requires that State Forests be self-sufficient in terms of funding. While some activities such as pine straw raking do not significantly impact RCW, they do not generate sufficient revenue to cover all management expenses. As a result, timber harvesting is a vital part of the SHSF revenue stream, and therefore it was necessary to devise silvicultural regimes that are compatible with the Recovery Guidelines while still allowing a regular source of annual revenue.

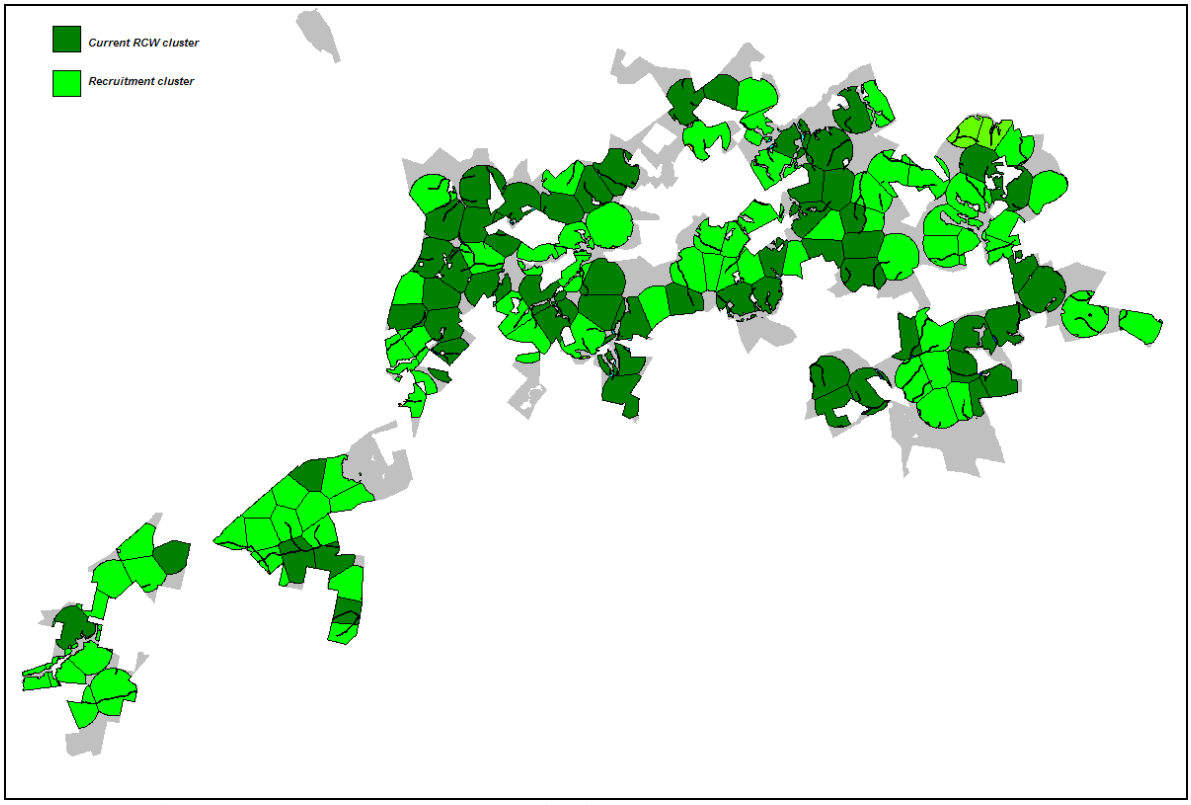

Figure 9. Delineation of RCW partitions on Sand Hills State Forest.

2 Planning Approach

FORSight was contracted by SCFC to develop strategic and tactical harvest schedules for Manchester, Wee Tee and Sand Hills State Forests. FORSight used the Remsoft Spatial Planning Suite (Remsoft, 2007) to develop these models, with Spatial Woodstock as the strategic planning model and Stanley as the tactical planning model.

2.1 Overview

SCFC provided GIS data dumps from the webFRIS ™ inventory system to FORSight staff who conducted extensive data audits on the tabular and spatial data. SCFC also provided silvicultural regimes (with timing choices and minimum removal values), cost estimates for stand establishment, tending and other management activities, product specifications and prices, and overall guidance on goals and constraints related to finances, woodflows, work load, and RCW habitat.

2.2 Data Auditing

As part of the modeling process, FORSight conducted a rigorous screening and cleaning of the data received from SCFC. The forest database was checked for missing data, data that fall outside biologically reasonable bounds, and data that were suspect or may have produced incorrect results.

The analysis of the Sand Hills dataset revealed several sources of error. These are detailed below along with the appropriate corrective action:

1. Wee Tee Property had no designated State or County (25 stands).
    a. Set State to South Carolina.
    b. Set County to Williamsburg.
2. Missing cruise data in swamp bottomland hardwood.
    a. Loaded 6 stands of newly cruised data into stand table.
3. Incorrect/missing attributes for polygons labeled as clearcuts (34 stands).
    a. Set modeling age to 1.
    b. Determined that clearcuts have not been site prepared (S. Phillips, pers. comm.)
4. 16 Forest Types incorrect
    a. Fixed based on % species composition {BA} from reviewed list (S. Phillips, pers. comm.).
5. Incorrect Age.
    a. 1451 Stands whose current age (using "YEAROFORIGIN" and assuming current year 2006) does not equal calculated age.
        i. Set age equal to: 2006 - "YEAROFORIGIN".
    b. Ages with "YEAROFORIGIN " greater than or equal to 2006 (21 stands).
        i. Set modeling age to 1
6. Incorrect density values - TPA value was null or zero.
    a. Planted stands with artificial regeneration records.
        i. Apply average survival percentages based on stands of equal Property, ForestType, and Age (8 stands).
        ii. Stands with ages less than or equal to 11.
            1. Species Longleaf pine: 0.89* Planted TPA (207 stands).
            2. Species Loblolly pine: Sand Hills: 0.95* Planted TPA (6 stands).
            3. Species Loblolly pine: Manchester: 0.90* Planted TPA (22 stands).
            4. Other (10 stands).
        iii. Stands with ages greater than 11 but less than or equal to 20.
            1. 0.90*Planted TPA (4 stands).
        iv. Stands with ages greater than 20
            1. 0.75*Planted TPA (3 stands).
        v. Clearcuts - load with artificial regeneration TPA.
            1. Sand Hills State Forest, Wee Tee State Forest: 908 TPA(20 stands).

2. Manchester State Forest: 622 TPA (13 stands).

b. Planted stands with no artificial regeneration records.
   i. Manchester State Forest:
      1. Stand ages less than or equal to 11.
         a. Species Longleaf pine: 0.89* Planted TPA (1 stand).
         b. Species Loblolly pine: 0.90* Planted TPA (3 stands).
         c. Other species: 0.95* Planted TPA (1 stand).
   ii. Sand Hills, Wee Tee State Forests:
      1. Stand ages less than or equal to 11.
         a. Species Longleaf pine: 0.89* Planted TPA (5 stands).
         b. Species Loblolly pine: 0.95* Planted TPA (2 stands).
      2. Stand ages greater than 11 but less than or equal to 20
         a. 0.90*622 (3 stands).

c. Calculated average stand characteristics based on original cruise stratification defined in the field STANDDESCRIPTION and applied these strata averages to stands that had no initial information (16 stands).

d. Calculated hardwood BA & TPA using hardwood equations for ten young natural hardwood stands:
   i. 4 Upland Hardwood stands of age 10 {StandIDs 1027, 764, 452, 2050}
   ii. 1 Bottomland Hardwood stand of age 9 {StandID 3797}
   iii. 1 Hardwood-Pine stand of age 11 with stand note "Cutover Wet Soils Condition". Assume that all pine was removed in cutover and regenerating hardwood exists {StandID 1093}.
   iv. 4 Swamp Bottomland Hardwood stands, ages 17, 13, 10, 8 {StandIDs 93, 377, 380, 374)

e. Calculate average stand condition by Property/ForestType/Age and select closest match to stand without TPA/BA (5 stands).

f. Two Natural Longleaf pine stands with age three with no TPA.
   i. Set TPA to 908.
   ii. Assume at least the same stocking as artificially regenerated stands.

7. Errors in stand attributes
   a. STANDID 4091
      i. Changed from cultivated Field to Loblolly Plantation; planted 2006; 908 TPA.
   b. STANDID 3620
      i. Stand age four showing unreasonable basal area.
      ii. Zeroed BA & volume.
   c. STANDID 3080
      i. Note specifies seed tree harvest was completed.
      ii. Age is 1; TPA is 141..
      iii. Set volume & BA to zero.
      iv. Currently this stand will be grown from age 1 with 141 TPA.
   d. STANDID 1838
      i. Designated as 12 year old Loblolly Natural Stand.
      ii. Note states "Planted Longleaf - very poor survival".
      iii. Changed stand to Longleaf pine and applied reduced TPA. (Average for Longleaf pine 0-10 strata is 571 pine TPA - applied $^{1}/_{3}$ of average TPA = 188).
8. Stands classed as cultivated fields & upland grass
   a. Overlaid non-productive mask with stands layer and tagged remainder of stands as convertible.
9. Incorrect or missing site index (59 stands).
   a. SI were assigned based on a combination of overlay with SSURGO Soils Data and adjacent stands.
10. Status of active clearcuts.
   a. Clearcut areas finalized.

2.3 Classification of the Land Base

For the purpose of generating existing and future yields for candidate management regimes, stratification of the land base by biological parameters was necessary. FORSight utilized the following parameters to create strata for the growth and yield modeling effort:

Theme2: Forest Type

1. Hardwood
    a) BH: Bottomland Hardwood
    b) SBH: Swamp Bottomland Hardwood
    c) OA: Oak
    d) OH: Oak-Hickory
    e) HP: Hardwood Pine
2. Pine
    a) LOB: Loblolly Pine
    b) LL: Longleaf Pine
    c) SL: Slash Pine
    d) MP: Mixed Pine
    e) MPB: Mixed Pine Bottom
    f) PH: Pine-Hardwood
    g) SND: Sand Pine
    h) SHP: Shortleaf Pine
    i) VP: Virginia Pine
3. Other
    a) ERC: Eastern Red Cedar
    b) CF: Cultivated Field (to be afforested)
    c) UH: Upland Hardwood

Theme3: Plantation/Natural

1. Natural: N
2. Planted: P

Theme4: SI Class

1. 5' Classes
2. 0: Non-Productive

Theme5: BA Class

1. 30 ft^2 Classes

Theme6: TPA Class

2. 150 TPA Classes

Theme7: Inventory Age Class

1. 1 Year Age Classes from Age 1 – 50
2. 5 year Age Classes > Age 50

2.4 Management Regimes

For modeling purposes, management regimes are defined as a series of silvicultural treatments and the associated timings of those treatments for the life of a stand or stratum. Existing strata, once harvested, are regenerated (either naturally or through planting) and placed on a management regime until the next final harvest. By providing a variety of potential management regimes (decision variable) for a stratum to follow, Woodstock evaluates each regime and determines which one maximizes the objective while meeting other constraining conditions.

Prior to the beginning of the modeling effort, SCFC staff had identified a set of management regimes for both even-aged and uneven-aged management on the State Forests of South Carolina:

Even Aged Silviculture

- Intensive Plantation Management

- Extended Rotation Plantation Management for Sawtimber
- Extended Rotation Plantation Management for Sawtimber with Pine Straw Enhancement
- Extended Rotation Natural Pine Management for Sawtimber
- Extended Rotation Natural Pine Management for Sawtimber with Pine Straw Enhancement
- Plantation Management for Sawtimber with optimum economic rotation
- Plantation Management for Sawtimber with optimum economic rotation with Pine Straw Enhancement
- Natural Pine Management for Sawtimber with optimum economic rotation
- Natural Pine Management for Sawtimber with optimum economic rotation with Pine Straw Enhancement
- Shelterwood Rotation for Plantation Management
- Shelterwood Rotation for Plantation Management with Pine Straw Enhancement
- Shelterwood Rotation for Natural Pine Management
- Shelterwood Rotation for Natural Pine Management with Pine Straw Enhancement
- RCW Modified Two-Age Management
- RCW Modified Two-Age Management with Pine Straw Enhancement

Hardwood Plantation Management

- Natural Upland Hardwood Management
- Natural Swamp Bottomland Hardwood Management
- Natural Bottomland Hardwood Management

Uneven Aged Silviculture

- RCW Group Selection Harvest
- RCW Group Selection Harvest with Pine Straw Enhancement
- RCW Individual Tree Selection Harvest
- RCW Individual Tree Selection Harvest with Pine Straw Enhancement
- Group Selection with optimum economic rotation
- Individual Tree Selection with optimum economic rotation

Following consultation with USFWS and FORSight staff, SCFC removed from consideration individual tree selection (ITS) as a management regime; no suitable growth and yield models were available that could adequately simulate individual tree selection without resorting to tree-based versus stand-based growth models. Since the stand-based models were considered more robust overall, it seemed reasonable to drop the ITS regimes (Table 1).

Table 1. Original regimes planned for MAWT and SHSF models.

Regime	Description	Forest where implemented
0	No mid-rotation thinning (HW, other pines)	MAWT, SHSF
1	Modified two-age management (loblolly, longleaf)	MAWT*, SHSF
2	Extended plantation rotation for sawtimber production (loblolly, longleaf)	MAWT
3	Group selection (loblolly, longleaf)	MAWT*, SHSF
4	Extended natural rotation for sawtimber production	MAWT
5	Individual tree selection for RCW	-
6	Plantation economic rotation (loblolly, longleaf)	MAWT
7	Individual tree selection economic	-
8	Natural economic rotation (loblolly)	MAWT
9	Intensive plantation (loblolly)	MAWT
10	Shelterwood natural rotation (loblolly, longleaf)	MAWT

** only implemented in RCW partitions on MAWT*

Because of the different management emphases for the MAWT and SHSF modeling efforts, each model had its own set of management regimes. Tables 2 through 5 describe the pine regimes used in the MAWT and SHSF models. MAWT included a range of longleaf and loblolly pine management alternatives to fully explore the economic potential of MSF and WTSF. Other pines and hardwoods were modeled without thinning options in a final-harvest only alternative (internally referred to as Regime 0 in the Woodstock model). SHSF included only two regimes each for longleaf and loblolly pine, which were deemed the only

alternatives that could successfully produce GQFH over the long-term. These regimes were also available in the MAWT model, but they were only available for pine stands in the five RCW partitions.

Table 2. Loblolly pine regimes used in MAWT model.

Regime 2. Extended Rotation Loblolly Pine Plantation for Sawtimber Production

Year	Range	Treatment	Minimum Removal (Tons/Acre)	Target Residual BA (ft^2/Acre)
-1		Heavy Chemical Site Prep		
-1		Med. Mech. Site Prep		
0	0	Hand Plant Loblolly (622 TPA)		
18	16,18,20	1st Thin	7.5	70 {G}
28	25,28,31,34	2nd Thin	7.5	70 {G}
60	45-65	Final Harvest	7.5	0

Regime 4. Extended Rotation Natural Loblolly Pine for Sawtimber Production

Year	Range	Treatment	Minimum Removal (Tons/Acre)	Target Residual BA (ft^2/Acre)
		Pre-Harvest Burn		
0	0-2	Chemical Release		
23	20,23,26	1st Thin	7.5	70 {G}
30	30,33,35	2nd Thin	7.5	70 {G}
60	45-65	Final Harvest	7.5	0

Regime 6. Optimum Economic Rotation Loblolly Pine Plantation

Year	Range	Treatment	Minimum Removal (Tons/Acre)	Target Residual BA (ft^2/Acre)
-1		Heavy Chemical Site Prep		
-1		Med. Mech. Site Prep		
0	0	Hand Plant Loblolly (622 TPA)		
20	18,20,22	1st Thin	7.5	70 {G}
37	35,37,39	2nd Thin	7.5	70 {G}
46	44-48	Final Harvest	7.5	0

Regime 8. Optimum Rotation Natural Loblolly Pine for Sawtimber Production

Year	Range	Treatment	Minimum Removal (Tons/Acre)	Target Residual BA (ft^2/Acre)
		Pre-Harvest Burn		
0	0-2	Chemical Release		
23	20,23,26	1st Thin	7.5	70 {G}
29	27,29,30,32	2nd Thin	7.5	70 {G}
45	43-47	Final Harvest	7.5	0

Regime 9. Intensive Loblolly Plantation

Year	Range	Treatment	Minimum Removal (Tons/Acre)	Target Residual BA (ft^2/Acre)
-1		Heavy Chemical Site Prep		
-1		Med. Mech. Site Prep		
0	0	Hand Plant Loblolly (622 TPA)		
15	13,14,15,16,17,18	1st Thin	7.5	70 {G}
26	20-50	Final Harvest	7.5	0

Regime 10. Shelterwood Rotation for Natural Loblolly Pine

Year	Range	Treatment	Minimum Removal (Tons/Acre)	Target Residual BA (ft^2/Acre)
		Pre-Harvest Burn		
0	0-2	Chemical Release		
23	20,22,24,26	1st Thin	7.5	70 {G}
29	27,29,32	2nd Thin	7.5	70 {G}
44	42,44,46	Chemical Release		
45	43,45,47	Shelterwood Harvest	7.5	30 {C}
50	48-52	Final Harvest	7.5	0

Table 3. Longleaf pine regimes used in MAWT model.

Regime 2. Extended Rotation Longleaf Pine Plantation for Sawtimber Production

Year	Range	Treatment	Minimum Removal (Tons/Acre)	Target Residual BA (ft^2/Acre)
-1		Heavy Chemical Site Prep		
0	0	Hand Plant Longleaf (726 TPA)		
14	12-16	Pine Straw Enhancement (4 year contract)		
19,22,25		Pine Straw Sales		
25	22,25,27	1st Thin	7.5	1 in 5 Row Thin {E}
27	24,27,29	Pine Straw Re-enhancement (4 Year Contract)		
32,35		Pine Straw Sales		
35	33,35,37	2nd Thin	7.5	70 {G}
50	48,50,52	3rd Thin	7.5	70 {G}
65	63,65,67	4th Thin	7.5	70 {G}
80	60-80	Final Harvest	7.5	0

Regime 6. Optimum Economic Rotation Longleaf Pine Plantation

Year	Range	Treatment	Minimum Removal (Tons/Acre)	Target Residual BA (ft^2/Acre)
-1		Heavy Chemical Site Prep		
0	0	Hand Plant Longleaf (726 TPA)		
14	12-16	Pine Straw Enhancement (4 year contract)		
19,22,25		Pine Straw Sales		
25	22,25,27	1st Thin	7.5	1 in 5 Row Thin {E}
27	24,27,29	Pine Straw Re-enhancement (4 Year Contract)		
32,35, 38, 40		Pine Straw Sales		
40	38,40,42	2nd Thin	7.5	70 {G}
49	49-65	Final Harvest	7.5	0

Regime 10. Shelterwood Rotation for Natural Longleaf Pine (Note: No breast height adjustment to site index due to natural regeneration)

Year	Range	Treatment	Minimum Removal (Tons/Acre)	Target Residual BA (ft^2/Acre)
		Pre-Harvest Burn		
0	0-2	Chemical Release		
14	12-16	Pine Straw Enhancement (6 year contract)		
22,25,28,31,34		Pine Straw Sales		
35	32,35,37	1st Thin	7.5	1 in 5 Row Thin {E}
45	43,45,47	2nd Thin	7.5	70 {G}
64	61,64,66	Chemical Release		
65	62,65,67	Shelterwood Harvest	7.5	30 {C}
66	63,66,68	Burn		
75	75-80	Final Harvest	7.5	0

Table 4. Loblolly pine regimes used in SHSF model (and in MAWT RCW partitions).

Regime 1. Modified Two-Age Management for Loblolly Pine

Year	Range	Treatment	Minimum Removal (Tons/Acre)	Target Residual BA (ft^2/Acre)
0		Burn		
2	2,3,5	Chemical Release		
20	18,20,22,24	1st Thin	7.5	60 {F}
35	33,35,37	2nd Thin	7.5	60 {F}
50	48,50,52	3rd Thin	7.5	60 {F}
80	60,65,70,75,80	4th Thin	7.5	60 {F}
99	99,100,101,102,103,104	Chemical Release		
100	100-105	Final Harvest	7.5	20 This is zero in regimes

Regime 3. Group Selection for Loblolly Pine

Year	Range	Treatment	Minimum Removal (Tons/Acre)	Target Residual BA (ft^2/Acre)
0		Heavy Chemical Site Prep		
0		Hand Plant (622 TPA)		
20	16-20	1st Thin	7.5	60 {F}
40*	20 year lag	2nd Thin	7.5	60 {F}
60*	20 year lag	3rd Thin	7.5	60 {F}
80*	20 year lag	4th Thin	7.5	60 {F}
100	100-105	Final Harvest	7.5	0

* 20 year lag after previous thin

Table 5. Longleaf pine regimes used in SHSF model (and in MAWT RCW partitions).

Regime 1. Modified Two-Age Management for Longleaf Pine

Year	Range	Treatment	Minimum Removal (Tons/Acre)	Target Residual BA (ft^2/Acre)
-1		Heavy Chemical Site Prep		
0	0	Hand Plant Longleaf (726 TPA)		
14	12-16	Pine Straw Enhancement (4 year contract)		
19,22,25		Pine Straw Sales		
25	22,25,27	1st Thin	7.5	60 {F}
27	24,27,29	Pine Straw Re-enhancement (2 Year Contract)		
30,33,35		Pine Straw Sales		
35	33,35,37	2nd Thin	7.5	60 {F}
50	48,50,52	3rd Thin	7.5	60 {F}
80	60,65,70,75,80	4th Thin	7.5	60 {F}
119	119,120,121,122,123,124	Chemical Release		
120	120-125	Final Harvest (residual 6-10 TPA)	7.5	

Regime 3. Group Selection for Longleaf Pine*

Year	Range	Treatment	Minimum Removal (Tons/Acre)	Target Residual BA (ft^2/Acre)
-1		Heavy Chemical Site Prep		
0	0	Hand Plant Longleaf (726 TPA)		
14	12-16	Pine Straw Enhancement (4 year contract)		
19; Year of 1st Thin		Pine Straw Sales		
21	21-25	1st Thin	7.5	60 {F}
22	22-27	Pine Straw Re-enhancement (4 Year Contract)		
28,31,34,37,40		Pine Straw Sales		
41-45	20 year lag	2nd Thin	7.5	60 {F}
61-65	20 year lag	3rd Thin	7.5	60 {F}
81-85	20 year lag	4th Thin	7.5	60 {F}
101-105	20 year lag	5th Thin	7.5	60 {F}
120	120-125	Final Harvest	7.5	0

***Optimal situation is to conduct operations across age classes in the stand during each entry (i.e. regulated cutting cycle)**

2.5 Growth and Yield

The stratified current forest inventory data was projected forward to best meet the needs of the harvest schedule planning horizon and the management regimes. In general, existing longleaf pine was grown forward 110 years or a maximum of 126 years, whichever is less. Loblolly pine was grown forward 100 years or a maximum of 135, whichever is less. Regeneration yields were grown for 120 years or 100 years for longleaf and loblolly pines, respectively.

2.5.1 Model Assumptions

A variety of growth and yield models were used in developing current and future yield estimates. Growth and yield models were chosen based on cover type appropriateness and their ability to model required management regimes. For a complete description of each growth and yield model, as well as a discussion of their availability, please see Appendix I.

Mixed Pine on SHSF

FORSight's longleaf pine model (FORSim-Longleaf Pine Growth Simulator) was used to grow the mixed pine stands on the Sand Hills State Forest because the current SCFC management practices for SHSF are to favor Longleaf stems when thinning or during other tree removal. The consensus among FORSight and SCFC staff was that the longleaf model would more accurately predict volume in this timber type.

Natural Loblolly Pine on SHSF

FASTLOB was utilized to grow natural Loblolly pine to allow for thinnings; the NATLOB model does not allow thinning. One modification to the data was made due to the use of FASTLOB. Site Index (SI) was reduced by 8 points in both existing and regeneration stands and SI gains from silviculture were not allowed in the regeneration stands. This was done to account for the more optimistic plantation yields generated by FASTLOB when compared to those typical of natural loblolly stands.

All other forest types

Based on species composition and origin (planted vs. natural), separate growth models were used for each of the various cover types. These models included FASTLOB, NATLOB, UGA slash pine model (UGA),

Forest Vegetation Simulator (FVS) and FORSight's proprietary hardwood (HGS), sand pine (SPGS) and longleaf pine (FORSim-LPGS) models. Table 6 indicates the models used for the various forest strata.

Table 6. Enumeration of the growth models used to develop yield tables for Woodstock modeling.

Species Code	Description	Planning Model	Growth Model
LOB (plantation)	Loblolly pine	All	FASTLOB
LOB (natural)	Loblolly pine	MAWT	NATLOB
LOB (natural)	Loblolly pine	SHSF	FASTLOB
LL	Longleaf pine	All	LPGS
MP (non-intensive)	Mixed natural pine	MAWT	NATLOB
MP (intensive)	Mixed natural pine	MAWT	FASTLOB
MP (non-intensive)	Mixed natural pine	SHSF	LPGS
MP (intensive)	Mixed natural pine	SHSF	LPGS
SND	Sand Pine	All	SPGS
SHP	Shortleaf Pine	All	SPGS
SL	Slash Pine	All	UGA
VP	Virginia Pine	All	SPGS
OA	Oak	All	HGS
OH	Oak-Hickory	All	HGS
SBH	Swamp Bottomland Hardwood	All	FVS
UH	Upland Hardwood	All	HGS
BH	Bottomland Hardwood	All	HGS
ER	Eastern Red Cedar	All	HGS
HP	Hardwood Pine	All	Hardwood: HGS Pine: NATLOB
PH	Pine-Hardwood	All	Hardwood: HGS Pine: NATLOB
MPB	Mixed Pine Bottom	All	Hardwood: HGS Pine: NATLOB

All yields reported in the yield streams had units of tons/acre. The merchandizing specifications for sawtimber, chip-n-saw and pulpwood are given in Table 7.

Table 7. Merchandizing specifications for wood products.

Product	DBH Range	Minimum Top (dib)
Sawtimber	11.6"+	8.0"
Chip-n-saw (pine only)	8.6" – 11.5"	6.0"
Pulpwood	4.6"	2.0"

Validation of the yield streams was conducted by FORSight's biometricians. Yields were examined for consistency and reasonability for the given region and species. Sample yield curves were reviewed and validated by SCFC staff. Once validation was completed, the yields were formatted for input into the Woodstock modeling software.

2.6 Planning Model Overview

As originally envisioned by SCFC staff, FORSight would develop a single, comprehensive planning model for all the South Carolina State Forests. However, it soon became apparent in discussions about goals and objectives that SHSF was uniquely different from the other State Forests because it was encumbered with Recovery Guidelines for RCWs. It was decided that SHSF would be modeled on its own, and MSF and WTSF would be modeled together in a separate model. To facilitate comprehension and interpretation of results, FORSight attempted to make the two models as similar as possible, with common action and output keywords, and similar stratification schemes wherever possible.

2.6.1 Assumptions

The strategic harvest scheduling models have an objective function to maximize discounted net revenue from timber harvesting and other sources. The specified discount rate specified by SCFC is 5%. Prices and costs provided by SCFC are considered real, net of inflation. The planning horizon for MAWT is 101 years (2007 is considered year 1); the planning horizon for SHSF is 176 years (2007 is considered year 1). The longer planning horizon is necessary to demonstrate sustainability of good quality foraging habitat into the second rotation (100+ years). Tactical planning horizons for MAWT and SHSF were 16 and 20 years respectively. Both yielded 10 year spatial harvest schedules that were incorporated into a strategic Woodstock model for sustainability validation.

2.6.2 Model Development

The SCFC's primary goal for the State Forests is to provide a range of amenities for the citizens of South Carolina in an economically efficient manner. State Forests are to cover their own operational costs and, where possible, generate revenues to the State and the counties where they are located. Therefore, a discounted cash flow model that maximizes the discounted net revenue over the planning horizon was the appropriate model formulation, using the 5% (real) rate provided by SCFC.

SCFC provided FORSight with documents detailing the assumptions, parameters, and management regimes/silvicultural treatments to be included in the SHSF and MAWT model formulations. Tables 8 through 15 summarize some of the assumptions included in these documents, specifically estimated lease revenues, forest products prices, and costs and prices for various silvicultural treatments and forest products.

Table 8. Projected WMA receipts in real dollars.

	----------Fiscal Year----------									
Contract	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Initial	$30,048	$28,998	$27,985	$27,006	$26,063	$25,152	$24,273	$23,424	$22,606	$21,816
Oak Lea, etc.	$36,001	$53,273	$56,001	$57,549	$67,459	$69,325	$71,242	$73,212	$75,236	$77,317
Wee Tee	$30,048	$28,998	$27,985	$27,006	$26,063	$25,152	$24,273	$23,424	$22,606	$21,816
Total Receipts	**$96,504**	**$113,518**	**$115,885**	**$117,333**	**$129,168**	**$132,091**	**$135,486**	**$139,368**	**$143,757**	**$148,674**

Table 9. Projected agricultural lease receipts in real dollars.

	----------Fiscal Year----------									
Contract	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Oak Lea	$21,000	$21,000	$21,000	$21,000	$21,000	$0	$0	$0	$0	$0
Tourney	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Total Receipts	**$21,000**	**$21,000**	**$21,000**	**$21,000**	**$21,000**	**$0**	**$0**	**$0**	**$0**	**$0**

**Note: All agricultural lease payments apply only to Manchester model.*

Table 10. Projected user fee receipts in real dollars.

	----------Fiscal Year----------									
State Forest	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
MSF	$41,348	$42,566	$43,821	$45,112	$46,442	$47,811	$49,220	$50,671	$52,164	$53,702
SHSF*	$9,242	$9,514	$9,795	$10,083	$10,380	$10,686	$11,001	$11,326	$11,659	$12,003
HSF	$58,634	$60,362	$62,141	$63,972	$65,858	$67,799	$69,797	$71,854	$73,972	$76,152
Total	**$109,223**	**$112,442**	**$115,756**	**$119,168**	**$122,680**	**$126,296**	**$130,018**	**$133,850**	**$137,795**	**$141,857**

*Note: Project 50% reduction in User Fees from SHSF due to transfer of HC Black

Table 11. Projected stumpage prices for wood products in real dollars.

	----------Fiscal Year----------									
Product	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Pine Pulpwood	$ 6.87	$ 7.12	$ 7.37	$ 7.64	$ 7.91	$ 8.20	$ 8.49	$ 8.80	$ 9.12	$ 9.44
Pine CNS	$ 24.64	$ 24.15	$ 23.66	$ 23.19	$ 22.73	$ 23.19	$ 23.66	$ 24.15	$ 24.64	$ 24.64
Pine Sawtimber	$ 43.75	$ 43.75	$ 43.75	$ 43.75	$ 43.75	$ 43.75	$ 43.75	$ 43.75	$ 43.75	$ 43.75
Hardwood Pulpwood	$ 9.68	$ 9.84	$ 10.01	$ 10.18	$ 10.36	$ 10.53	$ 10.71	$ 10.89	$ 11.08	$ 11.27
Oak Sawtimber	$ 34.34	$ 34.89	$ 35.45	$ 36.01	$ 36.59	$ 37.18	$ 37.77	$ 38.38	$ 38.99	$ 39.61
Hardwood Sawtimber	$ 22.29	$ 22.47	$ 22.65	$ 22.83	$ 23.01	$ 23.20	$ 23.38	$ 23.57	$ 23.76	$ 23.95

**NOTE: Prices above reflect expected trends. Real stumpage prices from 2016* through the end of the planning horizon are assumed to be constant.

Table 12. Seedling costs in real dollars (2006).

	---------- $/thousand ----------		
Type	**1M - 99M**	**100M - 499M**	**500M +**
2nd Generation Loblolly	$42.00	$40.00	$38.00
Containerized Longleaf	$150.00	$150.00	$150.00

**SCFC expects no real change in seedling prices*

SCFC provided planting rates for loblolly pine and longleaf pine of 622 and 726 trees per acre, respectively. The seedling cost was estimated to be $24.88 per acre for loblolly and $108.90 per acre for longleaf pine, based on purchase quantities of 100,000 to 500,000 seedlings per year. The cost of physically planting the seedlings is given in Table 13, along with the costs for site preparation and other mid-rotation silvicultural treatments.

Table 13. Stand establishment and tending costs in real dollars.

	----------Fiscal Year----------									
Practice	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Solid Planting	$ 39.57	$ 40.08	$ 40.60	$ 41.13	$ 41.67	$ 42.21	$ 42.76	$ 43.31	$ 43.88	$ 44.45
Spot Planting (Group Selection)	$ 54.13	$ 54.83	$ 55.55	$ 56.27	$ 57.00	$ 57.74	$ 58.49	$ 59.25	$ 60.02	$ 60.80
Site Prep - Medium Mechanical	$ 157.39	$ 158.20	$ 159.00	$159.81	$ 160.63	$ 161.45	$ 162.27	$ 163.10	$163.93	$164.77
Site Prep - Heavy Chemical	$ 87.14	$ 87.48	$ 87.82	$ 88.16	$ 88.50	$ 88.85	$ 89.19	$ 89.54	$ 89.89	$ 90.24
Chemical Release	$ 74.29	$ 74.58	$ 74.87	$ 75.16	$ 75.45	$ 75.75	$ 76.04	$ 76.34	$ 76.64	$ 76.94
Herbaceous Control	$ 44.66	$ 44.83	$ 45.01	$ 45.18	$ 45.36	$ 45.53	$ 45.71	$ 45.89	$ 46.07	$ 46.25
Fertilization	$ 52.05	$ 53.07	$ 54.10	$ 55.16	$ 56.23	$ 57.33	$ 58.45	$ 59.59	$ 60.75	$ 61.93
Precommercial Thinning	$ 74.98	$ 74.98	$ 74.98	$ 74.98	$ 74.98	$ 74.98	$ 74.98	$ 74.98	$ 74.98	$ 74.98

**NOTE: Costs above reflect expected trends. Real costs from 2016 through the end of the planning horizon are assumed to be constant.*

Table 14. Personnel costs associated with silvicultural treatments.

Treatment	Man Hours/Acre
Sale Preparation -Timber Cruising	0.4
Sale Preparation - Timber Marking	1.7
Sale Preparation - Group Selection	3.4
Prescribed Burning	0.4

SCFC provided estimates of required labor for timber sale preparation and prescribed burning. While the salaries of these staff members were not included as costs in the model objective, limitations on the maximum available hours per year were included as constraints. These maximums were estimated by SCFC based on internal staff that count silvicultural work as part of their overall duties, and are provided in Table 15.

Table 15. Annual availability of personnel for silvicultural treatments.

	----- Available Man Hours -----	
State Forest	**Timber Sale**	**Prescribed Burning**
Manchester/Wee Tee	1329	1098
Sand Hills	2500	2000
Total	3829	3098

2.6.3 Management Regimes and Silvicultural Actions

Management of SHSF and MAWT are accomplished explicitly through the imposition of silvicultural regimes that were developed prior to the modeling exercise commencement. The SCFC staff believes that the regimes presented offered the best chance of success in achieving financial and social objectives, while complying with RCW guidelines in place on SHSF and MSF.

Regime-based prescriptions are better suited to Model I formulations[1], but they can be implemented in a Model II system like Woodstock. When there are many timing choices for silvicultural activities, this necessarily creates a large number of regimes, and, as a consequence of using the Wodostock modeling software, requires a large number of action and transition specifications. In terms of actual silvicultural activities to model, the MAWT and SHSF models required only four basic types: final harvest, site preparation, planting and commercial thinning.

Final Harvest

The regimes outlined for MAWT and SHSF included clearcut, shelterwood and group selection final harvests. Group selection is implemented in patches no larger than 2 acres in size with no additional green-up required. Softwood clearcuts may be upwards of 100 ac in size but require a 3-year green-up period before harvesting nearby harvest blocks. Hardwood clearcuts may be upwards of 150 acres in size, but need a larger minimum block size to be economically viable. In order to account for the different spatial parameters, three harvest actions are required to account for group selection, softwood clearcut and hardwood clearcut final harvests. Within the strategic model, all three actions could have been implemented as one because the conceptual model underlying them is the same, but having different action codes allows for different opening size limits to be imposed in the tactical planning phase.

[1] For a complete description of Model I and Model II formulations, see Johnson, K. N., and Scheurman, H. L. 1977. Techniques for prescribing optimal timber harvest and investment under different objectives: discussion and synthesis. For. Sci. Monogr. 18. 31p

Clearcut harvest operability criteria are generally age-based, with some additional criteria added to limit the overall number of timing choices. The actual operability limits for the three types of final harvest used in SHSF are presented in Tables 16 through 18.

Table 16. Clearcut harvest operability for Regime 0 cover types (SHSF).

Cover Type	Regime	Origin	Operability (Age)
Slash pine	aCC0	Existing	25-60
Sand pine	aCC0	Existing	25-60
Mixed pine bottom	aCC0	Existing	25-80
Pine hardwood	aCC0	Existing	20-40
Bottomland hardwood	aCC0	Existing	40-60
Oak-Hickory	aCC0	Existing	40-60
Bottomland hardwood	aCC0	Regenerated	>=40
Oak-Hickory	aCC0	Regenerated	>=40

Table 17. Clearcut harvest operability for Regime 1 cover types (SHSF).

Cover Type	Regime	Origin	Last Thinning Age	Operability (Years)	Planning Period
Longleaf pine	aCC1	Existing	60	70-111	1-25
Longleaf pine	aCC1	Existing	65	70-112	1-25
Longleaf pine	aCC1	Existing	70	70-113	1-25
Longleaf pine	aCC1	Existing	75	70-114	1-25
Longleaf pine	aCC1	Existing	80	70-115	1-25
Longleaf pine	aCC1	Existing/Regeneration	none	120	1-25
Loblolly pine	aCC1	Existing	60	70-111	1-25
Loblolly pine	aCC1	Existing	65	70-112	1-25
Loblolly pine	aCC1	Existing	70	70-113	1-25
Loblolly pine	aCC1	Existing	75	70-114	1-25
Loblolly pine	aCC1	Existing	80	70-115	1-25
Loblolly pine	aCC1	Existing/Regeneration	none	100	1-25
Longleaf pine	aCC1	Existing	60	100, 101, 106, 111, 116, 121, 126	26-176
Longleaf pine	aCC1	Existing	65	100, 102, 107, 112, 117, 122, 127	26-176
Longleaf pine	aCC1	Existing	70	100, 103, 108, 113, 118, 123, 128	26-176
Longleaf pine	aCC1	Existing	75	100, 104, 109, 114, 119, 124, 129	26-176
Longleaf pine	aCC1	Existing	80	100, 105, 110, 115, 120, 125, 130	26-176
Longleaf pine	aCC1	Existing/Regeneration	none	100	26-176
Loblolly pine	aCC1	Existing	60	100, 101, 106, 111, 116, 121, 126	26-176
Loblolly pine	aCC1	Existing	65	100, 102, 107, 112, 117, 122, 127	26-176
Loblolly pine	aCC1	Existing	70	100, 103, 108, 113, 118, 123, 128	26-176
Loblolly pine	aCC1	Existing	75	100, 104, 109, 114, 119, 124, 129	26-176
Loblolly pine	aCC1	Existing	80	100, 105, 110, 115, 120, 125, 130	26-176
Loblolly pine	aCC1	Existing/Regeneration	none	100	26-176

Table 18. Clearcut harvest operability for Regime 3 cover types (SHSF).

Cover Type	Regime	Origin	Last Thinning Age	Operability (Years)	Planning Period
Longleaf pine	aCC3	Existing	101	70-111	1-25
Longleaf pine	aCC3	Existing	102	70-112	1-25
Longleaf pine	aCC3	Existing	103	70-113	1-25
Longleaf pine	aCC3	Existing	104	70-114	1-25
Longleaf pine	aCC3	Existing	105	70-115	1-25
Longleaf pine	aCC3	Existing/Regeneration	none	120	1-25
Loblolly pine	aCC3	Existing	76	70-111	1-25
Loblolly pine	aCC3	Existing	77	70-112	1-25
Loblolly pine	aCC3	Existing	78	70-113	1-25
Loblolly pine	aCC3	Existing	79	70-114	1-25
Loblolly pine	aCC3	Existing	80	70-115	1-25
Loblolly pine	aCC3	Existing/Regeneration	none	100	1-25
Longleaf pine	aCC3	Existing	101	120, 121, 126, 131, 136, 141, 146	26-176
Longleaf pine	aCC3	Existing	102	120, 122, 127, 132, 137, 142, 147	26-176
Longleaf pine	aCC3	Existing	103	120, 123, 128, 133, 138, 143, 148	26-176
Longleaf pine	aCC3	Existing	104	120, 124, 129, 134, 139, 144, 149	26-176
Longleaf pine	aCC3	Existing	105	120, 125, 130, 135, 140, 145, 150	26-176
Longleaf pine	aCC3	Existing/Regeneration	none	100	26-176
Loblolly pine	aCC3	Existing	76	100, 101, 106, 111, 116, 121, 126	26-176
Loblolly pine	aCC3	Existing	77	100, 102, 107, 112, 117, 122, 127	26-176
Loblolly pine	aCC3	Existing	78	100, 103, 108, 113, 118, 123, 128	26-176
Loblolly pine	aCC3	Existing	79	100, 104, 109, 114, 119, 124, 129	26-176
Loblolly pine	aCC3	Existing	80	100, 105, 110, 115, 120, 125, 130	26-176
Loblolly pine	aCC3	Existing/Regeneration	none	100	26-176

Since group selection was limited to only the 5 RCW partitions on MAWT, the consensus among SCFC and FORSight staff was that the RCW partitions could be handled manually during the tactical planning exercise. Therefore only 2 types of final harvests were required in the MAWT model. The operability limits are presented in Tables 19 and 20.

Table 19. Clearcut harvest operability for softwoods (MAWT).

Cover Type	Regime	Origin	Operability (Years)
Longleaf pine	-	Existing	>81
Longleaf pine	1	Existing	>120
Longleaf pine	1	Regenerated	120-125
Longleaf pine	2	Existing	120-140
Longleaf pine	2	Existing	120-130
Longleaf pine	3	Existing	120-140
Longleaf pine	3	Regenerated	120-130
Longleaf pine	6	Existing	49-79
Longleaf pine	6	Regenerated	49-59
Longleaf pine	10	Existing	>75
Longleaf pine	10	Regenerated	75-85
Loblolly pine	-	Existing	>81
Loblolly pine	1	Existing	>100
Loblolly pine	1	Regenerated	100-105
Loblolly pine	2	Existing	45-65
Loblolly pine	2	Existing	45-55
Loblolly pine	3	Existing	100-120
Loblolly pine	3	Regenerated	100-110
Loblolly pine	4	Existing	45-75
Loblolly pine	4	Regenerated	45-55
Loblolly pine	6	Existing	44-74
Loblolly pine	6	Regenerated	44-54
Loblolly pine	8	Existing	43-73
Loblolly pine	8	Regenerated	43-53
Loblolly pine	9	Existing	20-50
Loblolly pine	9	Regenerated	20-40
Loblolly pine	10	Existing	>50
Loblolly pine	10	Regenerated	50-60
Slash pine	-	Existing	>25
Virginia pine	-	Existing	>25
Shortleaf pine	-	Existing	>25
Eastern red cedar	-	Existing	>25
Mixed pine bottomland	-	Existing	>25
Pine-hardwood	-	Existing	>25
Mixed natural pine	-	Exist/Regen	>25

Table 20. Clearcut harvest operability for hardwoods (MAWT).

Cover Type	Regime	Origin	Operability (Years)
Hardwood-pine	-	Existing	>40
Bottomland hardwood	-	Existing	>40
Upland hardwood	-	Existing	>40
Oak	-	Existing	>40
Oak-hickory	-	Existing	>40
Swamp-bottomland hardwood*	-	Existing	~40
All hardwoods	-	Regenerated	>80

*To favor early harvests on WTSF the minimum harvest age for existing SBH stands was set to 35 on WTSF and 55 on MSF (weighted avg ~ 40).

Site Preparation

Site preparation is performed following clearcut. The type of site preparation is dependent upon the composition of acreage clearcut and the future management regime:

- **Heavy chemical site preparation (aPrep0):** This site preparation is performed on the following covertypes; mixed natural pine (MP), slash pine (SL), shortleaf pine (SHP), virginia pine (VP), eastern red cedar (ERC), sand pine (SND), and Longleaf pine (LL). It is conducted one year after harvest.
- **Combo plow and woody control site preparation (aPrep1)**: This type of site preparation is performed on the following covertypes: hardwood pine (HP), pine hardwood (PH), mixed pine bottom (MPB), shortleaf pine (SHP), Virginia pine (VP), eastern red cedar (ERC), and loblolly pine (LOB). This site preparation is conducted up to 1 year after harvest.
- **Combo plow, weed control, and woody control site preparation (aPrep2)**: This type of site preparation is the same combo plow and woody control, with the addition of chemical weed control. The same cover types are eligible for this treatment.

In general, loblolly pine stands are to remain loblolly pine, and longleaf pine stands are to remain longleaf pine. Slash pine is considered off-site and is always regenerated to longleaf pine. However, some other covertypes such as shortleaf pine (SHP), virginia pine (VP), and eastern red cedar (ERC) can be planted following harvest to either loblolly pine or longleaf pine, and so are eligble for any site preparation treatment.

Planting

Plantations are planted to either longleaf pine or loblolly pine. In MAWT, the decision to plant is combined with the decision to assign a particular regime. For example, aPlantLL3 would plant a cutover area to longleaf pine and assign that plantation to regime 3 (group selection). Table 21 shows the planting actions used in MAWT.

Table 21. Planting actions implemented in the MAWT model.

Action code	Species	Regime
aPlantLL1	Longleaf pine	1
aPlantLL2	Longleaf pine	2
aPlantLL3	Longleaf pine	3
aPlantLL6	Longleaf pine	6
aPlantLLX	Longleaf pine	10
aPlantL1	Loblolly pine	1
aPlantL2	Loblolly pine	2
aPlantL3	Loblolly pine	3
aPlantL4	Loblolly pine	4
aPlantL6	Loblolly pine	6
aPlantL8	Loblolly pine	8
aPlantL9	Loblolly pine	9
aPlantLX	Loblolly pine	10

In SHSF, decisions about the species to plant and the regime under which to manage the resulting stand are separate, with the regime allocation choice occurring at age 6. Therefore, there are only 2 planting decisions in SHSF: aPlantLL (plant longleaf pine) and aPlantL (plant loblolly pine).

Thinning

The timing choices for commercial thinning are predetermined by the regime chosen. Commercial thinning may only be carried out in loblolly pine and longleaf pine plantations. In SHSF, thinning is implicit to the regime chosen, and thinning volumes are triggered through inventory measures. Conversely, MAWT uses explicit commercial thinning actions. Because actions are decision variables in the LP matrix, care must be taken to ensure that all required thinnings are carried out. This is accomplished by making thinnings a precondition for final harvest and disallowing managed stands from reaching stand senescence during the planning horizon. While this may appear to be redundant logic, it is necessary to implement Model I structures in Woodstock's inherent Model II modeling environment.

The actual timing choices implemented in the MAWT and SHSF models are provided in Table 22.

Table 22. Timing choices for thinning options in pine regimes.

		Removal					# of Timing
Species	Regime	1	2	3	4	5	Choices
Longleaf	1	22,25,27	33,35,37	48,50,52	60,65,70,75,80	-	135
Longleaf	2	22,25,27	33,35,37	48,50,52	63,65,67	-	81
Longleaf	3	21,22,23,24,25	T1+20	T2+20	T3+20	T4+20	5
Longleaf	6	22,25,27	38,40,42	-	-		9
Longleaf	10	32,35,37	43,45,47	62,65,67*	-	-	9
Loblolly	1	18,20,22,24	33,35,37	48,50,52	60,65,70,75,80	-	180
Loblolly	2	16,18,20	25,28,31,34	-	-	-	12
Loblolly	3	16,17,18,19,20	T1+19,20,21	T2+19,20,21	T3+19,20,21	-	135
Loblolly	4	20,23,26	30,33,35	-	-	-	9
Loblolly	6	18,20,22	35,37,39	-	-	-	9
Loblolly	8	20,23,26	27,29,30,32	-	-	-	12
Loblolly	9	13,14,15,16,17,18	-	-	-	-	5
Loblolly	10	20,22,24,26	27,29,32	43,45,47*	-	-	36

* The 3rd removal in regime 10 is the shelterwood cut. All other removals in all other regimes are commercial thins.

2.6.4 Non-biological stratification

In addition to the landscape themes used to drive the growth and yield modeling effort, another set of themes were used to differentiate administrative boundaries, management emphasis, and available silvicultural regimes. In both models, Theme 1 identified the state forest where the stratum was located.

Theme1: State Forest

- MA: Manchester State Forest
- WT: Wee Tee State Forest
- SH: Sand Hills State Forest

For MAWT, a Model II structure was used to model all silvicultural activities; for SHSF, Model I formulations were used. Although both MAWT and SHSF each used 17 landscape themes, there were significant differences in the non-biological stratification, designed to address the RCW concerns on SHSF.

Manchester/Wee Tee State Forest

The non-biological stratification used in the MAWT model was as follows:

Theme8: Site preparation

Existing

- E00: Existing stand, site prep type unknown.

Regenerated

- R99: Recent clearcut, no stand establishment.
- R00: Heavy chemical site prep.
- R01: Combo plow & woody control site prep.
- R11: Combo plow, weed control, & woody control site prep.

Theme9: Silvicultural regime (see Tables 1-4 for details).

- 0: Regime 0 – No intermediate thinnings, clearcut final harvest only.
- 1: Regime 1 – Modified two-age.
- 2: Regime 2 – Extended Rotation (plantation).
- 3: Regime 3 – Group Selection.
- 4: Regime 4 – Extended Rotation (natural).
- 6: Regime 6 – Economic Rotation (plantation).
- 8: Regime 8 – Economic Rotation (natural).
- 9: Regime 9 – Intensive loblolly plantation.
- X: Regime 10 – Shelterwood.

Theme10: First thin

- X: Unthinned.
- 99A: Age at thinning (2 numerals) + residual density (1 char).
  Age: 13 - 37
  Residual density code:
  - E: Row thin (1 in 5)
  - F: 60 ft^2/ac
  - G: 70 ft^2/ac

Theme11: Second thin

- X: Unthinned.
- 99A: Age at thinning (2 numerals) + residual density (1 char).
  Age: 25 - 47
  Residual density code:
  - F: 60 ft^2/ac
  - G: 70 ft^2/ac

Theme12: Third thin

- X: Unthinned.
- 99A: Age at thinning (2 numerals) + residual density (1 char).
  Age: 43 - 67

Residual density code:

- C: 30 ft^2/ac
- F: 60 ft^2/ac
- G: 70 ft^2/ac

Theme12: Fourth thin

- X: Unthinned.
- 99A: Age at thinning (2 numerals) + residual density (1 char).
  Age: 60 - 89
  Residual density code:
  - F: 60 ft^2/ac
  - G: 70 ft^2/ac

Theme13: Fifth thin

- X: Unthinned.
- 99A: Age at thinning (2 numerals) + residual density (1 char).
  Age: 97 - 109
  Residual density code:
  - F: 60 ft^2/ac

Theme15: Management restrictions

- 1: RCW partition 1
- 2: RCW partition 2
- 3: RCW partition 3
- 4: RCW partition 4
- 5: RCW partition 5
- 11: Secondary SMZ
- 12: Primary SMZ
- 20: Aesthetic road buffer
- 99: Unrestricted timber management

Theme16: Unused

- U: Placeholder

Theme17: Pine straw raking schedule

- 1: No raking
- 9999: Age at start of 1st raking schedule + Age at start of 2nd raking schedule
  1st raking age: 21, **22**, 23, 24, **25**, **27**, 32, 35, 37
  2nd raking age: 33, 35, 37,__ (no 2nd raking)

In Theme 17, the timing choices for the first raking in boldface (22, 25 and 27) are the only ones that allow for a second raking following a second round of pine straw enhancement during the planning horizon. Otherwise, stands assigned a raking in years 21, 23, 24, 32, 35 or 37 are assumed to have already had the second round of pine straw enhancement in prior years.

Sand Hills State Forest

A Model II formulation of the thinning activities for RCW management was deemed inefficient because the main silvicultural decision variable was not whether to thin, but what timing choices to use for a particular four- or five-thinning regime. Therefore, a Model I structure was deemed a better choice to reduce the number of required decision variables and yield tables. Unfortunately, building the Model I structure within Woodstock's inherent Model II formulation, the Transitions section is made more complicated. In the MAWT model, there is strict correspondence between Themes 10 through 14, and thinnings for the various regime sets. For example, if the third thinning of regime 3 is carried out, only Theme 12 is changed in the Transitions section. In SHSF this is not the case for existing stands. If the third thinning of regime 3 is the

first thinning performed on that stand during the planning horizon (because the stand was too old at the beginning of the planning horizon to be eligible for previous thinnings in the regime), then it will be Theme 10 that is changed in the Transitions section, but the attribute will be the same as it would have been in the MAWT model (e.g. 67G). In other words, the key difference between the two models is that in SHSF Themes 10 – 14 keep track of how many times the stand was thinned during the planning horizon rather than the specific thin of the regime. The non-biological stratification used in the SHSF model was as follows:

Theme8: Site preparation

Existing

- E0: Existing stand, site prep type unknown.

Regenerated

- R9: Recent clearcut, no stand establishment.
- R0: Heavy chemical site preparation.
- R1: Combo plow, weed control, & woody control site preparation.

Theme9: Silvicultural regime (see Tables 1-4 for details).

- 0: Regime 0 – No intermediate thinnings, clearcut final harvest only.
- 1: Regime 1 – Modified two-age.
- 3: Regime 3 – Group Selection.

Theme10: First thin performed during planning horizon

- X: Unthinned.
- 99A: Age at thinning (2 numerals) + residual density (1 char).
  Age: 16 - 109
  Residual density code:
  - F: 60 ft^2/ac
  - G: 70 ft^2/ac

Theme11: Second thin performed during planning horizon

- X: Unthinned.
- 99A: Age at thinning (2 numerals) + residual density (1 char).
  Age: 33 - 109
  Residual density code:
  - F: 60 ft^2/ac
  - G: 70 ft^2/ac

Theme12: Third thin performed during planning horizon

- X: Unthinned.
- 99A: Age at thinning (2 numerals) + residual density (1 char).
  Age: 48 - 109
  Residual density code:
  - F: 60 ft^2/ac
  - G: 70 ft^2/ac

Theme13: Fourth thin performed during planning horizon

- X: Unthinned.
- 99A: Age at thinning (2 numerals) + residual density (1 char).
  Age: 60 - 109
  Residual density code:
  - F: 60 ft^2/ac
  - G: 70 ft^2/ac

Theme14: Fifth thin performed during planning horizon

- X: Unthinned.
- 99A: Age at thinning (2 numerals) + residual density (1 char).
  Age: 97 - 109
  Residual density code:
  - F: 60 ft^2/ac
  - G: 70 ft^2/ac

Theme15: RCW cluster
Non-RCW
- 99: Unrestricted timber management.
- 98: Road and stream buffers, no harvesting.

Existing RCW cluster (tract # + partition ID (1 char)
- 99X: Tract 99, Cluster ID (e.g., 17A).

Recruitment RCW partition ("RC" + partition ID (1 char)
- RC99: Recruitment cluster 99 (e.g., RC21).

Theme16: Unused
- 0: Placeholder value only.

Theme17: RCW ¼ mile radius
- 1: Within ¼ mile of RCW cluster centroid.
- 0: Beyond ¼ mile of RCW cluster centroid.

2.7 Outputs

Both models include outputs standard to most harvest scheduling models: volume by product, revenue by product, acres harvested or treated, etc. Harvest revenues were triggered by final harvest and thinning activities in MAWT, with mid-rotation silvicultural treatments triggered by inventory measures at specific ages or stand conditions. In SHSF, thinning revenues were also triggered by inventory measures. Tracking and constraining foraging habitat required the development of special yield table components.

2.7.1 Good Quality Foraging Habitat

To qualify as good quality foraging habitat (GQFH), a stand must meet several stand conditions simultaneously. The scoring system outlined in a paper by Lipscomb and Williams[2] is shown in Table 23. Because ground vegetation, fire return interval and season of burn were unavailable, they could not be included in the scoring matrix. Since SCFC actively manages stands in RCW partitions to remove unwanted hardwood competition, it can be safely assumed that managed stands across SHSF will consistently fall into the best scoring categories for hardwood midstory and canopy hardwoods. Thus, the parameters that are highlighted in Table 23 are used to score stands for GQFH.

[2] Lipscomb, Donald J. and Thomas M. Williams. 2006. IN Connor, Kristina F., ed. 2006. Proceedings of the 13th biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–92. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 640 p.

Table 23. Systems to score stands in relation to criteria specified in Lipscomb & Williams (2006).

	Score				
Stand characteristic	**1**	**2**	**3**	**4**	**5**
1. Number 14"+ pine stems	< 5	5-8	9-12	13-17	18+
2. Basal area >14" pines	< 5	5-9	10-14	15-19	20+
3. Basal area 10-14" pines	> 55	51-55	45-50	41-45	0-40
4. Basal area <10" pines	> 30	23-29	16-22	10-15	0-10
5. Number pines < 10"	> 40	33-39	26-32	20-25	0-20
6. Basal area of pine > 10"	< 20	21-26	27-32	33-39	40+
% vegetative ground cover	< 10	10-19	20-29	30-39	40+
Hardwood midstory:					
Tall = T (>15'), Dense = D	T-D	M-M	M-S	L-M	L-S
Medium = M (7-15')	M-D	T-S	L-D		
Low = L (<7'), Sparse = S	T-M				
hardwood pulpwood BA	> 30	22-30	16-22	10-16	<10
% canopy hardwoods					
longleaf stands	> 30	23-29	16-22	10-15	<10
loblolly/shortleaf stands	> 50	43-49	36-42	30-35	<30
7. Stand age	30	31-39	40-49	50-59	60+
Fire return interval (year)	7+	6	5	3-4	<3
Season of burn			NGS		GS

Since these parameters can be extracted from the pine growth and yield models used in this analysis, it was possible to evaluate changes in GQFH over time and over alternative planning regimes. We used the simple method for Habitat Score (HS) presented by Lipscomb and Williams (2006) that summed the scores across all criteria (maximum = 35). The yield components in the SHSF model tracked each criterion separately, along with an index (HSLo) that identified the two criteria that most limited attainment of GQFH status. For example, suppose that a stand met all the criteria for GQFH except for basal area of pines 14" or larger (criterion 2) and for the number of pine trees less than 10" in diameter (criterion 5). In the yield tables, such a stand might show HS = 33 and HSLo = 25. A stand that qualifies as GQFH would show HS = 35 and HSLo = 00. To estimate the number of acres in a partition that qualify as GQFH, we simply inventory pine stands where HS = 35.

2.7.2 Foraging Habitat

According to the Private Lands Guidelines[3], stands that qualify as foraging habitat (FH) exhibit basal areas between 40 and 70 ft^2/acre in trees greater than 10" dbh and no more than 20 ft^2/acre in trees less than 10" dbh; are at least 30 years of age; and no more than 10 ft^2/acre can be hardwood species. An examination of the yield tables showed that very few met the criteria for FH before age 30 (thus obviating the need to track stand age in the output definition) and once they did exceed the threshold of HS =10, virtually all met the crieteria for larger diameter pine trees. So, rather than devise a completely different HS system for MAWT, it was agreed upon that pine stands with HS values greater than 10 would qualify as FH on MAWT.

2.8 Objectives and Constraints

Given the different management emphases for MAWT and SHSF, it is not surprising that the constraint sets for these two models were quite different, even if the objective functions were essentially the same.

2.8.1 Manchester/Wee Tee

Objective Function

The original objective function for MAWT was to maximize discounted net revenue over the entire planning horizon. Due to infeasibilities related to foraging habitat in one of the RCW partitions, the objective function was changed to a goal formulation that added a penalty of $9999/acre when foraging habitat fell below the specified threshold. The intent therefore is to maximize discounted net revenue while minimizing shortfalls in foraging habitat.

Constraints

SCFC provided estimates of the time required (hours/ac) for field staff to conduct prescribed burning, timber marking, timber cruising and group selection, as well as the maximum number of hours that field

[3] Recovery Plan for the Red-cockaded Woodpecker (Picoides borealis), Second Revision. 2003. US Fish and Wildlife Service, Southern Region, Atlanta, GA. Appendix 5, pp 291-296.

staff are available for these tasks annually. Constraints imposing these annual maximums limited the number of acres that could be burned or harvested in a given year.

The five RCW partitions on MSF are managed according to Private Lands Guidelines specified in the Recovery Plan, which call for a minimum of 75 acres of foraging habitat within ¼ mile of the RCW cluster center. Since these ¼ mile circles overlap on MSF, the resulting RCW partitions are all smaller than the prescribed 125 acres, with one having a total area of only 38 acres. Clearly it is impossible to provide 75 acres of non-overlapping foraging habitat in all the partitions. Instead, it was decided to prorate the 75 acre threshold on each partition, requiring 60% of the area to be qualified foraging habitat in all periods.

The final SCFC objective for MAWT is to provide a minimum annual revenue stream to the state. SCFC pays 25% of the annual timber and non-timber revenues from MSF and WTSF to the counties where they are located in lieu of property taxes. After payments to the counties and covering silvicultural expenses, SCFC would like to net $2million in revenue from these two state forests.

2.8.2 Sand Hills

Objective Function

Due to the large number of RCW partitions on SHSF and the requisite number of constraints associated with them, it was assumed from the start that the appropriate objective function would be a goal formulation that maximizes discounted net revenue while minimizing shortfalls in habitat requirements on each of the RCW partitions. The inherent difficulty with goal formulations is the appropriate assignment of weights placed on the penalties for not achieving goals. Since the goals are all directed at maintaining GQFH in all periods, an acre of underachievement in any one RCW partition is equal to an acre of underachievement in any other. As a result, all the constraints associated with maintaining GQFH were assigned the same penalty – $9999 per acre – a value that is of the same order of magnitude as the highest annual timber revenue achievable from an acre of forest land on SHSF. Since it takes at least 60 years to achieve GQFH status, the chosen penalty weights are effective counters to the profit maximization objective.

Constraints

As with MAWT, there are a limited number of hours available for field staff to conduct prescribed burning, timber marking and cruising; as before, these were handled as explicit man-hour constraints.

There are 71 existing RCW clusters on SHSF and the USFWS has identified an additional 57 recruitment clusters which they expect RCW to occupy in the future. According to the RCW Recovery Plan[4], RCW partitions on SHSF must provide within the partition (.5 mile radius):

- 120 acres of Good Quality Foraging Habitat (GQFH).
- 50% of GQFH must be within .25 miles radius of RCW cluster center.
- 200 acres of pine within the partition.
- 200 acres of contiguous pine >= 30 years of age.

As was the case on MAWT, there is significant overlap among the partitions such that few, if any, encompass a full 500 acres of non-overlapping area within ½ mile of the cluster center, or 125 acres within ¼ mile of the cluster center. Moreover, it was unclear as to what the appropriate constraints should be to provide adequate GQFH over the planning horizon. If we consider a longleaf pine rotation for RCW management to be 120 years, and the minimum age for GQFH to be 60 years, no more than 50 percent of the stands can be expected to qualify as GQFH over the long term. With the current age distribution skewed

[4] Recovery Plan for the Red-cockaded Woodpecker (Picoides borealis), Second Revision. 2003. US Fish and Wildlife Service, Southern Region, Atlanta, GA. Part B – Assessment of Foraging Habitat, pp 195-197.

largely to 76 years of age, it was readily apparent that GQFH acres could be sustained and perhaps increased in the short-term, but eventually there would be a dramatic fall-down as those stands begin to senesce. Some harvesting of the older stands would need to commence immediately, to provide GQFH in future years. To that end, it was agreed upon that an appropriate management goal would be to maintain 50% of the RCW partitions in GQFH status at all times. Since such constraints would inevitably lead to infeasibility in one or more partitions, a goal formulation that penalizes shortfalls was implemented.

Because of the desire for GQFH to be in close proximity to RCW clusters, the 50% constraints were applied separately to the partition acres within ¼ mile of the cluster center and the acres beyond ¼ mile of the cluster center. If the constraints were applied partition-wide, GQFH within ¼ mile of the cluster center would be valued no more than GQFH further away, which is clearly not the intent. For existing clusters, the GQFH constraints were applied immediately and for the entire planning horizon; for recruitment clusters, the GQFH constraints were applied when they were expected to be occupied (20 – 70 years from now)[5]. The desired outcome of these constraints is to "demonstrate reasonable progress" toward meeting the recovery standard through continuous increases in the number of acres of nominal GQFH over time, as outlined in the Interim Guidelines section of the RCW Recovery plan.

The final set of constraints to the SHSF model was related to revenue. SCFC managers desired to see annual timber harvest revenues of $1 million/year. Recognizing that the age-class distribution was skewed so heavily to older age classes, they recognized that a discounted cash-flow model would likely tend to harvest heavily in the early years. Not only would this yield fluctuating cash-flows over time, but it would probably perpetuate the skewed age-class distribution for some time. Therefore it was decided to apply a sequential flow constraint on harvest revenues, allowing them to vary by ± 10% year-over-year.

3 Sensitivity Analysis

3.1 Manchester/Wee Tee

Five Alternative Management Strategies

Five harvest schedule alternatives were proposed by FORSight to test the biological feasibility of the model. Table 24 provides a brief description of each along with an abbreviation used throughout the remainder of this report. The first alternative, MaxFH, uses an objective function maximizing the quantity of Foraging Habitat (FH) in the five red cockaded woodpecker (RCW) clusters over the planning horizon. The second model, MaxPNV-None uses an objective function maximizing present net value (PNV) over the planning horizon. The only additional constraints included in these base models require that no stands are allowed to die and begin succession and all stands receiving final harvest must be regenerated.

Table 24. Descriptions of harvest schedule alternatives for sensitivity analysis of MAWT model.

Alternative Label	Description
MaxFH	Maximize foraging habitat (FH) within the five RCW clusters subject to no stand mortality and mandatory regeneration following final harvest.
MaxPNV-none	Maximize discounted net revenue subject to no stand mortality and mandatory regeneration following final harvest.
MaxPNV-FH	Same as MaxPNV-none plus constraints requiring minimum FH levels of 75 acres in RCW clusters 1,2,3,5 beginning in period 2 and 38 acres of FH in cluster 4 beginning in period 3
MaxPNV-partial	Same as MaxPNV-FH plus constraints setting a floor on net revenue and a ceiling on manpower required for prescribed burning and timber marking/cruising.
MaxPNV-full	Same as MaxPNV-partial plus constraints limiting net revenue and volume by product to fluctuations no greater than 20% period-to-period, and a nondeclining constraint on natural pine regeneration.

The remaining three alternatives iteratively apply additional constraints to the MaxPNV-None model. Model MaxPNV-FH adds constraints that require minimum FH levels in each of the five RCW clusters. The minimum levels are set at 75 acres for clusters one, two, three, and five beginning in planning period two and 38 acres in cluster four beginning in planning period three. The 75-acre minimums are consistent with Private Lands Guidelines but since cluster four never achieves that minimum standard under foraging

[5] The resulting constraints section had well over 25,000 constraint rows devoted only to the maintenance of GQFH in the RCW partitions.

habitat maximization, the maximum achievable was established as the floor value. The fourth alternative, MaxPNV-Partial, introduces additional constraints that set a floor on net revenue and a ceiling on man-hours available for prescribed burning and timber marking and cruising. The ceiling and floor values were determined from previous runs and were set to ensure feasibility. The final model, MaxPNV-Full, introduced additional constraints requiring maximum fluctuations in net revenue and harvest volume to be less than 20% in adjacent periods. In addition, natural pine regeneration area must be non-declining during the planning horizon. In all five cases, a 5% discount rate and a 101 year planning horizon were used.

Results

Tabular results summarized over the first ten and the first fifty years are provided in Tables 25 and 26. Net revenue and discounted net revenue are substantially lower with alternative MaxFH than with the other four alternatives because the objective focuses management almost exclusively on the RCW clusters, which comprise only about 10% of the total area, generally ignoring the remainder of the property. Harvests occur outside the RCW clusters only when the alternative is stand senescence. A constraint prevents stand senescence and the substantially lower harvest area compared to the other four alternatives clearly illustrates this. Another notable difference is the nearly 35% drop in 10-year revenue between alternatives three and four due to the introduction of man-power ceiling constraints in alternatives MaxPNV-Partial and MaxPNV-Full.

Table 25. Ten-year Manchester/Wee Tee tabular results by alternative (2008-2018).

	MaxFH	MaxPNV-None	MaxPNV-GQFH	MaxPNV-Partial	MaxPNV-Full
Volume (Tons)					
Pine Pulpwood	127,864	204,820	201,334	186,659	212,142
Pine Chip & Saw	54,212	85,018	82,126	94,173	109,193
Pine Sawlogs	64,962	373,156	369,809	328,061	288,843
Hardwood Pulpwood	11,369	533,095	533,095	317,416	235,956
Hardwood Sawlogs	4,255	1,010,759	1,010,759	514,821	335,788
Oak Sawlogs	0	250,322	250,322	104,490	68,387
Total	**262,662**	**2,457,170**	**2,447,445**	**1,545,620**	**1,250,309**
Revenue ($)					
Pine Pulpwood	1,004,526	1,651,591	1,625,973	1,533,525	1,754,027
Pine Chip & Saw	1,283,216	2,040,003	1,970,402	2,260,353	2,609,346
Pine Sawlogs	2,842,088	16,325,593	16,179,147	14,352,703	12,636,875
Hardwood Pulpwood	112,016	5,789,684	5,789,684	3,401,004	2,526,964
Hardwood Sawlogs	95,608	23,817,516	23,817,516	12,020,875	7,766,807
Oak Sawlogs	0	9,649,979	9,649,979	3,922,102	2,505,719
Other Revenue	2,380,155	2,540,910	2,540,910	2,549,760	2,548,440
Total Revenue	**7,717,610**	**61,815,276**	**61,573,611**	**40,040,322**	**32,348,178**
Cost ($)					
Seedlings & Planting	424,740	616,272	590,912	613,788	603,340
Site Prep (Chem. & Mech.)	372,715	525,384	510,503	585,503	565,641
Chemical Release	39,623	0	0	0	0
Fertilization	4,974	128,518	128,515	94,018	95,032
Payment to County in Lieu of Taxes	1,929,402	15,453,819	15,393,403	10,010,081	8,087,044
Total	**2,771,455**	**16,723,993**	**16,623,332**	**11,303,390**	**9,351,057**
Net Revenue ($)	4,946,155	45,091,283	44,950,279	28,736,932	22,997,121
Net Present Value ($)	5,122,792	41,393,561	41,219,687	27,688,503	22,954,630
Harvest Area (acres)					
Clearcut	3,290	21,317	21,148	14,402	12,646
Thinning	1,734	2,508	2,546	787	1,253
Shelterwood	0	0	0	0	0
Total	**5,024**	**23,825**	**23,694**	**15,189**	**13,899**
Silviculture Treatment Area (acres)					
Prescribed Burn	116	133	133	230	273
Site Prep (Chem. & Mech.)	3,519	5,307	5,138	5,733	5,551
Planting	3,293	4,528	4,359	4,665	4,552
Natural Regeneration	658	6,988	6,988	7,269	7,861
Fertilization	84	2,398	2,398	1,584	1,797
Chemical Release	520	0	0	0	0
Total	**8,190**	**19,354**	**19,017**	**19,481**	**20,034**

Table 26. Fifty-year Manchester/Wee Tee tabular results by alternative (2008-2058).

	MaxFH	MaxPNV-None	MaxPNV-GOFH	MaxPNV-Partial	MaxPNV-Full
Volume (Tons)					
Pine Pulpwood	666,178	1,269,345	1,252,968	186,659	212,142
Pine Chip & Saw	282,302	694,852	681,881	94,173	109,193
Pine Sawlogs	419,840	1,649,657	1,633,712	328,061	288,843
Hardwood Pulpwood	12,799	754,564	754,564	317,416	235,956
Hardwood Sawlogs	4,757	1,127,390	1,127,390	514,821	335,788
Oak Sawlogs	0	277,565	277,565	104,490	68,387
Total	**1,385,876**	**5,773,371**	**5,728,078**	**1,545,620**	**1,250,309**
Revenue ($)					
Pine Pulpwood	6,086,213	11,700,704	11,553,395	9,012,237	8,889,000
Pine Chip & Saw	6,903,355	17,066,308	16,748,358	9,756,424	10,801,405
Pine Sawlogs	18,368,019	72,172,484	71,474,881	70,335,626	65,980,993
Hardwood Pulpwood	128,122	8,285,637	8,285,637	7,555,451	7,945,829
Hardwood Sawlogs	107,636	26,610,829	26,610,829	29,305,577	30,205,101
Oak Sawlogs	0	10,729,061	10,729,061	12,878,617	13,571,435
Other Revenue	15,953,417	17,868,225	17,712,758	17,769,006	17,770,188
Total Revenue	**47,546,762**	**164,433,248**	**163,114,919**	**156,612,938**	**155,163,951**
Cost ($)					
Seedlings & Planting	721,938	1,915,333	1,898,376	1,546,862	1,485,881
Site Prep (Chem. & Mech.)	905,487	3,423,980	3,405,316	2,543,911	2,334,654
Chemical Release	287,667	0	0	26,459	4,566
Fertilization	5,259	1,143,675	1,139,903	806,761	773,669
Payment to County in Lieu of Taxes	11,886,690	41,108,312	40,778,730	39,153,235	38,790,986
Total	**13,807,041**	**47,591,299**	**47,222,325**	**44,077,228**	**43,389,756**
Net Revenue ($)	33,739,720	116,841,949	115,892,594	112,535,710	111,774,196
Net Present Value ($)	13,864,830	62,094,626	61,859,064	55,396,888	53,571,305
Harvest Area (acres)					
Clearcut	6,645	54,532	54,190	35,048	34,797
Thinning	20,033	23,355	23,096	18,775	18,408
Shelterwood	1,148	410	427	17	22
Total	**27,826**	**78,296**	**77,713**	**53,840**	**53,227**
Silviculture Treatment Area (acres)					
Prescribed Burn	2,516	2,298	2,315	1,264	1,760
Site Prep (Chem. & Mech.)	7,296	29,200	29,023	21,881	20,313
Planting	7,646	18,458	18,321	14,099	13,468
Natural Regeneration	720	34,005	34,005	20,637	21,392
Fertilization	88	19,025	18,964	13,451	12,773
Chemical Release	3,798	0	0	344	60
Total	**22,064**	**102,985**	**102,627**	**71,676**	**69,766**

Figure 10 graphically illustrates total man-hours over time for each alternative, along with the ceiling level set by the constraints. Over the first fifty years, alternatives MaxPNV-None and MaxPNV-FH exceed the ceiling values nine times, at times by more than twice the limit. Forcing the fourth and fifth alternatives below these levels means less area can be treated, and the reduction in treatment area in turn results in the lower net revenues shown in the last two columns of Table 26.

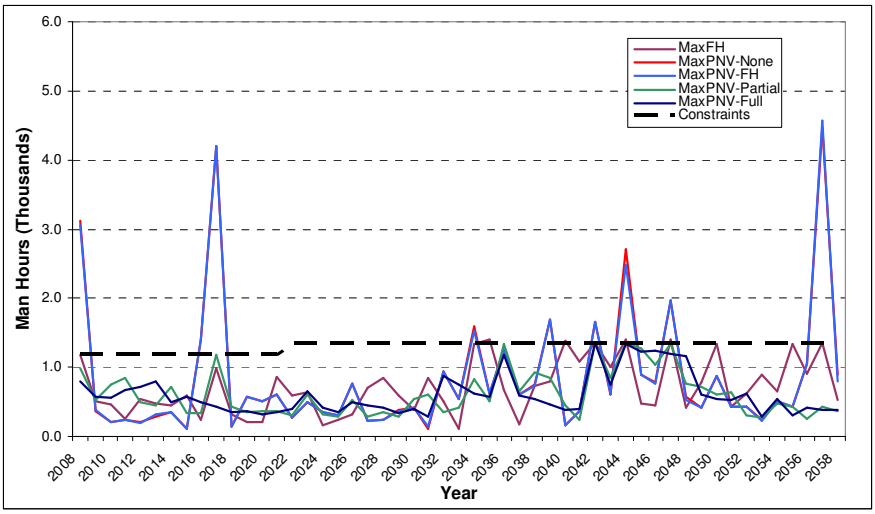

Figure 10. Total MAWT manpower requirements over the first 50 years, by alternative.

Tabular wildlife habitat results by RCW cluster and summarized across all clusters are shown in Tables 27 and 28. As expected, alternative MaxFH produces the highest average number of foraging habitat acres and alternative MaxPNV-None produces the least. Interestingly, after fifty years, the latter three models exhibit similar FH to model MaxFH, with similar values for clusters 3, 4 and 5 (see Table 28).

Table 27. MAWT tabular wildlife habitat results by RCW cluster and alternative (10-year averages).

	MaxFH	MaxPNV-None	MaxPNV-GQFH	MaxPNV-Partial	MaxPNV-Full
	Acres of Nominal Foraging Habitat				
RCW Zone 1	114.5	63.1	96.0	102.7	102.7
RCW Zone 2	115.1	72.2	96.6	103.7	103.8
RCW Zone 3	78.2	71.2	76.5	77.1	77.0
RCW Zone 4	36.0	23.3	36.0	36.0	36.0
RCW Zone 5	85.1	71.3	80.5	82.3	82.5
Average All Zones	**85.8**	**60.2**	**77.1**	**80.4**	**80.4**

Table 28. MAWT tabular wildlife habitat results by RCW cluster and alternative (50-year averages).

	MaxFH	MaxPNV-None	MaxPNV-GQFH	MaxPNV-Partial	MaxPNV-Full
	Acres of Nominal Foraging Habitat				
RCW Zone 1	114.5	43.4	82.3	83.9	84.4
RCW Zone 2	115.1	60.7	83.5	85.0	85.0
RCW Zone 3	78.2	62.9	75.5	75.6	75.6
RCW Zone 4	37.7	23.3	37.6	37.6	37.6
RCW Zone 5	85.1	63.5	77.3	77.5	77.5
Average All Zones	**86.1**	**50.8**	**71.2**	**71.9**	**72.0**

Eight management regimes were available for the Manchester and Wee Tee State Forests (see Table 29). Each regime has a slightly different management focus, achieved through differing levels of site preparation, mid-rotation treatments, and thinning (see Section 2.6.3). The specific activities carried out under each regime differ by forest type (longleaf pine, loblolly pine, and mixed pine). *No regime* (or Regime 0) simply implies that there are no intermediate harvests between regeneration and final clearcut harvest.

Table 29. Pine management regimes used on Manchester and Wee Tee State Forests.

	Description	Loblolly	Longleaf
Regime 1	Modified Two-Age Management	X	X
Regime 2	Extended Rotation for Sawtimber Production	X	X
Regime 3	Group Selection	X	X
Regime 4	Extended Rotation Natural Stands for Sawtimber Production	X	
Regime 6	Optimum Economic Rotation	X	X
Regime 8	Optimum Economic Rotation Natural Stands	X	
Regime 9	Intensive Management	X	
Regime 10	Shelterwood Rotation for Natural Stands	X	X

Figure 11 shows the area under each management regime after 50 years. All alternatives transition towards a 3-way split in pine management among *No regime* (Regime 0 - clearcut only), Regime 2 and other regimes[6]. Alternative MaxFH manages a majority of the remaining one-third under regimes six and ten; the remaining four alternatives manage the remaining one-third primarily under regime nine, but a small area is still managed under regimes six and ten. The stand conditions promoted by these two regimes provide better RCW habitat, helping explain the higher habitat score and FH values for alternatives MaxFH, MaxPNV-FH, MaxPNV-Partial, and MaxPNV-Full (see Table 27 and Table 28).

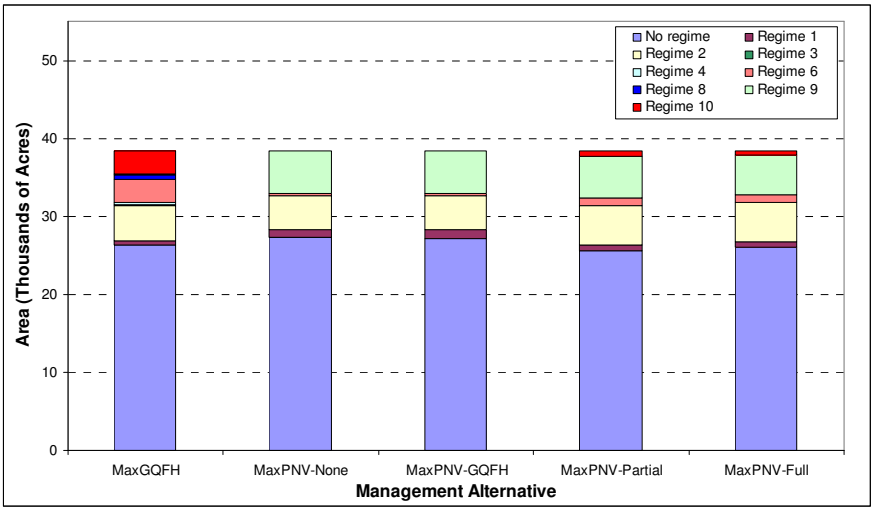

Figure 11. Manchester/Wee Tee area managed under each regime at year 2058, by alternative.

3.2 Sand Hills

3.2.1 Four Alternative Management Strategies

Four harvest schedule alternatives were proposed by FORSight. Table 30 provides a brief description of each along with an abbreviation used throughout the remainder of this report. The first alternative, MaxGQFH, uses an objective function maximizing the quantity of GQFH over the planning horizon. The remaining alternatives use an objective function that maximizes present net value (PNV) while enforcing slightly different management requirements. Alternative MaxPNV-cc50 includes constraints to limit deviation in the area clearcut between consecutive planning periods to be at most 50 acres. The third alternative, MaxPNV-10%, requires the fluctuation in net revenue to be no more than 10% between consecutive periods. Finally, alternative MaxPNV-MH imposes caps on the number of man-hours available for prescribed burning and timber marking/cruising in each period. In all cases a 5% discount rate and a 176 year planning horizon were used.

[6] Over 20,000 acres of the combined Manchester/Wee Tee land base is hardwood, eligible for no intermediate harvests (clearcut only). Therefore, pine only represents about half the total forest area.

Table 30. Descriptions of harvest schedule alternatives for sensitivity analysis of SHSF model.

Alternative Label	Description
MaxGQFH	Maximize good quality foraging habitat (FH) within all RCW clusters.
MaxPNV-cc50	Maximize present net value subject to maximum clearcut harvest area fluctuations of +/- 50 acres between consecutive planning periods.
MaxPNV-10%	Maximize present net value subject to maximum net revenue fluctuations of +/- 10% between consecutive planning periods.
MaxPNV-MH	Maximize present net value subject to maximum personnel hours for prescribed burning of 2000 hours/year and for timber marking/cruising of 2500 hours/year.

Results

Tabular results summarized over the first ten and the first fifty years are provided in Tables 31 and 32. With respect to wildlife habitat, alternatives MaxGQFH and MaxPNV-10% provide the highest average GQFH and habitat scores over both periods. Alternative MaxGQFH exceeds alternative MaxPNV-10% in all instances except for average GQFH over the first ten years. In this case, however, the difference is small. Figures 12 and 13 graphically illustrate habitat score and GQFH trends over time by alternative.

Table 31. Ten-year Sand Hills tabular results by alternative (2008-2018).

	MaxGQFH	MaxPNV-cc50	MaxPNV-10%	MaxPNV-MH
Volume (Tons)				
Pine Pulpwood	340,386	234,217	268,169	228,970
Pine Chip & Saw	234,604	158,738	195,421	159,247
Pine Sawlogs	375,484	557,639	557,800	513,490
Total	**950,474**	**950,594**	**1,021,390**	**901,706**
Revenue ($)				
Pine Pulpwood	2,749,685	1,903,236	2,147,353	1,799,388
Pine Chip & Saw	5,611,937	3,783,654	4,634,143	3,819,977
Pine Sawlogs	16,427,406	24,396,712	24,403,764	22,465,176
Other Revenue	1,676,450	1,207,346	1,589,143	1,263,219
Total Revenue	**26,465,479**	**31,290,947**	**32,774,403**	**29,347,760**
Cost ($)				
Loblolly Seedlings	90,716	88,480	95,056	105,432
Longleaf Seedlings	165,359	384,346	484,498	359,859
Planting	211,099	302,832	346,398	316,471
Heavy Chemical Prep	599,372	664,464	752,897	716,663
Chemical Release	1,458	1,423	1,528	1,695
Payment to County in Lieu of Taxes	6,616,370	7,822,737	8,193,601	7,336,940
Total	**7,684,375**	**9,264,281**	**9,873,979**	**8,837,060**
Net Revenue ($)	18,781,104	22,026,666	22,900,424	20,510,700
Net Present Value ($)	19,695,954	22,265,382	24,271,655	21,218,015
Harvest Area (acres)				
Clearcut	6,839	8,053	8,965	8,557
Thinning	4,857	4,397	3,549	3,691
Total	**11,696**	**12,450**	**12,513**	**12,248**
Silviculture Treatment Area (acres)				
Prescribed Burn	3,646	3,556	3,821	4,238
Chemical site prep	6,769	7,457	8,496	8,075
Planting	5,165	7,086	8,270	7,542
Chemical release	0	0	0	0
Total	**15,579**	**18,098**	**20,586**	**19,855**
Wildlife Habitat (average value)				
Good Quality Foraging Habitat (GQFH)	21%	19%	23%	14%
Habitat Score	19.66	18.25	19.01	17.89

Table 32. Fifty-year Sand Hills tabular results by alternative (2008-2058).

	MaxGQFH	MaxPNV-cc50	MaxPNV-10%	MaxPNV-MH
Volume (Tons)				
Pine Pulpwood	1,346,132	1,197,168	1,451,806	228,970
Pine Chip & Saw	870,773	763,044	809,756	159,247
Pine Sawlogs	1,893,180	2,404,228	2,658,392	513,490
Total	**4,110,085**	**4,364,441**	**4,919,954**	**901,706**
Revenue ($)				
Pine Pulpwood	12,243,932	10,993,491	13,320,888	11,744,276
Pine Chip & Saw	21,287,121	18,673,771	19,771,358	17,688,079
Pine Sawlogs	82,826,619	105,184,976	116,304,651	87,840,596
Other Revenue	13,530,869	11,006,486	15,176,274	12,626,079
Total Revenue	**129,888,541**	**145,858,725**	**164,573,171**	**129,899,030**
Cost ($)				
Loblolly Seedlings	114,244	112,621	129,383	112,713
Longleaf Seedlings	1,162,872	2,045,519	1,793,040	1,781,637
Planting	661,199	1,044,846	972,692	916,877
Heavy Chemical Prep	1,341,021	2,121,443	1,950,196	1,847,904
Chemical Release	1,837	1,811	2,080	1,812
Payment to County in Lieu of Taxes	32,472,135	36,464,681	41,143,293	32,474,757
Total	**35,753,308**	**41,790,920**	**45,990,685**	**37,135,701**
Net Revenue ($)	94,135,233	104,067,805	118,582,486	92,763,329
Net Present Value ($)	43,102,981	49,363,488	50,974,128	48,077,354
Harvest Area (acres)				
Clearcut	14,976	24,184	22,204	20,888
Thinning	35,801	41,437	29,222	44,223
Total	**50,777**	**65,621**	**51,427**	**65,112**
Silviculture Treatment Area (acres)				
Prescribed Burn	4,592	4,527	5,200	4,530
Chemical site prep	14,987	23,602	21,764	20,611
Planting	15,270	23,310	21,665	20,891
Chemical release	0	0	0	0
Total	**34,849**	**51,438**	**48,630**	**46,032**
Wildlife Habitat (average value)				
Good Quality Foraging Habitat (GQFH)	48%	38%	43%	34%
Habitat Score	24.11	19.91	22.84	19.47

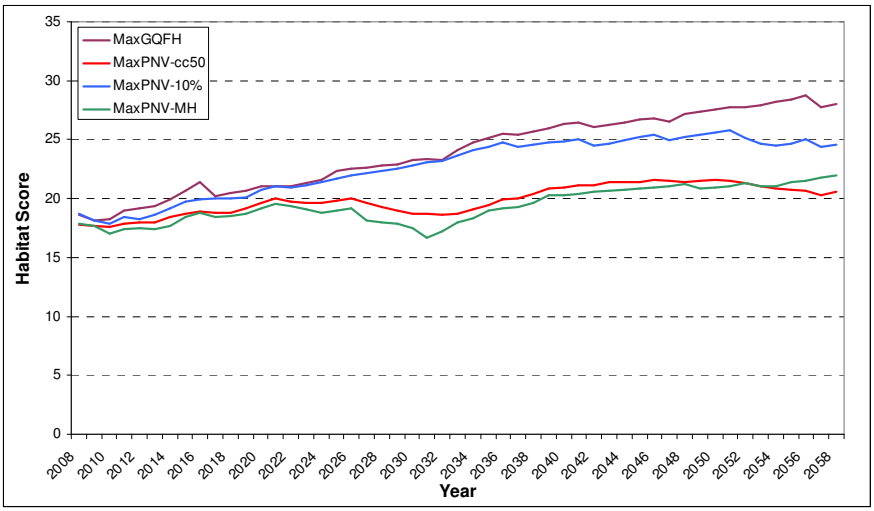

Figure 12. Sand Hills average habitat score by management alternative (2008-2058).

Alternative MaxPNV-MH indicates that the model is sensitive to the number of personnel hours available for timber management. In the case of foraging habitat, a shift to group selection requires a substantial investment of time for marking trees, without which the improvements in foraging habitat are foregone. Similarly, capping the number of personnel hours limits the amount of timber harvesting that can be performed, which in turn limits harvest revenues.

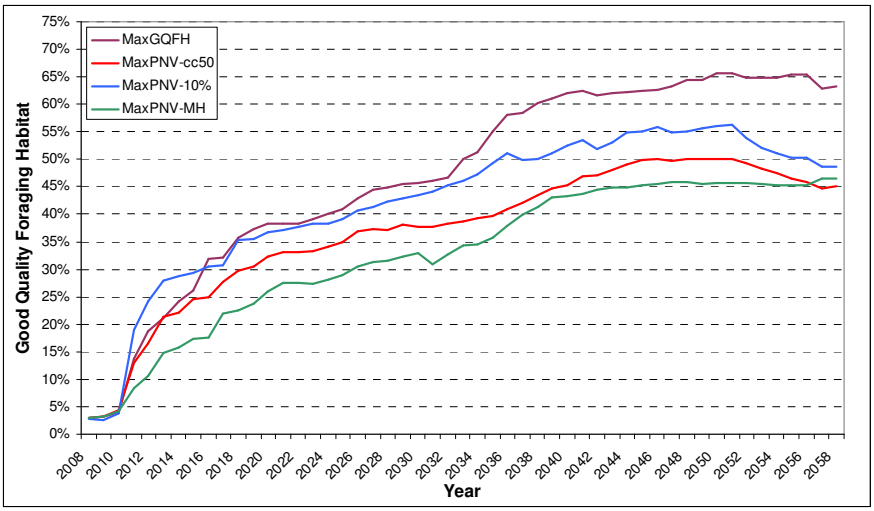

Figure 13. Sand Hills Proportion of GQFH by management alternative (2008-2058).

Alternative MaxGQFH results in the lowest net present value (at the 5% discount rate) and net revenue over both the ten year and fifty year periods. Although total harvest area is similar between the alternatives, the three that utilize a maximize PNV objective function (MaxPNV) result in larger silvicultural treatment areas. Together with the higher proportion of total volume attributed to sawtimber, this indicates more intensive management. Two management regimes were available for longleaf pine for the Sand Hills ownership. Regime 1 consists of intermediate thinnings near ages 10, 20, 35, 50, and 80 with final harvest at age 100 while regime 3 consists of thinnings every 20 years followed by final harvest at age 120. In both cases, thinnings leave 60 square feet of residual basal area.

Figure 14 shows the area under each management regime after 50 years. Alternatives MaxGQFH and MaxPNV-10% transition towards managing about 50% of the total area under regime three while the other alternatives shift towards managing about 70% of the total area under regime one. The stand conditions promoted by regime three provide better red cockaded woodpecker habitat, helping explain the higher habitat score and GQFH values for alternatives MaxGQFH and MaxPNV-10% (see Figures 12 and 13).

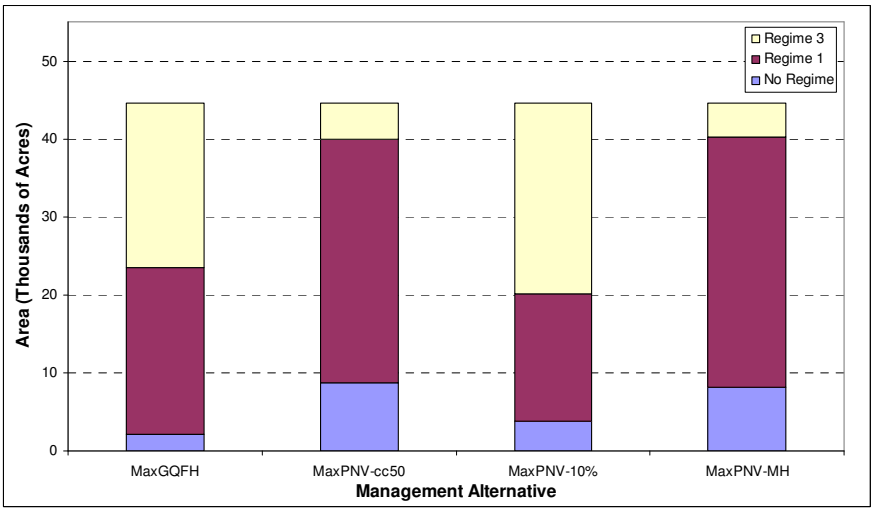

Figure 14. Sand Hills area managed under each regime at year 2058, by alternative.

4 Results

4.1 Manchester/Wee Tee

4.1.1 Strategic (Woodstock)

The Woodstock model used to develop the preferred alternative had a planning horizon of 101 years. Because the inventory had been updated to the end of 2006, the first year of the planning horizon was (2007). Since the activities for 2007 had been previously planned and implemented by SCFC, it seemed reasonable to model a full 100-year planning horizon beginning in 2008.

Initial runs showed high levels of hardwood harvesting in Tract 7 of MSF, an area that is considered well-stocked with high recreation values. Alternatively, the hardwood resource on WTSF is considered low-quality and had been targeted for aggressive harvesting to replace those stands with higher-quality hardwoods. To address these issues, the operability limits for hardwood harvests were altered to favor harvest of hardwoods on WTSF and disfavor those harvests on MSF. An upper limit was placed on hardwood clearcut harvesting of 600 acres/year. With these additional constraints, the resulting strategic harvest schedule yielded discounted net revenues of $57,964,392 over the first 50 years.

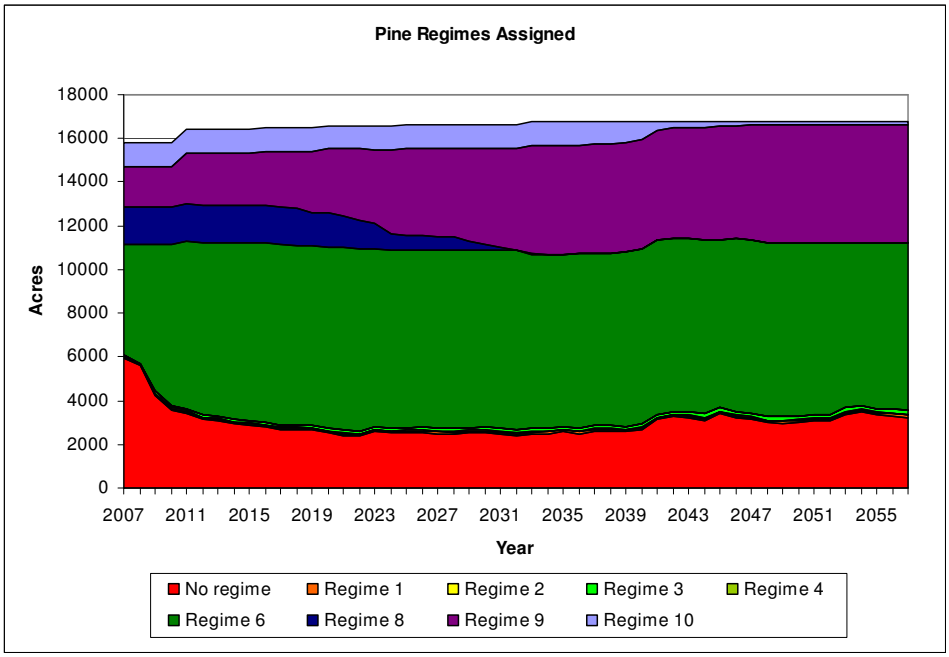

Figure 15. Manchester/Wee Tee timber management regimes assigned during the first 50 years. (See section 2.4 for regime descriptions).

Harvest revenues projected for the first 50 years are shown in Figure 16; other revenues for the same period are shown in Figure 17. Note how hardwood is a major contributor to harvest revenues over the first 30 years, as the poorer-quality swamp bottomland hardwood (SBH) on WTSF is harvested and replaced. The long-term plan by SCFC is to have the SBH stands on WTSF in good condition, similar to those in Tract 7 of MSF. Pine straw is also a major contributor to revenue in MAWT after 20 years.

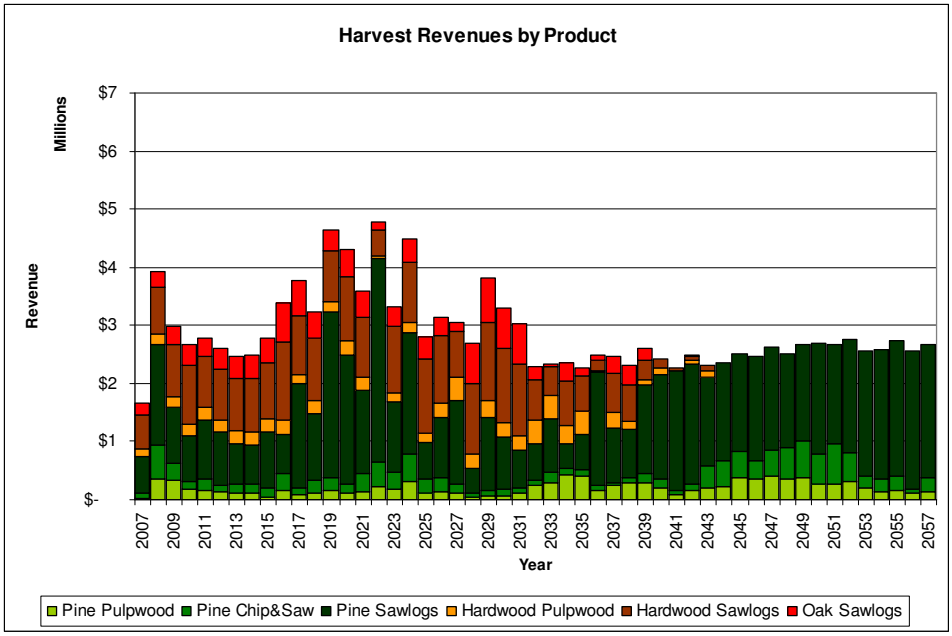

Figure 16. Manchester/Wee Tee timber harvest revenues (50 years).

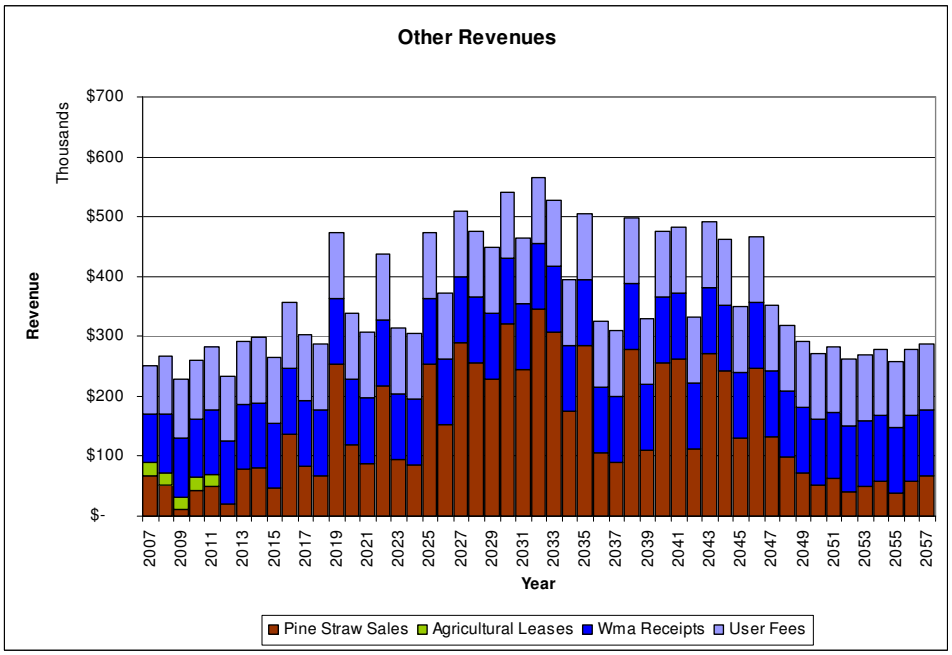

Figure 17. Manchester/Wee Tee other revenues (50 years).

Manpower requirements on MAWT remain well-below the maximum available hours in most years (Figure 19). Because of the extensive harvesting of WTSF, timber cruising consumes the majority of personnel hours in the first 30 years of the planning horizon. As more of the forest comes under regime management, there are fewer final harvests (requiring cruising) and more commercial thins and group selection harvests (requiring marking).

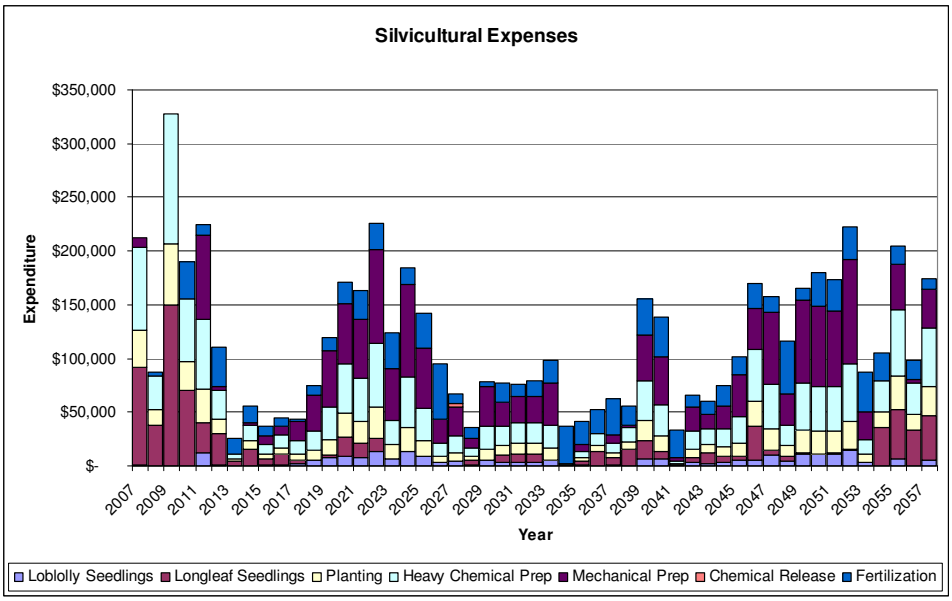

Figure 18. Manchester/Wee Tee silvicultural expenses (50 years).

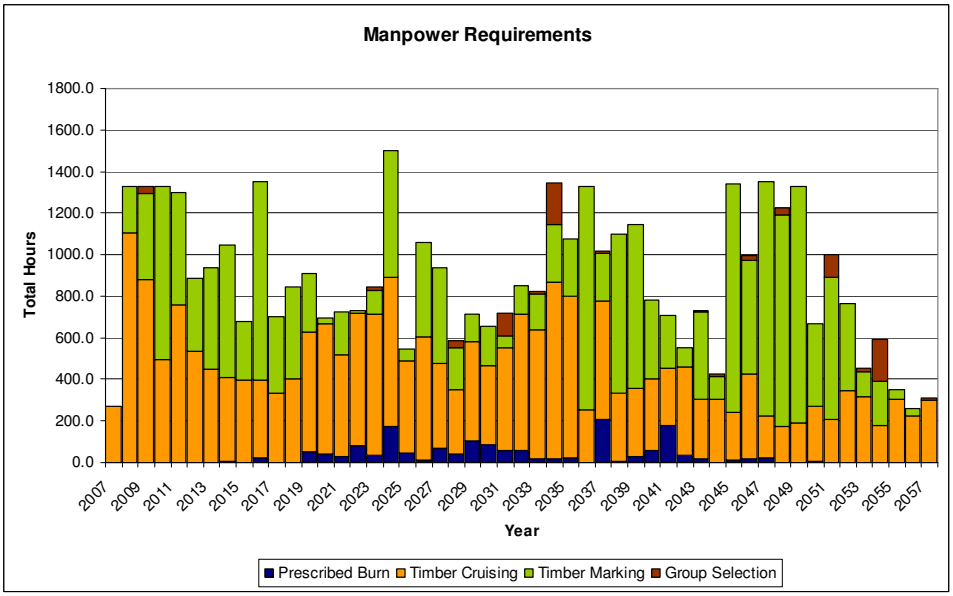

Figure 19. Manchester/Wee Tee manpower requirements (50 years).

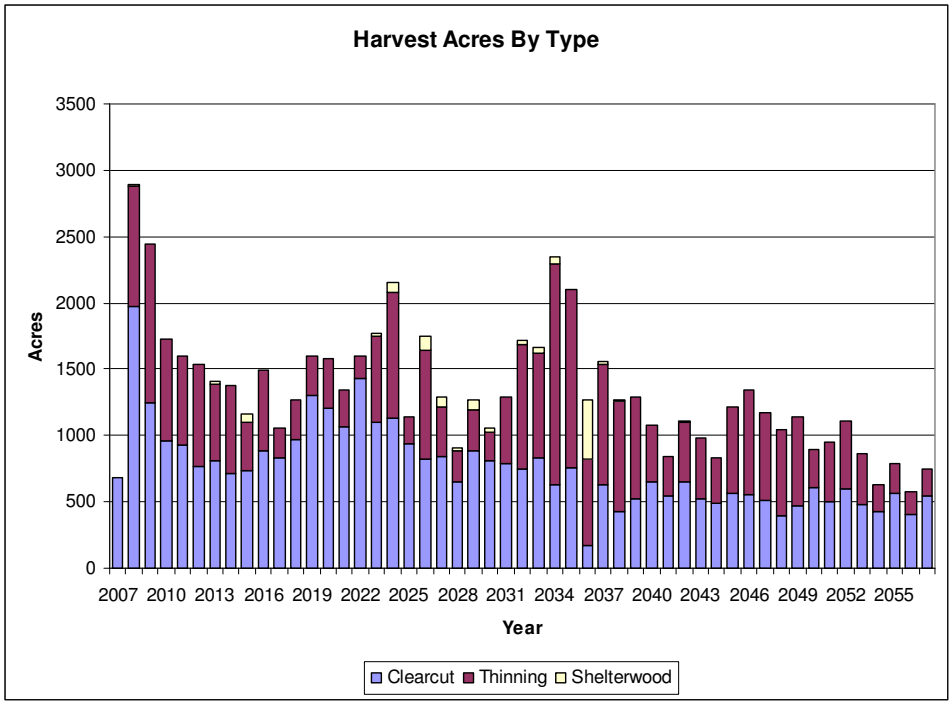

Figure 20. Manchester/Wee Tee harvest acres by type of harvest (50 years).

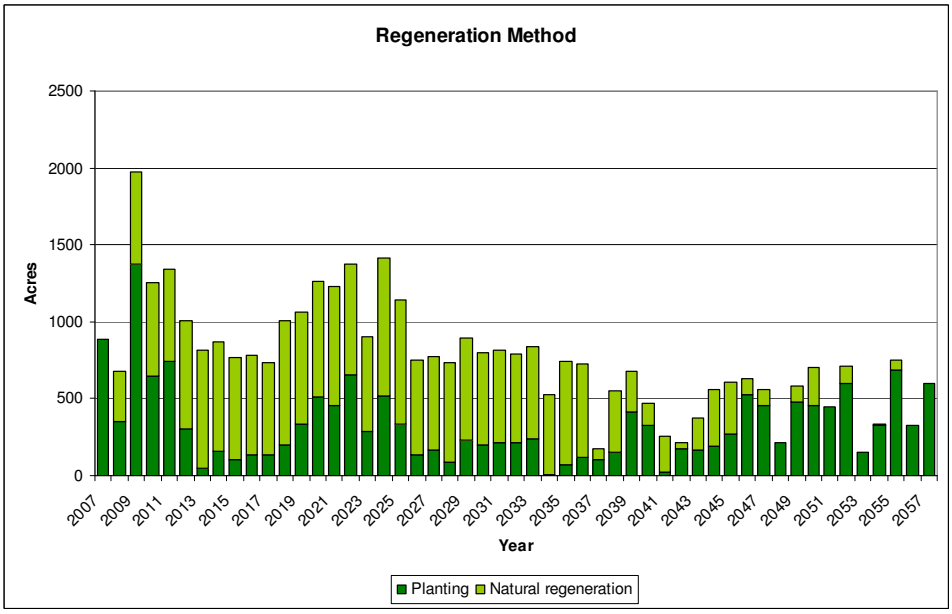

Figure 21. Regeneration methods employed over the first 50 years.

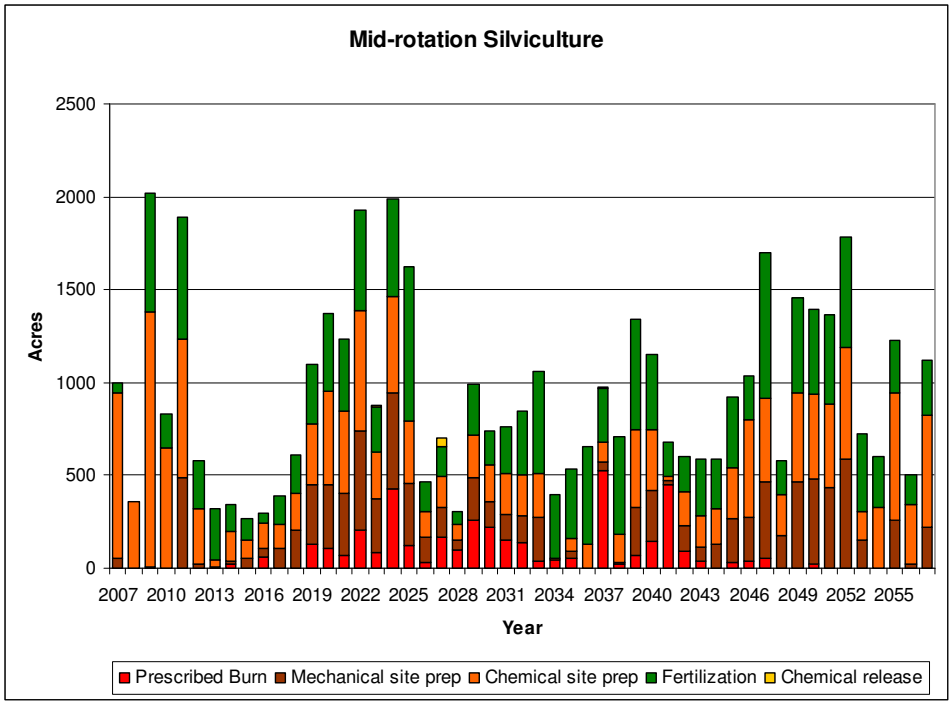

Figure 22. Mid-rotation silvicultural activities (50 years).

During the first 30 years of the planning horizon, harvesting of SBH on WTSF is a major component of the total harvest acres. Since these hardwoods are easily regenerated through root suckers, natural regeneration is the predominant method employed during this time periods. As the hardwood harvesting tapers off, final harvests in pine begin to require a shift toward artificial regeneration, requiring site preparation and planting (Figures 21 and 22).

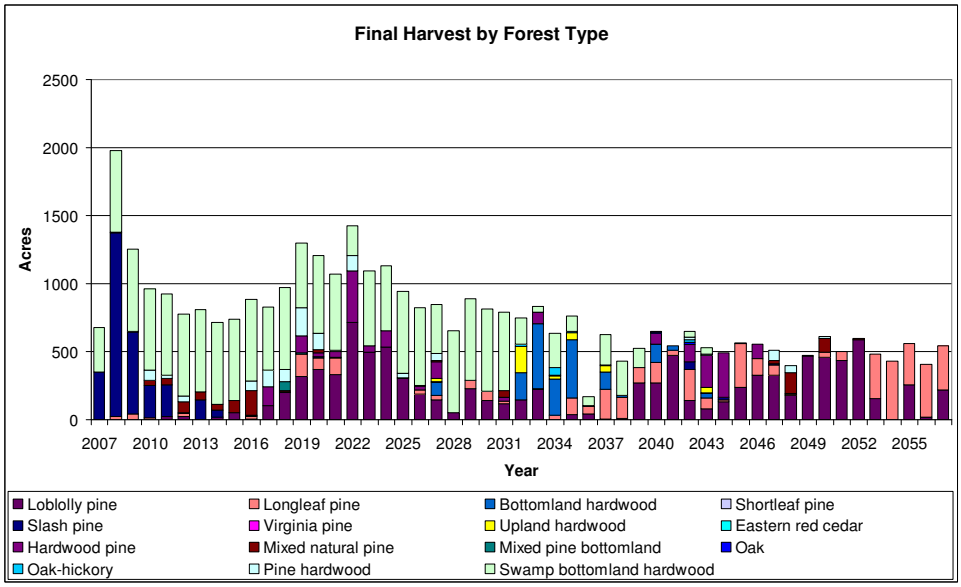

Figure 23. Manchester/Wee Tee final harvest by forest type (50 years).

As stated earlier, harvesting in WTSF is a major component of the total final harvest during the first 30 years. As a result, the predominant forest type harvested during the first 30 years is swamp bottomland hardwood (Figure 23), and a large proportion of this hardwood material is sawlog (Figure 24).

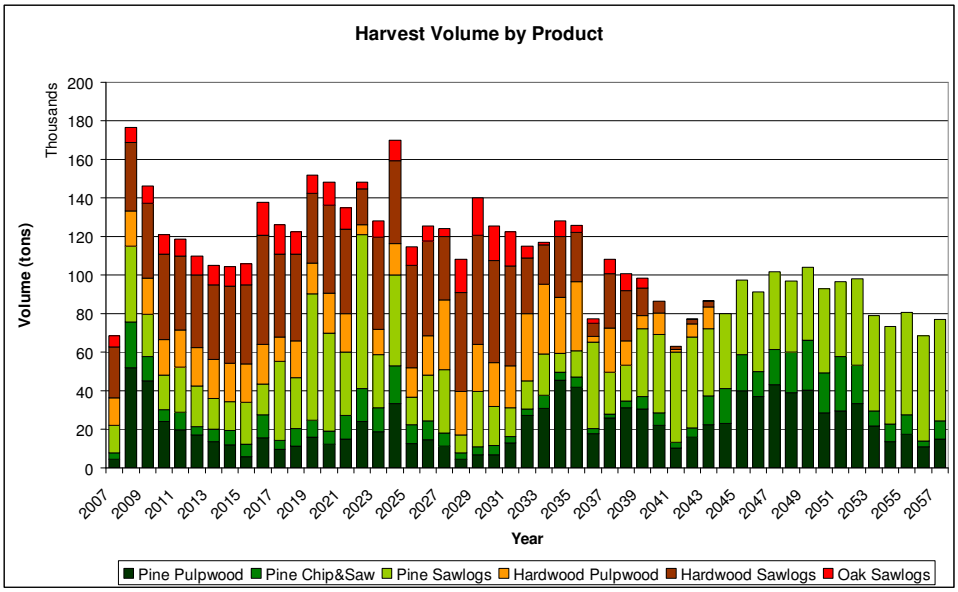

Figure 24. Manchester/Wee Tee harvest volume by product (50 years).

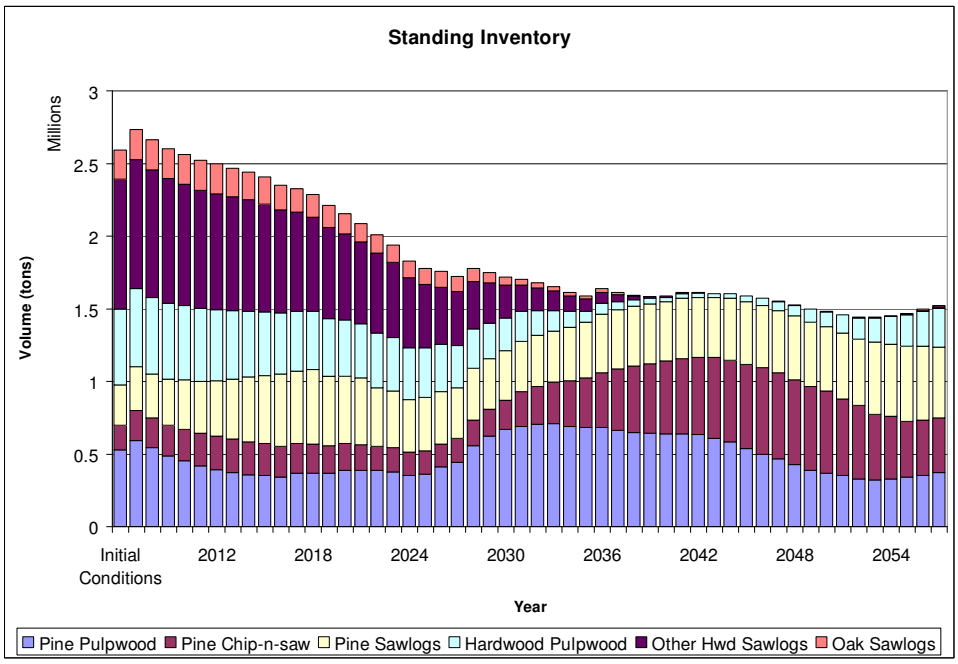

Figure 25. Manchester/Wee Tee changes in standing inventory (50 years).

Much of the decline in standing inventory over the first 30 years is due to the liquidation of the poorer-quality hardwoods on WTSF (Figure 25). Thereafter, total inventory stabilizes around 1.5 million tons, but most of that inventory is in pine. Pine pulpwood and chip-n-saw products both experience a surge in inventory but as time goes by, these products eventually shift into the next size-class, and eventually pine sawlogs become the largest component of the forest inventory after 50 years.

The MAWT model was constrained to maintain at least 50% of the area in each RCW partition in foraging habitat status. As Figure 26 clearly shows, there is a surplus of FH associated with clusters 1 & 2 in the early periods but within 10 years, all the partitions have essentially fallen to the floor level of FH and are maintained at no less than that level going forward. A brief spike in FH of 6 or 7 years occurs in 4 of the 5 partitions beginning in year 44, that likely corresponds to the harvests in the first few years, since FH status generally starts after a stand reaches age 30.

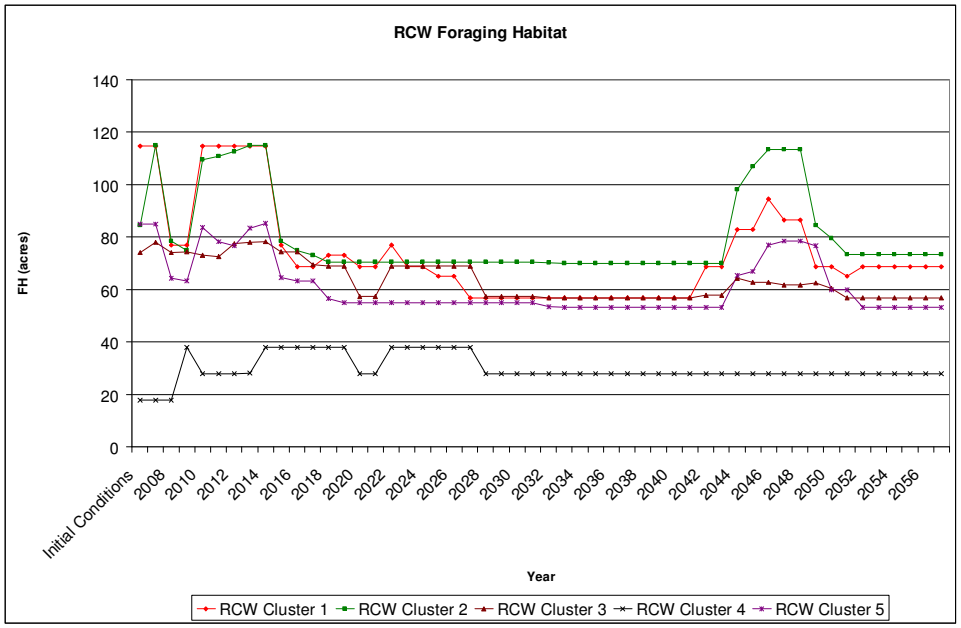

Figure 26. Manchester/Wee Tee changes in foraging habitat in each RCW partition (50 years).

4.1.2 Tactical (Stanley)

The next step in the modeling process is to allocate the forest management activities determined in the Woodstock model solution, and allocate them to forest polygons according to spatial-restriction rules as specified by SCFC. Softwood final harvests are limited to no more than 100 acres; hardwood clearcuts are limited to 150 acres. SCFC foresters specified the minimal harvest block size as 10 acres for softwood stands and 50 acres in hardwood stands. In all cases, a 3-year green-up interval is required before harvesting harvest blocks within a 300 foot proximal distance.

Since SCFC was interested in a 10-year tactical plan, the procedure used in Stanley was to allocate activities for the first 20 years[7]. To facilitate blocking and scheduling, Stanley was permitted to vary the final harvest timing by as much as one year (earlier or later) from that chosen in the Woodstock solution, subject to the operability criteria specified in the Woodstock model. For example, suppose a stand is scheduled for final harvest in period 7 at age 40. According to the rule, the Stanley algorithm can assign that stand to be harvested as late as age 41 (in period 8); it cannot harvest the stand earlier than period 7 because final harvests cannot occur younger than age 40, regardless of the timing choice deviations permitted.

The blocking and scheduling algorithm in Stanley was run until no further improvements were found for 60 minutes. Like most heuristics, Stanley tends to find better and better solutions as time passes, but the time between them gets longer as the incumbent solution approaches the global optimum. In an hour, Stanley can evaluate thousands of alternative solutions and so it seemed reasonable to stop if further improvements were not found at that point.

As shown in Figure 27, the Stanley solution (yellow bars) closely approximates the harvest and revenue levels of the strategic Woodstock model (green bars). There is no significant falldown in the achievement of revenue targets until period 12.

[7] Because of the small number of acres in the RCW partitions and the general lack of group selection activities scheduled during the tactical planning horizon, it was decided that these activities would be handled during plan implementation. The assumption in the hardwired tactical harvest schedule was that these activities were carried out exactly as originally planned.

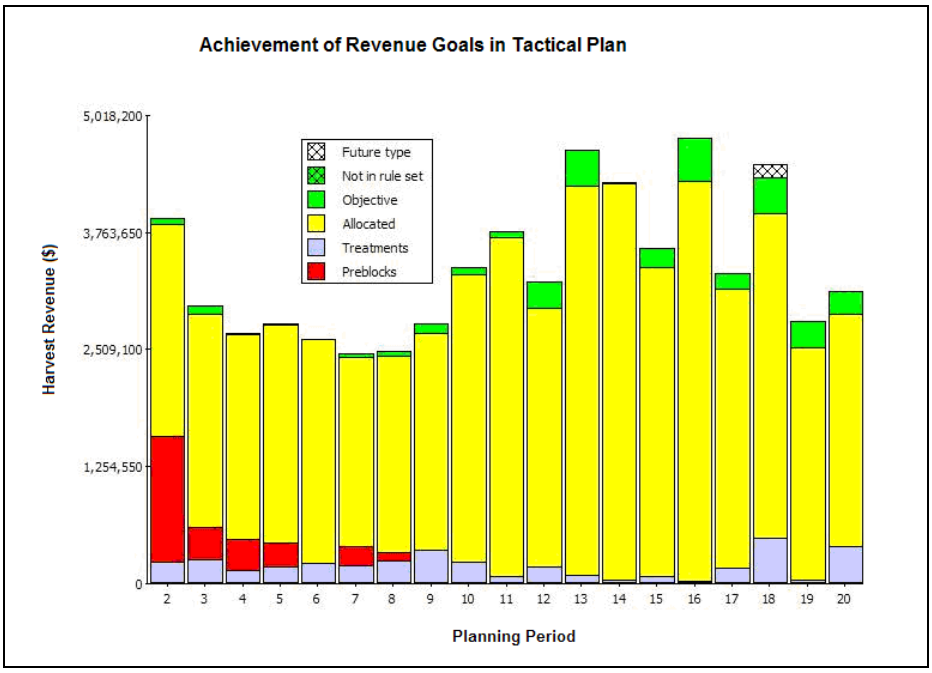

Figure 27. Achievement of strategic revenue targets in the MAWT spatially-feasible harvest schedule.

Once the blocks have been identified and scheduled, the resulting block harvest schedule for periods 2-11 is incorporated back into the Woodstock model as pre-planned activities to determine the impact of spatial restrictions on long-term management. While no changes to final harvests are permitted in the periods corresponding to the tactical planning horizon (years 2-11), the resulting solution may assign other regimes or timing choices to stands not allocated in the Stanley run. The rationale for this step is to see if the tactical plan imposes limitations on long-term management goals. A significant change in harvest revenues predicted in the future, or severe violations of the manpower constraints would indicate a problem with the spatial plan.

Ideally, there should be little difference in the results of this run, and the previous strategic harvest schedule. Indeed, other than the significant reduction in harvest volume and revenue in the first two periods, the strategic and tactical solutions are very similar. The discounted net revenue from the first 50 years of the strategic harvest schedule with the spatial harvest schedule hardwired into the solution was $58,039,398 (compared to $57,964,392 with the strategic harvest schedule). The reason this number is higher than the original strategic harvest schedule is that some of the original constraints were relaxed to achieve revenue goals and spatial feasibility. For example, hardwood clearcut acres were limited to no more than 600 acres per year in the original strategic harvest schedule but the tactical schedule included harvest areas as high as 793 acres in year 11. After year 11, the 600-acre constraint was imposed once more.

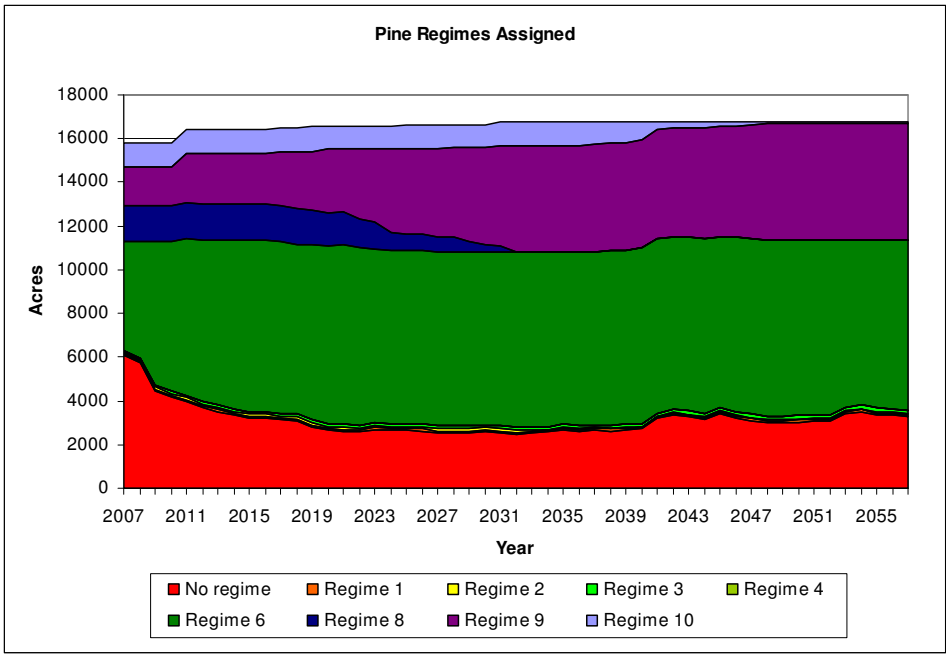

Figure 28. MAWT timber management regimes assigned during the first 50 years (20 years tactical).

Harvest revenues projected for the first 50 years are shown in Figure 29. The most significant change from the original strategic schedule is the harvest spike associated with 2018: in the original harvest schedule, just over $3 million in harvest revenue is predicted, but in the tactical harvest schedule, it is almost double that. When the tactical schedule from Stanley was hardwired into a Woodstock strategic schedule, only the harvests Stanley-generated harvest blocks were allowed to be harvested during periods 2-11. Thereafter, acres additional to the blocks from Stanley could be scheduled for harvest in any period. The harvest spike in year 2018 is largely due to the acres scheduled in the original strategic harvest schedule that could not be blocked by Stanley.

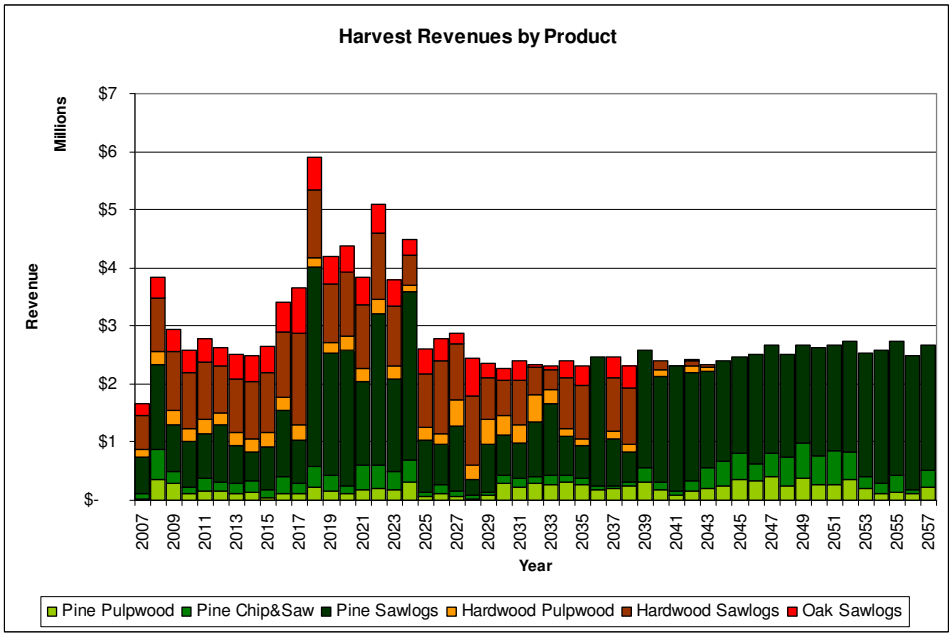

Figure 29. Manchester/Wee Tee timber harvest revenues (50 years, 20 years tactical).

Corresponding to the harvest spike in 2018 is a spike in timber marking in the previous year (Figure 30).

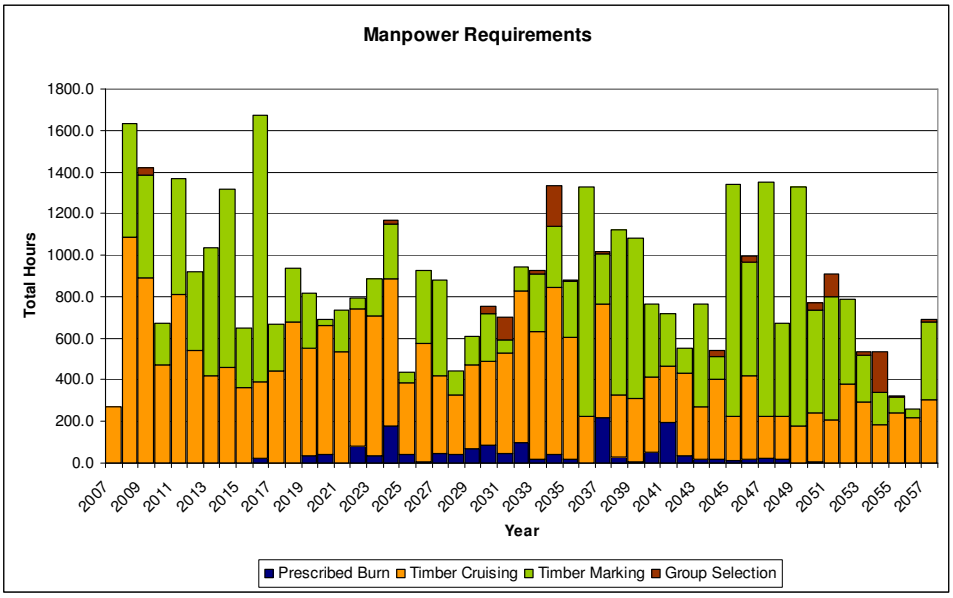

Figure 30. Manchester/Wee Tee manpower requirements (50 years, 20 years tactical).

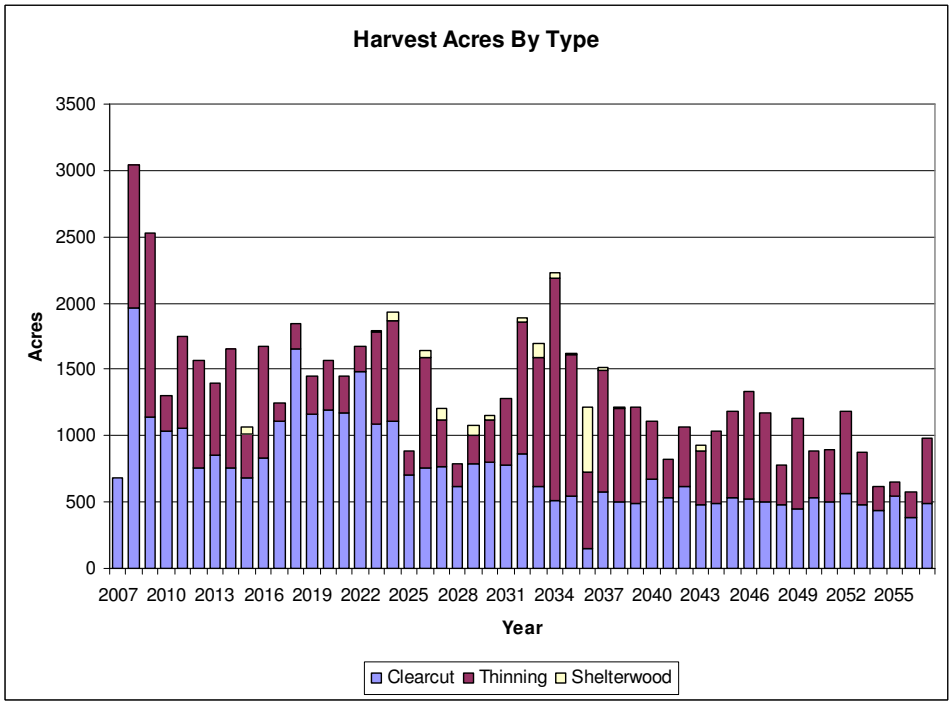

Figure 31. Manchester/Wee Tee harvest acres by type of harvest (50 years, 20 years tactical).

As stated earlier, only the Stanley-generated harvest blocks are eligible for harvest during periods 2-11 of the hardwired strategic harvest schedule. However, it appears that some of the falldown in harvest revenue due to spatial restrictions is made up by additional thinning volume when you compare acres of thinning in Figure 31 to Figure 20.

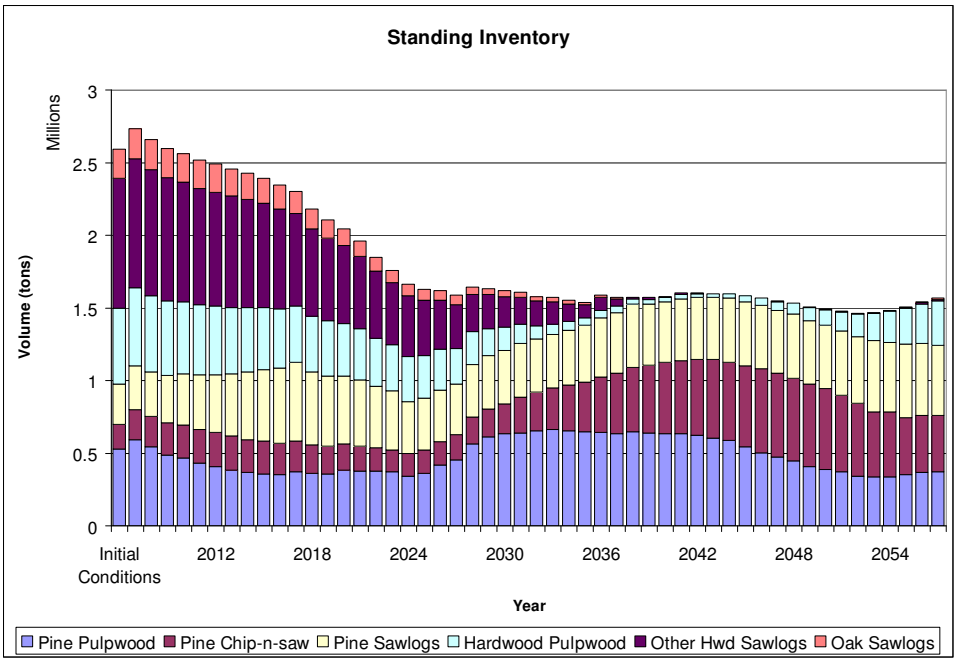

Figure 32. Manchester/Wee Tee changes in standing inventory (50 years, 20 years tactical).

The effect of the tactical blocking appears to have had little impact on standing inventory over time (Figure 32). While there appears to be a slightly steeper decline in total inventory over the 2018-2027 time period, the overall inventory profile is remarkably similar to that exhibited in the original strategic harvest schedule (Figure 25).

Since we did not use Stanley to block out group selection harvests in the RCW partitions on MAWT – we assumed that they would be implemented and carried out as scheduled – there are no significant differences in predicted foraging habitat between the original strategic harvest schedule and the hardwired tactical harvest schedule.

Figures 33 and 34 show the tactical harvest schedules generated by Stanley for MSF and WTSF, respectively. The period of harvest is color-coded according to the legend on the left side of each figure. Harvest blocks associated with harvest period 1 were developed by SCFC staff, and did not necessarily comply with the stated spatial restrictions used in the Stanley analysis; for example, notice the large harvest blocks in the northern-most part of WTSF (Figure 34). Overall, Stanley provided good solutions to both MSF and WTSF, and particularly so to the problem of systematically replacing the low-quality stands on WTSF. Observe that the harvest blocks are spatially and temporally distributed across the forest and they are of consistent size without an artificial, geometric pattern.

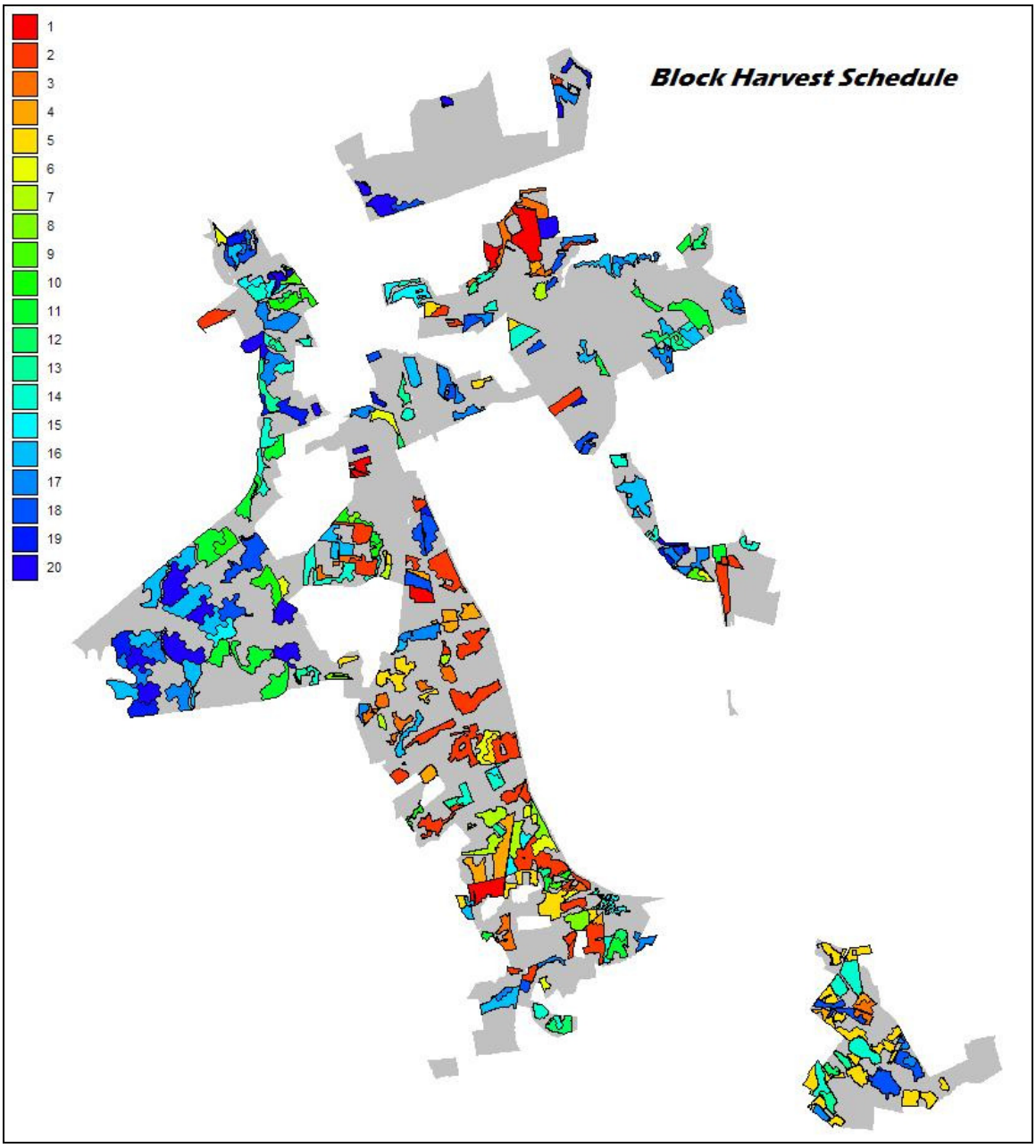

Figure 33. Block harvest schedule on Manchester State Forest (20 years).

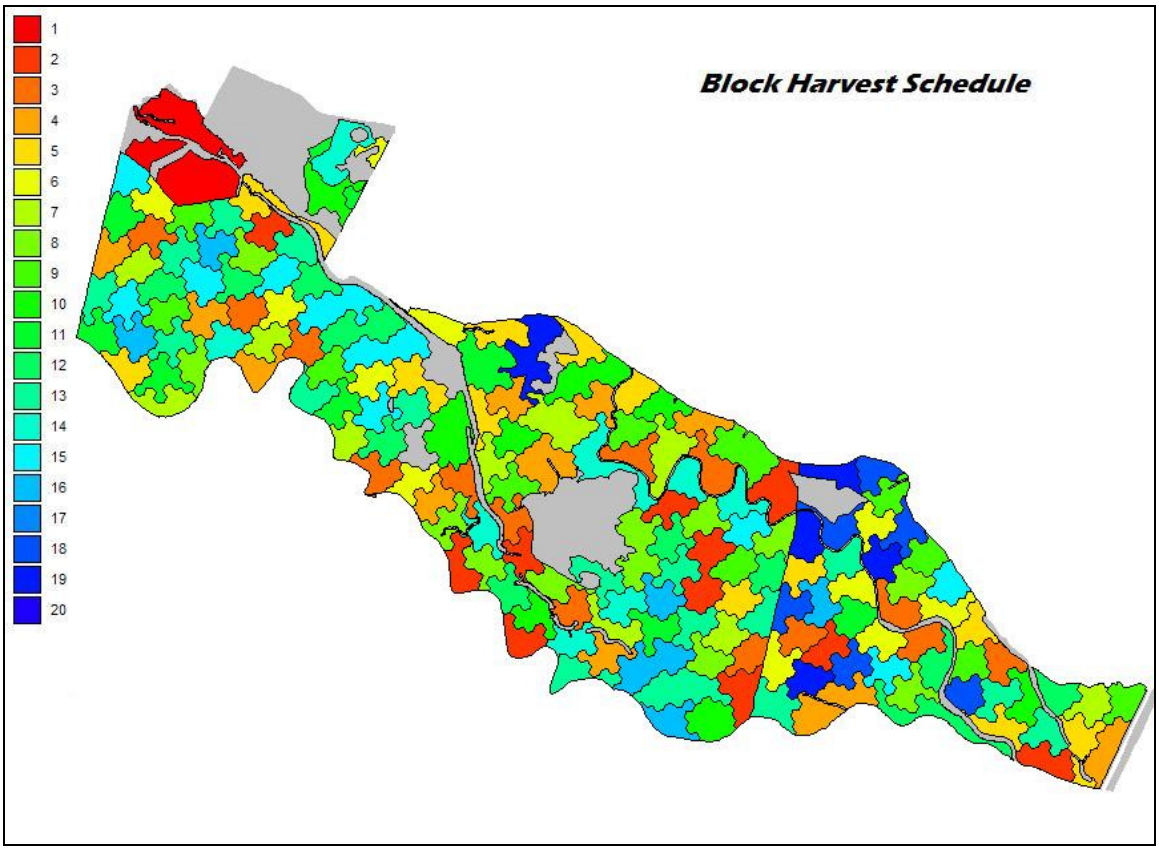

Figure 34.Block harvest schedule on Wee Tee State Forest (20 years).

4.2 Sand Hills

4.2.1 Strategic (Woodstock)

Because the inventory had been updated to the end of 2006, the first year of the planning horizon was (2007). Since the activities for 2007 had been previously planned and implemented by SCFC, it seemed reasonable to model a full 100-year planning horizon beginning in 2008. The Woodstock model used to develop the preferred alternative had a planning horizon of 176 years, 75 years longer than the planning horizon for MAWT. The rationale for the longer planning horizon was the longer rotations used in longleaf pine for RCW management: a planning horizon of 101 years would not have constituted a full rotation for the youngest stands on forest. Modeling two full rotations (240 years) produced a LP matrix that was too large to solve with available computer capacity, so the 175 year model horizon was agreed upon as a reasonable compromise, and approved by SCFC staff.

The preferred alternative Woodstock run yielded discounted net revenues of $51,778,892 over the planning horizon. As shown in Figure 35, to meet the requirements for increasing the number of acres of good quality foraging habitat, there is a gradual increase in the acres managed under group selection (Regime 3) and modified two-age regimes (Regime 1). Note that the no-regime component (Regime 0) includes both hardwood stands and pine stands too old to be effectively managed under regimes 1 or 3.

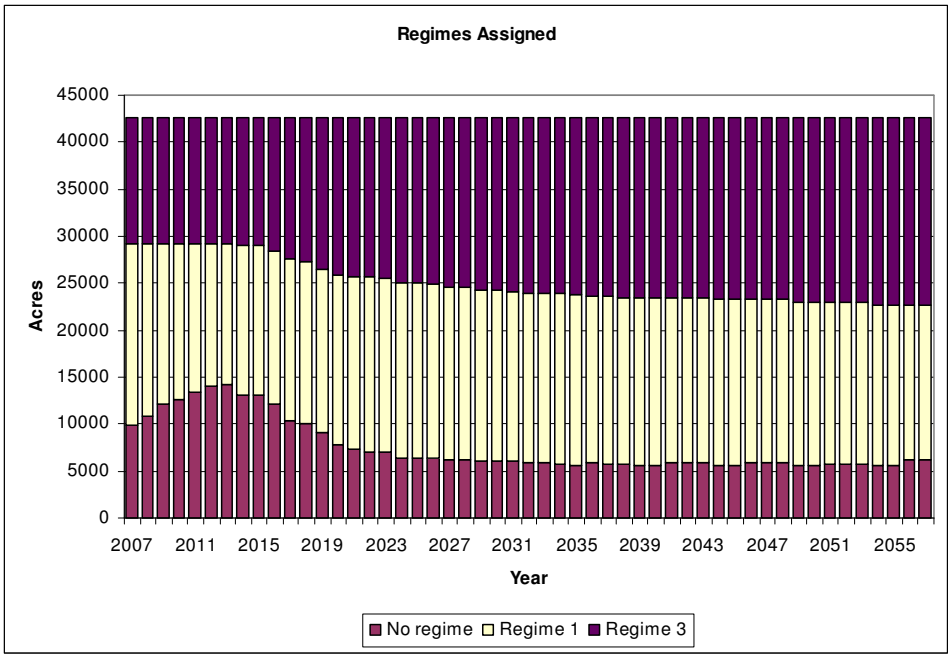

Figure 35. Sand Hills timber management regimes assigned during (50 years).

Harvest revenues projected for the first 50 years are shown in Figure 36; other revenues for the same period are shown in Figure 37. The smooth shape to the harvest revenues are due to the sequential flow constraints (±10% per period). Note how pine straw revenues increase dramatically over the first 20-30 years.

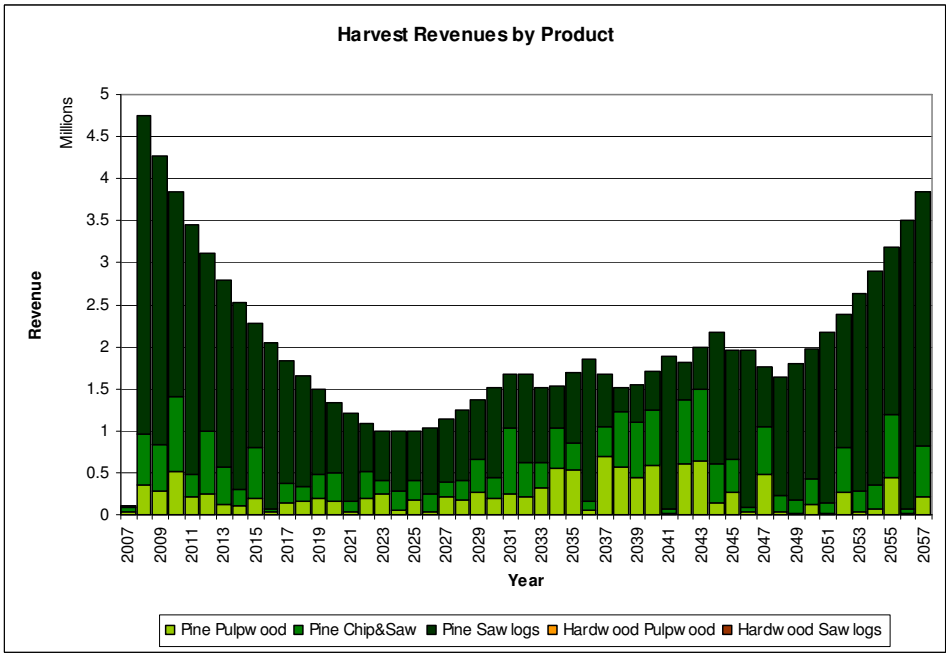

Figure 36. Sand Hills timber harvest revenues (50 years).

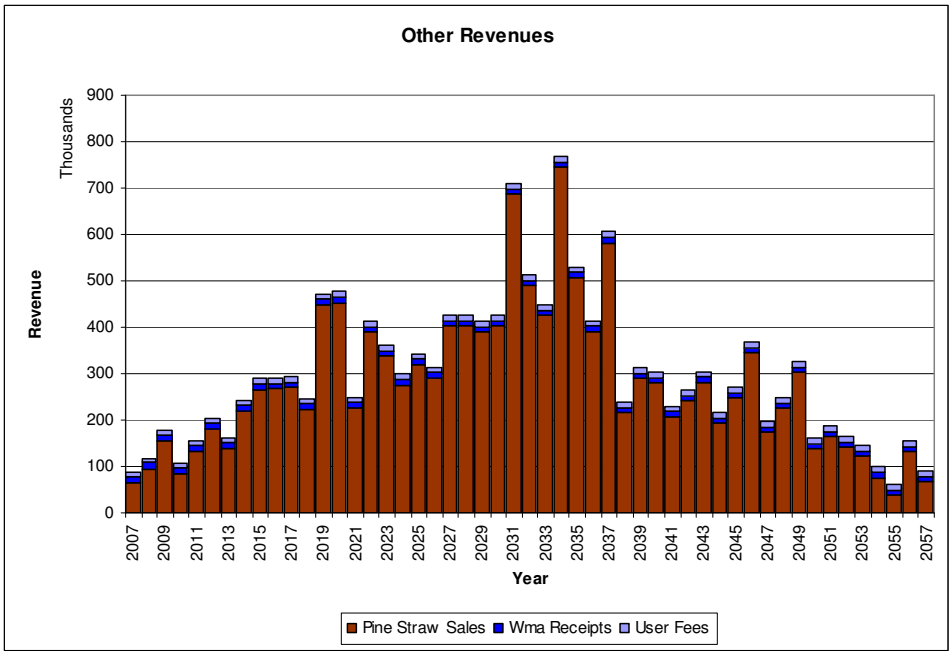

Figure 37. Sand Hills other revenues (50 years).

Due to the relatively heavy harvesting of the pine stands, regeneration costs associated with longleaf pine (seedlings, heavy chemical site preparation) were the major cost components in the early part of the planning horizon (Figure 38). As shown in Figure 35, group selection is the predominant regime for the RCW partitions, and so manpower hours devoted to timber marking were significant (Figure 39).

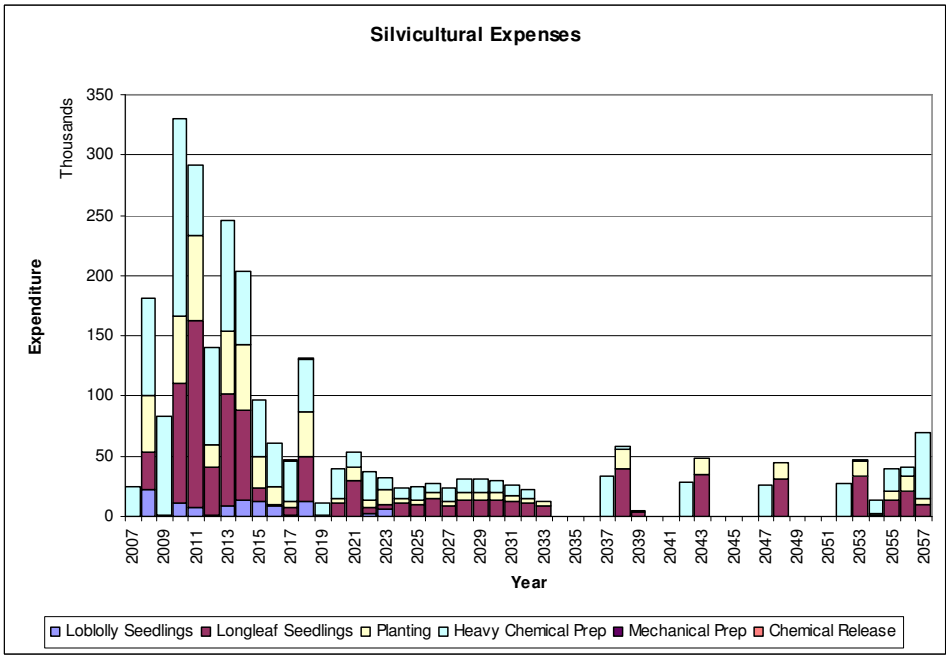

Figure 38. Sand Hills silvicultural expenses (50 years).

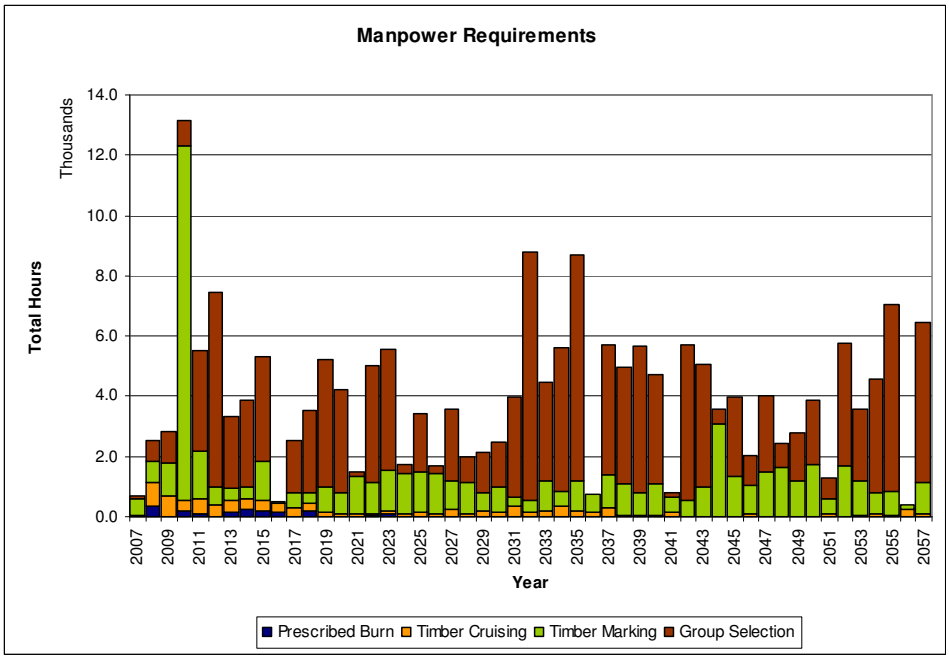

Figure 39. Sand Hills manpower requirements (50 years).

The initial 10 years of the planning horizon are dominated by final harvests rather than thinning activities, but within 15 years, the majority of the harvests occurring on SHSF are commercial thinnings (Figure 40).

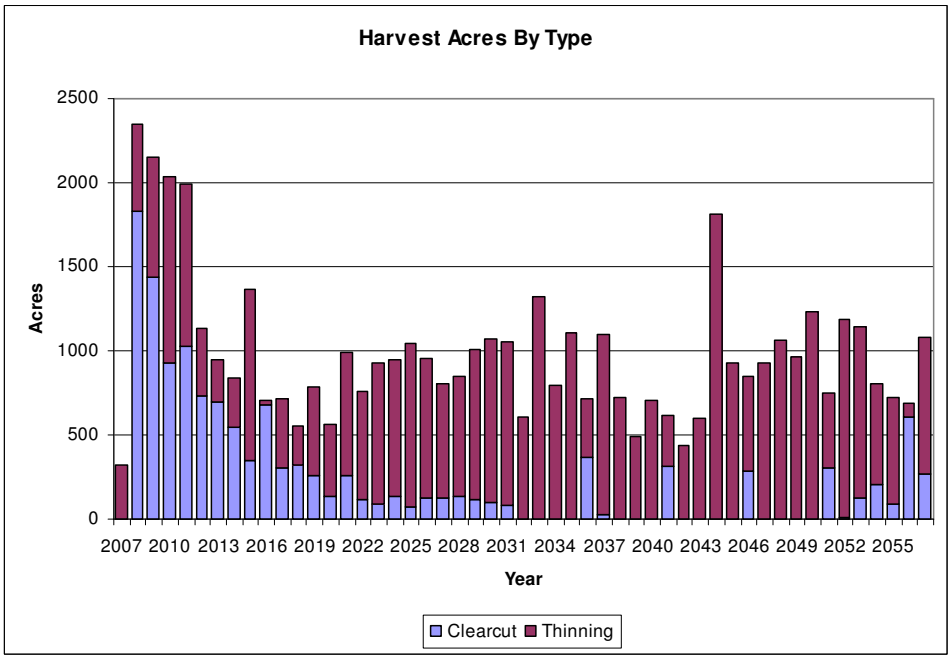

Figure 40. Sand Hills harvest acres by type of harvest (50 years).

Due to the need to increase and maintain GQFH within each of the RCW partitions, forest types such as mixed pine bottomland are targeted for immediate harvest. The rationale for this strategy is to harvest the underperforming stands (from a habitat perspective) and replace them with longleaf pine stands that will produce GQFH later. Since mixed pine bottomlands were modeled using NATLOB, we were unable to modify the program code to produce habitat scores, and therefore these entire stand types were considered to have no foraging habitat potential and so were targets for early harvest (Figure 41). Longer term, SCFC

intends to re-classify many of these mixed stands of pine and hardwood to determine those that are truly pine types (capable of sustaining RCW) and those that are predominantly bottomland hardwood (incapable of sustaining RCW).

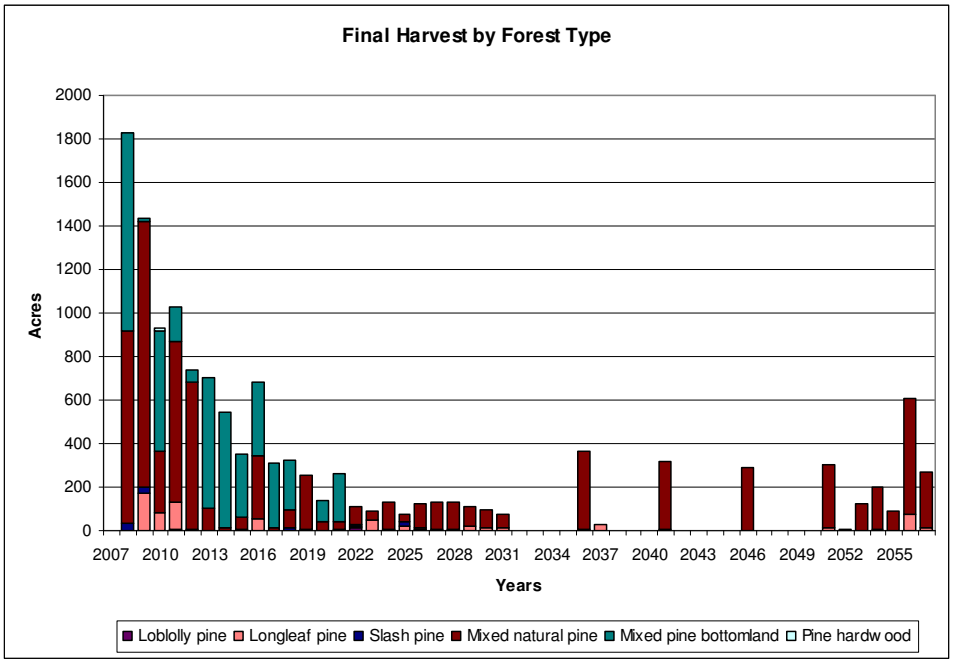

Figure 41. Sand Hills final harvest by forest type (50 years).

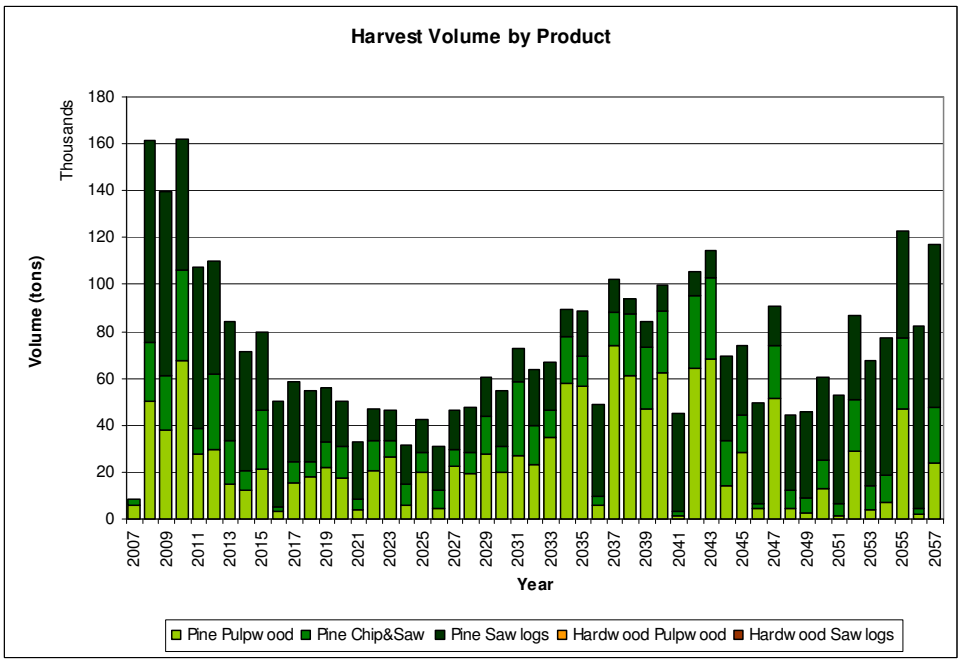

Figure 42. Sand Hills harvest volume by product (50 years).

Due to the older age classes in the forest, the majority of the harvest volume in the early planning periods is composed of pine sawlog material (Figure 42). Hardwoods make up a small proportion of the forest area overall and the contribution of hardwoods to the total harvest is negligible.

Despite some heavy harvests in the first few years, the total standing inventory on SHSF remains fairly constant over the first 15 years. Thereafter, there is a sustained increase in inventory to about 2030 where harvest levels generally increase and total inventory stabilizes around 3.0 – 3.5 million tons (Figure 43). Given the stand characteristics of GQFH (older, larger trees; low trees/acre), the significant increase in the proportion of pine sawlog material (and commensurate decrease in pulpwood) is not surprising.

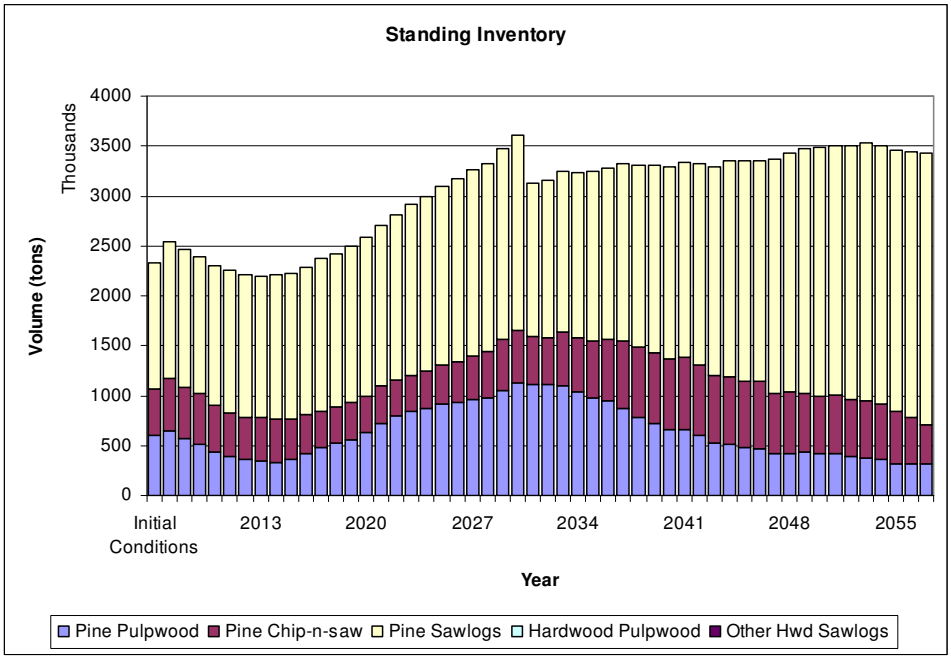

Figure 43. Sand Hills changes in standing inventory (50 years).

As stated earlier, the partition area within ¼ mile of the cluster centers, and the partition area beyond ¼ mile of the cluster centers were individually constrained using goal programming to maintain 50% GQFH over the planning horizon. Figure 44 shows the aggregate effect of these constraints over time. Notice the initial low preponderance of GQFH across the forest despite average habitat scores that change very little over 25 years.

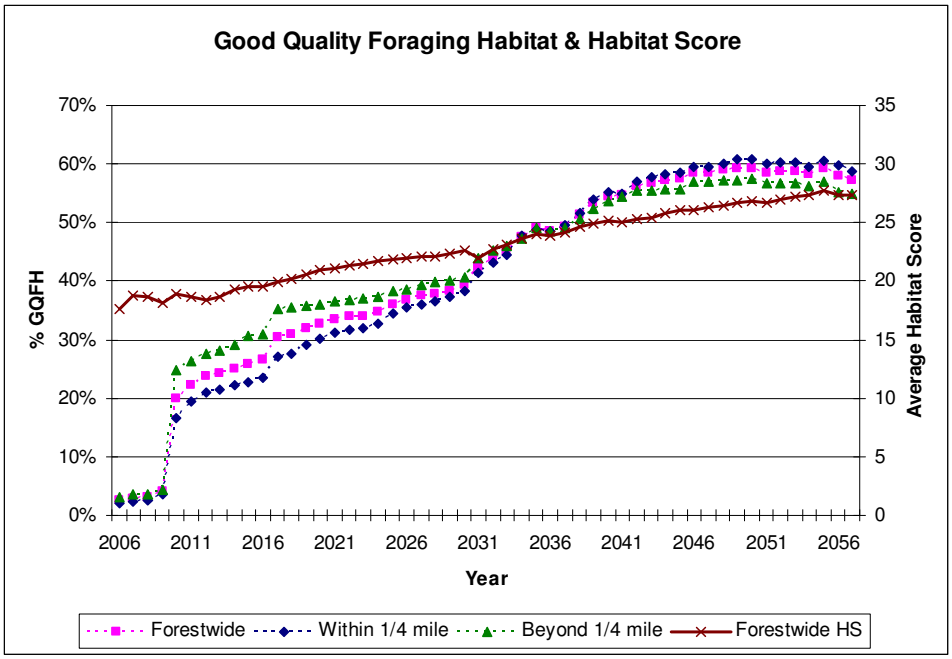

Figure 44. Sand Hills GQFH proportion & average habitat score (HS) (50 years).

Within 5 years, the proportion of GQFH has increased from less than 5% to over 20%; by 2018, it has increased to 30%. Part of the explanation lies in the habitat scoring metric: for example, stands may have all the characteristics of GQFH except age but because it is a pass-fail system it is possible to have large changes in acres that qualify with small changes in score. According to Figure 44, an overall score of 25 or higher would be necessary to maintain 50% GQFH forest-wide, but even then there are significant variations in GQFH within and among partitions.

4.2.2 Tactical (Stanley)

The next step in the modeling process is to allocate the forest management activities determined in the Woodstock model solution, and allocate them to forest polygons according to spatial-restriction rules as specified in the Recovery Guidelines. For example, final harvests under the modified two-age regime (regime 1) may not exceed 40 acres in size and they may not occur within 3 years of another, proximal final harvest area. SCFC foresters specified a minimum feasible harvest block size of 5 acres for implementation. Patch harvests in group selection may not exceed 2 acres, but there is no specific green-up interval or proximity distance given; patches should be dispersed throughout the stand to approximate an all-aged condition once the stand has been completely harvested.

Since SCFC was interested in a 10-year tactical plan, the procedure used in Stanley was to allocate activities for periods 2-16, to ensure that any activities occurring in periods 2-11 were fully subjected to the spatial constraints (period 1 being preblocked activities by SCFC staff). If only the periods 2-11 were allocated, activities scheduled for period 11 would be subject to green-up delays from 3 periods pre-treatment but no post-treatment periods. Also, since group selection final harvests generally did not begin until well past period 16, we did not include them in the Stanley blocking process; the group selections from period 13 forward were manually allocated.

To facilitate blocking and scheduling, Stanley was permitted to vary the final harvest timing by as much as five years (earlier or later) than that chosen in the Woodstock solution, subject to the operability criteria specified in the Woodstock model. For example, suppose a stand is scheduled for final harvest in period 7 at age 101. According to the rule, the Stanley algorithm can assign that stand to be harvested as early as age 100 (in period 6) or as late as age 106 (in period 12); it cannot occur earlier than period 6 because final harvests cannot occur younger than age 100, regardless of the timing choice deviations permitted.

The blocking and scheduling algorithm in Stanley was run until no further improvements were found for 60 minutes. Like most heuristics, Stanley tends to find better and better solutions as time passes, but the time between them gets longer as the incumbent solution approaches the global optimum. In an hour, Stanley can evaluate thousands of alternative solutions and so it seemed reasonable to stop if no further improvements were found at that point.

The initial set of Stanley runs used a proximity distance of 300 feet, consistent with MAWT. This means that any harvest block boundary within 300 feet of a proposed harvest block must have been harvested at least 3 years earlier or later than the proposed block to avoid a spatial violation. SCFC staff pointed out that the RCW Recovery Guidelines require that patches of GQFH be separated by no more than 200 feet, and so 300 feet proximity may represent an overly cautious approach to maintaining RCW habitat. Therefore a second set of Stanley runs was completed using a proximity distance of 200 feet. As shown in Figure 45, the Stanley solutions (yellow bars) closely approximate the harvest and revenue levels of the strategic Woodstock model (green bars) in both cases. There is a significant falldown in the first two periods due to spatial restrictions, but the resulting revenue still exceeds the minimum threshold significantly. However, the Stanley solution using a proximity distance of 200 feet outperformed the runs that used a proximity distance of 300 feet. In Figure 45, observe that the 300 foot runs yielded higher revenues in periods 2-5, but were generally lower the latter part of the tactical planning horizon. As a result, the 200 foot proximity distance runs were deemed the preferred alternative.

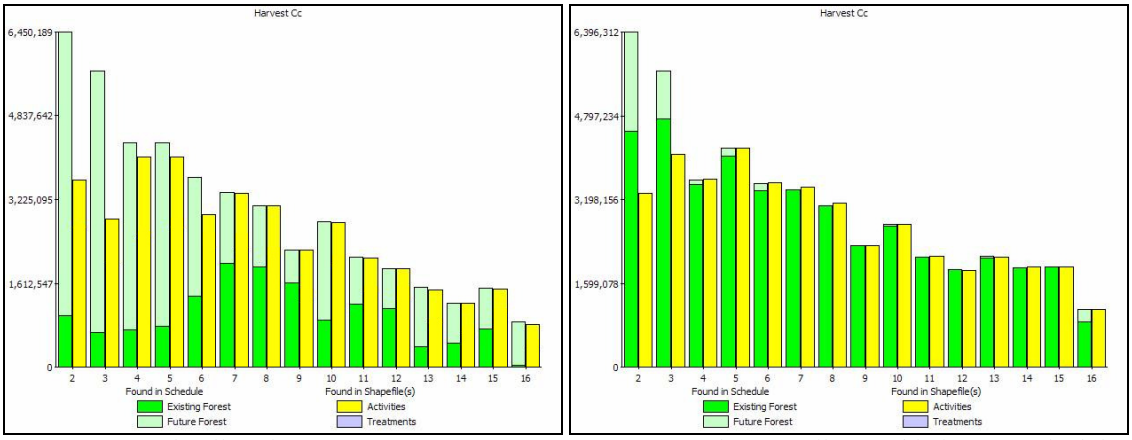

Figure 45. Sand Hills achievement of strategic revenue targets in the spatially-feasible harvest schedules. Results are for 300 ft proximity (left) and 200 ft proximity (right).

Once the blocks have been identified and scheduled, the resulting block harvest schedule is incorporated back into the Woodstock model as pre-planned activities to determine the impact of spatial restrictions on the long-term management of the forest. While no changes to final harvests are permitted in the periods corresponding to the tactical planning horizon (years 2-11), the resulting solution may assign other regimes or timing choices to stands not allocated in the Stanley run. The rationale for this step is to see if the tactical plan imposes any limitations on the long-term forest management goals. A significant change in GQFH predicted in the future, or severe violations of the revenue or manpower constraints would indicate a problem with the spatial plan.

Other than the significant reduction in harvest volume and revenue in the first two periods, the strategic and tactical solutions are very similar in both cases. More acres are assigned to group selection (Regime 3) instead of the modified two-age (Regime 1) because the Regime 1 final harvests originally scheduled could not be implemented due to spatial restrictions. Regime 3 appears to provide a means to recoup some of the lost harvest volume through additional thinning and group selection harvests later on. However, since this is based on strategic (non-spatial) rather than tactical evidence, these recouped harvest volumes may not be realizable.

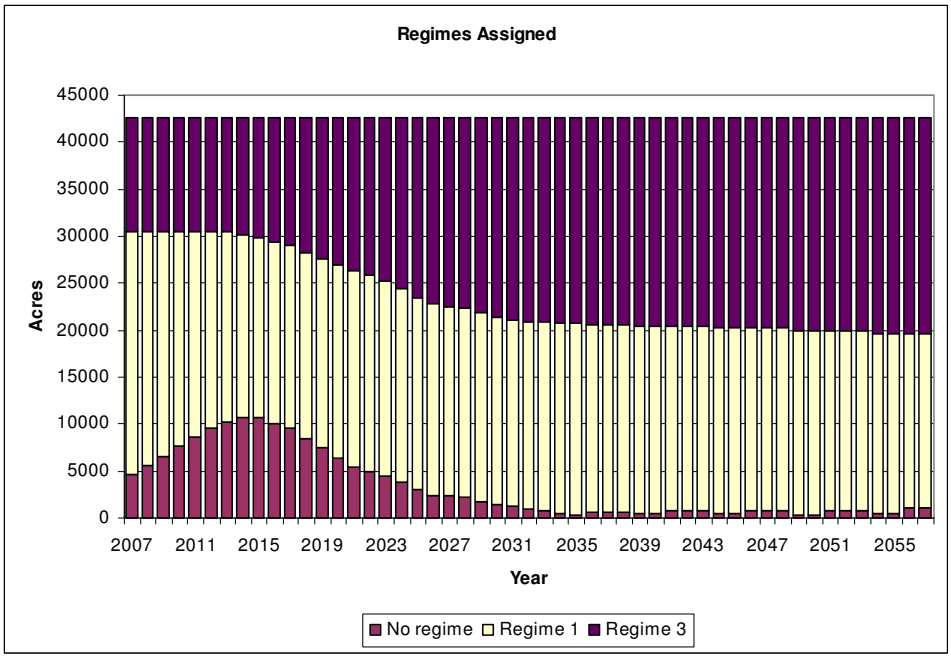

Figure 46. Sand Hills timber management regimes assigned during (50 years, 16 years tactical).

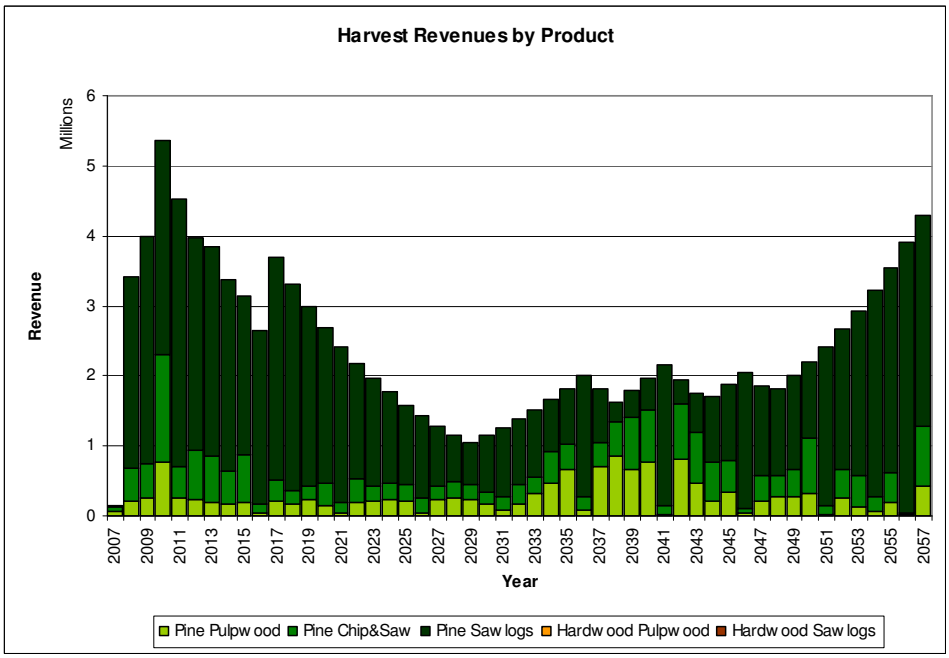

Figure 47. Sand Hills timber harvest revenues (50 years, 16 years tactical).

The harvest revenues graph in Figure 47 appears to contradict Figure 45, because the revenues in period 4 are much higher than what was predicted by Stanley in the 200 foot proximity run. However, when the hardwired tactical harvest schedule was run through Woodstock, only the final harvests were limited to the blocks chosen by Stanley; other thinning options could be selected that differed from the original strategic harvest schedule. Indeed, much more thinning is scheduled in period 4 than in periods 3 or 5 (Figure 49), and likely contributes to the significant increase in pine pulpwood and chip-n-saw product produced in that period (Figure 50).

With the shift to more acres managed under group selection, there is a greater demand for man-hours devoted to timber marking in 2010 (Figure 48). While this technically violates the manpower constraints

specified by SCFC, it is not sustained for many years and can probably be accommodated with little difficulty.

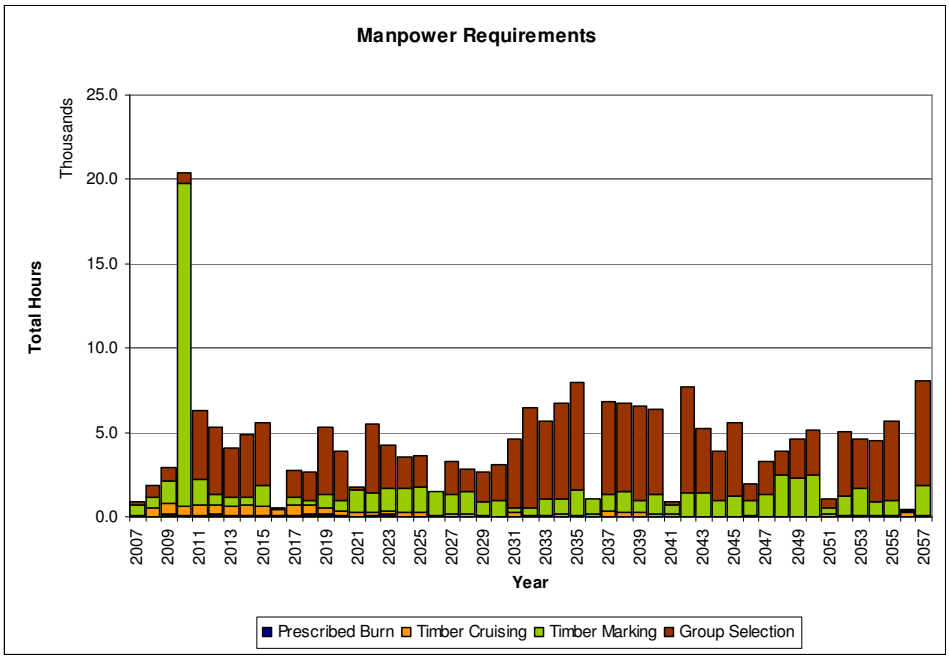

Figure 48. Sand Hills manpower requirements (50 years, 16 years tactical).

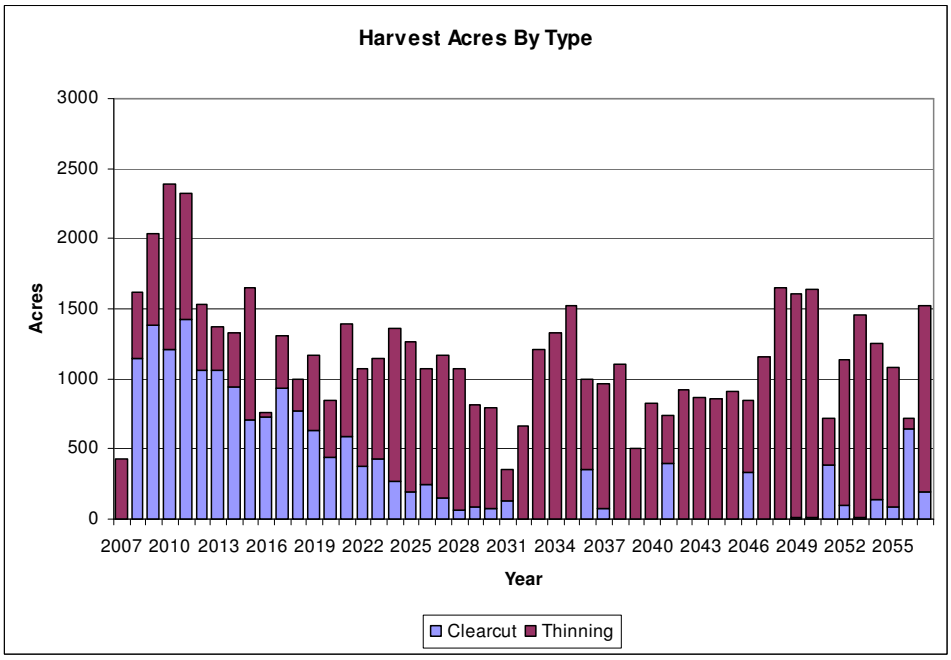

Figure 49. Sand Hills harvest acres by type (50 years, 16 years tactical).

A significant portion of the harvest in early years is due to final harvests of the existing stands (Figure 49). While part of the reason is simply to maximize discounted revenues, another important consideration is the age-class distribution. Over time, the forest needs to maintain roughly half the acres in age classes older than 60 to maintain GQFH in the RCW partitions. While the majority of the forest is older than that now, it is all largely one age class cohort that if held indefinitely would begin to senesce with a precipitous fall in

good quality foraging habitat. Some harvesting is required now just to ensure that age classes will be available to replace stands that are beginning to fall apart in the future.

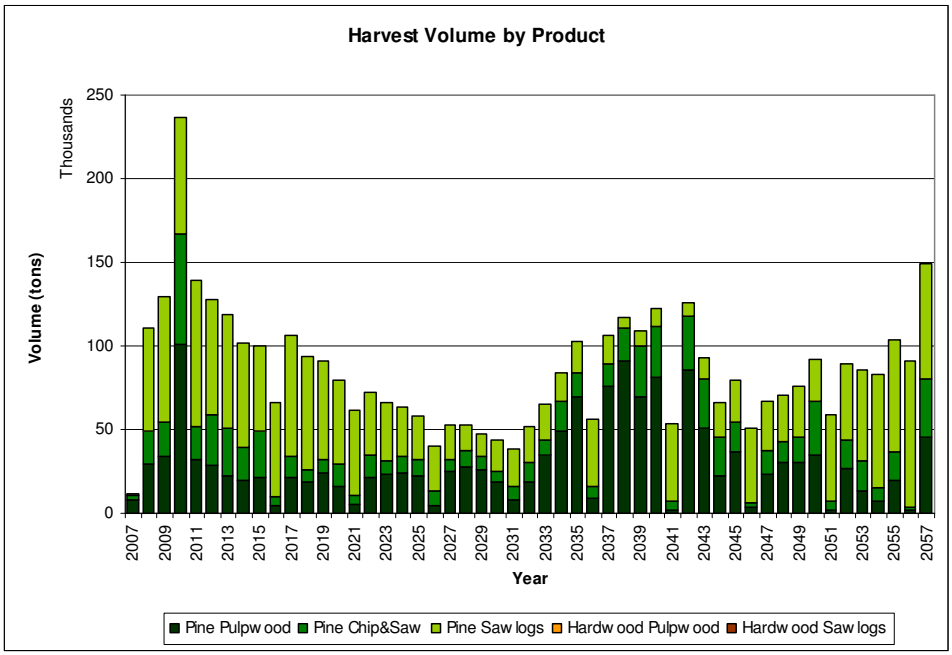

Figure 50. Sand Hills harvest volume by product (50 years, 16 years tactical).

The spatial harvest schedule captures less of the harvest volume in the first few periods than does the original strategic harvest schedule. As a result, the inventory accumulation is a bit less at first, but there is a greater accumulation of inventory as time goes by relative to the original strategic harvest schedule (compare to Figure 43).

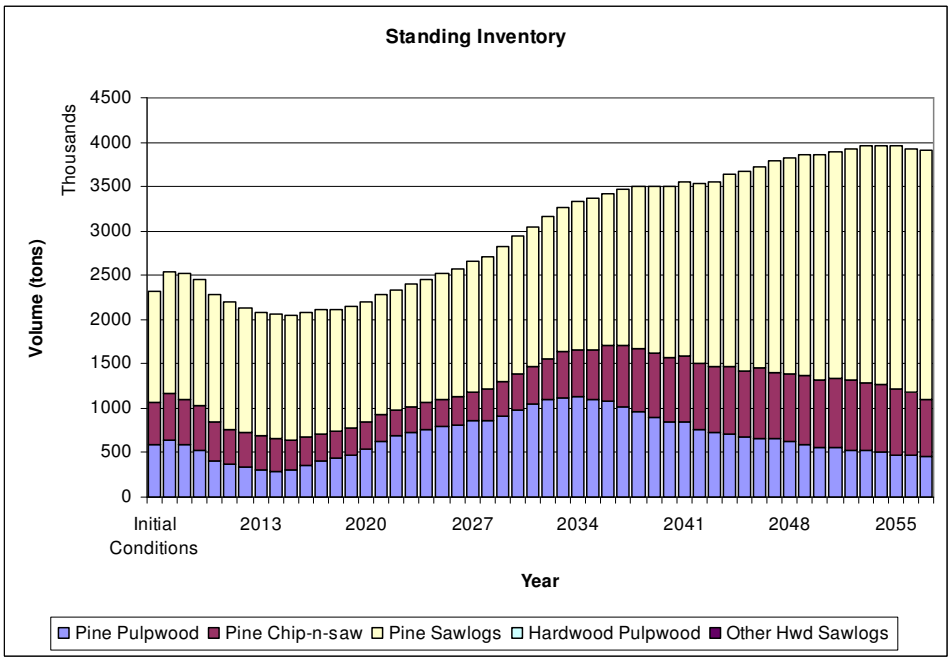

Figure 51. Sand Hills changes in standing inventory (50 years, 16 years tactical).

The spatial harvest schedule yields a slower trend toward 50% GQFH than was exhibited in the strategic harvest schedule. However, this non-spatial strategic plan represents an idealized situation ignoring where actual harvest blocks need to be located on the landscape. When spatial restrictions are imposed, many of the original scheduled activities are infeasible. An important observation from Figure 52 is the ongoing, steady improvement in the acres of good quality foraging habitat in a spatially feasible context.

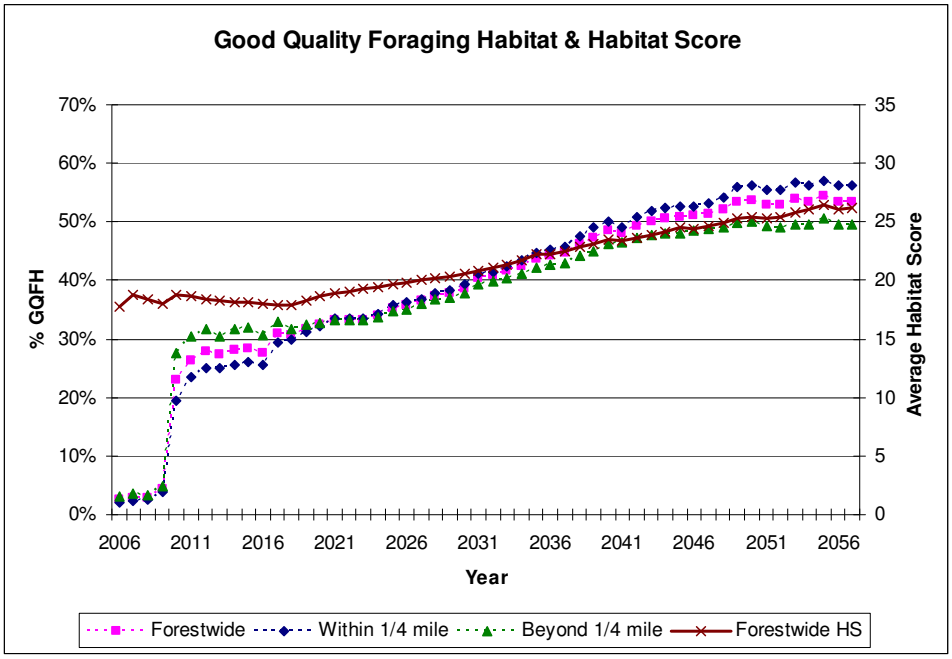

Figure 52. Sand Hills changes in good quality foraging habitat (50 years, 16 years tactical).

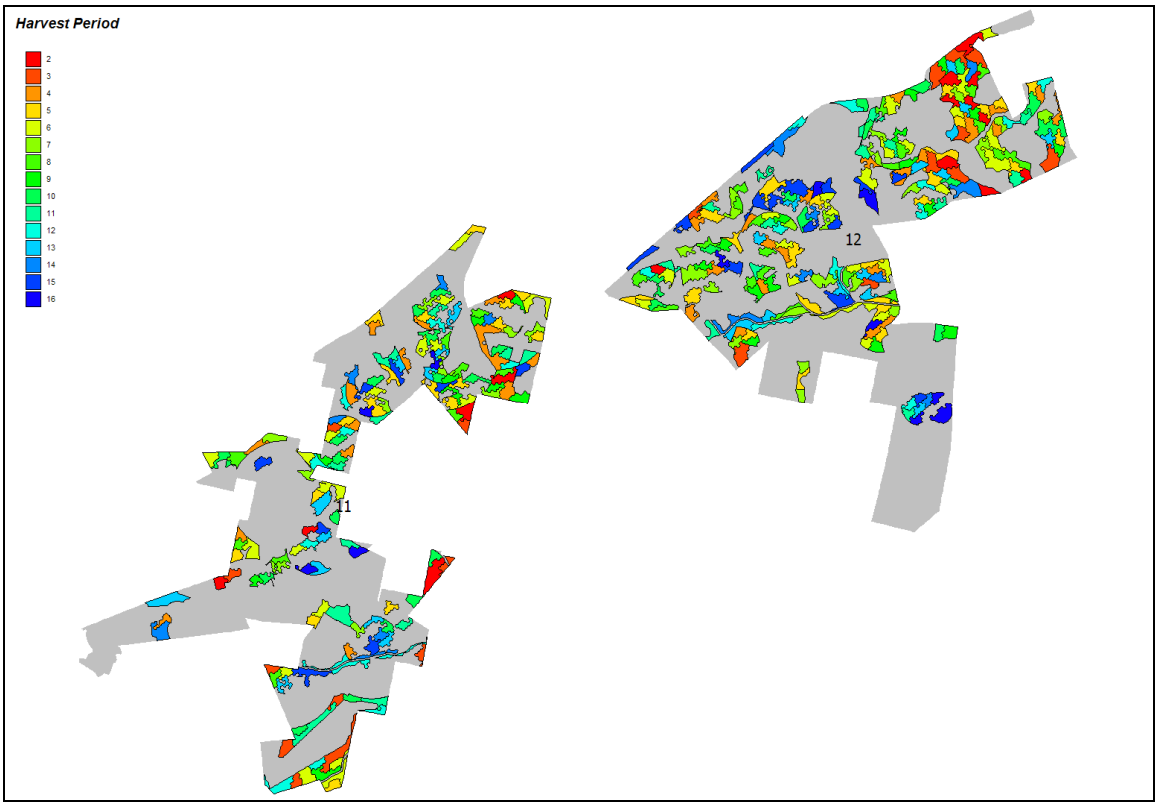

Figure 53. Spatial distribution of final harvests in Tracts 11 & 12 of SHSF (years 2-16).

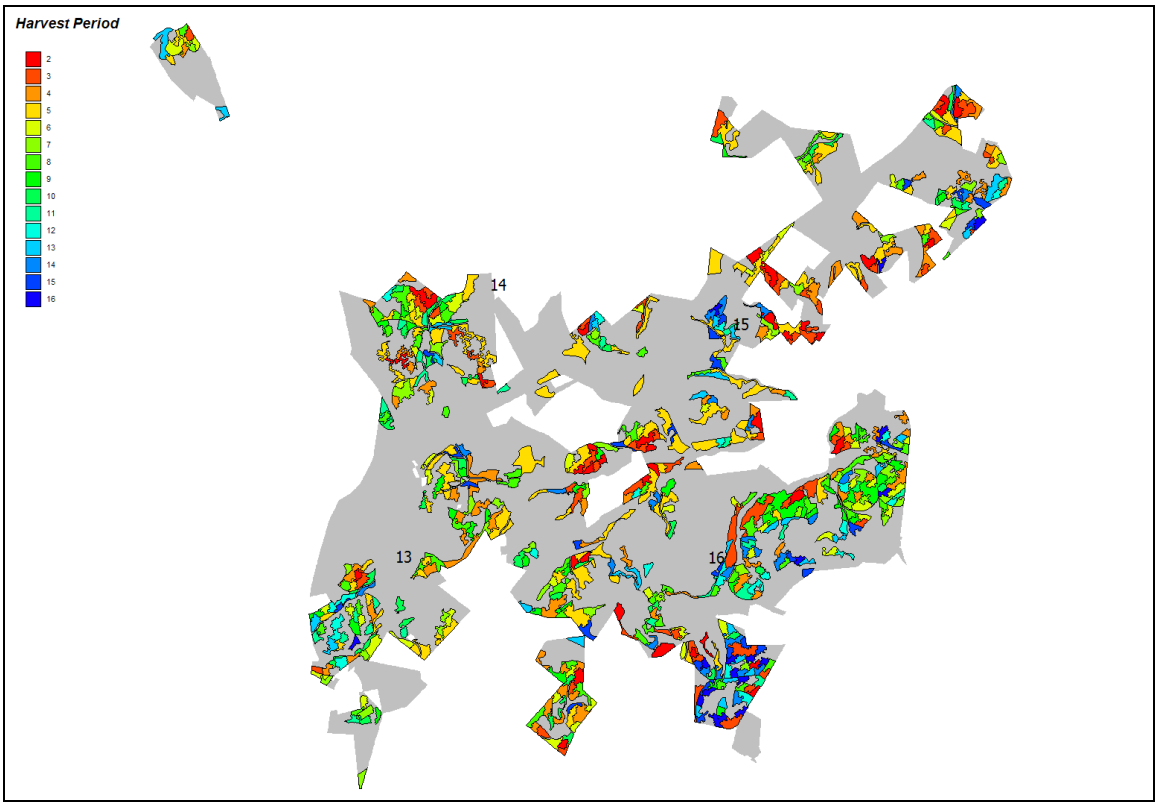

Figure 54. Spatial distribution of final harvests in Tracts 13 – 16 of SHSF (years 2-16).

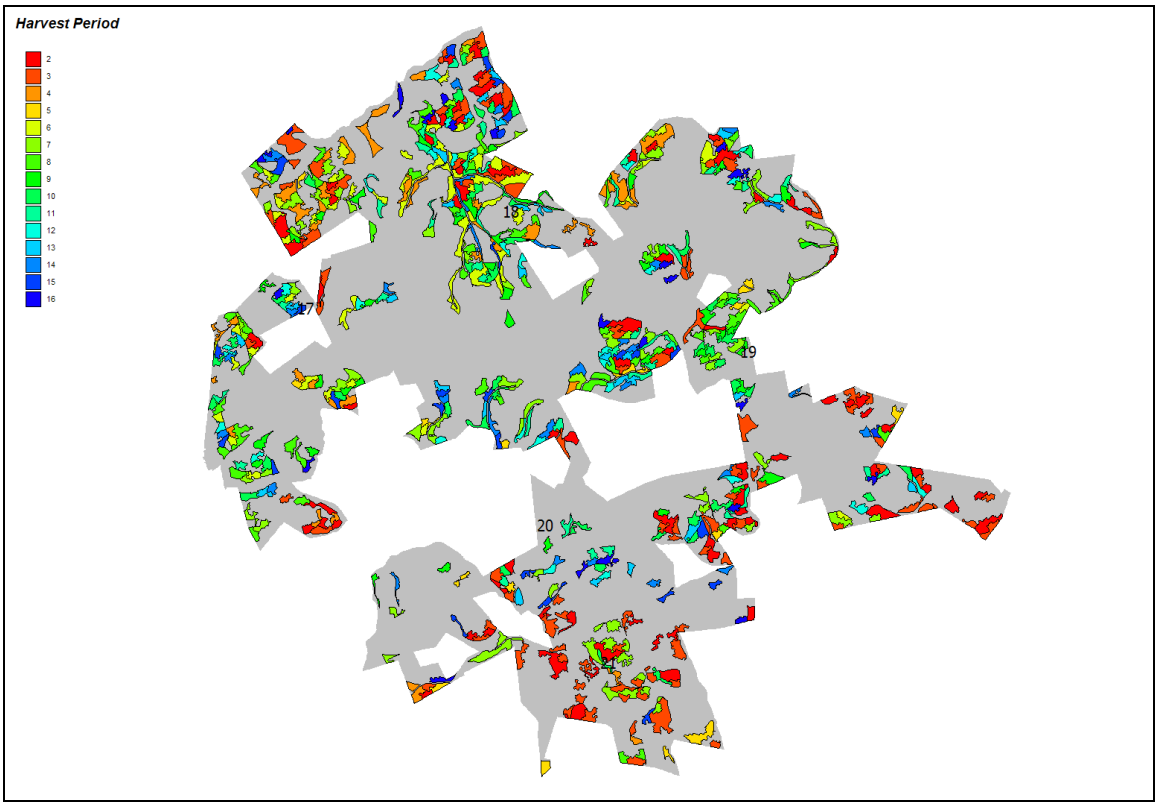

Figure 55. Spatial distribution of final harvests in Tracts 17 – 20 of SHSF (years 2-16).

Figures 62-64 illustrate the locations of final harvests across SHSF in periods 2 through 16 of the spatial harvest schedule. SCFC was provided with GIS data for SHSF that can be queried for harvest activity, silvicultural treatment, block identifier, harvest period, and other results of the spatial allocation.

4.2.3 Spatial Allocation of Foraging Habitat and Pine Straw Activities

Good Quality Foraging Habitat

While tabular estimates and graphs indicate the magnitudes of various outputs over time, GQFH is meaningless without consideration of the spatial dimension. The strategic and tactical Woodstock runs indicated that it should be possible to move toward improved GQFH over time. However, the spatial locations of those GQFH acres are important since RCWs require contiguous acres of foraging habitat to support their colonies.

The Recovery Guidelines stipulate that 120 acres of contiguous acres of GQFH is the minimum required to support a cluster. Despite the appearance of GQFH across the forest in Figure 56, the figure depicts the only the spatial distribution and extent of stands that *nominally* qualify as good foraging habitat. A more useful measure of GQFH was developed using Spatial Woodstock to identify spatial patches of GQFH that exceeded 120 acres in size (with no part of the patch separated from the remainder by more than 200 feet). In Figure 57, observe that at the end of the first year of the planning horizon, only one such zone exists containing over 700 GQFH-qualified acres. By the end of the fifth year of the planning horizon, however, 16 such zones are expected to exist (Figure 58).

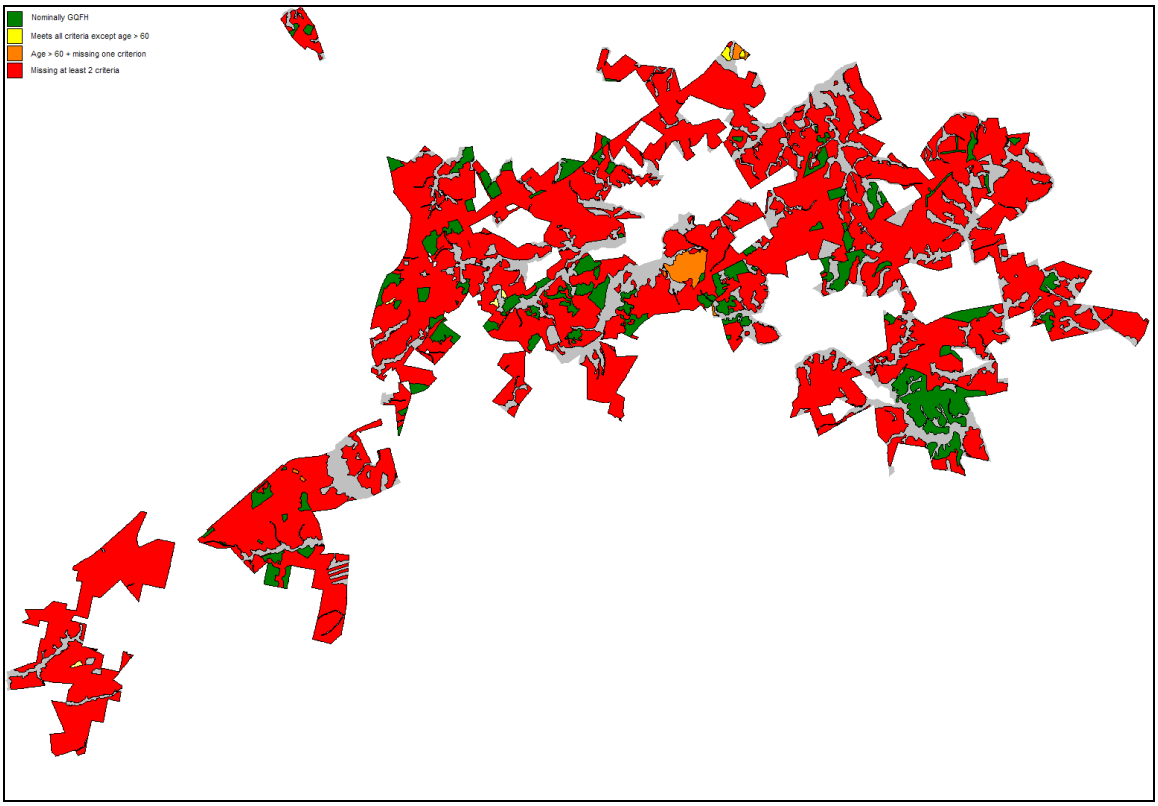

Figure 56. Sand Hills spatial distribution of nominal GQFH acres (year 1).

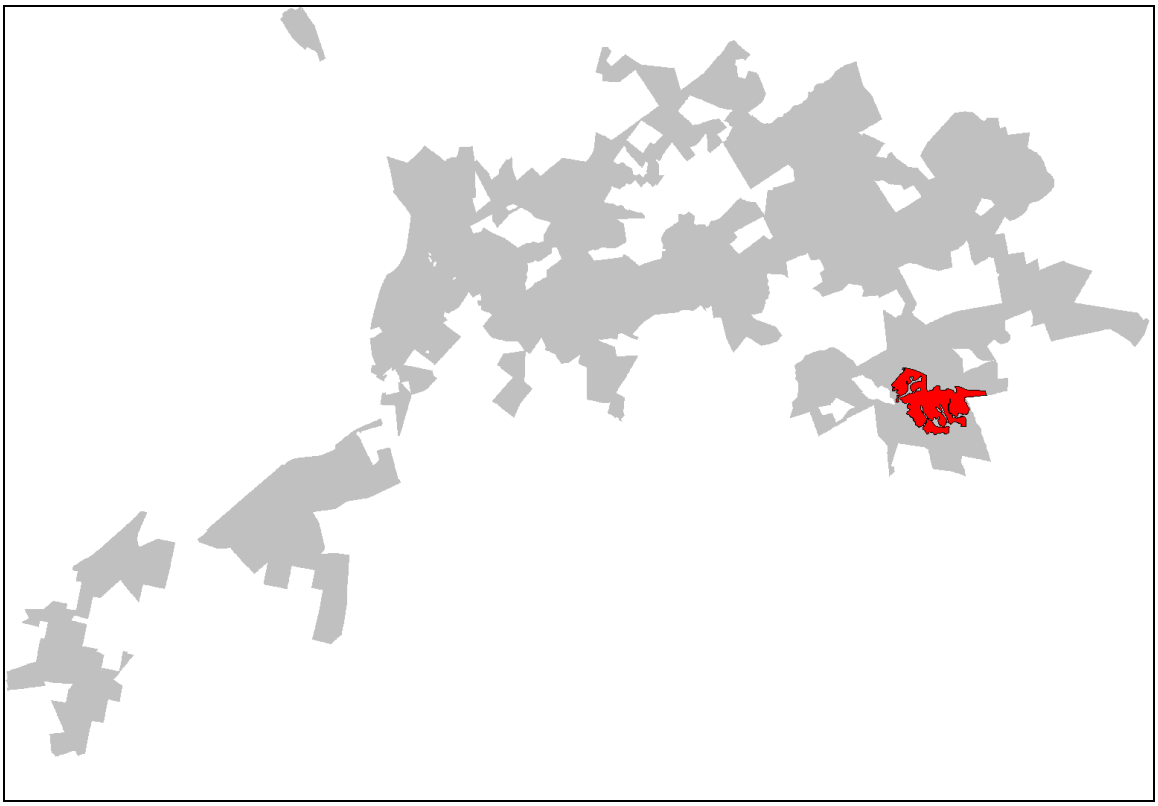

Figure 57. Sand Hills GQFH spatial zones exceeding 120 acre threshold (year 1).

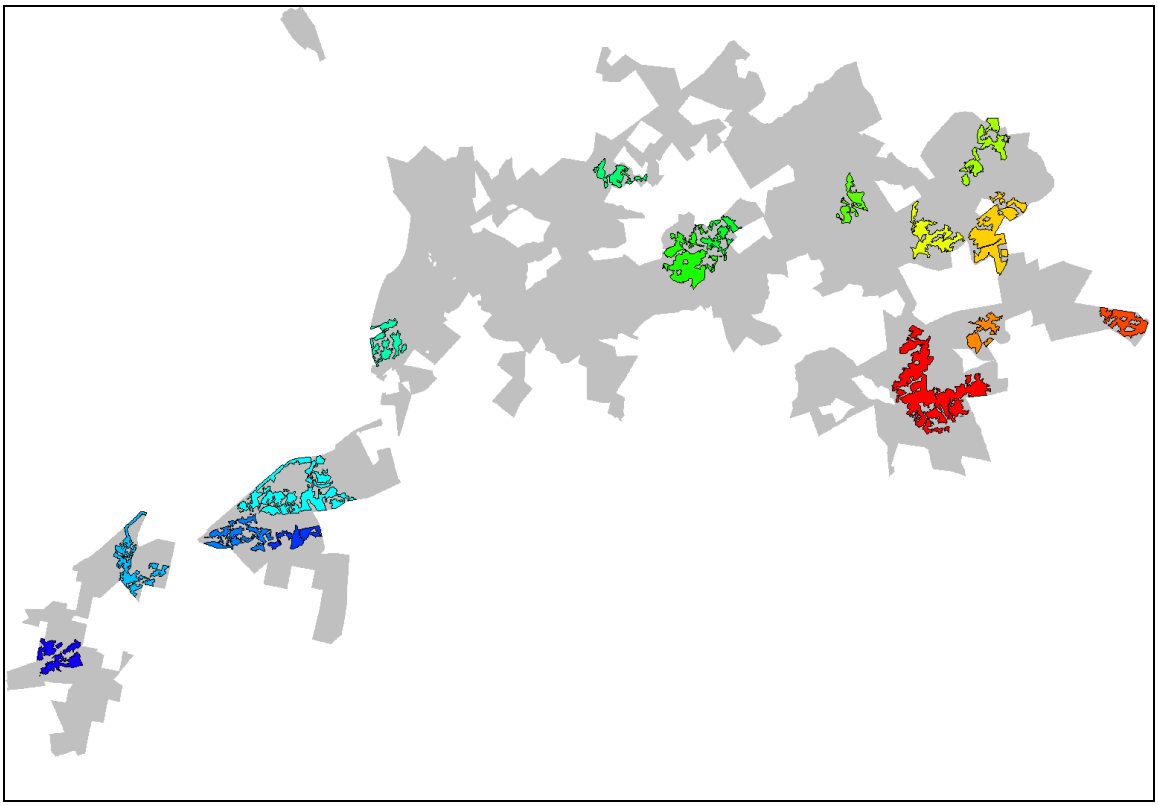

Figure 58. Sand Hills GQFH spatial zones exceeding 120 acre threshold (year 5).

After 10 years, the number of acres that nominally qualify as GQFH has increased significantly. In Figure 59, observe the number of patches colored green (signifying that all criteria for HS are met), and yellow (indicating that all stand parameters for HS are met except that the stand is not yet over 60 years of age). When these patches are subjected to the minimum 120 acre size threshold, 17 GQFH zones are predicted to exist at the end of year 10 (Figure 60). Note that the configuration of these zones is not static: over time, some acres of GQFH disappear as harvesting continues but other acres grow into GQFH status to replace them. Compare Figure 58 to Figure 60, and observe that in the intervening 5 years, some patches disappear altogether while others that are nearby merge into a single patch.

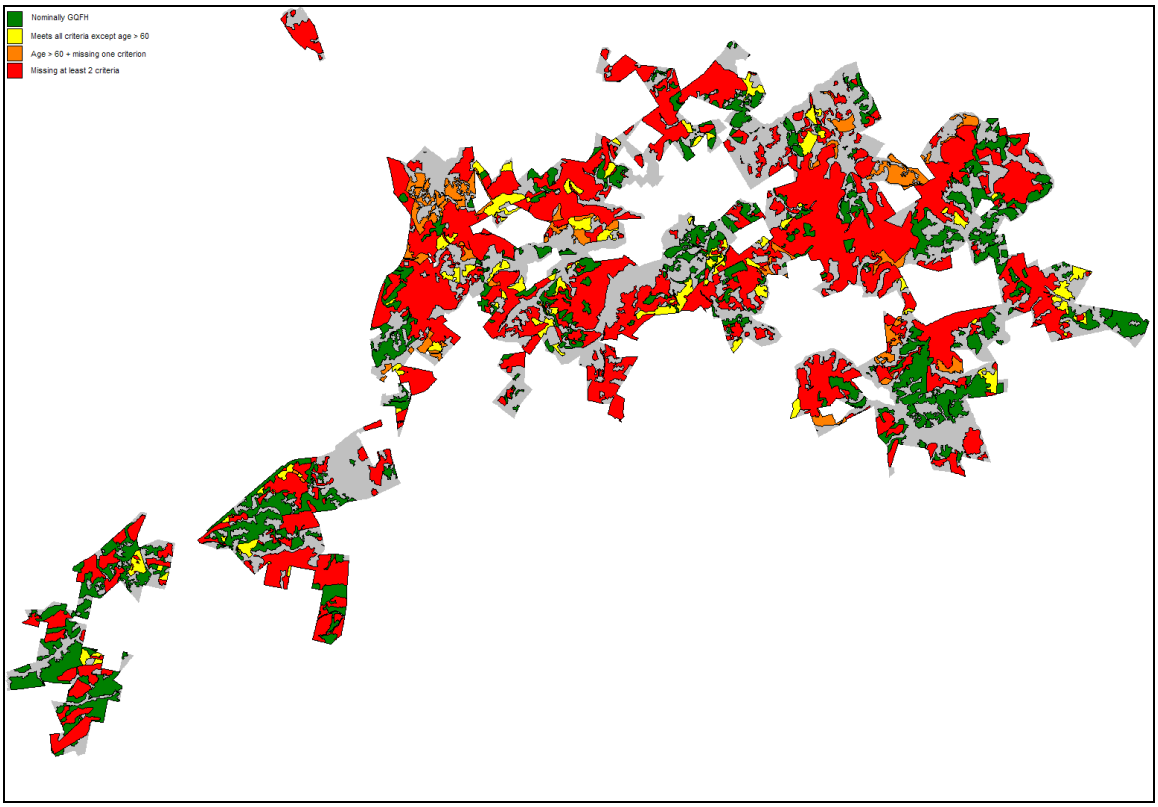

Figure 59. Sand Hills spatial distribution of nominal GQFH acres (year 10).

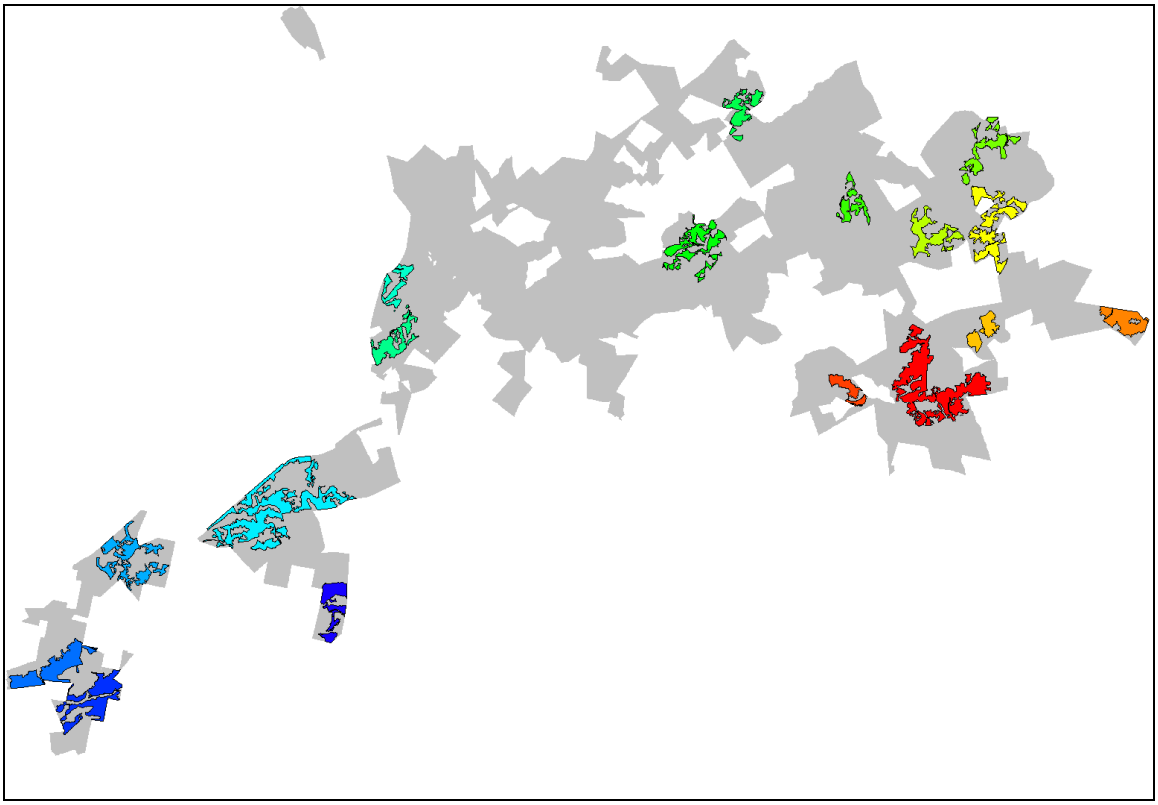

Figure 60. Sand Hills GQFH spatial zones exceeding 120 acre threshold (year 10).

Pine Straw Enhancement and Straw Raking

One of the important elements driving financial returns on SHSF is the sale of pine straw. Production of pine straw is maintained through regular scheduling of pine straw enhancement, an activity where contractors remove understory hardwood vegetation in exchange for the commitment to harvest pine straw at no additional cost during the contract period (4 years). Following enhancement, pine straw is raked every two or three years, at which time it is baled and sold. While the actual boundary layout for pine straw enhancement and raking is an operational concern, it is instructive to know the probable location of these activities as part of the overall forest management schedule. Exported database files (e.g., ENH200@5.DBF) were provided to SCFC that can be joined to the SHSF database to identify specific locations of enhancement and raking for years 1-10.

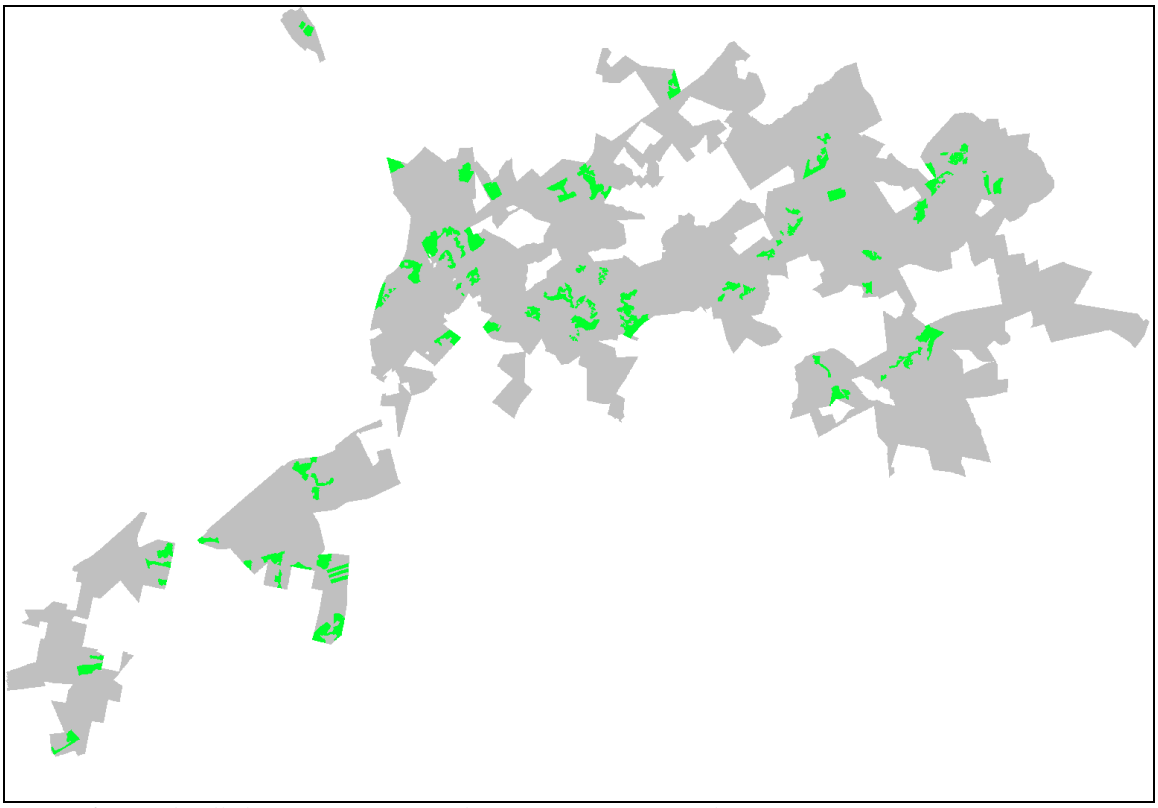

Figure 61. Sand Hills locations of potential sites for pine straw enhancement (year 2).

5 Conclusions

This project represents a number of firsts with regard to the South Carolina Forestry Commission, RCW management and FORSight Resources' forest planning capabilities. For SCFC, the MAWT and SHSF planning models represent the first, comprehensive forest planning exercises attempted, using the updated RCW recovery guidelines and explicit management objectives in a formal planning model. In the past, forest management was largely stand-based, implementing silvicultural treatments that would benefit individual stands, but without consideration of the forest-wide context. As the first exercise, the learning curve has been somewhat steep and long, but SCFC staff has gained new understanding of the processes involved with planning of this type, and are confident that future planning efforts will proceed smoothly.

To our knowledge, no other public land management agency has attempted active timber management of lands that have been encumbered by RCW Recovery Guidelines. Most federal lands managers have essentially withdrawn such lands from the productive land base, with the result that RCW recovery is the predominant management emphasis. SCFC staff instead undertook a detailed analysis of silvicultural regimes to determine those that are compatible with both timber production and RCW. Group selection

management regimes regenerate new age classes in uneven-aged stands by removing mature trees in small groups or clusters. This method will be beneficial in helping release young natural regeneration in stands by harvesting over-story trees within and around stands of natural regeneration. SHSF will continue to use the improvement cut method in combination with group selection and a modified two-age management regime. All thinnings will carefully follow guidelines set forth in the USFWS RCW Recovery Plan. This planning exercise should serve as a model for other management agencies in the region, demonstrating that careful planning can not only co-exist with RCW recovery but help to facilitate it.

For FORSight Resources, this project has yielded several significant achievements. In order to predict foraging habitat in future stands, a growth model for longleaf pine had to be developed from various published sources and with significant professional judgment from both FORSight biometrics experts and SCFC staff. The result is the Longleaf Pine Growth Simulator. A version of the FORSim interface has subsequently been constructed to facilitate use of the longleaf growth engine. In addition, the Virginia Tech FASTLOB model was extended to allow more thinning opportunities to meet the needs of extended rotations of loblolly pine.

Because of the complex nature of the silvicultural regimes (up to five commercial thinnings, pine straw enhancement alternatives, etc.) and the large number of constraints for GQFH on SHSF, the resulting LP models are some of the largest we have encountered, exhausting available software limits and hardware resources. Linking the solutions of the strategic models to on-the-ground tactical allocations was also a significantly more involved process than is typical for industrial or public agency forest planning exercises.

In terms of objectives, SCFC was interested in increasing revenues to the state coffers while simultaneously meeting RCW habitat requirements. Both the MAWT and SHSF models demonstrated that these seemingly comflicting objectives can be achieved, significantly increasing revenues and not only maintaining, but improving foraging habitat conditions over time. SCFC has invested significant time and financial resources in updating and revamping their forest management strategies, and the successful conclusion of the planning process justifies those efforts.

6 Recommendations

Consideration of the challenges faced in completing this project we feel that we can make a number of recommendations to improve future planning efforts.

6.1 Strategic planning software

While the Remsoft Spatial Planning Suite (RSPS) is sophisticated and powerful planning software, the current version of Woodstock presented some challenges to the overall process. The inherent Model II structure does not lend itself to the regime based approaches advanced by SCFC forest management staff. Had we completely enumerated the total number of thinning timing choices originally proposed by SCFC, we would have greatly exceeded the maximum problem size that can be feasibly handled by the solver software. A model I structure would have been better suited to the problem, and while planning software such as the USDA Forest Service Spectrum model can handle the strategic aspect of the problem, its linkages to tactical planning problems are clumsy at best and pale compared to Woodstock. Remsoft has recently announced a planned update to the software that will handle regime-based planning directly, and FORSight is participating in the testing of that software using the SHSF planning problem. We recommend that future strategic planning efforts of this type make use of Model I structures.

6.2 Tactical planning software

The Stanley tactical planning module in RSPS is flexible, powerful and easy to use, and generally works well in situations where spatial restrictions on harvesting are well-defined at the stand level (e.g., SFI and FSC operating rules for opening size, green-up and proximity). Unfortunately, the spatial restrictions presented by the RCW Recovery guidelines are more complicated, and the maximization of good quality foraging habitat requires consideration beyond any one stand or set of adjacent neighbors. Numerous heuristics have been developed over the years that have been shown to work well on these types of spatial

problems. FORSight has several staff members with experience in developing spatial planning tools and we recommend that SCFC invest in the development of a heuristic tactical planning tool specifically designed to address RCW foraging habitat management.

6.3 Collect pine growth data for calibrating growth models to SHSF

Much of the underlying growth data for existing longleaf pine growth models has been collected over scattered areas of the southeast and largely on federal lands. Loblolly models are generally designed for intensive silvicultural regimes typical of industrial forest management, or are for older natural stands. None of the models are calibrated for the types of silvicultural regimes advocated in the RCW Recovery Guidelines, nor do they span the range of ages required of such silvicultural regimes. Many of the findings about RCW management that are published come from federal land agencies with very different objectives than SCFC. As a result, many of the projections used in this analysis for future yields and habitat structures for loblolly and longleaf pine are extrapolated far beyond the measured data used to develop the projection systems. To reduce the uncertainty associated with these projections, we recommend that SCFC develop an inventory design to measure the growth of stands following treatments in the proposed forest management regimes.

6.4 Collect and retain silvicultural stand histories

SCFC has made large investments in new forest inventory systems (webFRIS ™) and data collection and management. One of the difficulties encountered in developing growth and yield estimates for this project was that stand histories were missing, in particular records about past thinnings. Without stand histories, it is impossible to know whether a stand has always had low-stocking, or whether the stocking level is due to a recent thinning. Recovering diameter distributions based on natural stocking from a thinned stand yields improbable results, and growth going forward will be similarly improbable. Therefore, we encourage SCFC to record all future silvicultural activities in stand histories, and locate any paper-based records that may exist and incorporate them into webFRIS.

6.5 Develop a more dynamic methodology for assessing GQFH?

In a sense, this recommendation ties in with Recommendation 6.2. The current metrics for assessing good quality foraging habitat are inherently non-linear, and so integrating them with a solution methodology would be extremely valuable. Incorporating concepts such as optimal foraging techniques and avian energetics into the assessment criteria could provide a much more robust assessment and planning tool, particularly when combined with a robust growth & yield model and GIS capabilities.

7 Appendix I – Growth Model Availability

7.1 FORSight Resources LLC Proprietary Growth Models

The following growth and yield models were implemented by, and remain proprietary to FORSight Resources, LLC.

Address: 8761 Dorchester Road - Suite 102, North Charleston South Carolina 29420
Web Address: http://www.forsightresources.com/index.html

7.1.1 Southern Hardwood Models

Growth and yield for southern hardwoods is done with two DLL's: a stand growth DLL that gives stand parameters (BA, TPA), and a volume DLL that predicts total stand and product volumes. The model will allow for a pine component and will grow it through time. Apportioning between hardwoods and pine is done using a ratio function that compares BA, TPA, QMD, and SDI for the two species.

7.1.2 Longleaf Pine Growth Simulator (LPGS)

The work was based on the following publications, supplemented by the professional and technical knowledge of FORSight Resources and SCFC staff, and empirical data from SCFC:

- H.E. Quicke, R.S. Meldahl, and J.S. Kush (1994) Basal Area Growth of Individual Trees: A Model Derived from a Regional Longleaf Pine Growth Study. Forest Science 40(3) 528 - 542.

- Brooks, John R.; Jack, Steven B. 2006. A whole stand growth and yield system for young longleaf pine plantations in Southwest Georgia. Gen. Tech. Rep. SRS-92. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. pp. 317-318.

- Farrar, Robert M., Jr. 1985. Volume and growth predictions for thinned even-aged natural longleaf pine stands in the East Gulf area. USDA Forest Service, Research Paper SO-220. Southern Forest Experiment Station, New Orleans, LA. 171 p.

- R.M. Farrar and T.G. Matney (1994) A Dual Growth Simulator for Natural Even-aged stands of Longleaf Pine in the South's East Gulf region. Southern Journal of Applied Forestry 18(4): 147 - 155.

- LeDuc, Matney, Belli and Baldwin: Predicting diameter distributions of longleaf pine plantations: A comparison between artificial neural networks and the accepted methodologies. Southern Research Station, Research Paper 25. Stands on prepared sites.

- R. M. Farrar (1987) Stem-profile Functions for Predicting Multiple-Product Volumes in Natural Longleaf Pines. Southern Journal of Applied Forestry. 11(3):161 – 167

- Somers (1991) - Biomathematical Growth Equations for Natural Longleaf Stands Using auadratic mean diameter equation to predict early stand BA.

- Rayamanhi, Kush, Meldahl (1999) - An Updated Site Index Equation for Naturally Regenerated Longleaf Pine Stands.

7.2 Sand Pine Model

This basis for this growth model was a publication detailing yield prediction in sand pine by Rockwood et al. (1997).

7.3 NATLOB

NATLOB was initially developed by the Growth and Yield Cooperative Department of Forestry of Virginia Tech. This program was converted to a DLL by FORSight Resources to run in a batch environment. This version of the program is proprietary to FORSight. The original version is available through the Virginia Tech Cooperative.

Address: Department of Forestry, Virginia Tech, Blacksburg, VA 24061.
Web Address: http://www.fw.vt.edu/g&y_coop/models.htm

Address: 8761 Dorchester Road - Suite 102, North Charleston South Carolina 29420
Web Address: http://www.forsightresources.com/index.html

7.4 FASTLOB

FASTLOB was initially developed by the Growth and Yield Cooperative Department of Forestry of Virginia Tech. This program was adapted to run in a batch environment by FORSight Resources, LLC. Several modifications were made to the program to allow it to be utilized for the South Carolina Forestry Commission modeling effort. The first was to release the 50 year model constraint allowing the program to generate yields past the 50 year limit. Secondly, the original program allowed for two thinnings to be preformed during a rotation. FORSight added the capability to run four thinnings during a rotation. Lastly, the original program required a minimum of 35 TPA to generate yields. This limitation was imposed in both the initialization procedures and growth procedures. This limit was reduced to 17 TPA in the growth procedures. This version of the program is proprietary to FORSight. The original version is available through the Virginia Tech Cooperative.

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