Improving Environmental Quality in South Florida through Silvopasture: An Economic Approach

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A dynamic optimization model is used to compare the profitability of silvopasture with traditional cattle ranching in south Florida. Silvopasture can reduce phosphorus runoff from cattle ranching—a major environmental concern for Lake Okeechobee and the Everglades. Silvopasture can also sequester carbon, thereby offsetting global climate change. The effectiveness of phosphorus runoff taxes and carbon sequestration payments for inducing landowners to adopt silvopasture is investigated. We find that phosphorus taxes alone would not induce landowners to adopt silvopasture. However, payments to landowners to sequester carbon, alone or in conjunction with phosphorus runoff taxes, can make silvopasture financially competitive with traditional ranching.

Key Words: carbon sequestration, cattle ranching, Faustmann model, global climate change, phosphorus runoff, silvopasture, slash pine, tax

JEL Classifications: Q57, Q23

Cattle ranching is an important agricultural enterprise in Florida, covering over 6 million acres and producing over $300 million each year with over 1.8 million cattle. Florida is the 10th largest cattle producer in the United States. Over 60% of cattle production in Florida occurs near Lake Okeechobee and the Everglades (South Florida), which is a subtropical ecosystem that is naturally low in phosphorus content. Since phosphorus runoff from cattle ranching can cause significant ecological degradation to Lake Okeechobee and the Everglades, cattle ranching has long been a significant environmental concern in this region. In this study we assess economic impacts of taxes to reduce phosphorus runoff and payments for carbon sequestration when trees are grown on ranchlands in the Lake Okeechobee watershed.

Lake Okeechobee is a large freshwater lake of 730 square miles and a drainage basin of approximately 5,000 square miles (Harvey and Havens). Historically, Lake Okeechobee would overflow in response to heavy rains and feed the Everglades—a vast slow-moving shallow river that empties into Florida Bay. During the last century, Lake Okeechobee and the Everglades have been subjected to massive water control projects by the Army Corps of

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Engineers and the South Florida Water Management District (SFWMD). Levees, drainage canals, and pump stations were constructed under these projects to drain parts of the Everglades, protect areas from flooding, and to make land available for agriculture (including cattle ranching) and urban development. The resulting land use changes have had a profound impact on environmental quality in South Florida. In particular, the phosphorus content of Lake Okeechobee has more than doubled over the past century, causing eutrophication and subsequent damage to its aquatic life (Harvey and Havens). The phosphorus content of the downstream Everglades ecosystem has also increased, causing a displacement of native sawgrass prairies with cattail and other plants (Rizzardi).

These environmental concerns were part of the impetus for the U.S. federal government and the state of Florida to adopt the Comprehensive Everglades Restoration Plan (CERP) in the late 1990s. CERP is a massive initiative projected to cost more than $7.8 billion over 30 years. The aim of this plan is to partly restore the Everglades and Lake Okeechobee ecosystems and to provide for the water needs of the agricultural industry and expanding urban areas in South Florida. In addition, in 1999 the SFWMD issued the Lake Okeechobee Action Plan in which it recommended that reduction of phosphorus runoff should be a major part of restoration of the lake and downstream Everglades (Harvey and Havens). These programs do not address alternative land uses or the incentives for land use changes that could be more effective at achieving the desired lower phosphorus levels.

Silvopasture, jointly managing the production of trees and livestock forage, may be an economically viable way to improve environmental quality associated with cattle ranching in South Florida. The trees' extensive root systems and litterfall can help reduce soil erosion, and trees' uptake of resources can reduce nutrient and pesticide loads in runoff (Zinkhan and Mercer). In addition, the reduction in livestock numbers in a two-commodity system could lead to a substantial reduction of phosphorus and nitrogen wastes (Boggess, Flaig,

and Fluck). Another environmental benefit from silvopasture is that growing trees sequester carbon from the atmosphere.

The potential for carbon sequestration is an important environmental service from adopting silvopasture techniques since there is growing concern over anthropogenic climate change. In particular, global climate change is expected to raise the average global temperatures by over 2 °C over the next decades, raise sea levels, and change regional precipitation patterns that can cause disruptions in agricultural systems and natural ecosystems. These changes are expected to have significant negative impacts on society in the form of reduced economic output, dislocation of people, and the degradation of environmental amenities (IPCC). However, because these environmental benefits are public goods they are generally not considered in the land use decisions of private landowners.

Historically, the combination of trees and cattle was a frequent land use in the southeastern United States. In the early 20th century much of the southern half of Florida supported good commercial pine timber stands. Most of this pineland was also used for cattle grazing (Rummell). Since the latter half of the 1900s, heavy logging and the trend to more intensive cattle grazing has significantly reduced silvopasture and timber production in South Florida. Today silvopasture is a minor land use, but there is an increasing interest in silvopasture systems by landowners. The benefits of silvopasture most cited by landowners in the southeastern United States are economic and include increased financial returns and diversification of income (Zinkhan and Mercer). There is also empirical evidence that silvopasture land management techniques can be profitable. For instance Lundgren, Conner, and Pearson found that pine silvopasture systems in the southeast could have as much as a 4.5% positive rate of return. Clason found that silvopasture utilizing loblolly pine (*Pinus taeda*) in Louisiana could produce greater net returns than either pure pasture systems or pure timber systems. Grado, Hovermale, and St. Louis found that combining beef cattle and pine plantations can be profitable in southern Mis-

sissippi. Silvopasture may not be as financially competitive in South Florida, however, because of lower timber prices due to typically farther transport distances. Thus, Florida landowners may be reluctant to adopt it as a land use.

Many economists, policymakers, and nongovernmental environmental groups have advocated internalizing environmental benefits and costs so that market forces (instead of regulatory action) can be used to address environmental concerns. Applying this concept to silvopasture in South Florida implies landowners would pay for the negative social costs generated from phosphorus runoff and receive payments for the positive social benefits from carbon sequestration. By internalizing the cost of phosphorus runoff and the benefits of carbon sequestration to private landowners, silvopasture could become financially competitive with traditional cattle ranching. No studies to date have investigated the potential of phosphorus runoff taxes to induce landowners to change land management. However, there have been studies that indicate that internalizing carbon benefits to pine plantation owners could significantly increase the profitability of forestry and induce landowners to lengthen their rotations to sequester more carbon (Alavalapati, Stainback, and Carter; Huang and Kronrad).

In this study we build an economic optimization model of traditional cattle ranching and silvopasture that includes taxes on phosphorus runoff and payments for carbon sequestration. We use this model to investigate how these taxes and payments would influence land values associated with traditional cattle ranching and silvopasture and the optimal tree density and rotation age associated with silvopasture.

Model Specification

Beef cattle ranching in South Florida generally occurs on both native and improved pasture in each year. During the fall and winter cattle are typically grazed on pasture where native grasses supply the forage. In the spring and summer, after calving, cattle are usually grazed on improved pasture where fertilizer is used more extensively and nonnative grasses (such as Bahia) are planted for forage. Thus, cattle grazing in this region is evenly split between native and improved pastures over the course of a year. Approximately 8 to 10 acres of native pasture is equivalent to 1 acre of improved pasture for the purpose of raising cattle (Felton).

In this paper, silvopasture on native pasture is a management option available to a private landowner[1]. If silvopasture techniques are adopted, a landowner would receive revenue from cattle and timber production. A landowner has the option of planting no trees, which is referred to as the traditional ranching scenario, or silvopasture with an initial tree density of 100, 200, 300, or 400 trees per acre. Higher tree densities result in less forage production available for cattle grazing but more timber.

Timber and Cattle Production

Slash pine (*P. elliottii*) is the most common timber species in South Florida and is frequently used in silvopasture. A slash pine growth model was developed by Pienaar and Rheney and has been used by Yin, Pienaar, and Aronow. This model is based on empirical data collected from even-aged, unthinned slash pine plantations in North Florida and South Georgia. This model predicts three measures of timber production—basal area, volume of sawtimber, and volume of pulpwood as a function of stand age, tree density, and site index. Although the climate and growing conditions of South Florida are slightly different from those in North Florida, this model is used in the analysis because of the lack of detailed growth and yield models for slash pine grown in South Florida.

The computational requirements of the subsequent economic model require the growth and yield model to have certain math-

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[1] This model assumes that silvopasture is adopted on native pasture where fertilizer is not used. As such, phosphorus runoff from fertilizer is not included in the model.
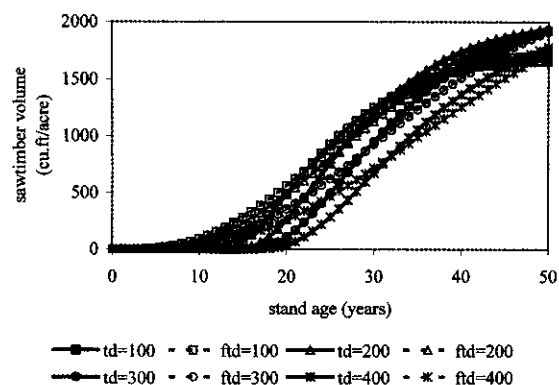
Figure 1. Original and Fitted Sawtimber Volumes as a Function of Stand Age and Tree Density at Age 2 (Fitted functions [ftd] were produced by fitting the results from the original function [td] to a new functional form using nonlinear regression.)

ematical properties—to be easily differentiable and integratable. The model developed by Pienaar and Rheney does not posses these properties. Therefore, we used nonlinear regression to fit the results from this model to the following functional form:

$$(1) \qquad v(t) = at^b e^{-ct},$$

where $v(t)$ is the basal area or volumes of sawtimber or pulpwood, t is the stand age in years, and a, b, and c are estimated parameters. Equations of the form represented by Equation (1) were estimated for basal area, sawtimber, and pulpwood volumes for tree densities at age 2 of 100, 200, 300, and 400 stems per acre. The site index was assumed to be 60 feet at a base age of 25 years.[2] Predictions of sawtimber volume from the original and fitted models are shown in Figure 1. All parameter estimates are given in the Appendix.

Forage production is a function of basal area. Following the empirical work of Wolters, the following equation was used to estimate

Figure 2. Animal Unit Months (AUMs) as a Function of Stand Age and Tree Density (td)

forage produced, $f(t)$, in pounds of dry biomass per acre per year:

$$(2) \qquad f(t) = 2048.9 - 14.7b(t),$$

where $b(t)$ is basal area in square feet per acre. If traditional ranching is followed and no trees are planted, basal area is zero. Forage production was converted to cattle production using standard animal unit months (AUMs). One AUM is defined as the amount of forage required to support one adult cow weighing 1,000 lbs for 1 month. Specifically, $f(t)$ was divided by 780 lbs. The production of AUMs as a function of stand age for varying tree densities is shown in Figure 2.

Economic Model

We utilize the Faustmann model as a basic framework and extend it to incorporate cattle production along with sawtimber and pulpwood. The model then is used to calculate the soil expectation value (SEV) associated with traditional ranching and silvopasture. For silvopasture SEV is calculated as:

$$(3) \qquad SEV = \left[p_s v(t)_{saw} e^{-rt} + p_p v(t)_{pulp} e^{-rt} \right.$$
$$\left. + \sum_{2}^{t} p_{aum} \, AUM(t) e^{-rt} - c \right]$$
$$\div (1 - e^{-rt}).$$

AUM(t), $v(t)_{saw}$ and $v(t)_{pulp}$ are AUMs, sawtimber volume, and pulpwood volume produced

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[2] Site index 60 refers to the height of the dominant trees at stand age 25. This is how site quality is expressed in forestry. Yin, Pienaar, and Aronow stand growth model that we used in our study predicts tree densities from age 2.
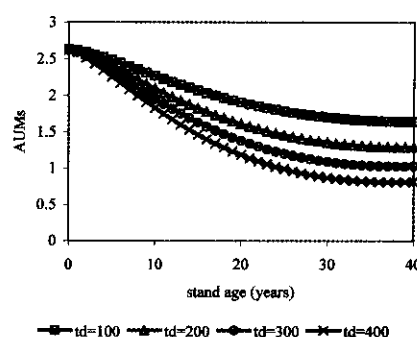
as a function of stand age *t*, respectively. p_s, p_p, and p_{aum} are the prices of sawtimber, pulpwood, and AUMs respectively. The price of sawtimber and pulpwood ($0.80 and $0.16 per cubic foot respectively) were obtained from Timber Mart-South. These are the lowest average prices for sawtimber and pulpwood; the lowest prices were used to account for the long distances between the production location in South Florida to timber and pulp mills. A typical lease price of $5 per AUM was assumed. The discount rate, *r*, is assumed to be 5%.

The present value of AUMs is calculated in Equation (3) with a summation that begins at year two to allow the young seedlings to develop without grazing. If traditional ranching is used, then $v(t)_{saw}$ and $v(t)_{pulp}$ are zero and the present value of AUMs is calculated beginning at age one. The stand age (optimal rotation age), *t*, and the tree density at age two that maximizes SEV comprise the optimal management regime. The present value of costs of traditional ranching and silvopasture are represented by *c* and are assumed to be $100, $300, $350, $400, and $450 per acre for traditional ranching and silvopasture with initial tree densities of 100, 200, 300, and 400 stems per acre at age two, respectively. These costs include fencing, seedlings, site preparation, and pruning (which is usually necessary for sawtimber production with low tree densities).

To incorporate a phosphorus runoff tax into the above model we first estimated the amount of phosphorus runoff associated with cattle ranching. There have been only a few studies investigating phosphorus runoff from cattle ranches in South Florida. These studies indicate that phosphorus runoff can vary significantly with precipitation and local soil conditions. We use an estimate of 0.33 lbs of phosphorus runoff per acre per year for native pasture (Capece et al.). Because of a lack of data on the relation between cattle density and phosphorus runoff, we assume a linear relation between AUM production and phosphorus runoff. From Equation (2) we assume that a native pasture produces approximately 2.6 AUMs per year if no trees are planted. From

this it is estimated that each AUM produces 0.13 lbs of phosphorus runoff. If phosphorus runoff is taxed under these assumptions, the present value of the cost of this tax to the landowner over one harvest rotation is equal to:

$$(4) \qquad pv_{tax} = \sum_{1 or 2}^{t} p_{phos} 0.13 \ AUM(t)e^{-rt},$$

where p_{phos} is the phosphorus tax per pound. The summation starts at year one if traditional ranching is used and age two if silvopasture is used. A sensitivity analysis on the phosphorus tax was conducted for taxes ranging from $0 per lb. to $20 per lb. This range is assumed because if the phosphorus tax rises much above $20 per lb, then the SEV of traditional ranching and silvopasture becomes negative.

As trees grow they sequester CO_2 from the atmosphere and store it as carbon in tree biomass. Thus, by engaging in silvopasture the landowner sequesters carbon from the atmosphere, thereby helping to reduce future global climate change. In this paper the landowner is paid yearly for carbon sequestration according to the biomass present in tree biomass. If the trees are harvested, the landowner is not penalized but does not receive a carbon payment in the following year. The present value of a carbon payment over one rotation is represented by:

$$(5) \qquad pvc = \sum_{1}^{t} p_c \alpha \beta v(t)_{merch} e^{-rt},$$

where $v(t)_{merch}$ is the volume of merchantable timber (sawtimber plus pulpwood), β is a conversion factor that converts merchantable timber volume to total tree volume including roots, branches, and leaves, α converts tree volume in cubic feet to metric tons (mt) of carbon, and p_c is the price of carbon storage for 1 year. Values of the parameters β and α were assumed to be 1.682 and 0.081, respectively, and are specific for southern pines (Birdsey).

Previous literature suggests that a conservative range of values for permanently sequestering carbon in forests ranges from $0 to $40 per mt (Stainback and Alavalapati). This

Table 1. Soil Expectation Value (SEV) for Traditional Ranching (No Trees) and Silvopasture as a Function of Carbon Price and Phosphorus Runoff Reduction Tax

Phosphorus Tax ($/lb)	SEV ($/acre) under Silvopasture Carbon Price $/Ton					SEV ($/acre) under Traditional Ranching
	$0.0	$0.5	$1.0	$1.5	$2.0	
$0	302	365	433	520	648	425
$5	221	285	353	448	590	320
$10	141	205	273	376	531	215
$15	60	125	166	306	473	110
$20	−20	45	125	242	415	5

price range translates into a 1-year carbon rental price of $0.50 to $2.00 per mt (assuming a discount rate of 5%). We use a 1-year rental price because it is likely that a carbon market based on sequestering carbon for 1 year will have lower transaction costs than obligating a landowner to keep carbon sequestered indefinitely.

The SEV of silvopasture and traditional ranching is thus represented as:

$$(6) \quad SEV = \left[v(t)_{saw}e^{-rt} + p_p v(t)_{pulp}e^{-rt} \right.$$
$$+ \sum_2^t p_{aum} \, AUM(t)e^{-rt} + pvc$$
$$\left. - pvp - c \right]$$
$$\div (1 - e^{-rt}).$$

Recall that the rotation age and initial tree density that maximizes SEV represents the optimal land management regime. If traditional ranching is used, then it is assumed that no phosphorus reduction or carbon sequestration occurs (i.e., no environmental benefits are produced) and Equation (6) reduces to Equation (3). Environmental benefits are represented by the supply of phosphorus reduced and carbon sequestered and are calculated respectively as:

$$(7) \quad S_{phos} = \frac{\sum_{1 or 2}^t 0.13 \, AUM(t)}{t}$$

$$(8) \quad S_{carbon} = \frac{\sum_{1^c}^t \alpha\beta v(t)_{merch}}{t}.$$

Results

The soil expectation value of traditional ranching and silvopasture are shown in Table 1 as a function of phosphorus runoff taxes and carbon payments. As the phosphorus tax increases, SEV decreases for both traditional ranching and silvopasture. However, SEV decreases less rapidly for silvopasture than traditional ranching because of there being less phosphorus runoff associated with silvopasture. Because traditional ranching does not produce any carbon benefits, it is unaffected by carbon prices. For silvopasture it can be seen that as the price of carbon increases, so does the SEV. Without any carbon payments silvopasture is not financially competitive with traditional ranching. This is shown by the line representing silvopasture with a carbon payment of $0, which is always below the line associated with traditional ranching.

With a carbon price of $1.0 per mt and above, silvopasture has a higher SEV than traditional ranching, even without a phosphorus tax. As the phosphorus tax increases, the price of carbon necessary to make silvopasture competitive declines. For instance, with a phosphorus tax of $15 per lb. a carbon payment of only $0.50 per lb. is needed to make silvopasture financially competitive. As stated before, if the phosphorus tax rises above $20 per lb. then the SEV for both traditional ranching and silvopasture falls below zero, which means that the revenue generated from these land uses would not cover their costs.

The optimal land management for various combinations of phosphorus runoff taxes and

Table 2. Optimal Management as a Function of Phosphorus Runoff Tax and Carbon Price

C Price	Phosphorus Runoff Tax ($/lb)				
($/ton)	0	5	10	15	20
0.00	TR	TR	TR	TR	TR
0.50	TR	TR	TR	100 (31)	100 (31)
1.00	100 (32)	100 (33)	100 (33)	200 (36)	200 (36)
1.50	200 (38)	200 (38)	200 (38)	300 (43)	300 (44)
2.00	400 (53)	400 (53)	400 (53)	400 (53)	400 (53)

Notes: Traditional ranching (TR) has no trees. The number to the left represents the optimal initial tree density (stems/acre) and the number to the right in parentheses represents the optimal harvest rotation (years).

carbon payments is shown in Table 2. Results indicate the need for a relatively high carbon price or a combination of carbon payments and phosphorus runoff taxes to make silvopasture financially competitive with traditional ranching. Results also indicate that the optimal management regime is more sensitive to carbon payments than to phosphorus runoff taxes. With a phosphorus runoff tax of $20 per lb., doubling the carbon payment from $1 per mt to $2 per mt increases the optimal initial tree density from 200 stems per acre to 400 stems per acre and increases the optimal rotation age by 17 years. However, at a carbon price of $1.50 per mt, doubling the phosphorus runoff tax from $10 per lb. to $20 per lb. only increases the optimal initial tree density from 200 to 300 stems per acre and increases the optimal rotation age by only 10 years.

Impacts on phosphorus runoff reduction and carbon sequestration from changes in the levels of runoff taxes and carbon prices are shown in Table 3.[3] At a carbon price of $1.50 per mt, phosphorus runoff is reduced by 0.03 lbs. per acre per year by increasing the phosphorus runoff tax from $5 per lb. to $20 per lb. In addition, the quantity of carbon sequestered increases by 6 mt. If the price of carbon is $2 per mt then there is no change in phosphorus runoff or carbon sequestration when higher phosphorus runoff taxes range from $0 to $20 per lb. However, if the phosphorus run-

off tax is $20 per lb., then increasing the carbon payments from $1 per mt to $2 per mt (100%) increases phosphors runoff reduction by 0.07 lbs. per acre per year (64%) and increases carbon sequestration by 10 mt (63%).

Conclusions

As a regulatory tool, a phosphorus runoff tax is not sufficient to induce landowners to adopt silvopasture. According to this analysis, a carbon payment is needed for silvopasture to be financially competitive with traditional ranching. This result is dependent on the assumed physical relation between silvopasture and phosphorus runoff. Because of the lack of data, there is a substantial amount of uncertainty about this relation. If we assume a stronger relation between silvopasture and phosphorus runoff reduction, a phosphorus tax alone may be effective in inducing landowners to adopt silvopasture. However, it is just as likely that silvopasture would be less effective in reducing phosphorus runoff than assumed here.

As an environmental policy tool, carbon payments provide a much stronger incentive compared to phosphorus runoff taxes for landowners to adopt silvopasture. In addition, such payments may be easier to implement than a tax, especially since knowledge about the relation between planting trees on pasture and carbon sequestration is more certain. It is fairly easy to get reliable estimates of carbon storage in forest systems from data on merchantable volume (Birdsey), which is routinely estimated by the landowner to make financial decisions regarding harvests and timber sales.

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[3] The estimates on phosphorus runoff reduction are the results of a decrease in cattle density due to adding trees. Trees might be reducing phosphorus runoff due to extensive root systems. As such, our estimates may be conservative.

Table 3. Phosphorus Runoff Reduction Supply and Carbon Sequestration Supply as a Function of Phosphorus Reduction Tax and Carbon Price

C Price ($/ton)	Phosphorus Runoff Tax ($/lb)				
	0	5	10	15	20
0.00	TR	TR	TR	TR	TR
0.50	TR	TR	TR	0.22 (10)	0.22 (10)
1.00	0.22 (10)	0.23 (11)	0.23 (11)	0.34 (16)	0.34 (16)
1.50	0.35 (17)	0.35 (17)	0.35 (17)	0.45 (23)	0.45 (23)
2.00	0.55 (26)	0.55 (26)	0.55 (26)	0.55 (26)	0.55 (26)

Notes: Traditional ranching (TR) produces zero phosphorus reduction and carbon sequestration benefits. The number to the left is phosphorus reduction (lbs/acre per year) and the number to the right in parentheses is carbon sequestered (metric tons/acre).

Phosphorus runoff taxes may be attractive from a societal welfare standpoint. It can be argued that requiring cattle producers and consumers of cattle products to bear the cost of phosphorus runoff is an equitable policy for reducing phosphorus loads in Lake Okeechobee and the Everglades. However, the results from this study indicate that phosphorus runoff taxes may not induce the land use changes desired. Further, phosphorus taxes, at least implemented without carbon payments, may be politically more challenging for a policymaker. There is considerable opposition to imposing additional costs onto agricultural production from the agricultural industry (Ruhl). Since carbon payments increase SEV, they benefit the landowner. Thus, a carbon market could be based on voluntary participation. Potential buyers of carbon credits could include electrical utility companies or other industries looking to reduce their greenhouse gas emissions. Therefore, establishing a carbon market alone or with low phosphorus taxes may be a more attractive option in South Florida. Such a policy could provide benefits to Lake Okeechobee and the Everglades by reducing phosphorus input in these systems and helping address global climate change—an international concern with potentially significant consequences for the state of Florida.

References

Alavalapati, J.R.R., G.A. Stainback, and D.R. Carter. "Restoration of the Longleaf Pine Ecosystem on Private Lands in the US South: An Ecological Economic Analysis." *Ecological Economics* 40(2002):411–19.

Birdsey, R.A. "Carbon Storage for Major Forest Types and Regions in the Conterminous United States." *Forest and Global Change: Volume II, Forest Management Opportunities for Mitigating and Adapting to Climate Change.* R.N. Sampson and D. Hair, eds., pp. 1–25. Washington, DC: American Forests, 1996.

Boggess, C.F., E.G. Flaig, and R.C. Fluck. "Phosphorus Budget-Basin Relationships for Lake Okeechobee Tributary Basins." *Ecological Engineering* 5(1995):143–62.

Capece, J.C., M.D. Fanning, K.L. Campbell, D.A. Graetz, and K.M. Portier. "Optimization of Best Management Practices for the Beef Cattle Ranching in the Lake Okeechobee Basin: Progress Report #4." University of Florida, Gainesville, FL, 1999.

Clason, T.R. "Economic Implications of Silvipastures on Southern Pine Plantations." *Agroforestry Systems* 29(1995):227–38.

Felton, E.R. *Cattle and Timber in South Florida.* Internet site: http://jrm.library.arizona.edu/data/1961/146/5felt.pdf (Accessed March 10, 2003).

Grado, S.C., C.H. Hovermale, and D.J. St. Louis. "A Financial Analysis of a Silvopasture System in Southern Mississippi." *Agroforestry Systems* 53,3(2001):313–22.

Harvey, R., and K. Havens. 1999. "Lake Okeechobee Action Plan." Lake Okeechobee Issue Team for the South Florida Ecosystem Restoration Working Group, West Palm Beach, FL, 1999.

Huang, H.F., and G.D. Kronrad. "The Cost of Sequestering Carbon on Private Forest Lands." *Forest Policy and Economics* 2(2001):133–42.

Intergovernmental Panel on Climate Change (IPCC). "Climate Change 2001: Impact, Ad-

aptation and Vulnerability." Contribution of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change. New York: Cambridge University Press, 2001.

Lundgren, G.K., J.R. Conner, and H.A. Pearson. "An Economic Analysis of Forest Grazing on Four Timber Management Situation." *Southern Journal of Applied Forestry* 7(1983):119–24.

Pienaar, L.V., and J.W. Rheney. "Modeling Stand Level Growth and Yield Response to Silvicultural Treatments." *Forest Science* 41(1995): 629–38.

Rizzardi, K. "Translating Science into Law: Phosphorus Standards in the Everglades." *Journal of Land Use and Environmental Law* 17(2001): 149–68.

Ruhl, J.B. "Three Questions for Agriculture and the Environment." *Journal of Land Use and Environmental Law* 17(2002):395–408.

Rummell, R.S. "Beef Cattle Production and Range Practices in South Florida." Southern Forest and Range Experiment Station. Forest Service, U.S. Department of Agriculture, Asheville, North Carolina, 1957.

Stainback, G.A., and J.R.R. Alavalapati. "Economic Analysis of Slash Pine Forest Carbon Sequestration in the Southern U.S." *Journal of Forest Economics* 8(2002):105–17.

Timber Mart-South. The Norris Foundation. Athens, GA: University of Georgia, 2002.

Wolters, G.L. "Southern Pine Overstories Influence Herbage Quality." *Journal of Range Management* 26(1973):423–26.

Yin, R., L.V. Pienaar, and M.E. Aronow. "The Productivity and Profitability of Fiber Farming." *Journal of Forestry* 96(1998):3–18.

Zinkhan, F.C., and D.E. Mercer. "An Assessment of Agroforestry Systems in the Southern U.S.A." *Agroforestry Systems* 35(1997):303–21.

Appendix

Table A1. Regression Parameters for Basal Area, Sawtimber Volume, and Pulpwood Volume

Regression Parameter	Tree Density (age 2)							
	100		200		300		400	
Basal Area								
a	0.7166300	(12.296)	1.308400	(12.662)	1.895900	(12.892)	2.483700	(13.483)
b	1.589600	(49.337)	1.497600	(47.922)	1.437400	(46.649)	1.392300	(47.186)
c	−0.039395	(−42.828)	−0.038323	(−43.156)	−0.037570	(−42.582)	−0.036990	(−43.369)
Sawtimber Volume								
a	0.037300	(6.6897)	0.020582	(7.1974)	−0.091896	(8.1031)	0.010160	(6.0608)
b	3.723400	(67.298)	3.832600	(76.930)	3.959400	(78.049)	3.734300	(58.127)
c	−0.076842	(−47.496)	−0.070748	(−41.518)	−0.064852	(−25.576)	−0.051197	(−22.520)
Pulpwood Volume								
a	336.430000	(5.0521)	22.603000	(3.5403)	5.660200	(3.7402)	2.791500	(4.4638)
b	0.473620	(5.4672)	1.827700	(15.300)	2.468500	(22.326)	2.781200	(30.483)
c	−0.055479	(−17.878)	−0.083087	(−20.1924)	−0.091820	(−26.131)	−0.093088	(−33.433)

Note: Numbers in parentheses are *t*-ratios.