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Coarse woody debris characteristics of managed and unmanaged bottomland hardwood forests

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COARSE WOODY DEBRIS CHARACTERISTICS OF MANAGED AND UNMANAGED BOTTOMLAND HARDWOOD FORESTS

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Increasingly, attention is being paid to the role coarse woody debris (CWD) plays in forest ecosystems. CWD has been shown to provide valuable wildlife habitat, support food webs and contribute to nutrient storage and cycling, and mediate hydrological and geomorphic process. Timber management may be altering CWD dynamics by replacing aging stands with younger, more vigorous ones. The specific objectives of this study were 1) to quantify differences in coarse woody debris characteristics among bottomland hardwood forest stands with different management histories, and 2) to determine how differences in tree species composition and forest structure in bottomland hardwood forests influence coarse woody debris characteristics. Transects were established in ten forest stands with different management histories. Line intercept sampling was conducted to evaluate CWD characteristics, and point-centered-quarter sampling was used to compare characteristics in live vegetation. Large standard deviations were associated with most parameters measured, but results suggested that stands that have not been recently managed support more characteristics associated with structurally mature forest than stands that have been recently harvested. In particular, the Bayou Cocodrie NWR old growth natural area expressed characteristics such as relatively large volumes of CWD, a relatively high frequency of large diameter logs, snags, and trees, and a more stratified canopy and established mid-story. More research is needed to better understand the inherent variability in CWD and live vegetation characteristics among bottomland hardwood forests before explicit correlations between forest management and CWD dynamics can be inferred.

INTRODUCTION

In recent years, increased attention has been paid to the ecological importance of coarse woody debris to forest ecosystems. As downed wood, it provides foraging habitat and refugia for forest floor vertebrates; and as standing snags it serves as foraging and nesting sites for birds and mammals (Harmon et al 1986). Coarse woody debris provides structural heterogeneity for aquatic organisms, serving as sites for feeding, mating, and shelter for larvae and adults (Bragg and Kershner 1999). The importance of coarse woody debris to invertebrates, microbes, and fungi are myriad, hence the implications of coarse woody debris for the food web are also great. Coarse woody debris can also serve as a nutrient source and germination site for plants (Harmon 1986).

Coarse woody debris affects the quality and quantity of riparian habitat, stream geomorphology and channel stability, biogeochemical dynamics, and intact old-growth forests (Bragg and Kershner 1999). Major geomorphic and hydrologic processes can be mediated by coarse woody debris, such as the impediment of water and the deposition of sediment in stream channels and on the floodplain (Harmon 1986). In fact, in Coastal Plain riparian systems, debris jams are the predominant retentive devices that trap organic matter and increase habitat diversity for wildlife (Sharitz et al. 1992). The influences coarse woody debris exerts over a stand can last for decades or centuries (Van Lear 1993).

Most forests display population characteristics that have been greatly controlled by known disturbance (Foster 1988). For instance, the frequency of disturbance in most temperate forests relative to tree species life spans suggests that species composition and age structure are largely results of previous disturbance (Oliver 1981). Bottomland hardwood systems are well adjusted to, if not maintained by, disturbance in the form of

periodic destructive flooding (Hupp and Osterkamp 1985). Dynamic flooding patterns within and among years can have drastic effects on the type, frequency, distribution, and intensity of disturbances in bottomland hardwood forests (King and Antrobus 2001).

In natural stands, coarse woody debris input follows a “reverse J” pattern, with accumulation being the greatest in disturbed sites, then declining in aggrading stands, and finally increasing and leveling off in degrading stands (Muller 2003). The large volume of woody debris that is contributed to a stand after a major disturbance eventually decays, often quickly in hot, humid regions such as the southeastern United States, or in floodplain habitat where decay rates could be relatively high due to abundant moisture and the abrasive action of water impacting CWD.

Immediately after a disturbance when the stand is at an early stage of succession, seedlings increase in stem volume while maintaining a constant or increasing stem density (Franklin 2002). During this period, some debris is produced, but stem mortality is mainly suppressed individuals, so debris generated is small and decays quickly. As mean stem size increases, so does the size of generated woody debris. However, maturing trees are more vigorous and less susceptible to disturbance and disease than trees at or reaching biological maturity. Therefore, coarse woody debris volume usually decreases as trees mature and the residual debris from initial disturbance decays (Spies et. al 1988). Conversely, biologically mature trees are more susceptible to windthrow and other damage (Foster 1988). King and Antrobus (2001) found that in bottomland hardwood forests, the six most common tree species that formed canopy gaps were significantly larger than individuals from the general population. The rate of woody debris input rises to a maximum as the even-aged trees reach biological maturity and the stand transitions toward uneven-aged structure (Sturtevant et al. 1997). Input of small

dead wood from trees is fairly steady from year to year, but the addition of large pieces of wood to the ground and the death of whole trees is irregular and may be episodic (Kirby et al. 1998). In southern forests with moderate climates or frequent fires, coarse woody debris may be short lived and require constant replacement.

Site productivity, decomposition rates, and disturbance regime all influence the maximum accumulation of CWD in any forest stand (Gore and Patterson 1986). Warmer, wetter sites have less coarse woody debris than drier, cooler sites (Muller 2003), and decay coefficients are greater on wetter sites (Abbott and Crossley 1982). Furthermore, coarse woody debris loading may be lower in warmer, periodically flooded sites (Van Lear 1993, Muller 2003). Coarse woody debris dynamics can vary greatly within a site as well. Tree species, aspect, soil moisture, and coarse woody debris position can all influence input and decay rate (Van Lear 1993). Additionally, in floodplain habitat, small changes in topography can presumably have large influences on the volume, distribution, and decay state of local woody debris.

Anthropogenic alteration of the forest can alter coarse woody debris dynamics by affecting patterns of succession and disturbance. In many forests, timber harvesting has had the greatest impact on altering coarse woody debris input by replacing aging stands with younger, more vigorous ones (Bragg and Kershner 1999). Unlike clearcutting, natural disturbances rarely eliminate all structure in a stand Franklin 2002. Fire consumes only a portion of the affected structure; and windthrow, one of the most common types of disturbance in southeastern forests, consumes even less. Thinnings, characteristic of longer-rotation sawtimber silviculture, usually remove coarse woody debris candidates (Van Lear 1993). Changes in technology and a growing demand for wood means that small or decaying trees that were historically left on the ground are also

now being removed (Butts 2000). These effects of harvesting on coarse woody debris could be cumulative, as the amount of remaining coarse woody debris usually declines with subsequent forest management rotations (Thompson 2003). When a stand is harvested, the trees most likely to contribute coarse woody debris to the landscape are removed from the stand, and the stand is maintained in a perpetual state of aggradation, because subsequent harvests remove trees before they reach biological maturity. Because younger, more vigorous trees are less susceptible to damage, timber management may not only be altering the nature of major disturbances in managed stands, but perpetually reducing its susceptibility to natural disturbance.

The complex relationship between forest succession and coarse woody debris input has received little attention in the silviculture literature. Few studies address the difference between CWD characteristics in managed forests and in natural stands, let alone investigating thresholds for sustaining various ecological processes. Some studies of eastern forests (Lang and Foreman 1978, MacMillan 1981, MacMillan 1988, Muller and Liu 1991, Tyrell and Crow 1994) have evaluated volume and biomass of woody debris in old-growth stands, but few have made comparisons to managed stands. Nonetheless, silviculturists who want to manage for ecological and economic goals must understand the natural biological legacies such as coarse woody debris and other structural characteristics that influence each stand. Management strategies could be tailored to increase structural heterogeneity through an understanding of the types, number, spatial distribution, and origin of structures in a stand. Silvicultural practices that mimic large to medium scale disturbances should leave snags and downed wood to ensure the continuation of the structural legacy from the previous stand (Sharitz et al. 1992). Although the specific approach will be determined by the region and forest type

being harvested, structural retention at the time of harvest or actively creating structural complexity may help to ease some of the effects of harvest on CWD characteristics (Butts 2000, Franklin 2002).

It is a challenge in managed stands to maintain coarse woody debris as well as other structural components while producing timber commodities (Sharitz et al. 1992). In general, managed stands typically lack the multilayered canopy, diverse tree sizes, and abundant snags and downed wood that exist in a natural forest. Canopy removal can alter coarse woody debris microclimate, and shaded logs can be three to five times cooler than exposed logs (Dupuis 1995). Furthermore, the ecological value of CWD for many animals is largely determined by the size and decay state of the wood (Harmon 1986, Hayes and Cross 1987). Most coarse woody debris left after harvest is too small to benefit forest floor vertebrates. Two studies conducted in eastern hardwoods (Gore and Patterson 1986, Hardt and Swank 1997) found no difference in CWD volume among managed and unmanaged stands, but did find a difference in size class distribution. Clearcutting, one of the most common silvicultural techniques used to regenerate hardwoods in the southeastern United States (Meadows and Stanturf 1997), produces a pulse of woody debris consisting of smaller twigs and branches that are largely unsuitable for forest floor vertebrates or the organisms they prey upon (Abbott and Crossley 1982). Developing forest management guidelines for deadwood must take into account not only woody debris volume, but also size class and decay state distributions.

Preserving biological integrity after harvesting requires that attention be paid to the spatial arrangement of the remaining coarse woody debris as well as the amount and diameter distribution (Franklin 2002). A common post-harvest practice is the pushing of coarse woody debris into slash piles. Although the per-acre volume of coarse woody

debris may not change, the suitable habitat for forest floor wildlife may be greatly reduced by this practice. Because the debris is piled instead of spread across the forest floor, much of it is elevated off the ground and therefore lacks the cool, moist microclimate that would naturally occur (Thompson 2003). Coarse woody debris distribution at the landscape scale depends on the history and pattern of catastrophic disturbance (Kirby 1998). In natural systems, fallen logs are unlikely to be randomly distributed or oriented (Falinski 1978). The distribution of CWD in natural stands is patchy (Muller and Liu 1991), and tends to be most abundant in and around canopy gaps (Kirby 1998). Further insight into the dynamics of CWD will help managers understand the effects of management practices on CWD characteristics, and incorporate this resource to produce more productive, diverse, and healthy forest ecosystems.

The specific objectives of this study were 1) to quantify differences in coarse woody debris characteristics among bottomland hardwood forest stands with different management histories, and 2) to investigate whether differences in tree species composition and forest structure in bottomland hardwood forests influence coarse woody debris characteristics.

Hypotheses and Predictions

These hypotheses and predictions address in specific terms the general thesis which states that forest stands that have not been managed for timber in the relatively recent past will express characteristics associated with structurally mature forests to a greater degree than will stands with a more contemporary management history. Unmanaged stands will be populated with trees that are near or at biological maturity. These mature trees will contribute dead wood from crown breakage and whole tree mortality. These mature trees will also contribute larger snags and pieces of woody debris. Furthermore,

the stand as a whole will be at a later successional stage than a more recently managed stand. Therefore, characteristics of later seral stages, such as canopy break-up, vertical stratification, and species composition shifts will also be more prevalent in unmanaged stands. Differences between managed and unmanaged stands depend on the species-specific life spans of the trees populating each stand. For example, a sixty-year-old stand dominated by water oak (*Quercus nigra*) will have more characteristics of later seral stages than a stand of the same age dominated by sweetgum (*Liquidambar styraciflua*) and sugarberry (*Celtis laevigata*).

Coarse Woody Debris Volume

H_1: Coarse woody debris volume will be different among stands with different management histories

H_0: Coarse woody debris volume will not be different among stands with different management histories

In general, coarse woody debris volume will be the greatest in stands that have been managed least recently. Coarse woody debris volume will increase as the time since last disturbance increases. Coarse woody debris volume should, therefore, be highest at the Bayou Cocodrie NWR old growth natural area, and lowest at the Bogue Chitto NWR clearcut. In general, stands designated as control stands should have higher coarse woody debris volumes than more recently managed stands.

Fine Woody Debris Volume

H_1: Fine woody debris volume will be different among stands with different management histories

H_0: Fine woody debris volume will not be different among stands with different management histories

Fine woody debris volumes will mirror the trends for coarse woody debris volumes. However, because the input of fine woody debris will be constant regardless of stand structure, fine woody debris input, and therefore volume, will be less affected by management history than will coarse woody debris volume.

Coarse Woody Debris Diameter Distribution

H_1: Coarse woody debris diameter distributions will be different among stands with different management histories

H_0: Coarse woody debris diameter distributions will not be different among stands with different management histories

Unmanaged stands will support higher densities of large diameter trees, many of which could be silviculturally overmature trees that are damaged or dying and therefore more likely to contribute woody debris to the stand. Therefore, these stands will have higher densities of larger-diameter pieces of woody debris than will managed stands.

Coarse and Fine Woody Debris Decay Class Distribution

H_1: Coarse woody debris and fine woody debris decay class distributions will be different among stands with different management histories

H_0: Coarse woody debris and fine woody debris decay class distributions will not be different among stands with different management histories

The distribution of woody debris decay classes will be different in stands with different management histories, but this effect will be masked to a degree by the effects of different hydrologic regimes. Stands with less developed canopies will have a larger percentage of pieces of woody debris in advanced stages of decay, due to the increased exposure of the woody debris stock to the elements and the concurrent increase in decay rates.

Stem Density of Standing Dead Trees (Snags)

H_1: Snag densities will be different among stands with different management histories

H_0: Snag densities will not be different among stands with different management histories

Unmanaged stands will contain a higher density of standing dead trees than will managed stands. These stands will have a higher density of silviculturally overmature trees, and therefore the rate of whole-tree mortality will be higher than in managed stands. Snag density will, therefore, be highest at the Bayou Cocodrie NWR old growth natural area, and lowest at the Bogue Chitto NWR clearcut. In general, stands designated as control stands will have higher densities of standing dead trees than more recently managed stands.

Basal Area of Standing Dead Trees

H_1: The basal area of standing dead trees will be different among stands with different management histories

H_0: The basal area of standing dead trees will not be different among stands with different management histories

Unmanaged stands will have a higher basal area of standing dead trees than will managed stands. Unmanaged stands will have a higher density of larger, older trees. These trees are more likely to be damaged or dying and, therefore, more likely to contribute larger dead trees, and dead trees in general, to the stand. Snag basal area will be highest at the Bayou Cocodrie NWR old growth natural area and lowest at the Bogue Chitto NWR clearcut.

Diameter Distribution of Standing Dead Trees

H_1: Standing dead tree diameter distributions will be different among stands with different management histories

H_0: Standing dead tree diameter distributions will not be different among stands with different management histories.

Unmanaged stands will have higher densities of large-diameter standing dead trees than will managed stands. This will be a result of more numerous large, silviculturally overmature trees in unmanaged stands that contribute large dead trees to the stand through single-tree mortality.

METHODS

Study Sites

Study sites were located on the Pearl River Wildlife Management Area (WMA), Bogue Chitto National Wildlife Refuge (NWR), and Bayou Cocodrie NWR (Figure 1). Pearl River WMA and Bogue Chitto NWR are within the Pearl River basin in extreme eastern St. Tammany Parish, LA. While both areas combined cover a gradient of habitats including baldcypress (*Taxodium distichum*) swamps and fresh marsh, all stands surveyed were located within bottomland hardwood forest. There is an elevational gradient that runs from north to south; the northern portion of these two sites (southern terminus of the Bogue Chitto NWR) are flooded less frequently than the southern portion and support more *Pinus* than other areas in the basin. The southern portion of the study area (southern extent of bottomland hardwoods in the Pearl River WMA) are flooded more frequently and with greater intensity than the northern portion. This area has sparse ground cover and a higher density of characteristically flood-tolerant trees such as water tupelo (*Nyssa aquatica*) and baldcypress. Common tree species in the drier portion of these study sites include *Quercus nigra, Quercus laurifolia, Liquidambar styraciflua, Carpinus caroliniana,* and *Ilex opaca.* Common tree species in the more frequently flooded areas include *Taxodium distichum, Nyssa aquatica, Persea borbonia, Fraxinus pennsylvanica.,* and the shrub *Morella cerifera. Acer rubrum* and *Nyssa sylvatica* occur in both groups.

Both Bogue Chitto NWR and the Pearl River WMA were harvested for timber through the 1960s and 1970s. Some areas of the Pearl River WMA may not have been harvested after1960, but incomplete timber records make definitive histories difficult.

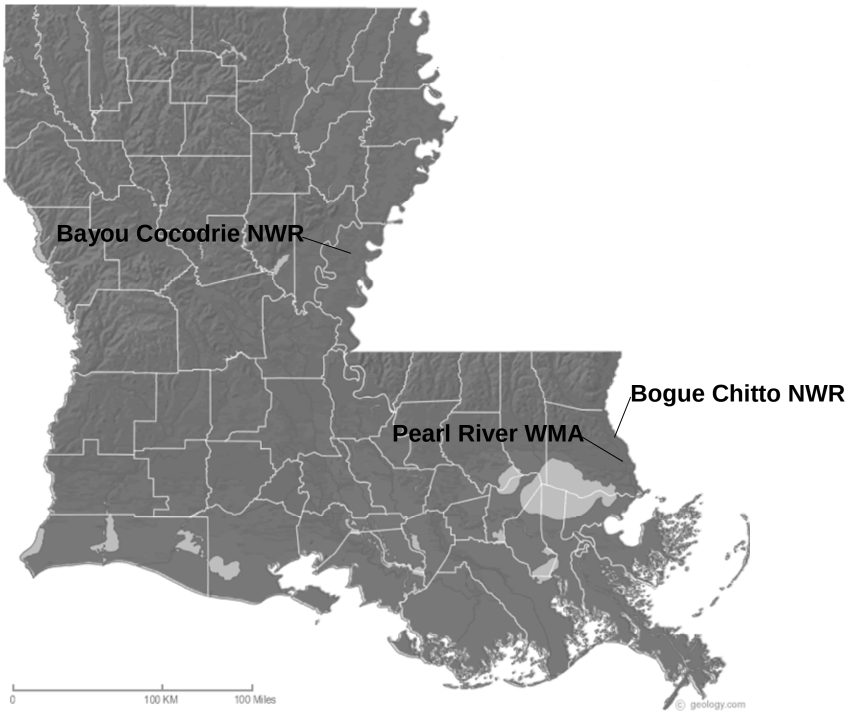

Figure 1. Study sites in southeastern and east central Louisiana

Sampling occurred in designated control stands (those stands least recently harvested) and designated managed stands, where timber management has occurred most recently (Table 1). While several different timber management treatments have been used in stands at Pearl River WMA, only mid-story removal treatments were examined in this study. Mid-story removal treatments included stands where individuals of the dominant mid-story species (*C. caroliniana, L. styraciflua,* and *F. pennsylvanica.*) were removed to promote red oak regeneration.

Control stands and managed stands on the Pearl River WMA included stands at relatively high and low elevations. The mid-story removal stand at a relatively high elevation consisted of a 300 ha compartment harvested in 1986. The mid-story removal stand at a relatively low elevation consisted of a 127 ha compartment harvested in 1987 (Table 2).

On Bogue Chitto NWR, managed stands included a clearcut and a stand where the mid-story was removed by chemical injection. This chemical-injection-mid-story removal stand was implemented to increase understory stem density and create habitat for songbird species of special concern. The tree species targeted for this mid-story removal injection were similar to that of the mid-story removal treatments on the Pearl River WMA. However, the injected trees were not removed, and the coarse woody debris species included *Quercus phellos*, *Quercus nigra*, *Liquidambar styraciflua*, *Carya aquatica*., *Fraxinus*, *pennsylvanica*., *Ulmus crassifolia*, and *Ulmus americana*. The most common understory tree species was *Celtis laevigata*.

Sampling was conducted in two stands at Bayou Cocodrie NWR. The first was the 405-ha Old Growth Natural Area. Although the management history of this stand is disputed by some, portions of it have likely not been harvested in the last 100 years or

Table 1. Name, treatment type employed, and number of transects in each stand at each study site.

Site	*Stand name*	*Treatment type*	*# of transects*
Pearl River WMA	control wet	unmanaged	19
	control dry	unmanaged	15
	managed wet	mechanical mid-story removal	12
	managed dry	mechanical mid-story removal	15
Bayou Cocodrie NWR	old growth natural area	unmanaged	29
	selective cut	selective harvest	13
Bogue Chitto NWR	control	unmanaged	10
	injection / treated	chemical mid-story removal	6
	injection / untreated	unmanaged	8
	clearcut	clearcut	3

Table 2. Tree species, bd-ft/acre, and cords of pulpwood harvested from Pearl River WMA treatment stands.

Treatment	*tree species*	*sawtimber (bd-ft/acre)*	*pulpwood (cords/acre)*
PRWMA managed dry	*L. styraciflua*	800	5
	N. sylvatica	50	0.5
	Ulmus spp.	70	0.3
	Fraxinus spp.	0	0.1
	A. ruburm	50	1
	C. caroliniana	0	4
	Pinus spp.	0	Trace
PRWMA managed wet	*L. styraciflua*	1350	1.2
	N. sylvatica	264	0.1
	Fraxinus spp.	36	0.2
	Populus deltoids	Trace	Trace
	C. caroliniana	0	1.2

more. The tree heights, diameter distributions, and canopy stratification all suggest a stand that is, in part, silviculturally overmature. Preliminary tree ages obtained from increment cores taken by Aaron Pierce in the summer of 2005 revealed tree ages ranging from 60-150 yr. Transects were also established in a recently managed stand near the Old Growth Natural Area. Portions of this compartment were selectively harvested in the mid 1970s and the late 1980s.

Woody Debris Surveys

Coarse woody debris and fine woody debris were surveyed at managed and unmanaged stands along randomly-positioned 100 m transects. This method of transect sampling was selected following a recent evaluation of dead wood survey techniques by Wolendorp et al. (2004), and was cited as being sufficient to yield a coefficient of variation of less than 50%. Coarse woody debris was defined as any piece of down wood with a diameter greater than 7.6 cm (Brown 1974). Fine woody debris (FWD) was defined as any piece of downed wood with a diameter between 2.5 cm and 7.6 cm (Harmon 1986). The diameter of each piece of coarse woody debris encountered along each transect was measured at the point of intersection. This measurement was used to calculate woody debris volume per unit area (see Statistical Analysis). Each piece of woody debris was assigned to a decay class of 1-5: Class 1 consisted of debris with no visible decay; Class 2 consisted of debris with bark sloughing or slight visible decay, but with its cylindrical shape still intact; Class 3 consisted of debris losing their cylindrical structure; Class 4 consisted of woody debris with slight fragmentation; and Class 5 was nearly completely disintegrated debris that was distinguishable as coarse woody debris. This method was modified from Tyrell and Crow (1994). The heights and diameters at

breast height (dbh) of all standing dead wood (snags) within 3 m of the transect center were also measured. Standing dead wood was defined as dead trees having a dbh greater than 7.6 cm and a height greater than 2 m.

Vegetation Surveys

To relate dead wood characteristics to species composition and stand structure, vegetation surveys were conducted along the sampling transect. The stand structure at each transect was classified in the field as even aged or uneven aged, predominantly based on live tree diameters and canopy structure. The stand development at each transect was characterized as initiation, stem exclusion, transition, or mature old-growth (Oliver 1980).

All trees were tallied and identified to species using the point-centered-quarter survey technique (Cottam and Curtis 1956). Eleven points were established 10 m apart along each 100 m transect. At each point, an imaginary line was run perpendicular to the sampling transect. The line and transect divided the stand into four quarters. In each quarter, the distance to the nearest tree to the sampling point was measured.

All trees (dbh > 7.6 cm) were classified based on crown position as either dominant, co-dominate / intermediate, or suppressed. A tree was considered dominant if the tree canopy was above all surrounding trees. A co-dominant / intermediate tree was defined as having its canopy beneath a dominant tree, and receiving full sun from directly above but not receiving side light. A tree was considered suppressed if it received no direct sunlight. This method was modified from Oliver and Larson (1996). Each tree was also given a stress rating of 1-4 based on the estimated mortality of branches within the crown (King 1998), with class 1 being the healthiest trees and class 4 being dead stems. The dbh of each tree was measured with a standard diameter tape. The height of the five

tallest trees on each transect was measured with a clinometer. Canopy cover was measured at the center of each point-centered-quarter using a spherical densitometer.

Statistical Analysis

The volume of CWD and FWD was calculated at each transect. Assuming that CWD (diameter > 7.6 cm) and FWD (2.5 cm < diameter > 7.6 cm) were cylindrical, horizontal, and randomly distributed, the volume of downed woody debris was calculated using:

$$V = \pi^2 * \sum d^2 / 8L$$

where V = volume per unit area, d = piece diameter at point of intersection, and L = length of sampling line (Van Wagner 1968). For all stands, the proportion of the total pieces of downed woody debris in each decay class was determined, as was the proportion of the total pieces of CWD in selected diameter classes. Because of the small range of diameters, FWD diameter was not analyzed.

The density of standing snags at each transect was determined by tallying the number of snags within each 600 m^2 belt transect and scaling up to the density of snags per hectare by multiplying by 10000/600. The basal area per ha of standing snags at each transect was determined by summing the basal area of all snags at each 600 m^2 belt transect and multiplying by [10000/600]. For all stands, the proportion of total standing snags in selected diameter classes was determined.

The proportion of total live stems in selected diameter classes was calculated at each stand. Total density and total basal area of live stems at each transect and relative density and relative cover of each tree species at each transect were calculated (Mitchell 2001). The point-centered-quarter method has no fixed area and therefore relies on the distance-

to-nearest-tree measurement to arrive at a theoretical stem density value based on the average distance between trees at each transect and assumes that trees are regularly distributed throughout a forest. The total density of live stems is the total number of uniformly distributed trees that could be expected in a forest of one hectare where the minimum distance between trees is given by the mean distance χ. That is,

$$\text{Total density of live stems} = \text{number of trees / ha.}$$

But in a uniform forest each tree occupies an area $(\chi\ m)^2$. So,

$$\text{Total density of live stems} = 10{,}000\ m^2\ ha^{-1} / (\chi\ m)^2\ tree^{-1}.$$

The relative density of live stems for each tree species is the proportion of quarters at each transect in which the species was found multiplied by the total density of lives stems at that transect.

The accompanying basal area values were calculated in part by using the total stem density and relative density values for each sampling transect. At each transect, the area covered by each tree is calculated from the dbh measurement and using the formula for the area of a circle. Then, the average area covered by each tree species is calculated. This value is then multiplied by the relative stem density of that species to obtain basal area in m^2/ha. The sum of the basal areas for all species at each transect is the total basal area for that sampling transect.

The mean frequency of each tree species each stand was estimated. Frequency was defined as the percentage of sample points at each transect in which a tree species occurs. To normalize for the fact that the total frequencies of all tree species will sum to more than 100%, the relative frequency is computed as the frequency of a species at a transect divided by the total frequency of all species at the transect. Higher relative frequencies indicate more uniform spatial distributions, while lower frequencies indicate clumping.

Species composition at each stand was described using importance values. The importance value of each tree species was defined as the sum of the relative density, relative cover, and relative frequency values for that species at each stand. For each stand, the proportion of total trees in each tree stress rating and crown class was determined.

Mean CWD and FWD volume, snag density and basal area, live tree density and basal area, canopy height, and canopy cover were calculated for each of the ten stands. Also, the individual managed and unmanaged stands within each site were combined, and the above variables were calculated for these combined managed and unmanaged stands. Analysis of variance and Tukey's lsd tests (Littell 1991) were used to compare the ranked sums of these variables among the ten stands and between managed and unmanaged stands at each site. A randomized block design was used, blocking for site and treating each stand as an experimental unit. Transects within each stand were treated as sub-samples. Below is an example of the model statement used in SAS:

```
proc mixed data= CWD;
classes site stand transect;
model volume= site stand site*stand;
random transect(site*stand);
lsmeans site stand site*stand / pdiff adjust = tukey;
```

Study sites and individual stands were treated as fixed effects, while transects within stands were treated as random effects. Two groups were considered to be different when $p \leq 0.05$. The Bogue Chitto NWR clearcut treatment was not included in comparisons of combined managed and unmanaged stands because it was the only clearcut.

RESULTS

Tree Species Importance Values

Species composition was similar among the managed and unmanaged stands at Pearl River WMA (Table 3). As expected, species composition differed between the wet and dry stands at Pearl River WMA, although few are particularly striking. The most important tree species at all Pearl River WMA stands were *Q. nigra*, *L. styraciflua*, and *C. caroliniana*. At the Pearl River WMA control dry stand, *L. styraciflua* was the most important species, while *Q. nigra* was most important at all other Pearl River stands. The most important tree at the Bayou Cocodrie NWR old growth natural area was *L. styraciflua,* followed closely by *C. laevigata*. At the Bayou Cocodrie NWR selective cut stand, *L. styraciflua* also was the most important species, followed by *Q. texana* and *F. pennsylvanica* At Bogue Chitto NWR, *L. styraciflua* was the most important species at all stands.

Coarse Woody Debris Volume

Coarse woody debris volumes ranged from 23.29 m^3/ha +/- 21.7 m^3/ha at the Bayou Cocodrie NWR selective cut to 1.07 m^3/ha +/- 1.23 m^3/ha at the Bogue Chitto clearcut. When coarse woody debris volumes were compared between combined managed and unmanaged stands at each study site (Figure 2), a difference was found between the Bayou Cocodrie NWR old growth natural area and the Pearl River WMA managed stands but this difference was attributed to differences between the study sites. When coarse woody debris volumes were compared among all ten stands (Table 4), the Bogue Chitto NWR clearcut was found to be different from the Bayou Cocodrie NWR old growth natural area and the Bogue Chitto NWR injection / untreated stand.

Table 3. Relative density, relative cover, relative frequency, and Importance Values (IV) of all tree species at each stand.

	Species	Relative Density	Relative Cover	Relative Frequency	IV
Pearl River WMA control wet	*Quercus nigra*	15.3%	30.2%	15.0%	0.61
	Liquidambar styraciflua	23.9%	24.2%	0.3%	0.48
	Carpinus caroliniana	20.8%	4.7%	0.3%	0.26
	Magnolia virginiana	1.2%	1.6%	21.2%	0.24
	Halesia diptera	0.1%	0.0%	20.4%	0.21
	Acer rubrum	9.3%	7.5%	2.3%	0.19
	Quercus laurifolia	6.2%	11.3%	0.6%	0.18
	Nyssa sylvatica	6.3%	3.3%	5.7%	0.15
	Ilex opaca	3.8%	2.7%	4.6%	0.11
	Diospyros virginiana	0.4%	0.3%	10.3%	0.11
	Quercus michauxii	2.3%	4.4%	1.4%	0.08
	Quercus texana	0.3%	0.5%	6.6%	0.07
	Fraxinus pennsylvanica	2.2%	2.7%	0.1%	0.05
	Ilex deciduas	1.6%	0.3%	2.5%	0.04
	Ulmus americana	1.4%	0.9%	1.8%	0.04
	Taxodium distichum	1.4%	1.4%	1.0%	0.04
	Nyssa aquatica	0.8%	1.4%	1.0%	0.03
	Sapium sebiferum	0.5%	0.5%	2.1%	0.03
	Carya aquatica.	0.8%	0.7%	0.9%	0.03
	Pinus glabra	0.3%	1.1%	0.3%	0.02
	Planera aquatica	0.6%	0.2%	0.6%	0.01
	Quercus lyrata	0.4%	0.1%	0.5%	0.01
	Salix nigra	0.3%	0.2%	0.4%	0.01
Pearl River WMA control dry	*Liquidambar styraciflua*	20.6%	33.0%	19.0%	0.73
	Carpinus caroliniana	21.1%	5.5%	17.5%	0.44
	Quercus nigra	7.9%	14.4%	8.6%	0.31
	Ilex opaca	11.7%	7.8%	11.2%	0.31
	Nyssa sylvatica	9.9%	4.8%	10.1%	0.25
	Quercus michauxii	3.9%	10.7%	4.5%	0.19
	Magnolia virginiana	5.3%	7.2%	6.3%	0.19
	Acer rubrum	5.2%	4.3%	5.9%	0.15
	Ulmus americana	3.6%	2.7%	4.2%	0.11
	Quercus laurifolia	2.3%	2.7%	2.6%	0.08
	Halesia diptera	2.7%	0.3%	3.4%	0.06
	Fraxinus pennsylvanica	1.1%	1.4%	1.3%	0.04
	Ilex deciduas	1.7%	0.2%	1.8%	0.04
	Carya aquatica.	0.8%	1.3%	1.0%	0.03
	Magnolia grandiflora	0.8%	1.4%	0.7%	0.03
	Pinus glabra	0.6%	1.4%	0.8%	0.03
	Fagus grandifolia	0.3%	0.2%	0.3%	0.01
	Taxodium distichum	0.2%	0.2%	0.2%	0.01

(Table 3 continued)

	Quercus phellos	0.2%	0.1%	0.2%	0.01
	Diospyros virginiana	0.2%	0.1%	0.2%	0.00
	Betula nigra	0.2%	0.2%	0	0.00
	Morus rubra	0.2%	0.0%	0.2%	0.00
Pearl River WMA managed wet	*Quercus nigra*	19.0%	38.6%	19.6%	0.77
	Liquidambar styraciflua	31.3%	11.7%	24.6%	0.68
	Carpinus caroliniana	16.9%	7.0%	15.5%	0.39
	Acer rubrum	4.6%	8.4%	5.1%	0.18
	Nyssa sylvatica	6.8%	2.8%	8.1%	0.18
	Ilex opaca	5.1%	6.0%	6.3%	0.17
	Quercus michauxii	2.1%	6.7%	2.8%	0.12
	Magnolia virginiana	2.3%	5.2%	2.8%	0.10
	Carya aquatica.	1.7%	5.0%	1.7%	0.08
	Ulmus americana	2.3%	2.4%	2.9%	0.08
	Sapium sebiferum	2.1%	1.5%	2.7%	0.06
	Quercus lyrata	0.9%	2.0%	1.3%	0.04
	Ilex deciduas	1.0%	1.1%	1.1%	0.03
	Persea borbonia	1.1%	0.3%	1.5%	0.03
	Fraxinus pennsylvanica	0.8%	0.6%	1.3%	0.03
	Halesia diptera	0.8%	0.1%	1.1%	0.02
	Quercus laurifolia	0.4%	0.2%	0.5%	0.01
	Diosyros virginiana	0.4%	0.2%	0.5%	0.01
	Betula nigra	0.4%	0.2%	0.4%	0.01
	Planera aquatica	0.2%	0.1%	0.0%	0.00
Pearl River WMA managed dry	*Quercus nigra*	19.1%	30.2%	17.8%	0.67
	Liquidambar styraciflua	19.9%	16.6%	3.4%	0.40
	Carpinus caroliniana	20.1%	10.3%	0.6%	0.31
	Halesia diptera	5.6%	1.7%	18.6%	0.26
	Ilex opaca	7.1%	5.8%	7.7%	0.21
	Magnolia virginiana	0.5%	2.3%	17.1%	0.20
	Carya aquatica.	2.7%	6.1%	3.4%	0.12
	Acer rubrum	3.6%	3.9%	4.4%	0.12
	Ulmus americana	3.2%	3.7%	3.4%	0.10
	Nyssa sylvatica	3.5%	2.4%	4.1%	0.10
	Ilex deciduas	2.6%	0.7%	5.8%	0.09
	Quercus michauxii	2.0%	5.0%	0.6%	0.08
	Sapium sebiferum	2.9%	1.8%	1.7%	0.06
	Magnolia grandiflora	0.5%	3.5%	2.4%	0.06
	Ligustrum sinense	0.5%	0.1%	3.0%	0.04
	Persea borbonia	1.2%	0.5%	1.4%	0.03
	Melia azedarach	1.2%	0.2%	1.3%	0.03

(Table 3 continued)

	Fagus grandifolia	0.3%	2.0%	0.4%	0.03
	Fraxinus pennsylvanica	1.4%	0.7%	0.4%	0.02
	Taxodium distichum	0.3%	1.3%	0.2%	0.02
	Morus rubra	0.6%	0.2%	0.8%	0.02
	Diospyros virginiana	0.5%	0.3%	0.4%	0.01
	Crataegus spp.	0.3%	0.1%	0.6%	0.01
	Quercus lyrata	0.2%	0.6%	0.2%	0.01
	Albizia julibrissin	0.2%	0.1%	0.2%	0.00
	Sassafras albidum	0.2%	0.0%	0.2%	0.00
	Quercus laurifolia	0.2%	0.1%	0.0%	0.00
Bayou Cocodrie NWR old growth	*Liquidambar styraciflua*	18.6%	25.2%	15.5%	0.59
	Celtis laevigata	18.6%	6.6%	16.0%	0.41
	Quercus texana	7.3%	9.9%	7.7%	0.25
	Fraxinus pennsylvanica	8.7%	6.3%	8.3%	0.23
	Quercus lyrata	6.7%	9.2%	6.7%	0.23
	Quercus phellos	4.5%	11.6%	5.2%	0.21
	Carya pennsylvanica	5.7%	6.0%	6.5%	0.18
	Quercus nigra	4.0%	7.8%	4.9%	0.17
	Ulmus americana	5.5%	3.9%	6.7%	0.16
	Acer rubrum	5.2%	1.6%	5.9%	0.13
	Ulmus crassifolia	3.6%	3.3%	3.9%	0.11
	Ilex deciduas	3.6%	0.2%	4.0%	0.08
	Taxodium distichum	2.1%	2.9%	2.0%	0.07
	Nyssa aquatica	1.7%	2.7%	1.6%	0.06
	Crataegus spp	1.6%	0.1%	2.0%	0.04
	Gleditsia aquatica	0.5%	1.1%	0.6%	0.02
	Populus deltoides	0.3%	1.1%	0.4%	0.02
	Planera aquatica	0.7%	0.2%	0.9%	0.02
	Nyssa aquatica	0.5%	0.0%	0.6%	0.01
	Diospyros virginiana	0.3%	0.1%	0.4%	0.01
	Quercus laurifolia	0.3%	0.0%	0.3%	0.01
	Platanus occidentalis	0.1%	0.0%	0.0%	0.00
Bayou Cocodrie NWR selective cut	*Liquidambar styraciflua*	21.7%	25.6%	17.7%	0.65
	Quercus texana	10.0%	17.1%	10.2%	0.37
	Fraxinus pennsylvanica	9.8%	9.1%	9.5%	0.28
	Ulmus americana	8.7%	7.2%	9.5%	0.25
	Celtis laevigata	8.9%	3.1%	8.5%	0.21
	Quercus phellos	5.9%	8.7%	5.7%	0.20
	Quercus lyrata	5.3%	5.9%	5.8%	0.17
	Quercus nigra	5.8%	3.7%	6.0%	0.15
	Ulmus crassifolia	4.7%	3.6%	5.2%	0.14
	Carya aquatica	3.7%	3.7%	4.5%	0.12
	Nyssa aquatica	3.5%	5.7%	2.4%	0.12

(Table 3 continued)

	Acer rubrum	4.5%	0.9%	5.4%	0.11
	Taxodium distichum	2.6%	3.9%	2.6%	0.09
	Gleditsia aquatica	0.7%	1.5%	0.9%	0.03
	Ilex deciduas	1.2%	0.2%	1.4%	0.03
	Acer negundo	0.9%	0.2%	1.2%	0.02
	Crataegus spp.	0.7%	0.1%	0.8%	0.02
	Planera aquatica	0.5%	0.2%	0.7%	0.01
	Morus rubra	0.5%	0.1%	0.7%	0.01
	Diospyros virginiana	0.3%	0.0%	0.5%	0.01
	Nyssa sylvatica	0.2%	0.2%	0.2%	0.01
	Cornus florida	0.2%	0.0%	0.2%	0.00
Bogue Chitto NWR control	*Liquidambar styraciflua*	26.4%	37.6%	23.9%	0.88
	Quercus laurifolia	13.9%	23.4%	13.2%	0.50
	Carpinus caroliniana	22.7%	5.8%	19.3%	0.48
	Acer rubrum	7.3%	5.1%	7.6%	0.20
	Quercus lyrata	5.5%	6.4%	6.9%	0.19
	Fraxinus pennsylvanica	4.1%	3.8%	4.8%	0.13
	Quercus texana	2.3%	5.9%	3.2%	0.11
	Nyssa aquatica	3.4%	3.0%	1.4%	0.08
	Halesia diptera	4.1%	0.3%	2.2%	0.07
	Nyssa sylvatica	2.3%	0.7%	3.2%	0.06
	Carya aquatica	1.8%	2.3%	1.9%	0.06
	Ilex deciduas	2.3%	1.0%	2.4%	0.06
	Quercus nigra	1.1%	0.3%	4.0%	0.05
	Ilex opaca	1.4%	1.1%	1.8%	0.04
	Taxodium distichum	1.6%	1.4%	1.2%	0.04
	Ulmus americana	0.7%	1.0%	0.9%	0.03
	Quercus phellos	0.5%	0.7%	0.6%	0.02
	Celtis laevigata	0.7%	0.1%	0.9%	0.02
	Diospyros virginiana	0.5%	0.3%	0.5%	0.01
	Morus rubra	0.2%	0.0%	0.3%	0.01
Bogue Chitto NWR injection/treated	*Liquidambar styraciflua*	31.1%	46.2%	22.4%	1.00
	Quercus nigra	12.1%	16.9%	12.5%	0.42
	Nyssa sylvatica	14.8%	4.4%	14.2%	0.33
	Quercus laurifolia	7.6%	14.2%	8.7%	0.30
	Carpinus caroliniana	6.4%	1.1%	7.3%	0.15
	Acer rubrum	5.7%	3.1%	5.7%	0.15
	Carya aquatica	3.0%	5.0%	4.1%	0.12
	Ilex deciduas	4.5%	0.6%	5.8%	0.11
	Ilex opaca	4.2%	0.6%	5.5%	0.10
	Quercus lyrata	2.3%	1.7%	2.9%	0.07

(Table 3 continued)

	Ulmus americana	2.3%	1.1%	3.2%	0.07
	Halesia diptera	2.3%	1.0%	3.1%	0.06
	Quercus texana	1.5%	2.0%	2.0%	0.06
	Taxodium distichum	0.8%	0.3%	1.0%	0.02
	Fraxinus pennsylvanica	0.8%	0.1%	1.2%	0.02
	Nyssa aquatica	0.4%	1.1%	0.5%	0.02
	Quercus michauxii	0.4%	0.6%	0.5%	0.02
Bogue Chitto NWR injection/untreated	*Liquidambar styraciflua*	21.6%	32.1%	19.8%	0.74
	Carpinus caroliniana	17.9%	5.6%	15.7%	0.39
	Quercus laurifolia	8.8%	17.7%	9.7%	0.36
	Quercus nigra	0.3%	19.0%	8.4%	0.28
	Acer rubrum	9.4%	4.6%	9.2%	0.23
	Nyssa sylvatica	8.8%	3.7%	8.4%	0.21
	Ilex deciduas	6.8%	1.2%	7.7%	0.16
	Ilex opaca	6.3%	1.2%	6.0%	0.13
	Planera aquatica	7.4%	0.9%	0.3%	0.09
	Quercus texana	2.3%	3.4%	2.9%	0.09
	Quercus lyrata	2.5%	2.6%	2.5%	0.08
	Carya aquatica	2.0%	2.8%	2.5%	0.07
	Ulmus americana	2.0%	0.9%	2.1%	0.05
	Morus rubra	1.4%	1.3%	1.7%	0.04
	Halesia diptera	0.9%	0.2%	1.1%	0.02
	Quercus michauxii	0.3%	1.3%	0.4%	0.02
	Platanus occidentalis	0.3%	0.8%	0.4%	0.01
	Sapium sebifera	0.6%	0.2%	0.7%	0.01
	Fraxinus pennsylvanica	0.3%	0.6%	0.4%	0.01
	Crataegus spp.	0.3%	0.0%	0.4%	0.01
Bogue Chitto NWR clearcut	*Carya aquatica.*	15.2%	5.0%	13.9%	0.34
	Quercus texana	1.5%	1.1%	2.4%	0.05
	Pinus sp.	22.0%	36.8%	20.7%	0.79
	Acer rubrum	2.3%	1.7%	2.3%	0.06
	Quercus michauxii	9.1%	3.4%	10.7%	0.23
	Liquidambar styraciflua	38.6%	34.8%	35.4%	1.09
	Quercus nigra	8.3%	14.7%	9.8%	0.33
	Morella cerifera	1.5%	1.5%	2.4%	0.05
	Platanus occidentalis	0.0%	1.0%	2.3%	0.03

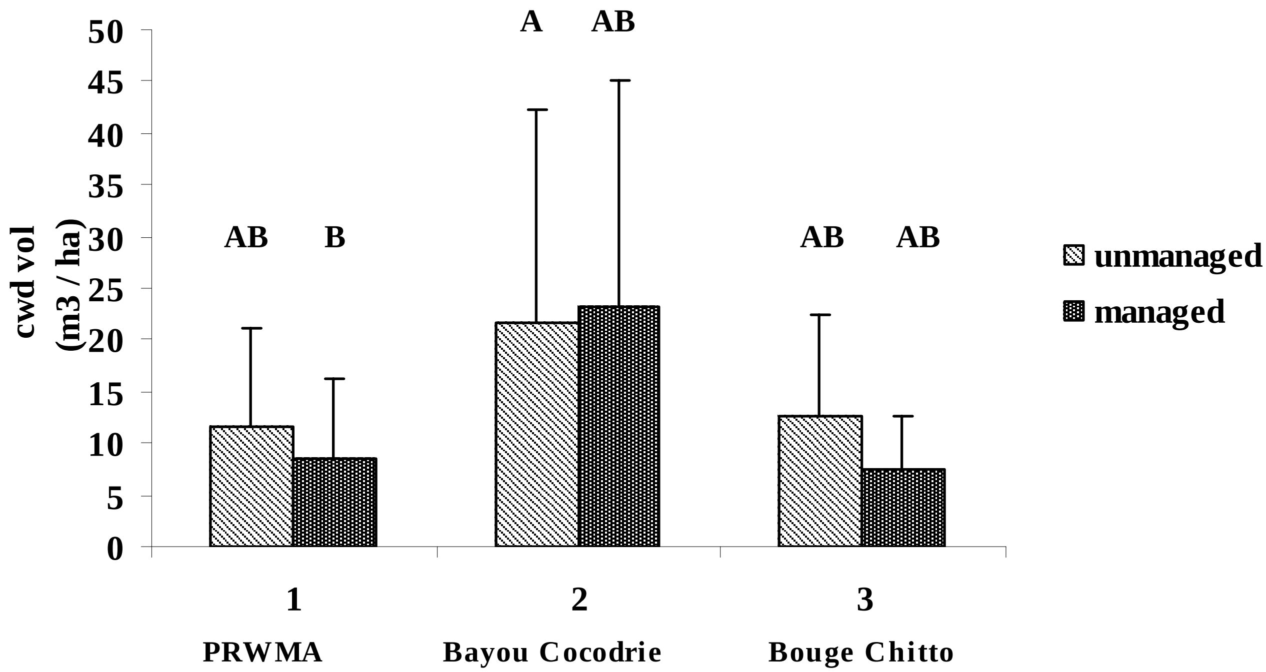

Figure 2. Mean coarse woody debris volume (m^3 ha^{-1}) +/- 1 SD of managed and unmanaged stands at each study site. Means sharing a letter do not differ ($p > 0.05$).

Table 4. Mean volume of coarse woody debris ($m^3\ ha^{-1}$), SD, and coefficient of variation at each stand. Means sharing a letter do not differ ($p > 0.05$).

Site	*Stand name*	*Mean (m^3/ha.)*	*Std. dev.*	*CV*
Pearl River WMA	control wet	13.31 AB	10.69	80.32%
	control dry	9.51 AB	7.01	73.75%
	managed wet	9.21 AB	9.74	105.76%
	managed dry	8.09 AB	6.04	74.68%
Bayou Cocodrie NWR	old growth natural area	21.73 A	20.51	94.43%
	selective cut	23.29 AB	21.71	93.19%
Bogue Chitto NWR	Control	9.26 AB	8.34	90.01%
	Injection / untreated	16.99 A	10.10	59.47%
	Injection / treated	7.43 AB	5.21	70.10%
	Clearcut	1.07 B	1.23	115.32%

Fine Woody Debris Volume

Fine woody debris volumes ranged from 4.98 m^3/ha +/- 1.73 m^3/ha at the Bayou Cocodrie NWR old growth area to 0.81 m^3/ha +/- 0.39 m^3/ha at the Bogue Chitto NWR clearcut. When comparing the combined managed and unmanaged stands at each study site (Figure 3), the Bayou Cocodrie NWR old growth natural area differed from the Bogue Chitto NWR managed stands and Pearl River WMA managed and unmanaged stands. However, these differences were due to variation among the study sites. A significant difference at the stand level was detected between the Bogue Chitto NWR unmanaged stands and the Pearl River WMA managed stands. When comparing FWD volumes among all ten stands (Table 5), the Bayou Cocodrie NWR old growth natural area had a greater volume of FWD than all stands at the Pearl River WMA, the Bogue Chitto NWR control, injection / treated stand, and the Bogue Chitto NWR clearcut.

Coarse Woody Debris Diameter distribution

The distribution of coarse woody debris diameter was negatively skewed at all stands (Figures 4a-4j). At each stand, more than half of the pieces of coarse woody debris encountered were less than 15.0 cm in diameter. Bayou Cocodrie NWR selective cut had the highest percentage of pieces of coarse woody debris in larger diameter classes (Figure 5), while the largest individual pieces of woody debris were in the Bayou Cocodrie NWR old growth natural area. All woody debris encountered at the Bogue Chitto NWR clearcut was smaller than 15.0 cm in diameter. Both managed stands at the Pearl River WMA had a higher percentage of pieces of coarse woody debris in larger diameter classes than did the control stands.

The relative frequency (total number of pieces with diameter > 50 cm divided by

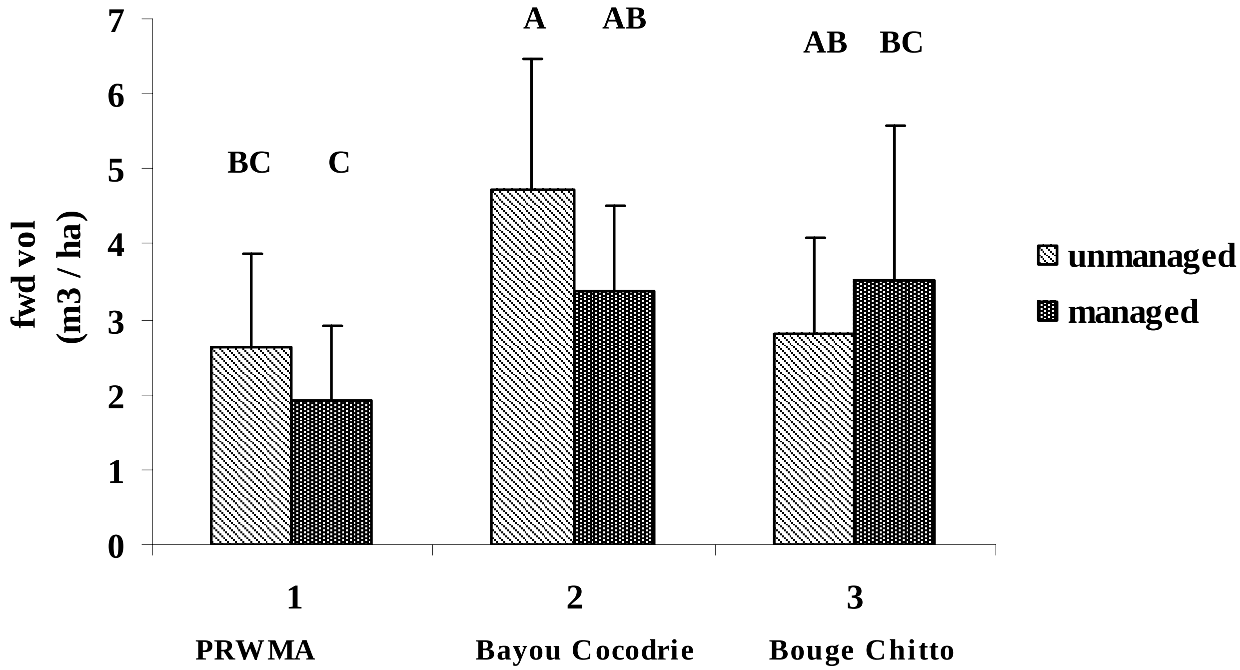

Figure 3. Mean fine woody debris volume (m^3 ha^{-1}) +/- 1 SD of managed and unmanaged stands at each study site. Means sharing a letter do not differ ($p > 0.05$).

Table 5. Mean volume of fine woody debris (m^3 ha^{-1}), SD, and coefficient of variation at each stand. Means sharing a letter do not differ ($p > 0.05$).

Site	*Stand name*	*Mean (m^3/ha.)*	*Std. dev.*	*CV*
Pearl River WMA	control wet	2.95 BC	1.38	46.63%
	control dry	2.21 CD	0.84	38.04%
	managed wet	2.33 CD	0.96	41.07%
	managed dry	1.62 D	0.95	58.84%
Bayou Cocodrie NWR	old growth natural area	4.98 A	2.15	43.26%
	selective cut	3.38 ABC	1.15	33.85%
Bogue Chitto NWR	control	2.86 BCD	1.27	44.38%
	injection / untreated	4.59 AB	2.15	46.82%
	injection / treated	2.12 CD	0.61	28.84%
	clearcut	0.81 D	0.39	48.66%

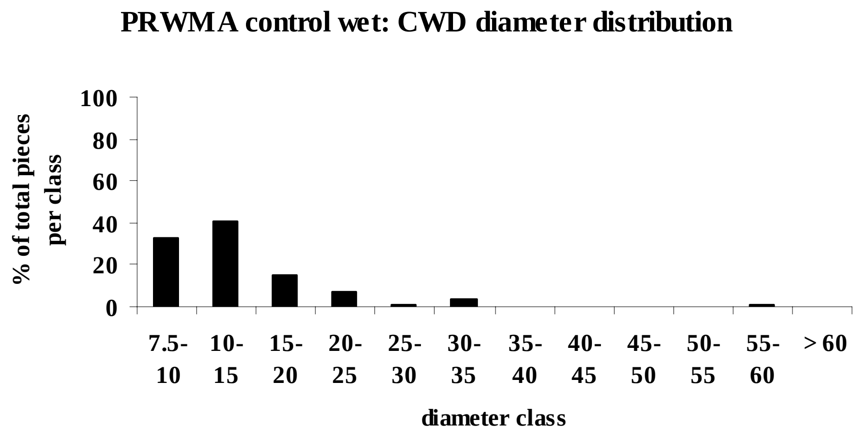

Fig 4a.

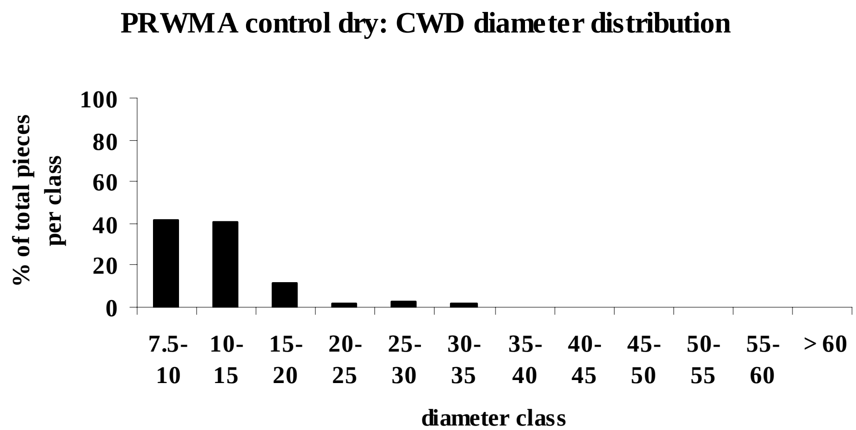

Fig 4b.

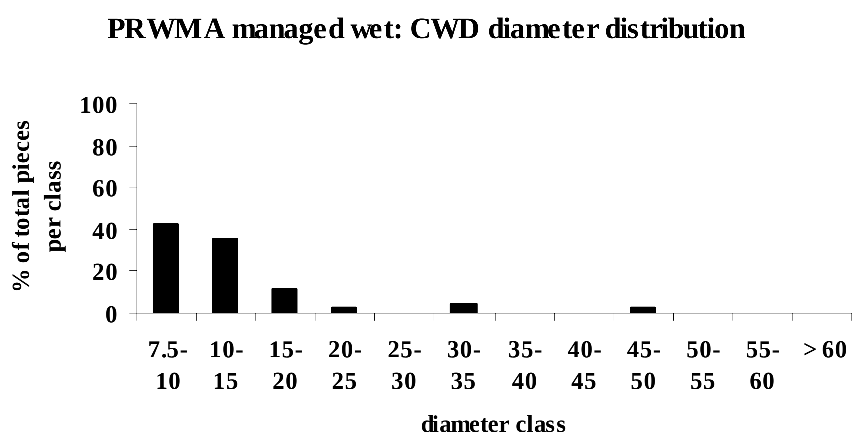

Fig 4c.

Figures 4a-4j. Distribution of coarse woody debris diameter classes (cm) at each stand.

(Fig. 4a-4j continued)

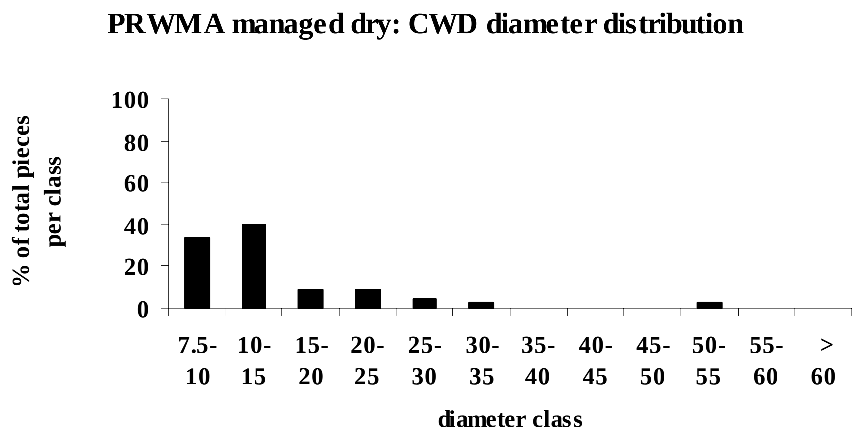

Fig. 4d.

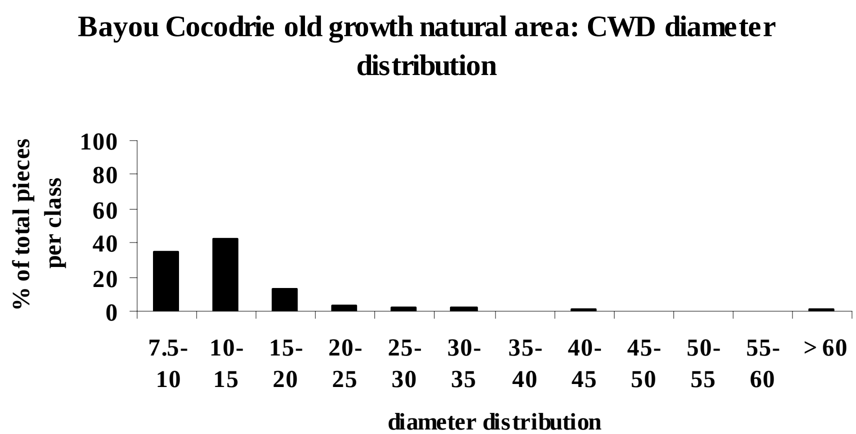

Fig 4e.

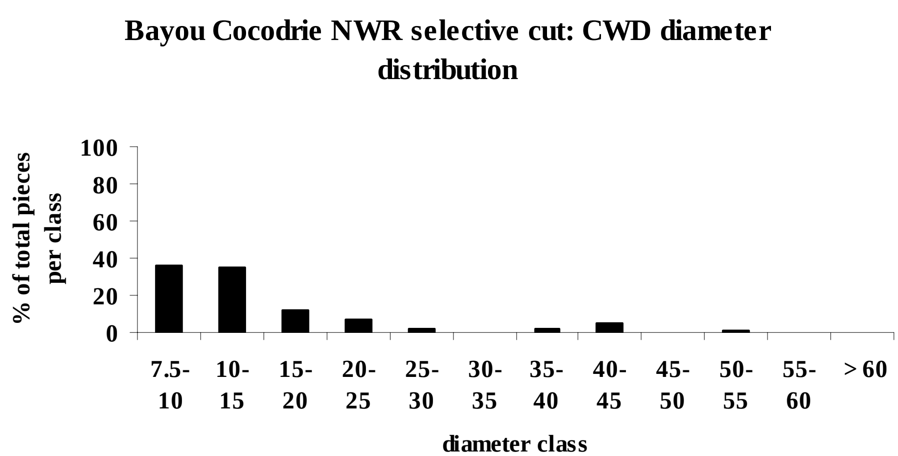

Fig. 4f.

(Fig. 4a-4j continued)

Bouge Chitto NWR control: CWD diameter distribution

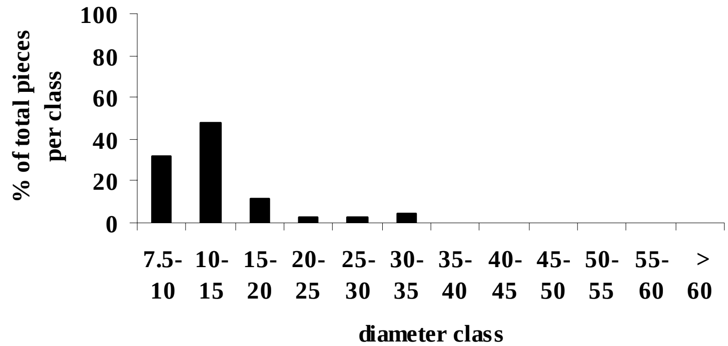

Fig 4g.

Bouge Chitto NWR injection/treated: CWD diameter distribution

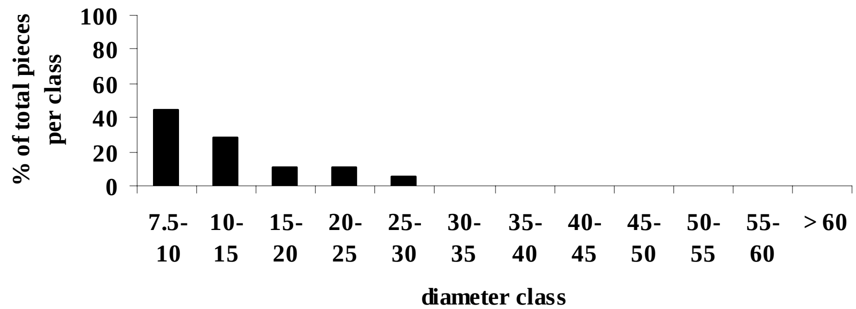

Fig 4h.

Bouge Chitto NWR injection/untreated: CWD diameter distribution

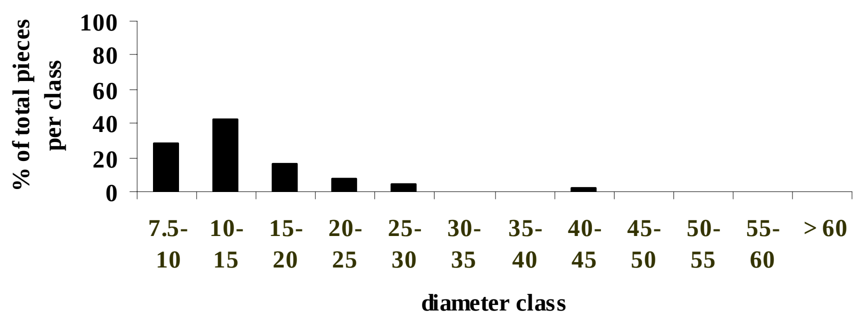

Fig 4i.

(Fig. 4a-4j continued)

Bogue Chitto NWR clearcut: CWD diameter distribution

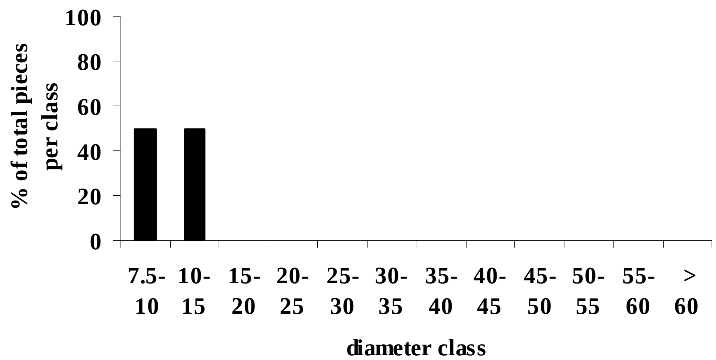

Fig 4j

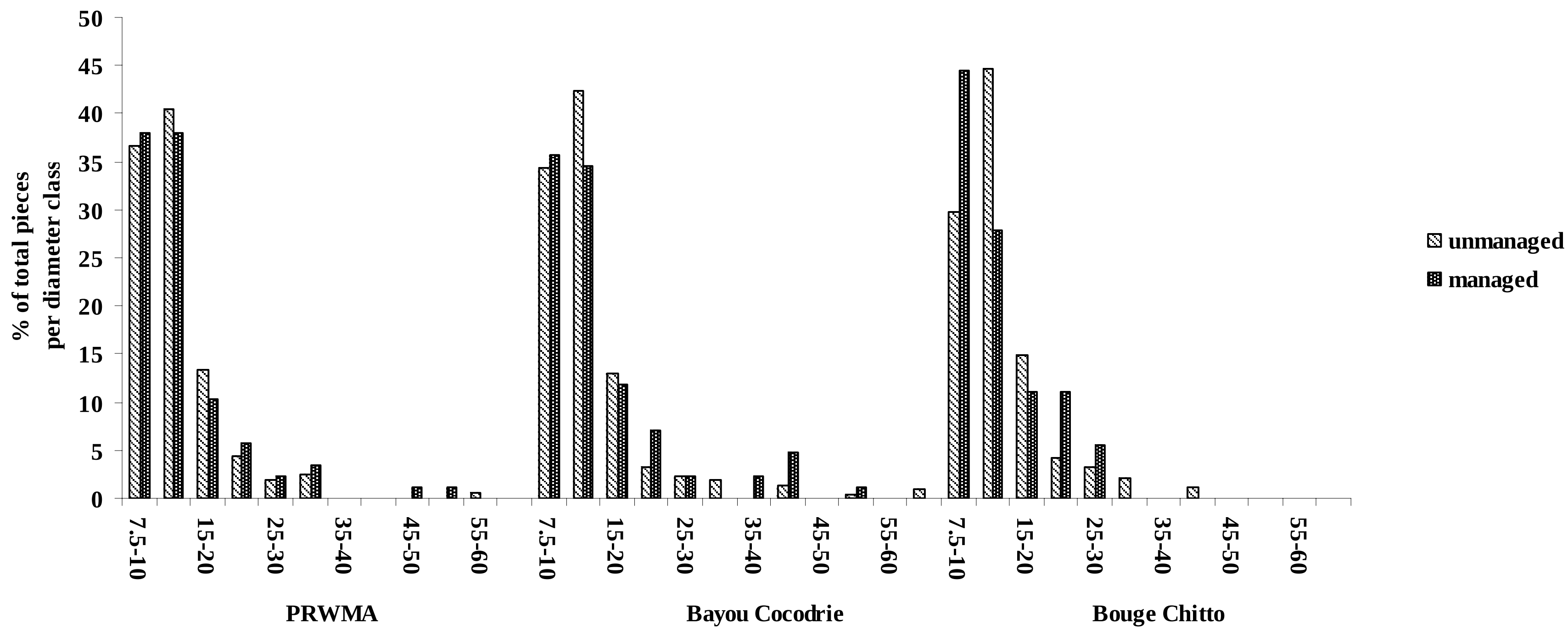

Figure 5. Distribution of coarse woody debris diameter classes (cm) at managed and unmanaged stands at each study site.

the number of transects sampled) of large-diameter downed woody debris at Bayou Cocodrie old growth natural area was 0.24. This relative frequency was three times that of any other stand. Most other stands had no pieces of woody debris with diameters that large except Bayou Cocodrie NWR selective cut (relative frequency = .08), Pearl River WMA control wet (relative frequency = .07) and Pearl River WMA managed dry (relative frequency = .05).

There were no differences in mean or median diameters among the ten stands (Table 6). Mean coarse woody debris diameters ranged from 14.4 cm +/- 10.0 cm at the Bayou Cococdrie NWR selective cut to 11.0 cm +/- 0.0 cm at the Bogue Chitto NWR clearcut; and median diameters ranged from 11.0 cm at both the Bayou Cocodrie NWR old growth natural area and the Bogue Chitto NWR clearcut, to 8.0 cm at the Bogue Chitto NWR injection/untreated stand.

Coarse Woody Debris and Fine Woody Debris Decay Class

The managed stands at Bayou Cocodrie NWR had a higher percentage of total coarse woody debris in more advanced decay classes than did the unmanaged stands (Figure 6). Also, decay class 5 was only encountered in unmanaged stands at Pearl River WMA and Bogue Chitto NWR.

The decay state of CWD was skewed towards more advanced decay classes across all stands (Figures 7a-7j). The highest proportion of pieces of woody debris was classified as decay class 4 in all stands. The distribution of pieces of FWD across decay classes was more uniform, with slightly smaller proportions being in decay class 1, and decay classes 2 through 4 each having similar numbers of FWD (Figures 8a-8j). When the managed and unmanaged stands at each site were pooled and compared, the pattern remained the same.

Table 6. Mean and median estimates of coarse woody debris diameters (cm) and coefficient of variation at each stand. Means sharing a letter do not differ (p > 0.05).

Site	*Stand name*	*Mean diameter (cm)*	*Median diameter (cm)*	*CV*
Pearl River WMA	control wet	13.4 A	10.5	58%
	control dry	11.65 A	10	42.4%
	managed wet	12.63 A	10	64.3%
	managed dry	13.89 A	10	63.4%
Bayou Cocodrie NWR	old growth natural area	14.23 A	11	75.5%
	selective cut	14.4 A	10	69.4%
Bogue Chitto NWR	control	12.51 A	10	48.3%
	injection / untreated	13.4 A	8	50%
	injection / treated	12.81 A	10	47.2%
	clearcut	11 A	11	n/a

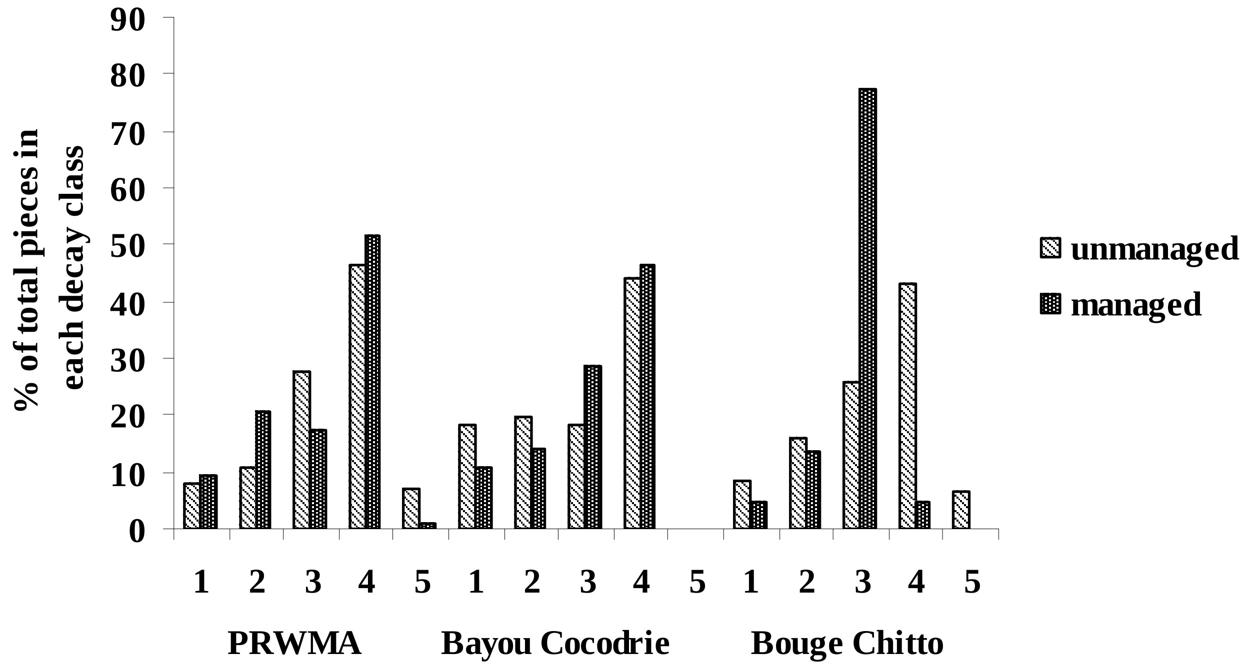

Figure 6. Distribution of coarse woody debris decay classes at managed and unmanaged stands at each study site.

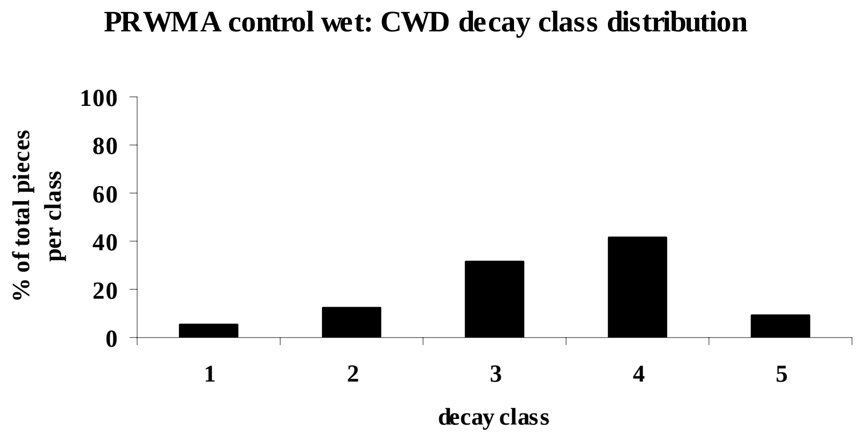

Fig 7a.

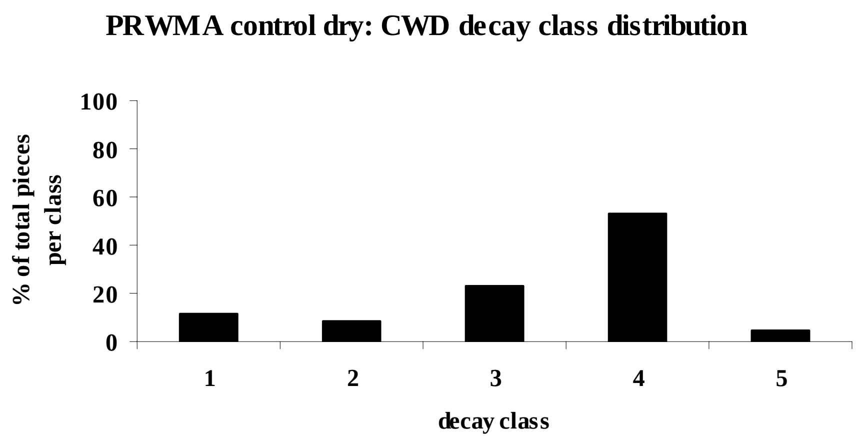

Fig. 7b.

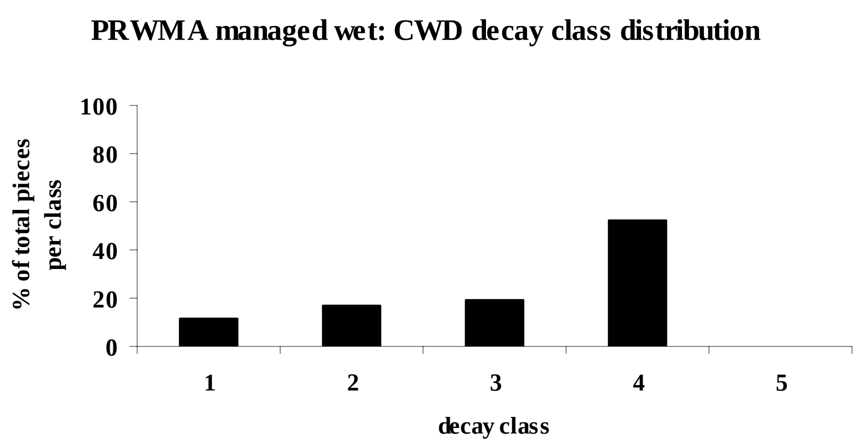

Fig. 7c.

Figures 7a-7j. Distribution of coarse woody debris decay classes at each stand.

(Figures 7a-7j continued)

PRWMA managed dry: CWD decay class distribution

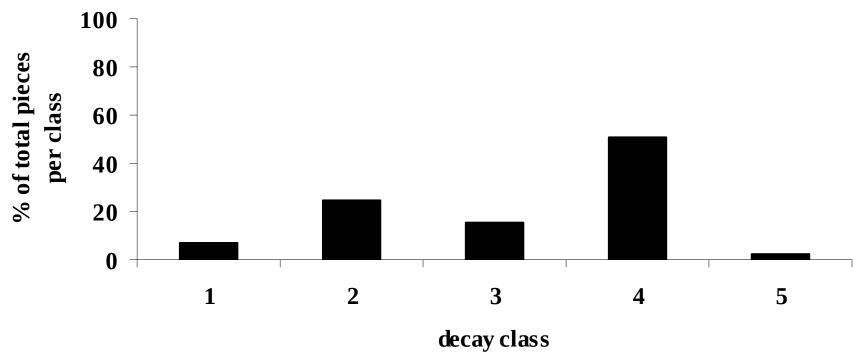

Fig. 7d.

Bayou Cocodrie NWR old growth natural area: CWD decay class distribution

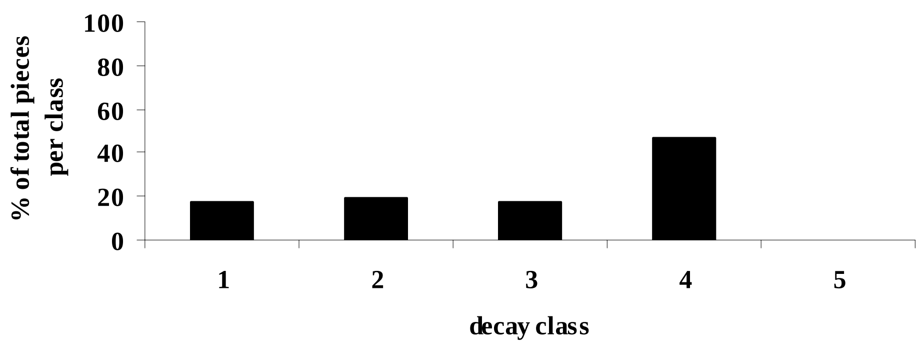

Fig. 7e.

Bayou Cocodrie NWR selective cut: CWD decay class distribution

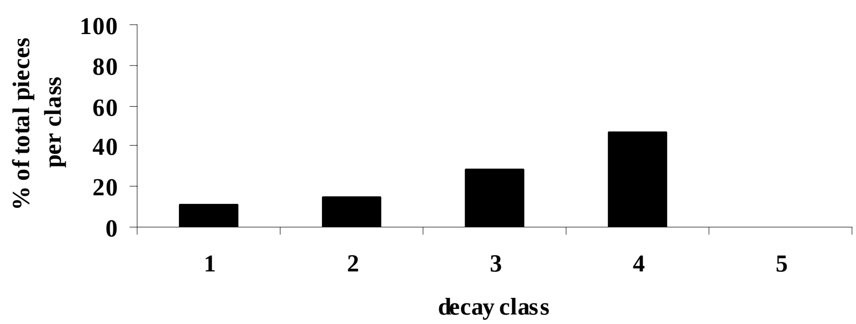

Fig. 7f.

(Figures 7a-7j continued)

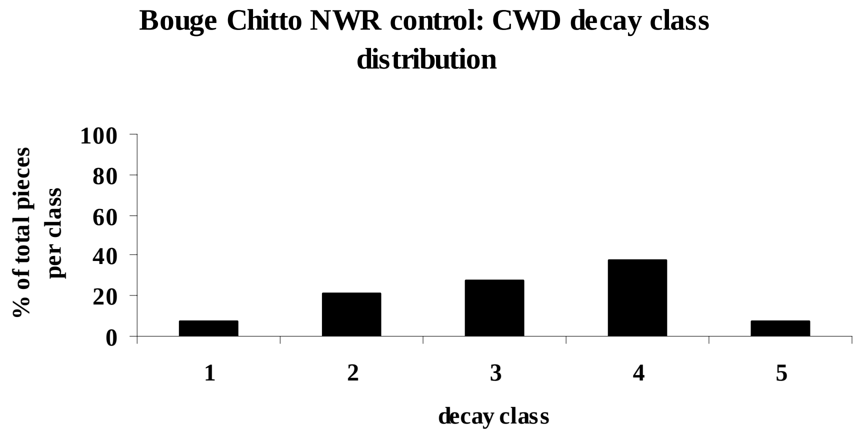

Fig. 7g.

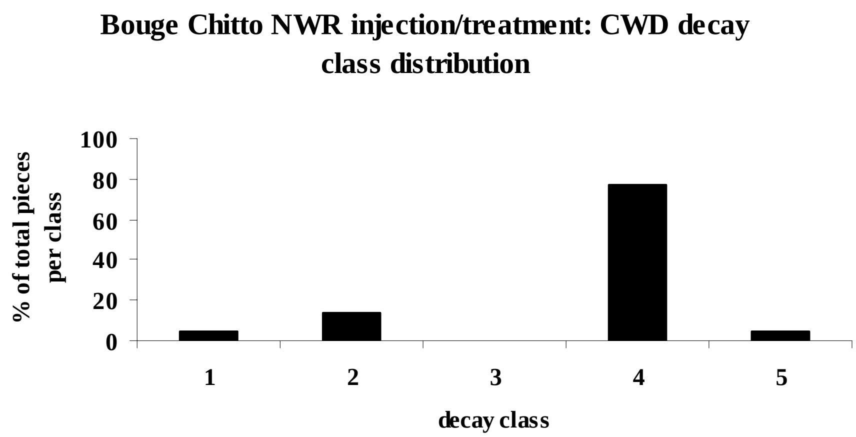

Fig. 7h.

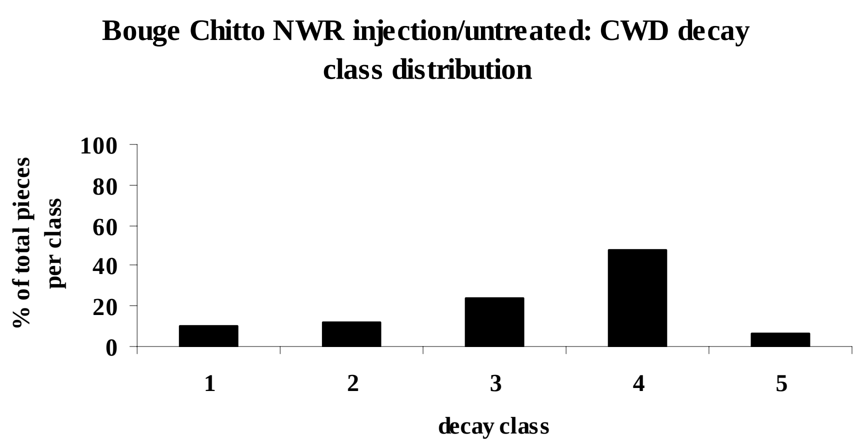

Fig. 7i.

(Figures 7a-7j continued)

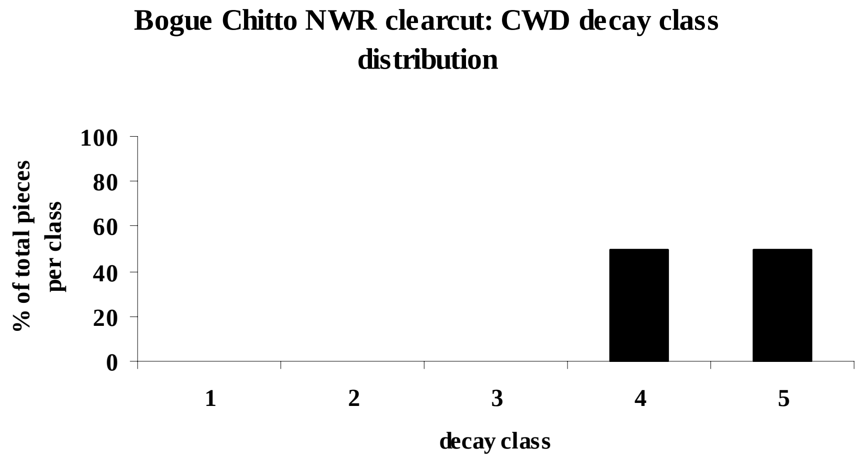

Fig. 7j.

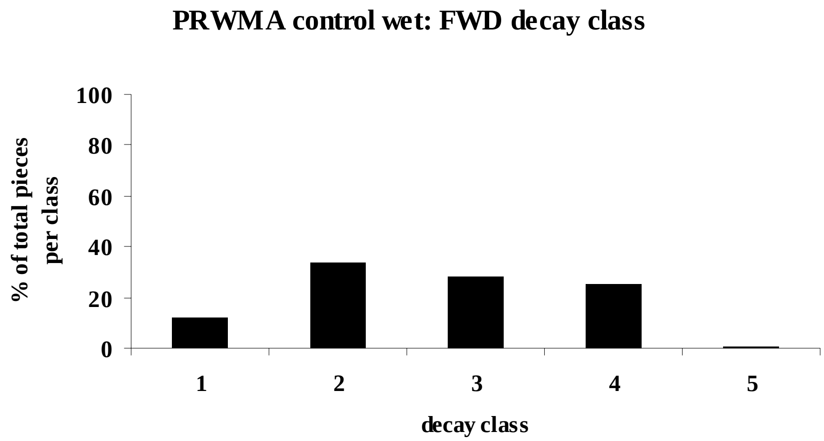

Fig. 8a.

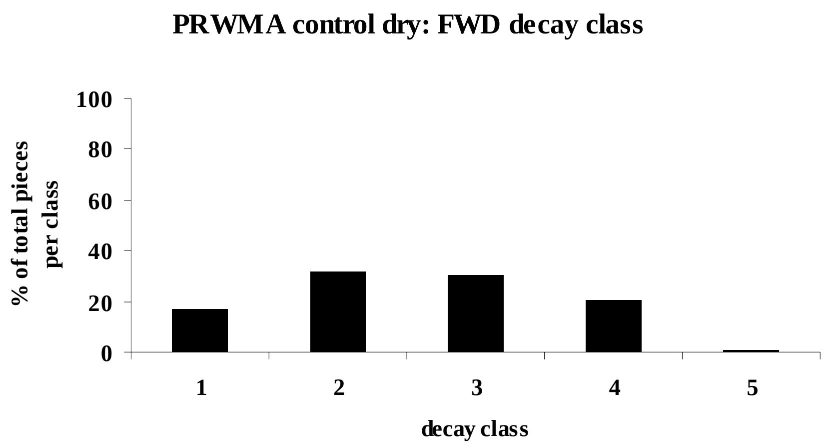

Fig. 8b.

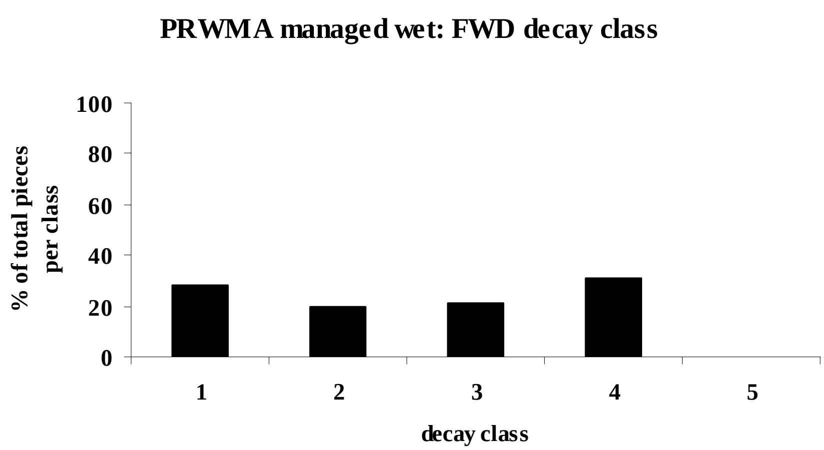

Fig. 8c.

Figures 8a-8j. Distribution of fine woody debris decay classes at each stand.

(Figures 8a-8j continued)

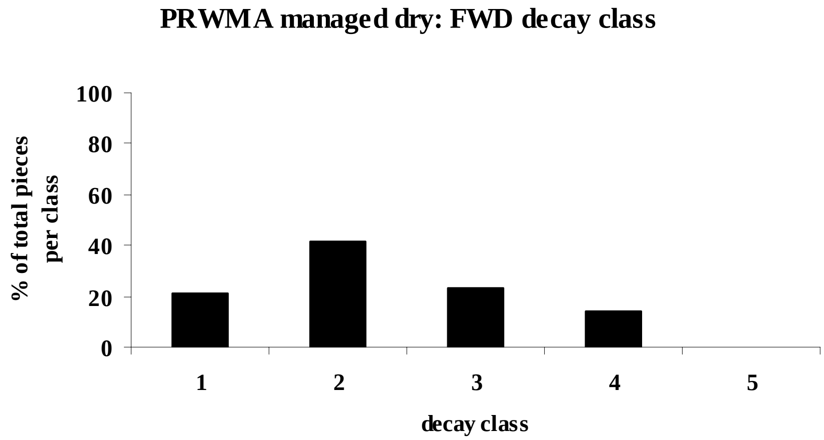

Fig. 8d.

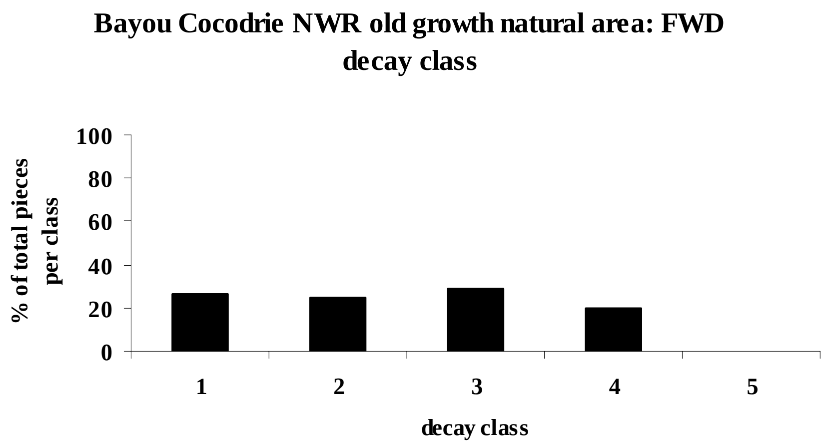

Fig. 8e.

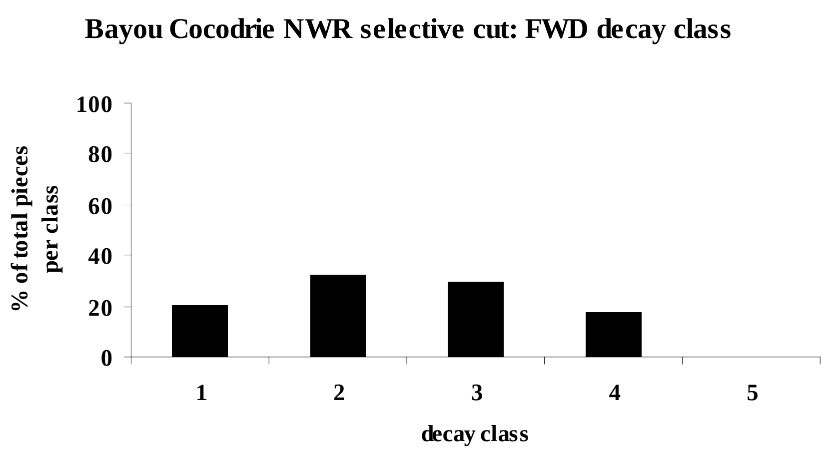

Fig. 8f.

(Figures 8a-8j continued)

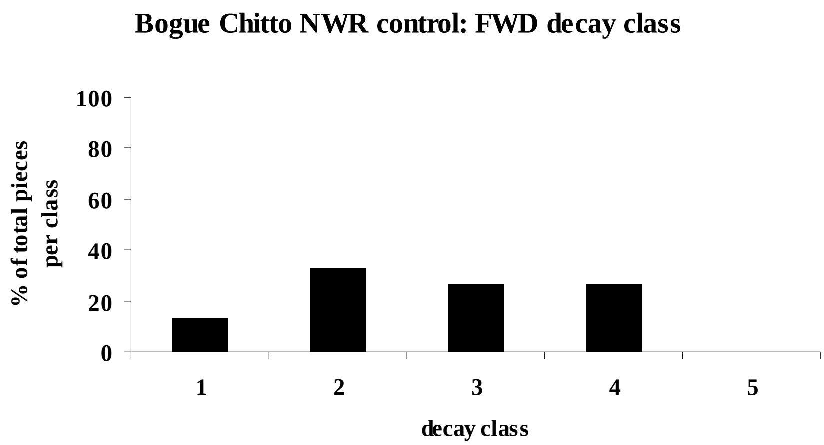

Fig. 8g.

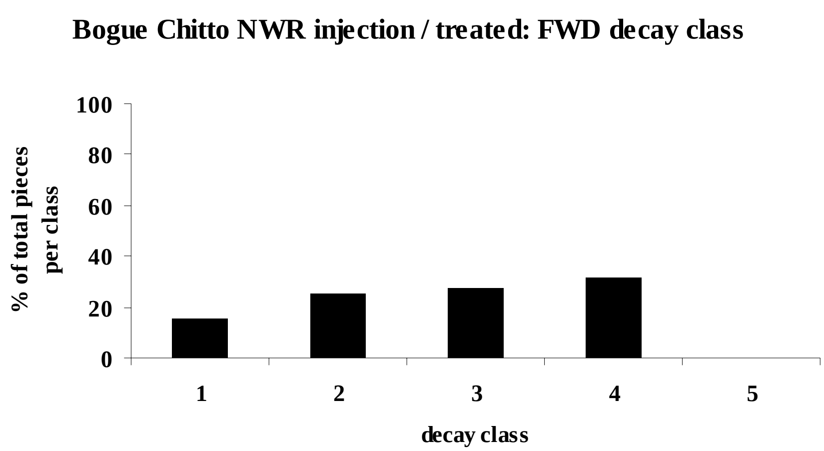

Fig. 8h.

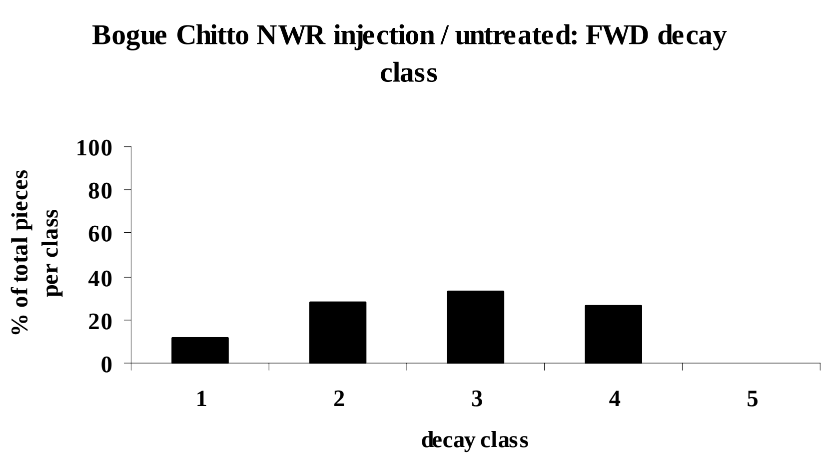

Fig. 8i.

(Figures 8a-8j continued)

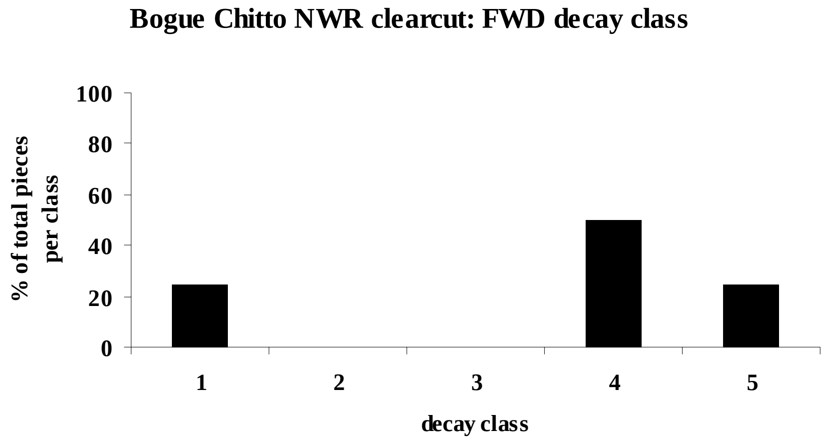

Fig. 8j.

Density of Standing Dead Trees (Snags)

When snag densities were compared among managed and unmanaged stands at each site (Figure 9), the Bogue Chitto NWR unmanaged stands had a higher density of snags than the Pearl River WMA managed stands. However, this effect was attributed to differences between the study sites. No differences in snag density were found among the ten stands (Table 7). Snag densities ranged from 35.42 stems / ha +/- 13.91 stems / ha at the Bogue Chitto NWR injection / untreated stand to 12.50 stems / ha +/- 12.56 stems / ha at the Pearl River WMA managed stand. The Bogue Chitto NWR clearcut had no snags.

Snag Basal Area

Snag basal areas ranged from 3.43 m^2 / ha +/- 4.69 m^2 / ha at the Bayou Cocodrie NWR old growth natural area to (with the exception of the Bogue Chitto NWR clearcut treatment) 0.74 m^2 / ha +/- 1.04 m^2 / ha at the Pearl River WMA managed wet stand. There were no differences in snag basal areas between managed and unmanaged stands(Figure 10) or among the ten stands (Table 8). Snag basal area did differ among study sites, with Pearl River WMA supporting a smaller basal area than both Bayou Cocodrie NWR and Bogue Chitto NWR.

Snag Diameter Distribution

Snag diameters did not differ among any of the ten stands, however, snag diameters ranged from a mean snag diameter of 30.1 cm +/- 12.8 cm and a median of 29.5 cm at the Bogue Chitto NWR injection/untreated stand to a mean and median snag diameter of 0 cm at the Bogue Chitto NWR clearcut (Table 9). Bayou Cocodrie NWR old growth natural area had a relatively large mean diameter (31.5 cm +/- 27.0 cm), but the

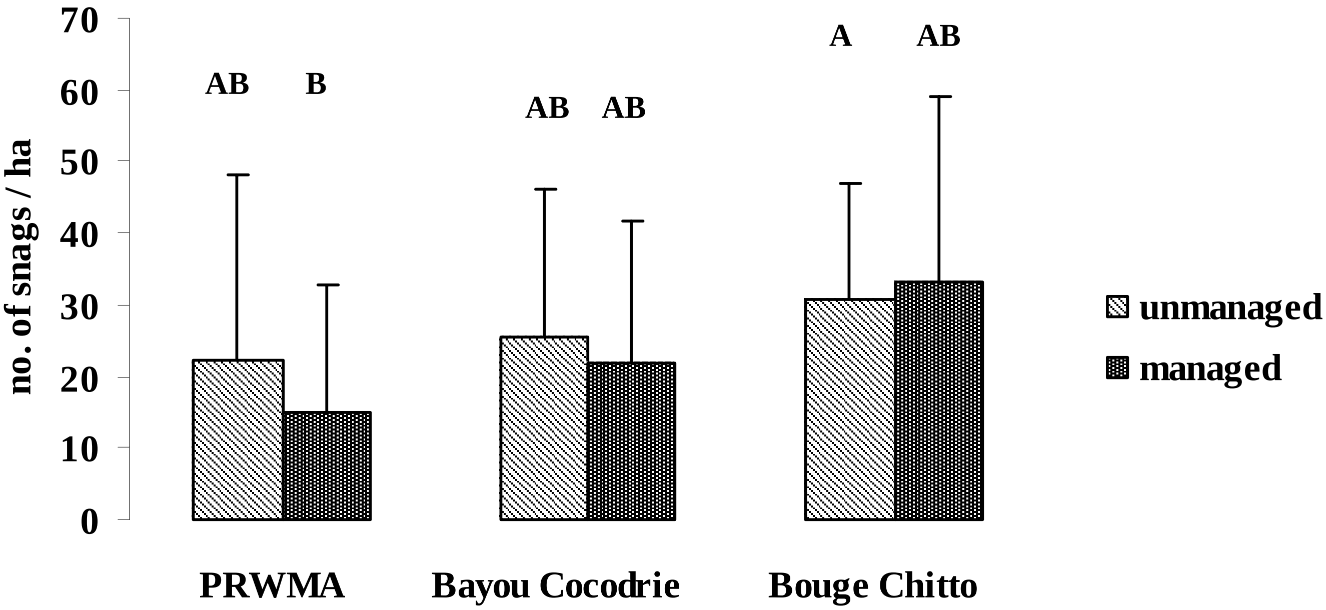

Figure 9. Mean density of standing dead trees (stems ha^{-1}) +/- 1 SD at managed and unmanaged stands at each study site. Means sharing a letter do not differ ($p > 0.05$).

Table 7. Mean density of standing dead trees (stems ha^{-1}), SD, and coefficient of variation at each stand. Means sharing a letter do not differ ($p > 0.005$).

Site	*Stand name*	*Mean (stems / ha.)*	*Std. dev.*	*CV*
Pearl River WMA	control wet	21.05 A	22.8	108.30%
	control dry	23.33 A	30.73	131.71%
	managed wet	12.5 A	12.56	100.49%
	managed dry	16.67 A	21.83	130.92%
Bayou Cocodrie NWR	old growth natural area	25.56 A	20.4	79.84%
	selective cut	21.8 A	19.7	90.39%
Bogue Chitto NWR	control	26.67 A	17.92	67.18%
	injection / untreated	35.42 A	13.91	39.27%
	injection / treated	33.34 A	25.82	77.46%
	clearcut	0 B	n/a	n/a

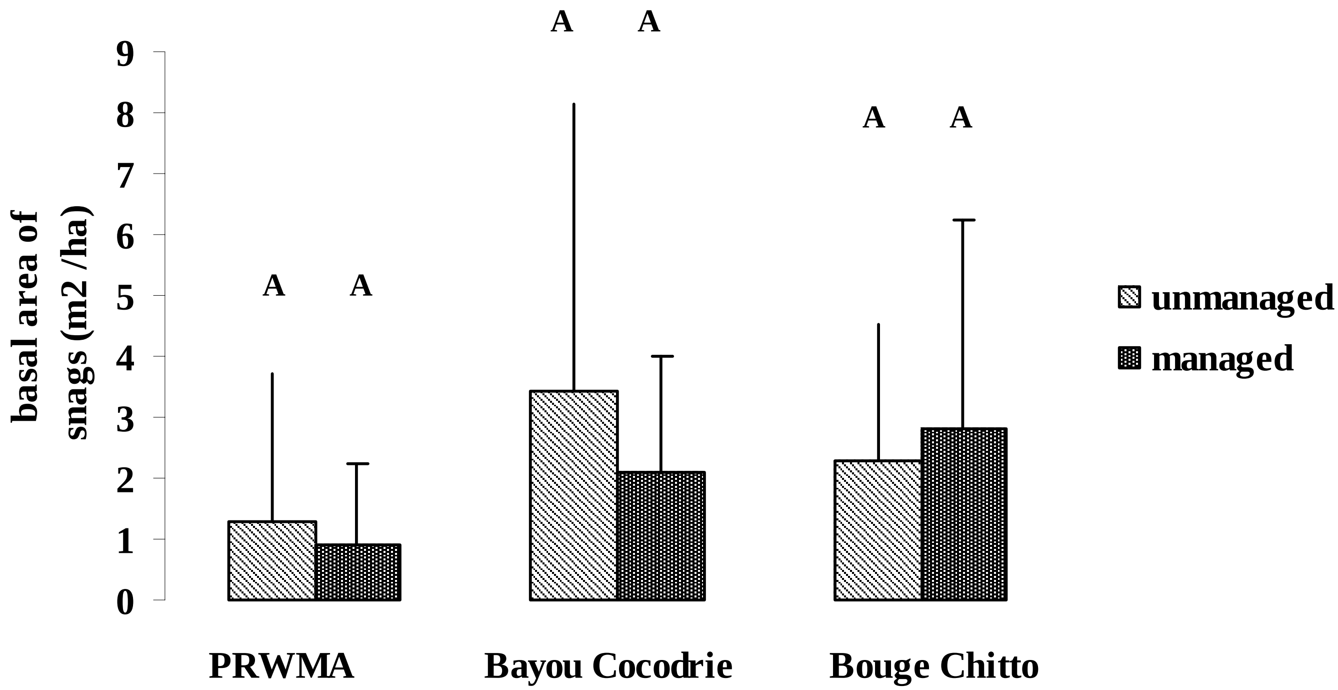

Figure 10. Mean basal area of standing dead trees (m^2 ha^{-1}) + 1 SD at managed and unmanaged stands at each study site. Means sharing a letter do not differ ($p > 0.05$).

Table 8. Mean basal area of standing dead trees ($m^2 ha^{-1}$), SD, and coefficient of variation at each stand. Means sharing a letter do not differ ($p > 0.005$).

Site	*Stand name*	*Mean (m^2/ha.)*	*Std. dev.*	*CV*
Pearl River WMA	control wet	0.90 A	1.24	137.58%
	control dry	1.79 A	3.34	186.97%
	managed wet	0.74 A	1.04	140.89%
	managed dry	1.04 A	1.55	149.85%
Bayou Cocodrie NWR	old growth natural area	3.43 A	4.69	136.84%
	selective cut	2.11 A	1.90	90.22%
Bogue Chitto NWR	control	1.72 A	1.83	106.17%
	injection / untreated	2.94 A	2.34	79.54%
	injection / treated	2.80 A	3.42	121.85%
	clearcut	0	n/a	n/a

Table 9. Mean and median estimates of standing dead tree diameters (cm), and coefficient of variation at each stand. Means sharing a letter do not differ ($p > 0.05$).

Site	*Stand name*	*Mean diameter (cm)*	*Median diameter (cm)*	*CV*
Pearl River WMA	control wet	20.93 A	17.25	50.62%
	control dry	24.99 A	20	76.87%
	managed wet	24.03 A	20	58.28%
	managed dry	24.49 A	22.3	58.53%
Bayou Cocodrie NWR	old growth natural area	31.54 A	15	85.69%
	selective cut	30.73 A	27.4	56.89%
Bogue Chitto NWR	control	25.6 A	23.7	51.72%
	injection / untreated	30.1 A	29.5	42.59%
	injection / treated	27.9 A	19.6	63.84%
	clearcut	0	0	

median diameter at that stand was only 15.0 cm. The Bayou Cocodrie NWR old growth natural area did, however, contain the largest snags of any stand, with individuals measuring 112.5 cm, 90.4 cm, 83.0 cm, and 74.0 cm at breast height At all stands except the Bayou Cocodrie NWR old growth natural area, the majority of standing dead trees had diameters of less than 40 cm (Figures 11a-11i), (Figure 12).

The relative frequency of large diameter snags (dbh > 50 cm) was the greatest at Bayou Cocodrie old growth natural area (0.48). The difference between this and the other stands was not as pronounced, however, as it was for downed woody debris diameter distributions. Bogue Chitto NWR injection / treated, Bogue Chitto NWR injection / untreated, and Bogue Chitto NWR control all had relatively high frequencies of large diameter snags (0.33, 0.31, and 0.25 respectively). The remaining stands had only a fraction of the number of 50+ cm snags found at Bayou Cocodrie NWR old growth natural area.

Live Tree Stem Density

When live tree stem density was compared between managed and unmanaged stands at each site (Figure 13), managed stands at Pearl River WMA were found to be different from both managed and unmanaged stands at Bayou Cocodrie NWR and the managed stands at Bogue Chitto NWR. However, these differences were attributed to an interaction between site and stand effects. When compared among all ten stands (Table 10), stem densities were higher at the Pearl River WMA managed wet stand than at the Bouge Chitto NWR control stands and injection / treated stand. Tree densities ranged from 631.08 stems / ha +/- 121.12 stems / ha at the Pearl River WMA managed wet stand to 387.67 stems / ha +/- 83.93 stems / ha at the Bogue Chitto NWR injection / treated stand.

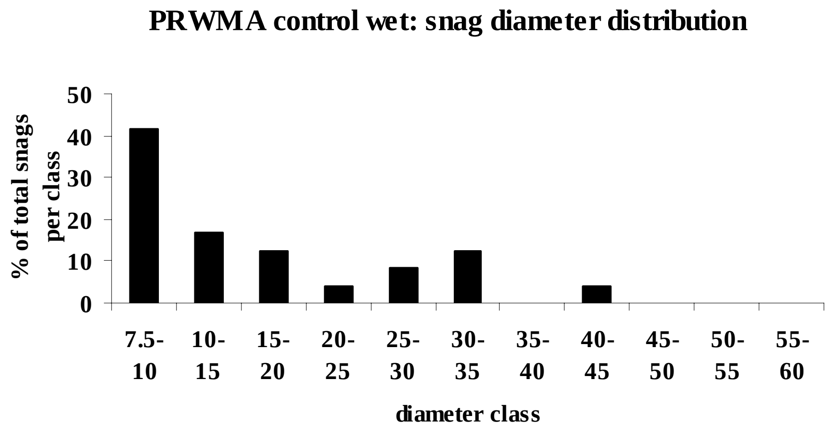

Fig. 11a.

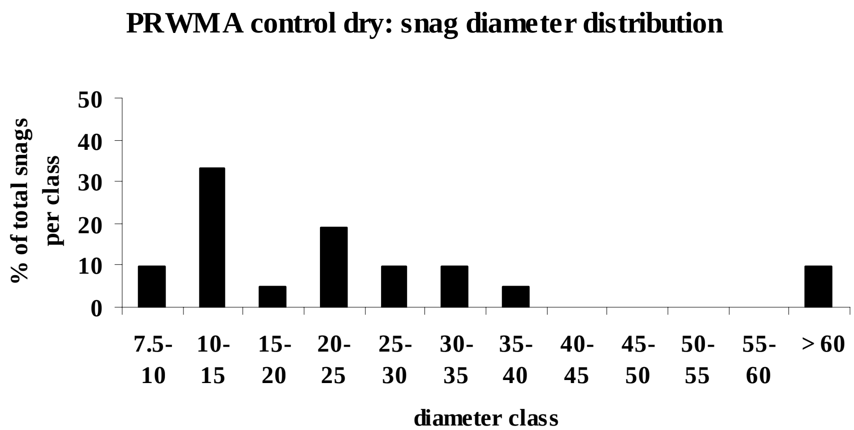

Fig 11b.

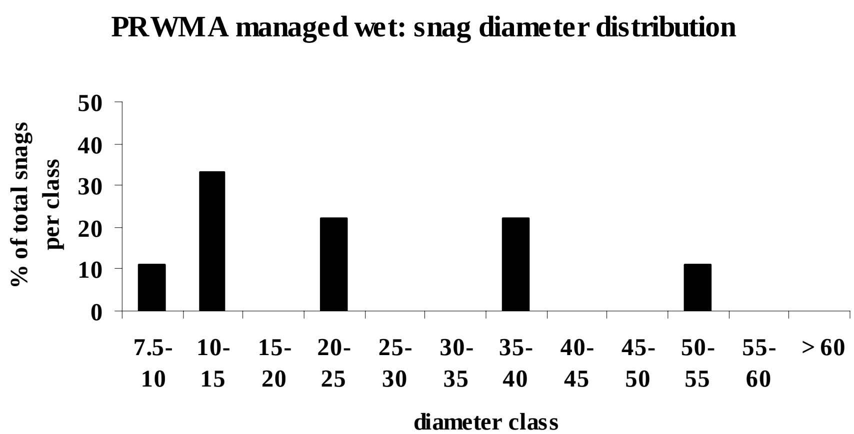

Fig. 11c.

Figures 11a-11i. Distribution of standing dead tree diameter classes (cm) at each stand.

(Figures 11a-11i continued)

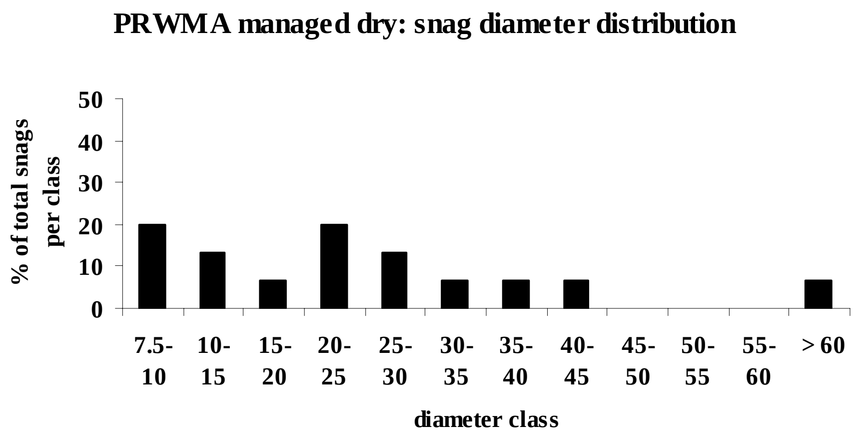

Fig. 11d.

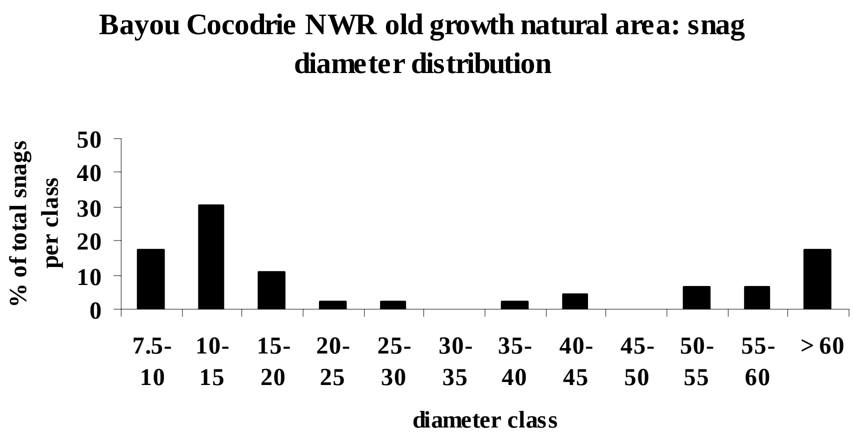

Fig. 11e.

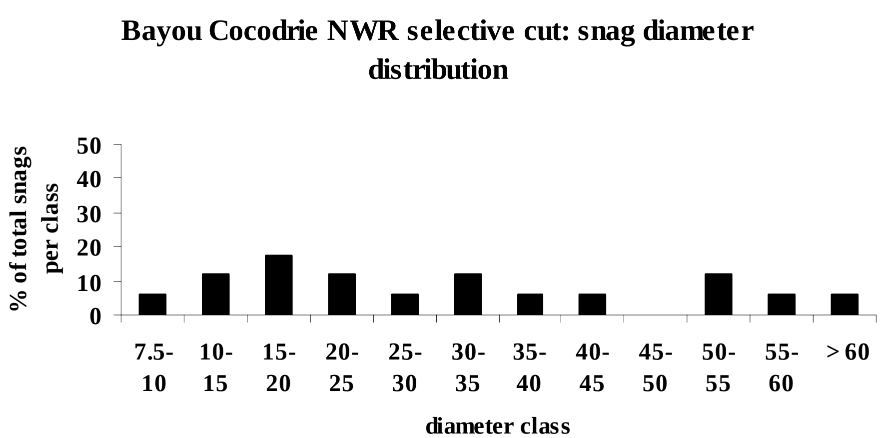

Fig. 11f.

(Figures 11a-11i continued)

Bouge Chitto NWR control: snag diameter distribution

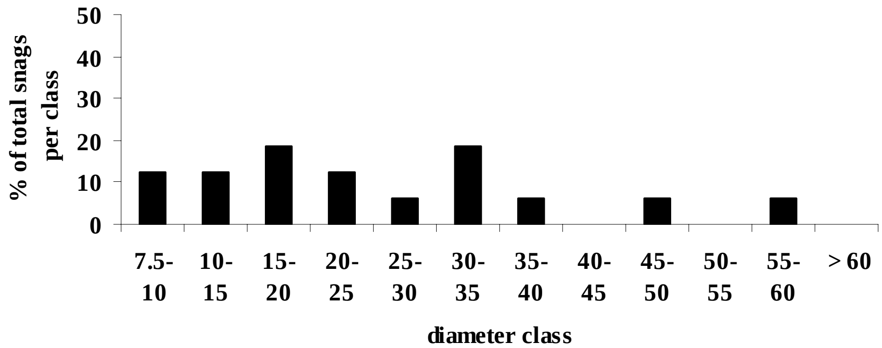

Fig. 11g.

Bouge Chitto NWR injection/treatment: snag diameter distribution

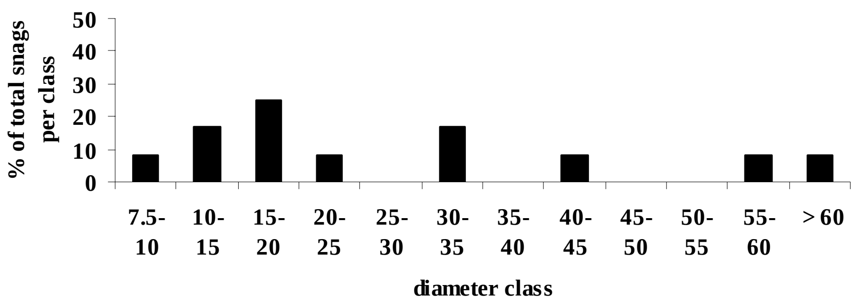

Fig. 11h.

Bouge Chitto NWR injection/untreated: snag diameter distribution

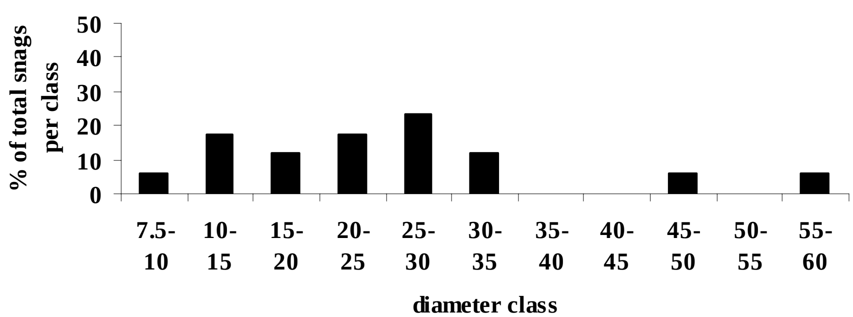

Fig. 11i.

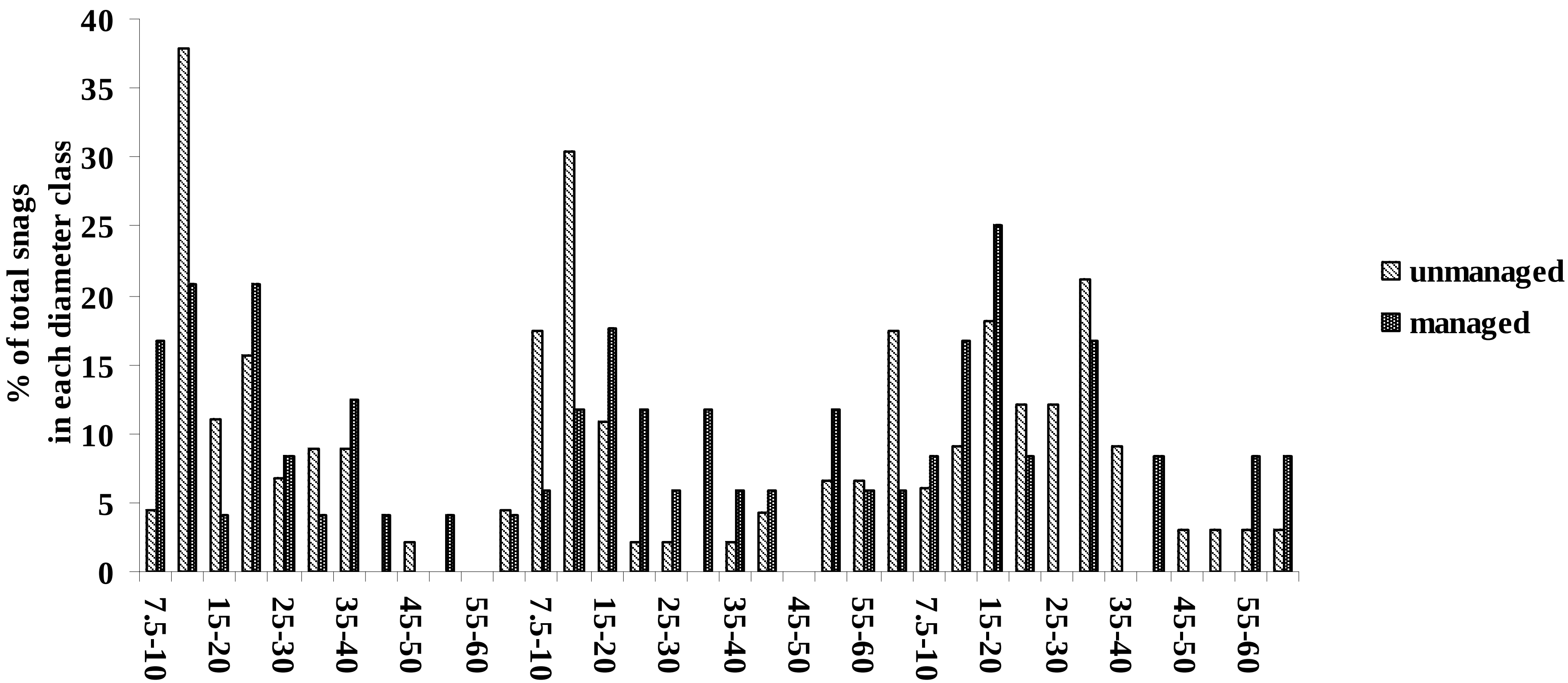

Figure 12. Distribution of standing dead tree diameter classes (cm) at managed and unmanaged stands at each study site.

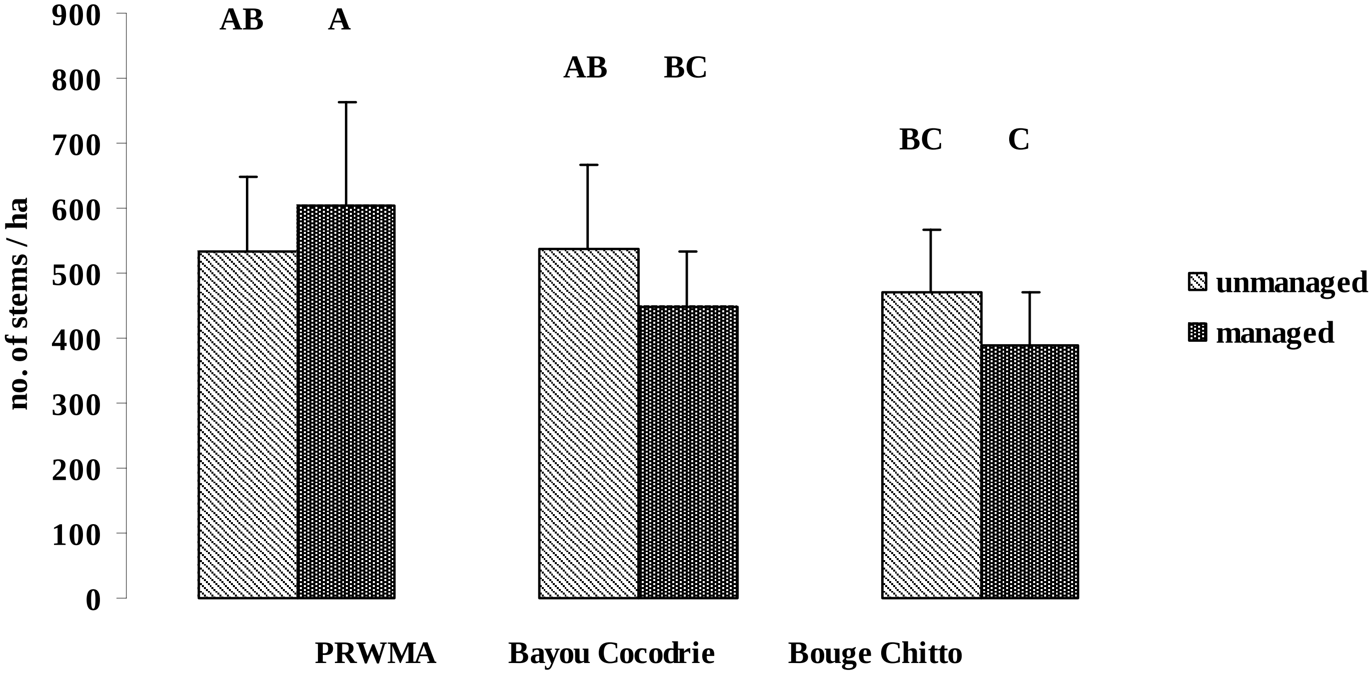

Figure 13. Mean density of live trees (stems ha^{-1}) + 1 SD at managed and unmanaged stands at each study site. Means sharing a letter do not differ ($p > 0.05$).

Table 10. Mean density of live stems (stems ha^{-1}), SD, and coefficient of variation at each stand. Means sharing a letter do not differ ($p > 0.05$).

Site	*Stand name*	*Mean (stems / ha)*	*Std. dev.*	*CV*
Pearl River WMA	Control wet	524.79 ABC	120.02	22.87%
	control dry	540.27 ABC	119.39	22.10%
	managed wet	631.08 A	121.12	19.19%
	managed dry	584.53 AB	182.56	31.23%
Bayou Cocodrie NWR	old growth natural area	535.97 ABC	130.65	24.38%
	selective cut	449.08 BC	85.46	19.03%
Bogue Chitto NWR	control	424 C	60.18	14.19%
	injection / untreated	532 ABC	95.71	18%
	injection / treated	387.67 C	83.93	21.65%
	clearcut	448 ABC	299.89	66.94%

Live Tree Basal Area

When live tree basal area was compared between the combined managed and unmanaged stands at each site (Figure 14), the Bayou Cocodrie NWR old growth natural area was found to be different from the Bayou Cocodrie NWR selective cut. Also, the unmanaged stands at Pearl River WMA were different from the Pearl River WMA managed stands. Differences were also found between the old growth natural area and the managed and unmanaged stands at Pearl River WMA, but these differences were attributed to differences between the study sites. When all ten stands area compared (Table 11), the Bayou Cocodrie NWR old growth natural area had a larger tree basal area than the managed wet and dry stands at Pearl River WMA and the Bogue Chitto NWR clearcut. Tree basal areas ranged from 53.63 m^2 / ha +/- 17.81 m^2 / ha at the Bayou Cocodrie NWR old growth natural area to 7.85 m^2 /ha +/- 3.92 m^2 / ha at the Bogue Chitto NWR clearcut.

Live Tree Diameter Distribution

Tree diameters ranged from a mean of 31.1 cm +/- 18.7 cm and a median of 26.6 cm at the Bogue Chitto NWR control stand to a mean of 13.3 cm +/- 7.7 cm and a median of 11 cm at the Bogue Chitto clearcut (Table 12). No clear pattern emerged in live tree diameter distributions by stand despite statistical differences. While still representing a small percentage of total stems, the Bayou Cocodrie old growth natural area had more large diameter trees than did other stands (Figures 15a-15j) (Figure 16), with individual tree diameters including nine trees more than 120 cm in diameter, two more than 130 cm, and one more than 140 cm.

The relative frequency of large trees (dbh > 100 cm) was 1.17 at the old growth natural area. Of these trees, nine had a dbh of 120 cm or greater, two with a dbh of 130

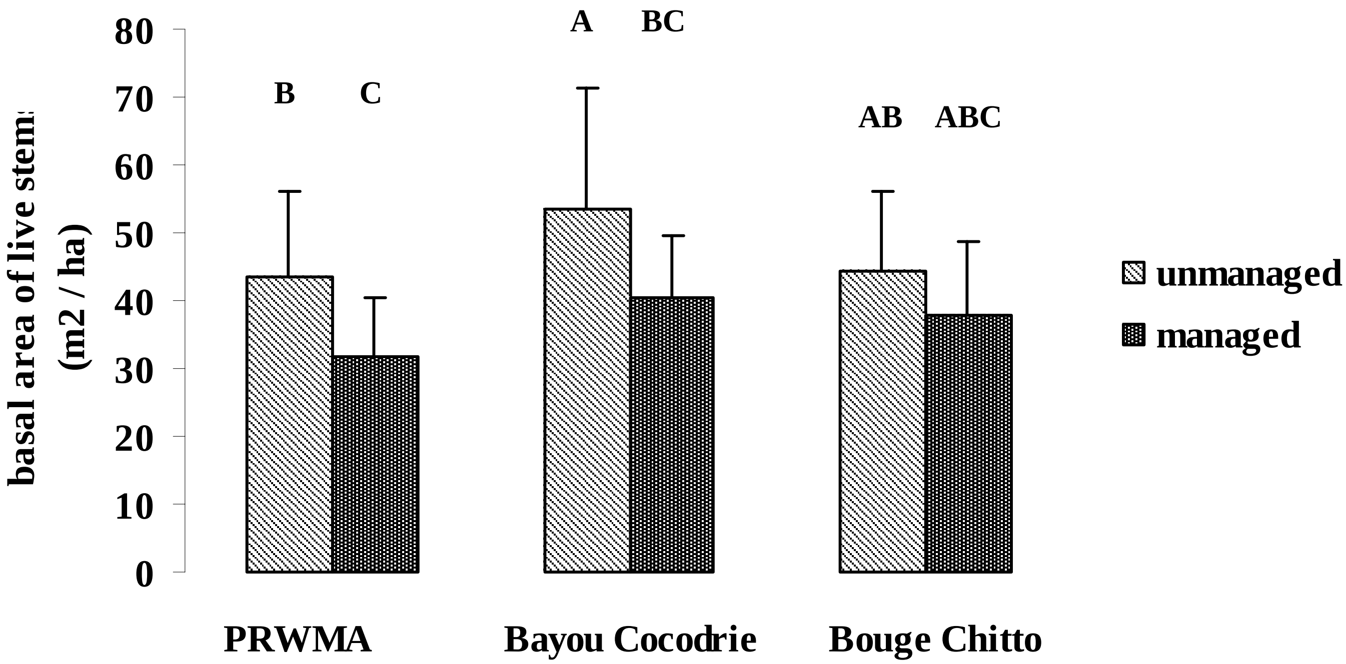

Figure 14. Mean basal area of live trees (m^2 ha^{-1}) + 1 SD at managed and unmanaged stands at each study site. Means sharing a letter do not differ ($p > 0.05$).

Table 11. Mean basal area of live stems ($m^2 ha^{-1}$), SD, and coefficient of variation at each stand. Means sharing a letter do not differ ($p > 0.05$).

Site	*Stand name*	*Mean (m²/ha.)*	*Std. dev.*	*CV*
Pearl River WMA	control wet	45.636 AB	13.692	30.00%
	control dry	41.088 ABC	10.621	25.85%
	managed wet	36.221 BCD	9.506	26.24%
	managed dry	28.194 D	6.686	23.71%
Bayou Cocodrie NWR	old growth natural area	53.63 A	17.811	33.21%
	selective cut	40.622 ABCD	9.091	22.38
Bogue Chitto NWR	control	43.59 AB	12.818	29.40%
	injection / untreated	45.174 AB	10.832	23.98%
	injection / treated	37.889 ABCD	10.854	28.65%
	clearcut	7.846 CD	3.91240693	49.86%

Table 12. Mean and median estimates of live stem diameters (cm), and coefficient of variation at each stand. Means sharing a letter do not differ ($p > 0.05$).

Site	*Stand name*	*Mean diameter (cm)*	*Median diameter (cm)*	*CV*
Pearl River WMA	control wet	28.3 AB	22.6	66.1%
	control dry	26.4 B	21.2	66%
	managed wet	22.0 C	15.8	77.1%
	managed dry	20.6 C	15.7	71.3%
Bayou Cocodrie NWR	old growth natural area	28.8 B	20.1	79%
	selective cut	29.2 AB	22.8	67%
Bogue Chitto NWR	control	31.1 A	26.6	60.1%
	injection / untreated	27.9 B	20.6	71.3%
	injection / treated	30.4 AB	25	64%
	clearcut	13.3 D	11	58.2%

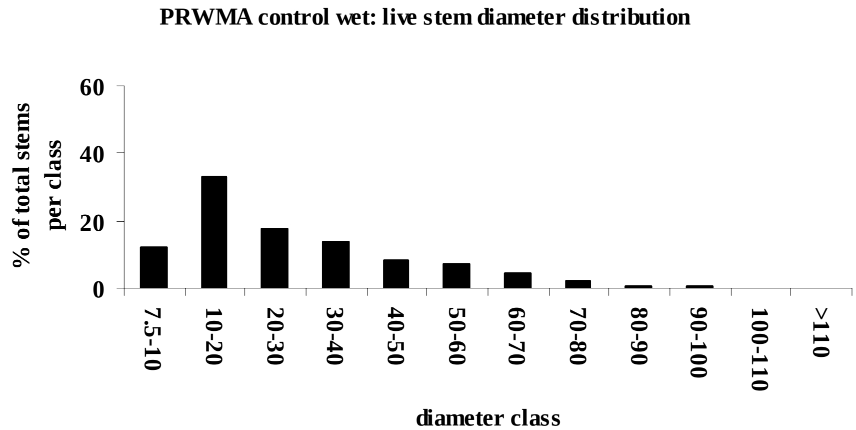

Fig. 15a.

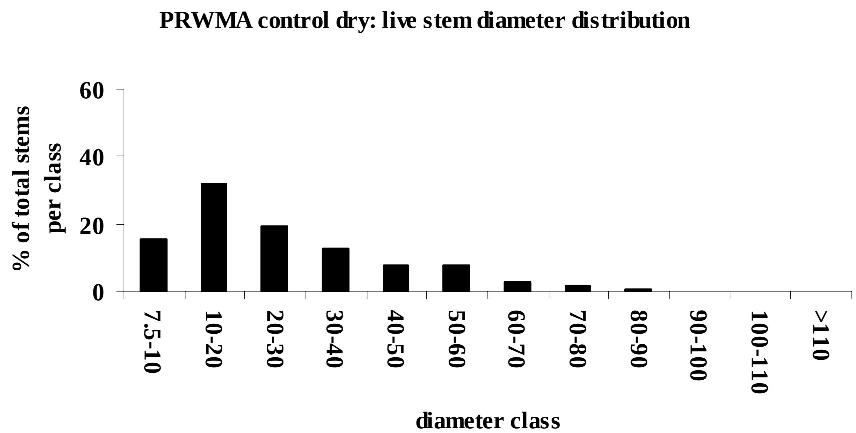

Fig. 15b.

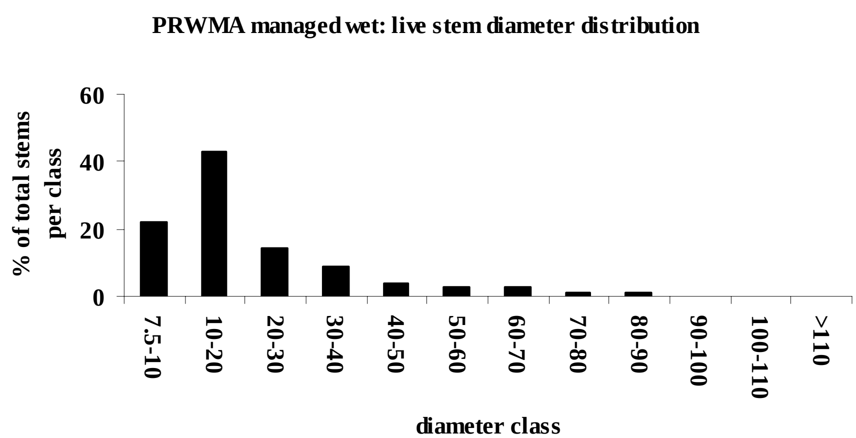

Fig. 15c.

Figures 15a-15j. Distribution of live tree diameter classes (cm) at each stand.

(Figures 15a-15j continued)

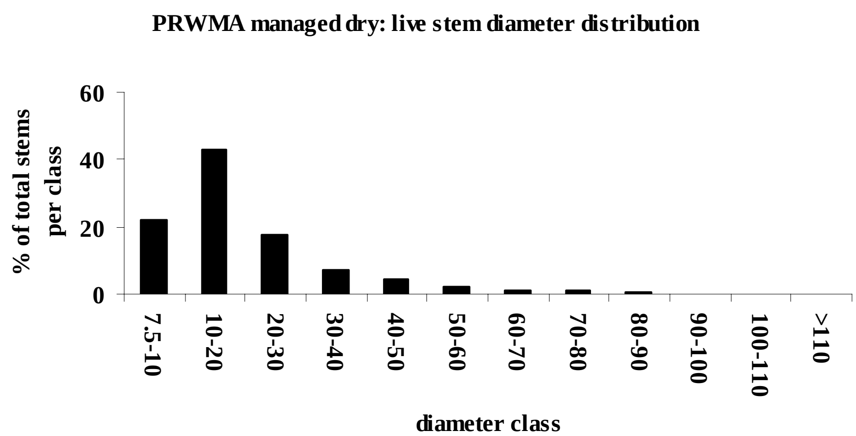

Fig. 15d.

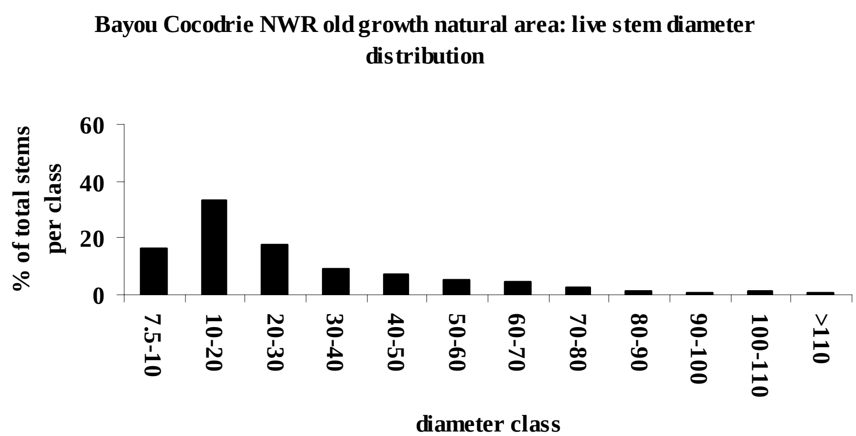

Fig. 15e.

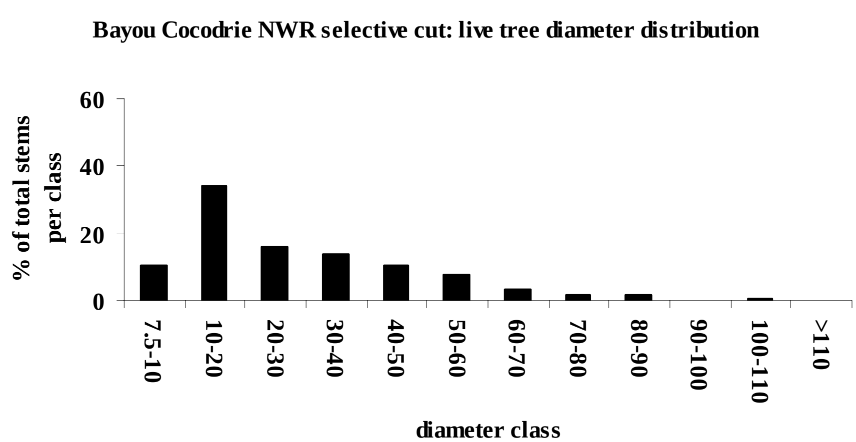

Fig. 15f.

(Figures 15a-15j continued)

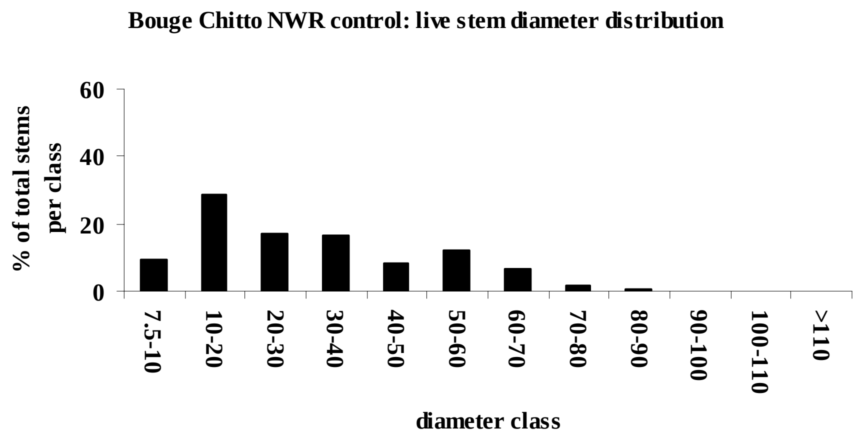

Fig. 15g.

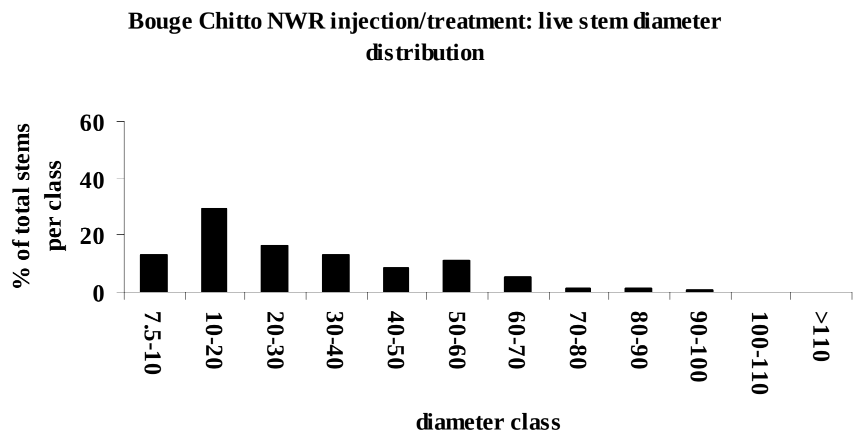

Fig. 15h.

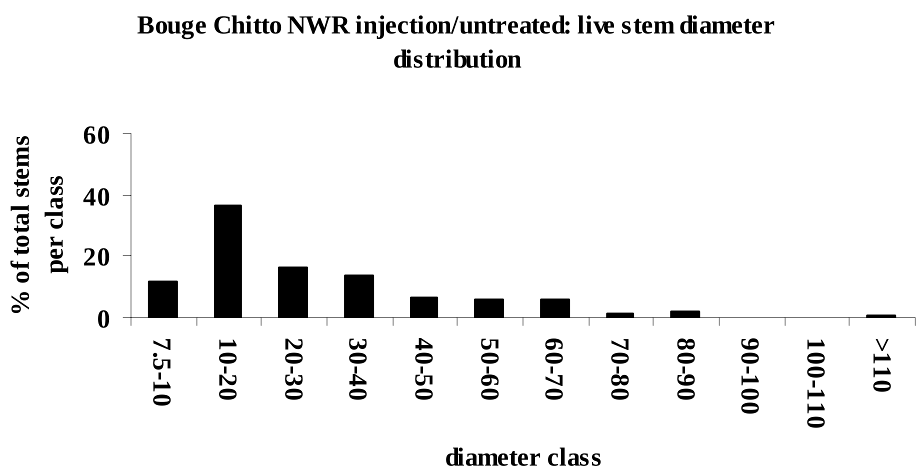

Fig. 15i.

(Figures 15a-15j continued)

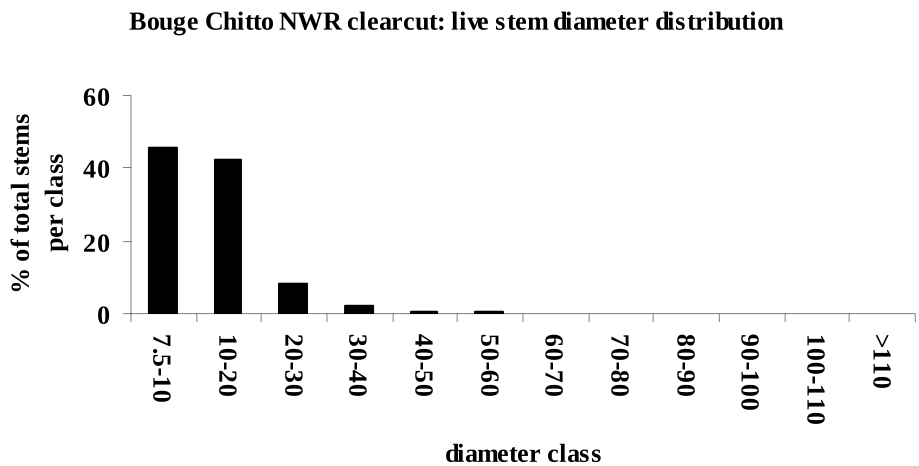

Fig. 15j.

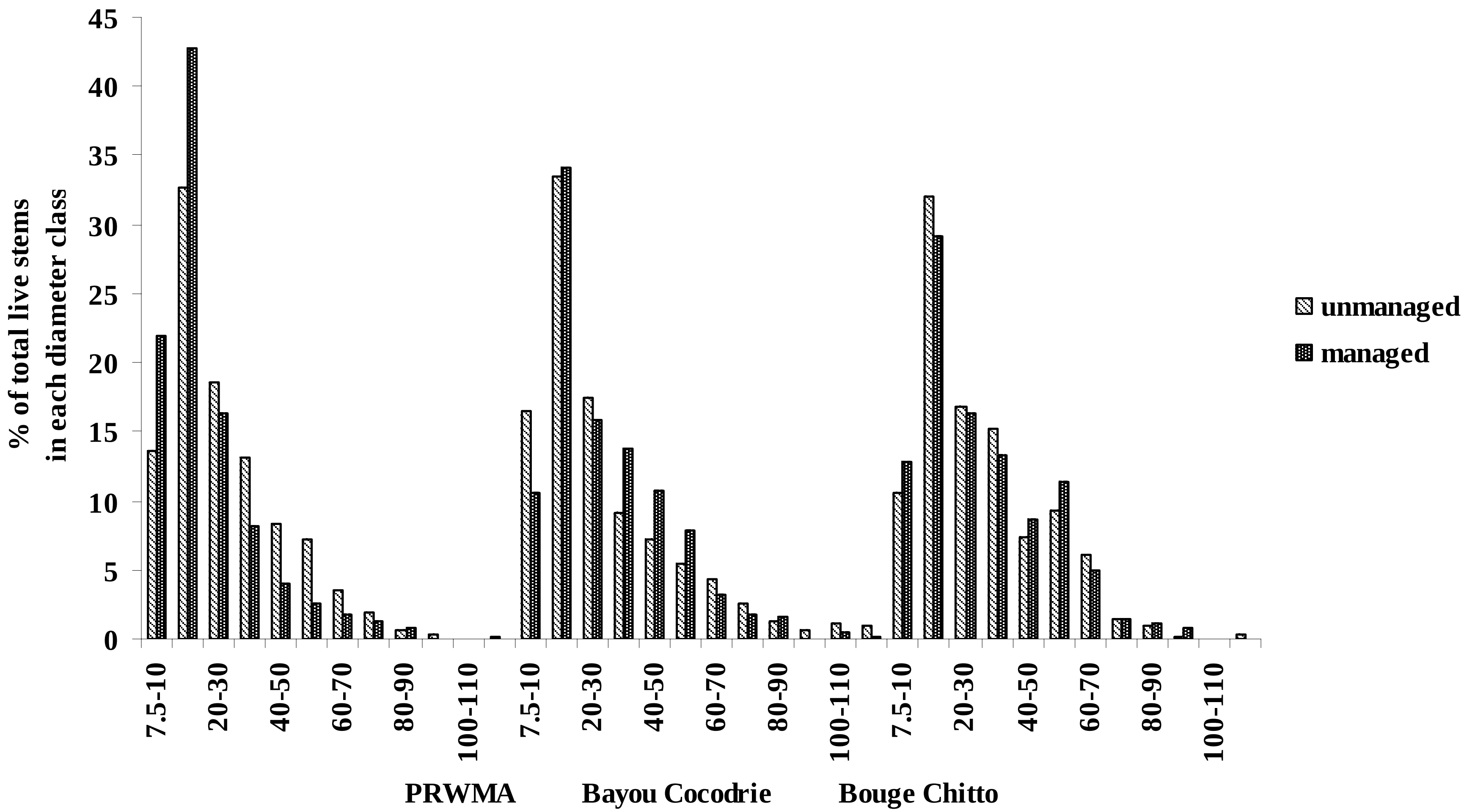

Figure 16. Distribution of live tree diameter classes (cm) at managed and unmanaged stands at each study site.

or greater, and one tree over 140 cm in diameter. Bogue Chitto NWR injection / treated stand had the next highest relative frequency of large trees of only 0.33. Half of the ten stands surveyed had a relative frequency of large trees of 0.10 or less.

Canopy Height

The Pearl River WMA managed stands had a lower mean canopy height than all other stands (Figure 17). Differences between other stands existed, but no clear trends were present, and these differences were attributed to an interaction between site and stand effects. The Bogue Chitto NWR clearcut had the lowest mean canopy height among the ten stands, but no obvious pattern emerged. Canopy height ranged from 31.6 m +/- 4.79 m at the Bayou Cocodrie NWR old growth natural area, to 11.93 m +/- 1.66 m at the Bogue Chitto NWR clearcut (Table 13).

Canopy Cover

Canopy cover at the Pearl River WMA managed stands was greater than all other stands (Fig 18), but this difference was attributed to an interaction between site and stand effects. When canopy cover was compared among all ten stands, the Bogue Chitto NWR clearcut had less canopy closure than all other stands. Canopy cover ranged from 86.5% +/- 4.6% at the Pearl River WMA managed wet stand to 35.3% +/- 18.3% at the Bogue Chitto NWR clearcut site (Table 14).

Live Tree Stress Rating

There were proportionally more stems rated as stress class 3 in the unmanaged stands than the managed stands (Fig 19). At all stands, the majority of live trees were rated as stress class 1 (Figures 20a-20j). The percentage of stems in stress class 1 ranged from 53.6% at the Pearl River WMA control wet stand to 97.0% at the Bogue Chitto NWR clearcut. Stems in stress class 2 ranged from 3.0% at the Bogue Chitto NWR

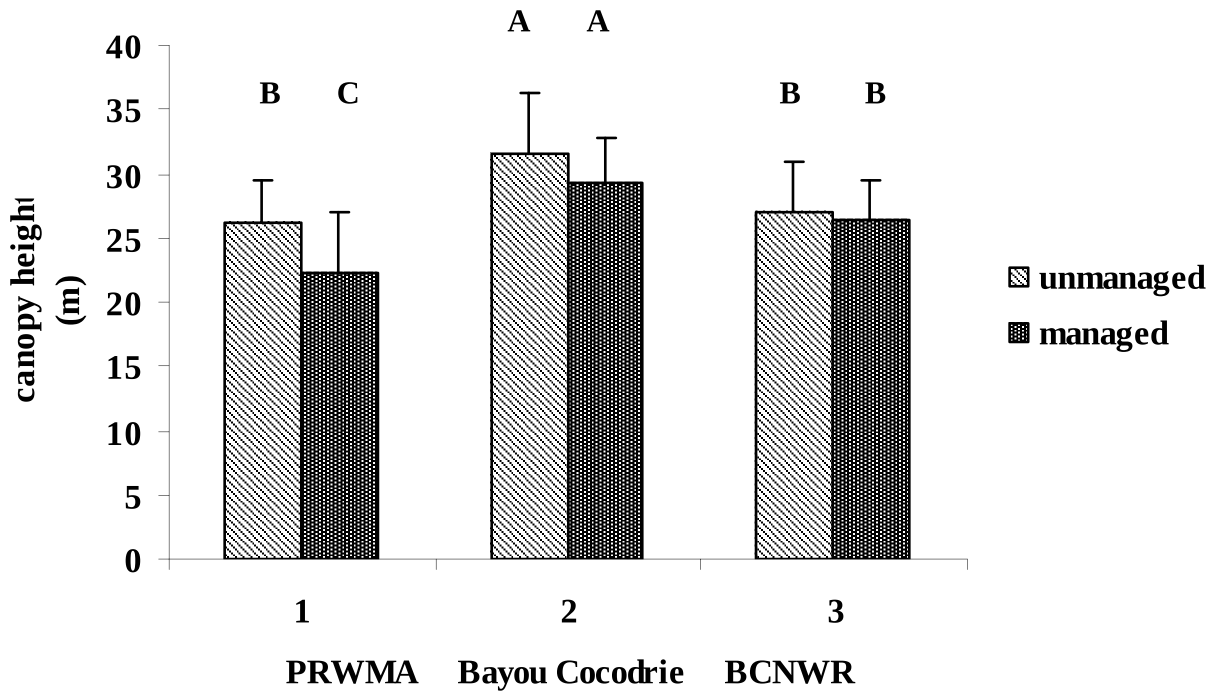

Figure 17. Mean canopy height (m) +/- 1 SD at managed and unmanaged stands at each study site. Means sharing a letter do not differ (p > 0.05).

Table 13. Mean canopy height (m), SD, and coefficient of variation at each stand. Means sharing a letter do not differ ($p > 0.05$).

Site	*Stand name*	*Mean (m)*	*Std. dev.*	*CV*
Pearl River WMA	control wet	25.74 CD	3.21	12.5%
	control dry	26.73 C	3.35	12.5%
	managed wet	23.11 DE	4.69	20.3%
	managed dry	21.56 E	4.81	22.3%
Bayou Cocodrie NWR	old growth natural area	31.6 A	4.79	15.1%
	selective cut	29.2 AB	3.58	12.2%
Bogue Chitto NWR	control	27.24 BC	3.71	13.6%
	injection / untreated	26.68 BC	4.08	15.3%
	injection / treated	26.73 BC	2.88	10.8%
	clearcut	11.93 F	1.66	13.9%

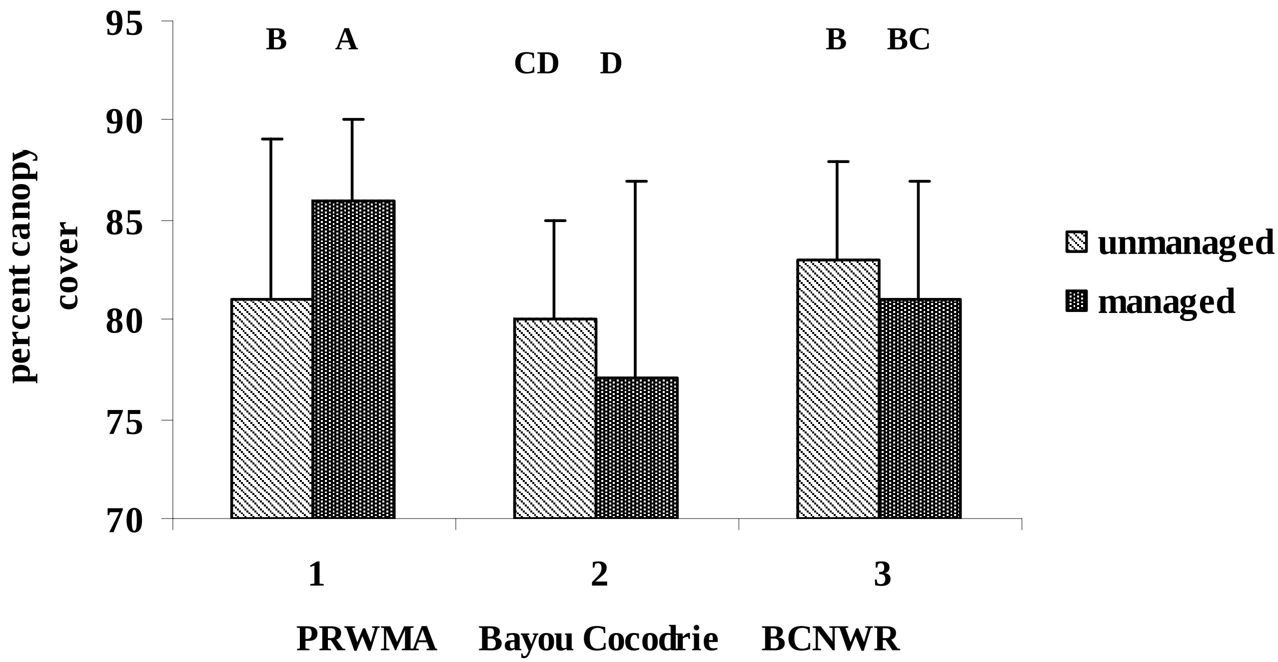

Figure 18. Mean percent canopy cover +/- 1 SD at managed and unmanaged stands at each study site. Means sharing a letter do not differ ($p > 0.05$).

Table 14. Mean percent canopy cover, SD, and coefficient of variation at each stand. Means sharing a letter do not differ (p > 0.05).

Site	*Stand name*	*Mean % canopy closure*	*Std. dev.*	*CV*
Pearl River WMA	control wet	78.8% CD	9.1%	11.6%
	control dry	84.8% C	3.9%	4.5%
	managed wet	86.5% DE	4.6%	5.3%
	managed dry	85.3% E	3.5%	4.1%
Bayou Cocodrie NWR	old growth natural area	79.7% A	5.4%	6.7%
	selective cut	76.9% AB	10.3%	13.4%
Bogue Chitto NWR	control	84.0% BC	5.0%	6.0%
	injection / untreated	82.2% BC	5.3%	6.5%
	injection / treated	81.4% BC	5.7%	7.0%
	clearcut	35.3% F	18.3%	52.0%

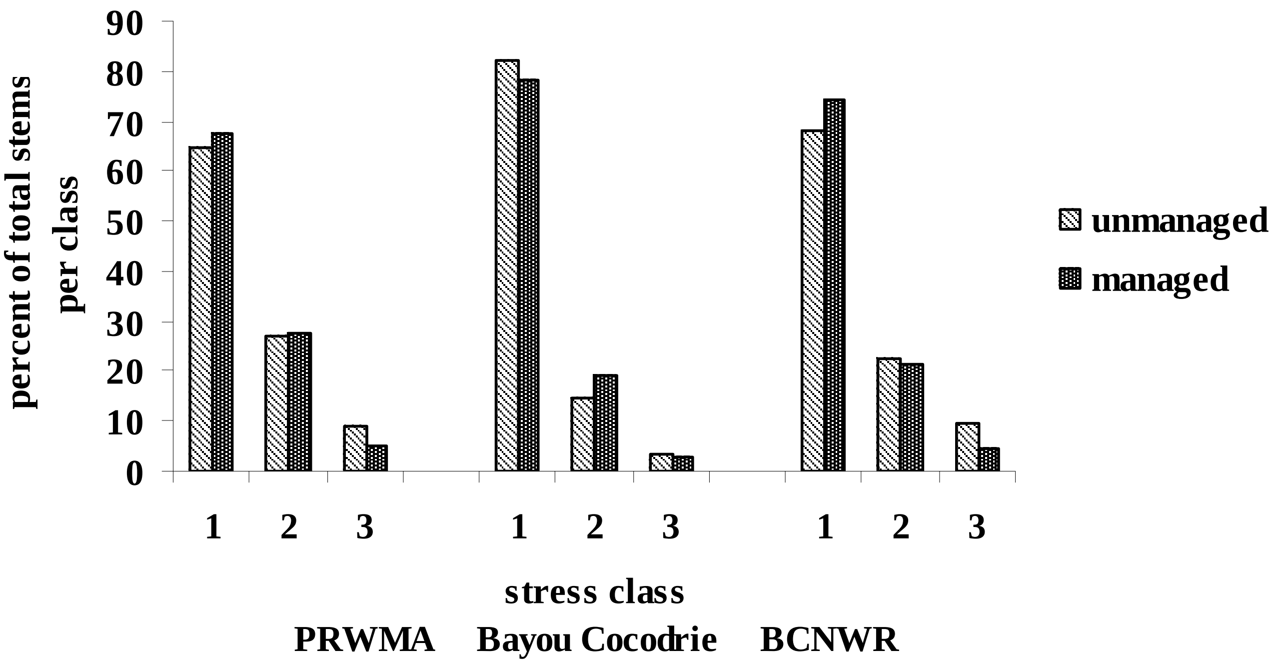

Figure 19. Mean tree stress rating at managed and unmanaged stands at each study site.

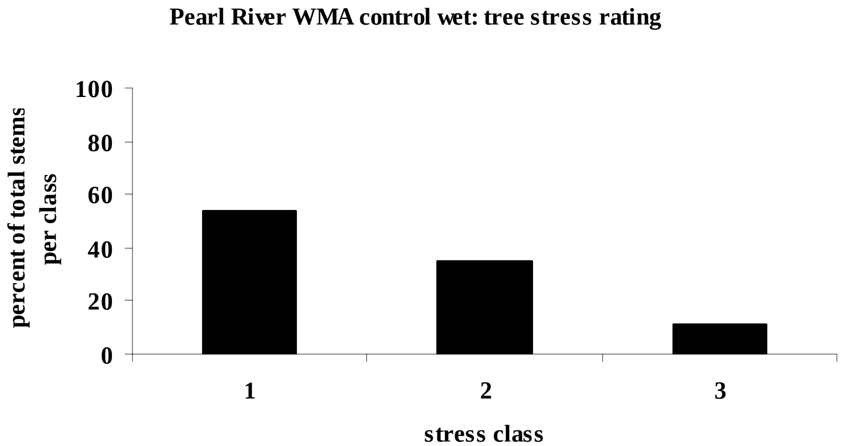

Fig. 20a.

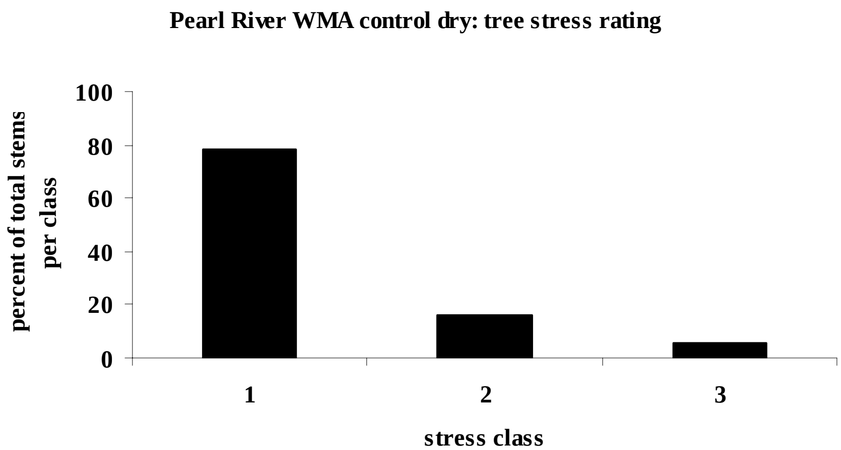

Fig. 20b.

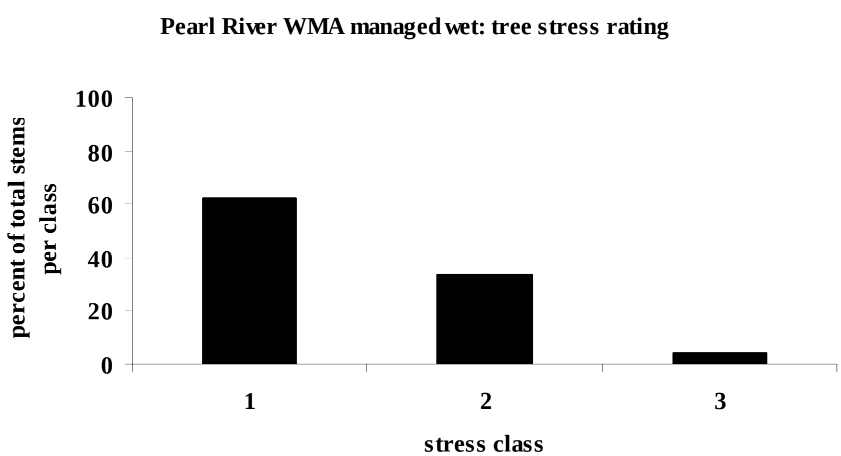

Fig. 20c.

Figures 20a – 20j. Mean tree stress rating at each stand.

(Figures 20a-20j continued)

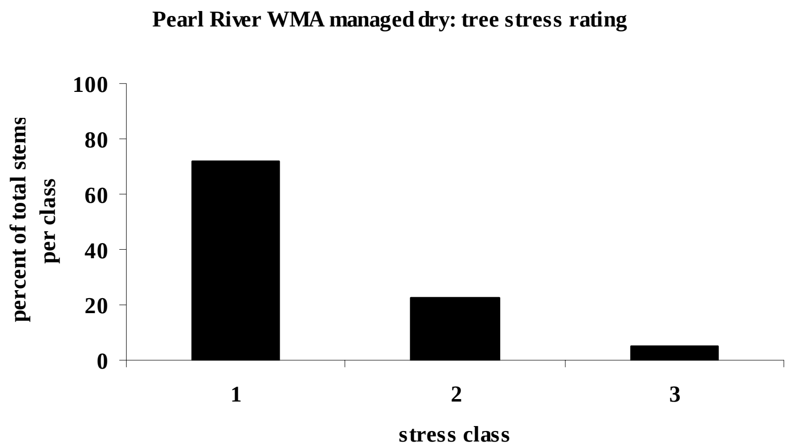

Fig. 20d.

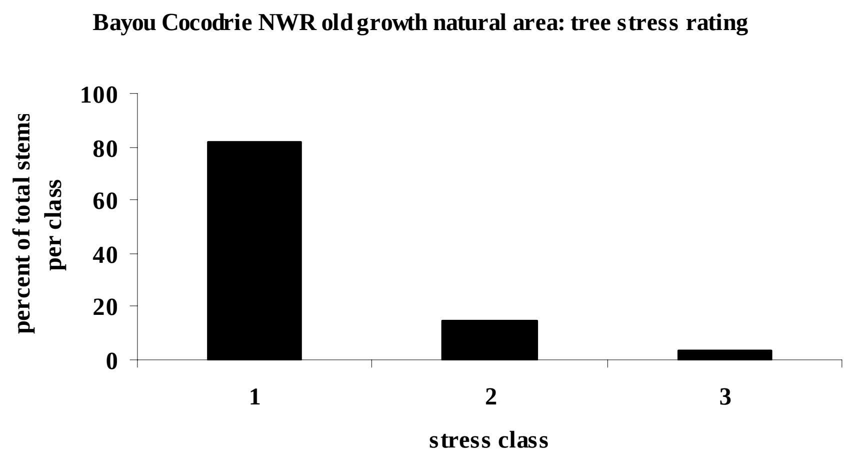

Fig. 20e.

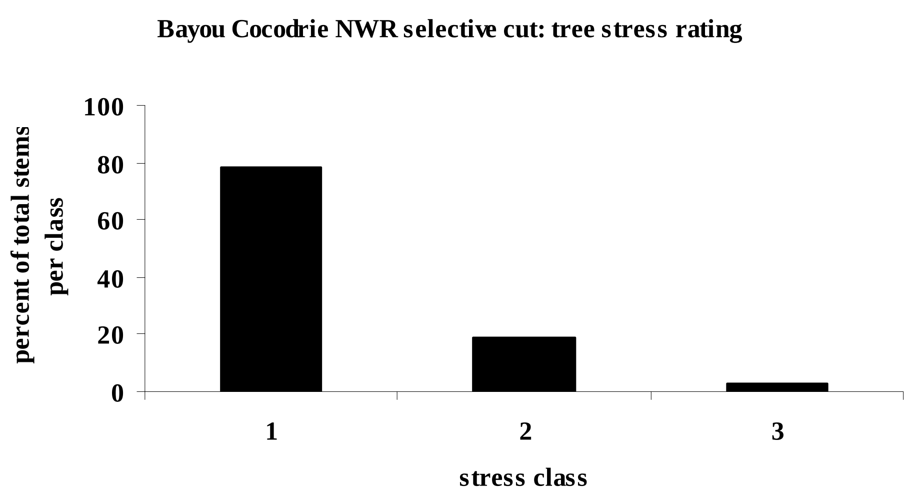

Fig. 20f.

(Figures 20a-20j continued)

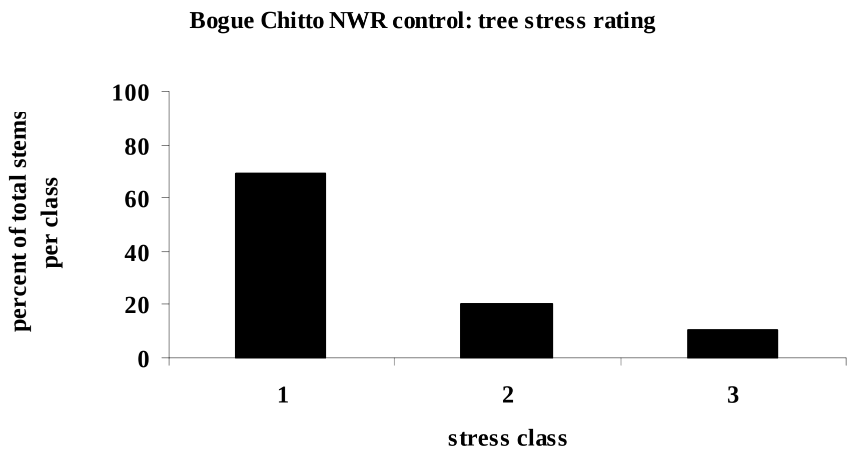

Fig. 20g.

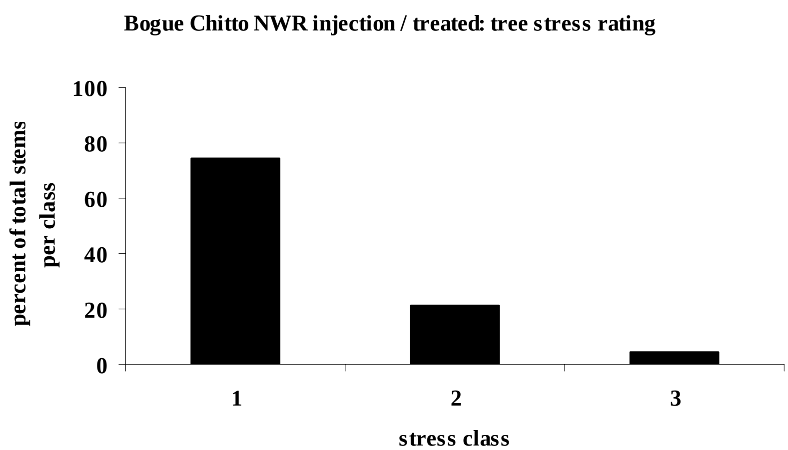

Fig. 20h.

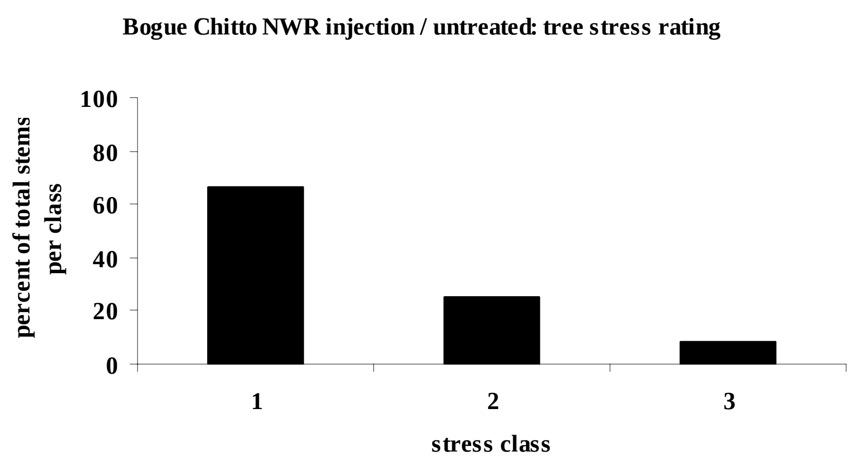

Fig. 20i.

(Figures 20a-20j continued)

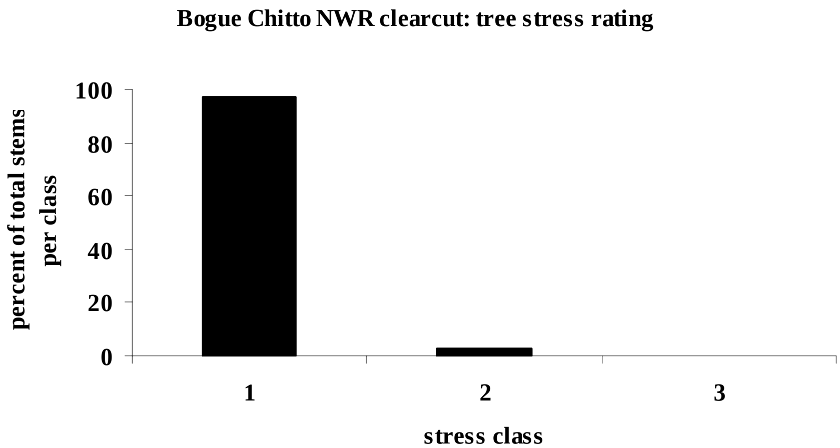

Fig. 20j.

clearcut to 35.1% at the Pearl River WMA control wet stand. Stress class 3 was the least frequent, with values ranging from 0% of total stems at the Bogue Chitto NWR clearcut to 11.4 % at the Pearl River WMA control wet stand.

Crown Class

Trees were more evenly distributed among crown classes at the unmanaged stands at the Pearl River WMA and Bogue Chitto NWR (Fig 21). The distribution of canopy classes was similar between the two stands at Bayou Cocodrie NWR. At all forested sites, the majority of live trees were co-dominant / intermediate crown class except at the Pearl River WMA control wet treatment, where the percentage of co-dominant / intermediate trees was only slightly higher than that of suppressed trees (Figures 22a-22j). With the exception of the Bogue Chitto NWR clearcut treatment, the dominant crown class was the least frequent at each treatment. Trees were more evenly distributed among crown classes at the unmanaged stands at the Pearl River WMA and Bogue Chitto NWR than at the managed stands at those sites.

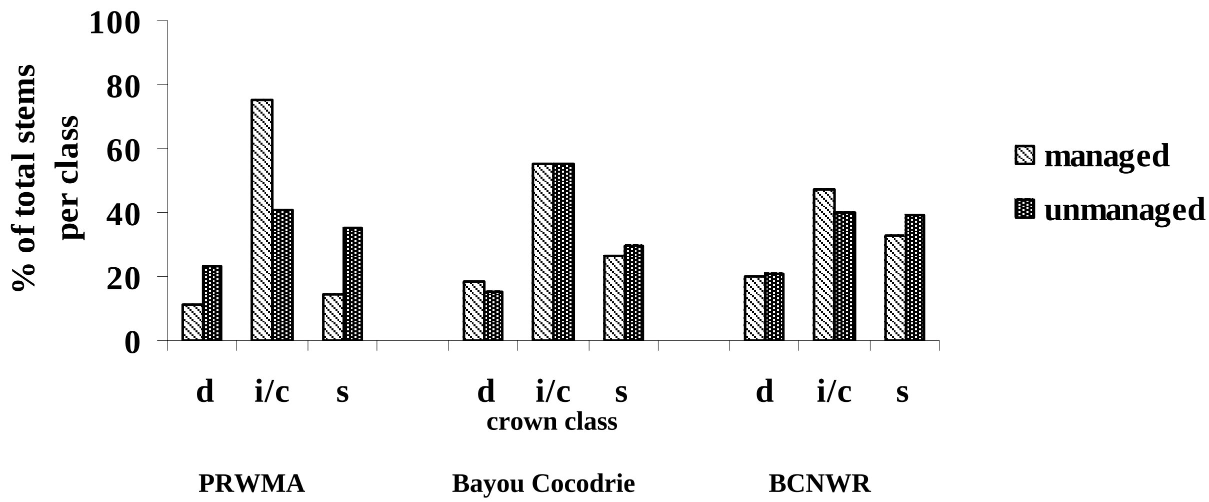

Figure 21. Mean tree crown class at managed and unmanaged stands at each study site. d= dominant, i/c= intermediate/co-dominant, and s=suppressed.

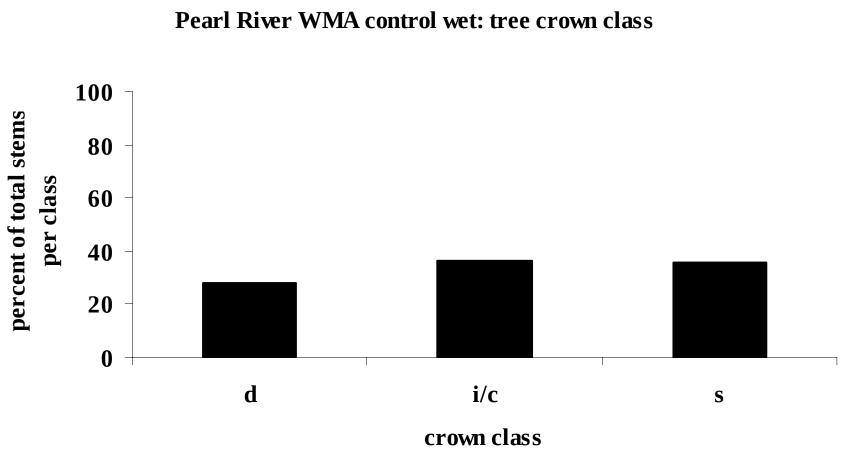

Fig. 22a.

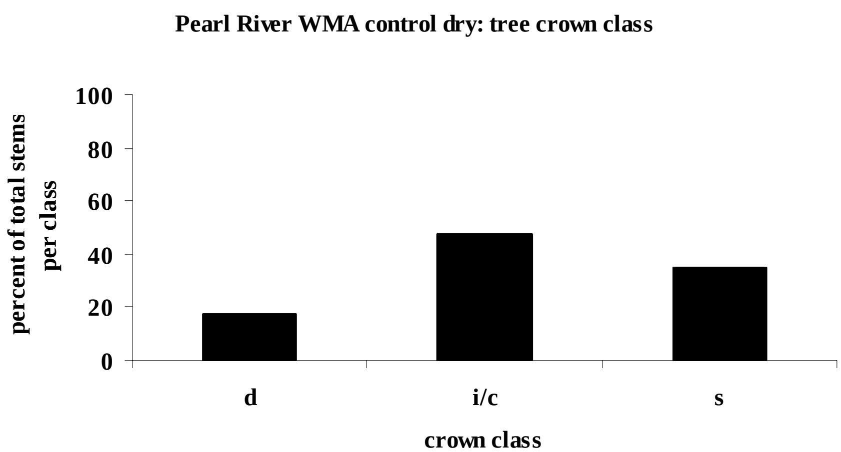

Fig. 22b.

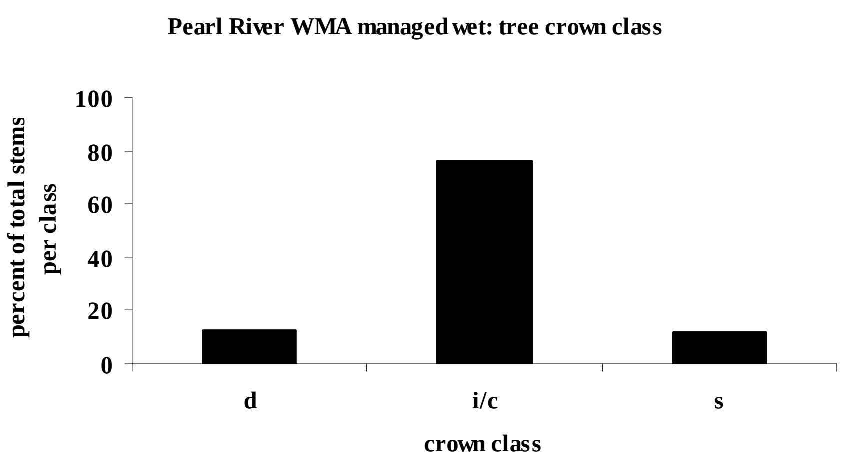

Fig. 22c.
Figures 22a-22j. Mean tree crown class at each stand.

(Figures 22a-22j continued)

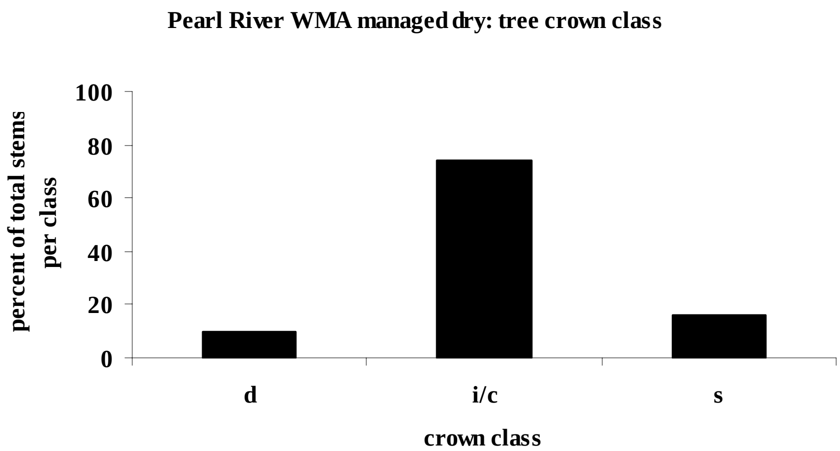

Fig. 22d.

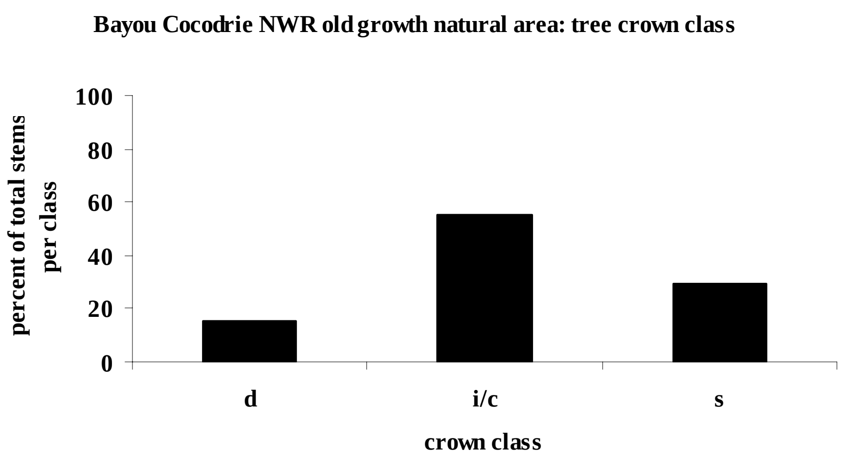

Fig. 22e.

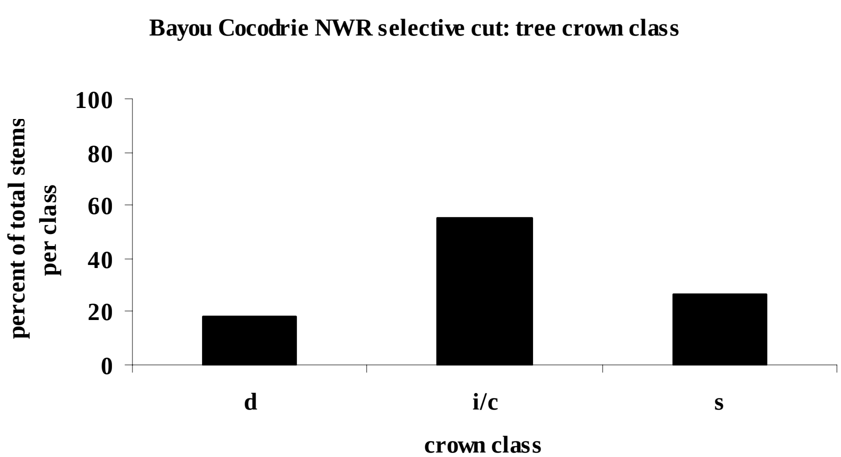

Fig. 22f.

(Figures 22a-22j continued)

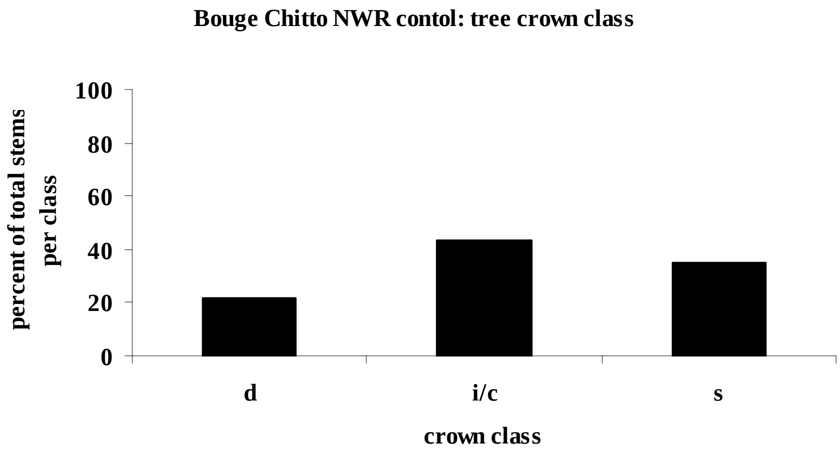

Fig. 22g.

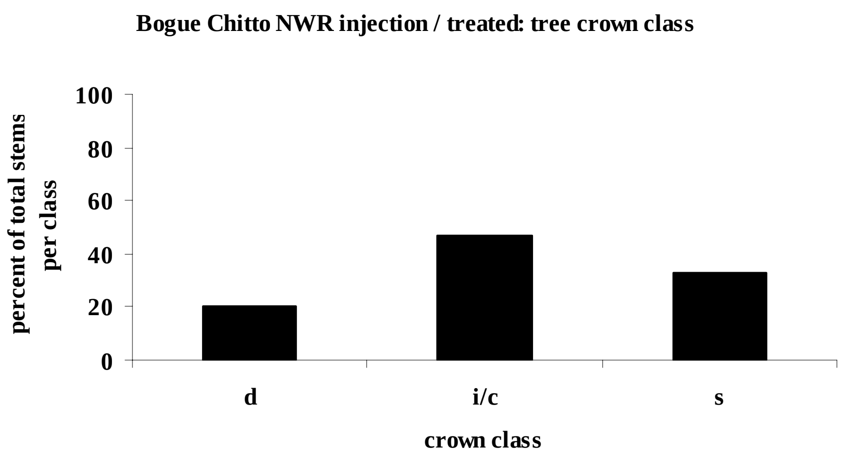

Fig. 22h.

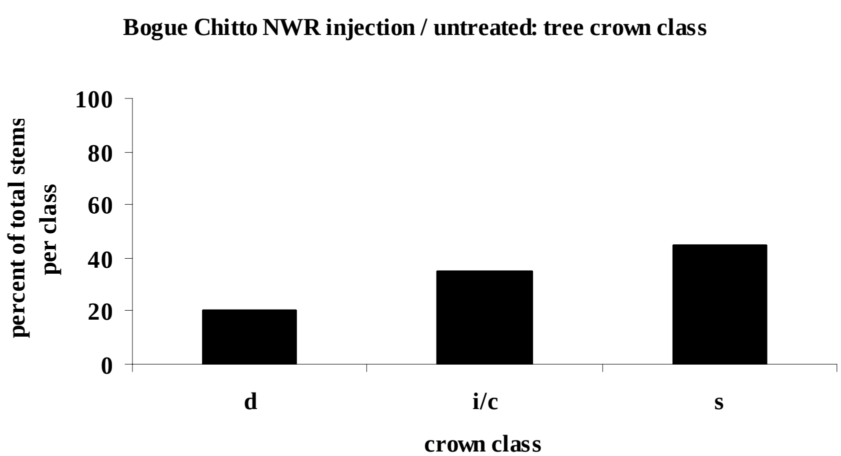

Fig. 22i.

(Figures 22a-22j continued)

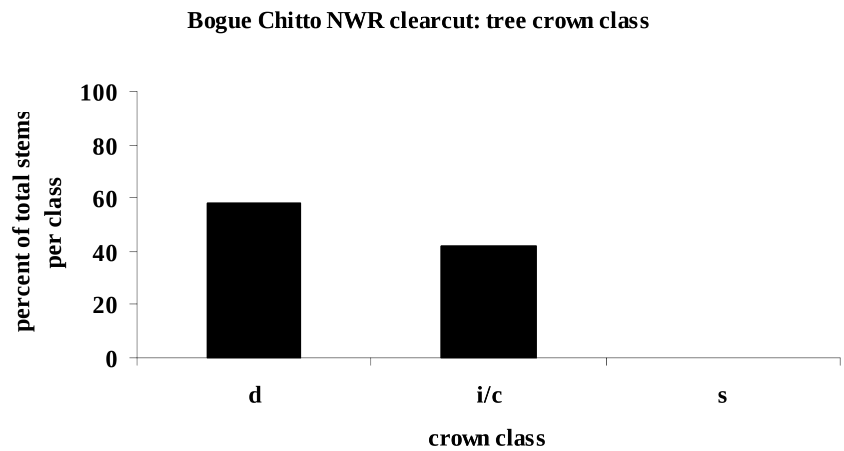

Fig. 22j.

DISCUSSION

The results of this study indicate that woody debris and live vegetation characteristics are highly variable within and among bottomland hardwood stands regardless of whether or not they were treated or how they were treated by timber management practices. Few of my predictions were supported by statistical analyses. However, there is evidence of differences in dead wood and live vegetation characteristics among managed and unmanaged stands.

CWD volumes in this study are low relative to other forest types from across the U.S. and Europe (Table 15). Both the managed and unmanaged stands at Pearl River WMA had lower CWD volumes than any cited study. Furthermore, all stands in this study, including the old growth natural area, had lower CWD volumes than have been reported from any mixed hardwood stand in the U.S. It is possible that this is the result of a natural latitudinal gradient, as it has already been established that warmer, wetter forests have lower woody debris loading than cooler drier sites. However, CWD data from tropical systems are scarce, and no representative studies were found and included in the table below.

The low volumes of CWD in BLH could also be due to processes and conditions unique to this system. The regular, often destructive flooding that is characteristic of BLH no doubt creates an environment that alters the nature of CWD input and turnover. Specifically, it is likely that decay rates in BLH are relatively high compared to other forested systems, particularly those in the U.S. and Europe. It is also important to remember that most, if not all, of the stands surveyed in this study are relatively young. All of these stands were certainly harvested within the last century, and many have management histories that likely ended only a few decades ago. If the stands in this

Table 15. CWD volumes compared to results from various forested types across the United States and Europe.

Reference	Forest Type / Location	Downed CWD Volume (m3/ha)
This study	BCNWR managed	7
This study	PRWMA managed	9
Guby and Dobbertin 1996	Swiss forests, managed	9
Motta et. al 2006	Italian Alps	9
This study	PRWMA unmanaged	12
This study	BCNWR unmanaged	13
Guby and Dobbertin 1996	Swiss forests, unmanaged	13
Pedlar et. al 2002	Boreal Canada, spruce	18
Kirby et. al 1998	British forests	20
This study	Bayou Cocodrie old growth	22
This study	Bayou Cocodrie managed	23
Macmillan 1981	USA, *Quercus* mixed	46
Muller and Liu 1991	USA, *Quercus* mixed	54
McGee et. al 1999	USA, Northern hardwoods, maturing	61
McGee et. al 1999	USA, Northern hardwoods, partially cut	69
Lang and Foreman 1978	*Quercus* mixed	76
Gore 1986	USA, *Acer-Fagus*	78
Pedlar et. al 2002	Boreal Canada, pure aspen	81
Harmon et. al 1986	USA, *Fagus-Betula*	82
Tyrell and Crow 1994	USA, hemlock (WI, MN, MI)	85
Hardt and Swank 1997	USA, *Acer*	86
Harmon et. al 1986	USA, *Quercus* mixed	94
Lee et. al 1997	Alberta, aspen-dominated mixedwoods	101
Pedlar et. al 2002	Boreal Canada, mixed woods	132
Harmon et. al 1986	USA, *Quercus prinus*	132
Tritton 1980	USA, *Acer-Fagus*	137
McGee et. al 1999	USA, Northern hardwoods, old growth	139

study were relatively young and vigorous regardless of whether they were managed recently or not, rates of woody debris input could be relatively low.

In addition to having relatively low volumes of CWD, woody debris characteristics were also highly variable within and among stands, as well as between sites. Within-stand variability is inherent to CWD studies and is likely a result of the patchy and irregular nature of woody input and distribution. This natural variability could be exacerbated in BLH by the effect of heterogeneous conditions on the forest floor, particularly differences in microtopography and the concurrent differences in hydrology. Although not quantified, ridges appeared to have greater volumes of CWD. Decay coefficients in swales may be higher because of accelerated fragmentation from flood activity and increased moisture content of the wood, both of which accelerate decomposition (Harmon 1986). A stratified sampling design that allows for separate sampling of ridges and the adjacent swales could have examined this variability.

Detecting differences in woody debris characteristics among the ten stands and between managed and unmanaged stands was also difficult. In addition to high variability, it is important to note that the forest management activities included in this study are not representative of those implemented in commercial timber harvests. In fact, some of these management activities could very well have created stand conditions that favor increased CWD loading. For example, the chemical injection treatment employed at Bogue Chitto NWR was designed to allow dead trees to persist in the stand; and mid-story removal treatments at Pearl River WMA were employed to support the growth of larger canopy trees.

Additionally, with the exception of the Bogue Chitto NWR clearcut, none of these management activities were stand-replacing. Therefore, the changes made to the

structure of the stand may not have been substantial enough to alter the nature of woody debris dynamics in that stand. Furthermore, these activities occurred over twenty years ago, which means that any debris generated from that management has long since decayed. In other words, the current state of woody debris in these stands is likely influenced more by stand conditions that are wholly separate from contemporary management activities.

Differences among the three sites also confounded attempts to compare CWD among different stands. In many cases, particularly when making comparisons between managed and unmanaged stands, significant differences were found only among the sites. The Mississippi Alluvial Valley and the Gulf Coastal Plain certainly function differently from one another, and this was reflected in the fact that both Bayou Cocodrie NWR stands were often different from stands at both Coastal Plain sites, but not from each other. One possible reason for this effect could be the relatively high productivity of BLH in the Mississippi valley. The larger trees present at Bayou Cocodrie NWR could conceivably contribute larger pieces of woody debris and generate larger diameter snags. But, in addition to the possible effect of site productivity, differences in the species-specific life spans of the important canopy trees among the sites could also be telling.

Dominant overstory species at Pearl River WMA and Bogue Chitto NWR are shorter-lived than those at Bayou Cocodrie. For example, water oak, the dominant species at Pearl River WMA, has a maximum life span of 175 years, whereas sweetgum, the dominant species at Bayou Cocodrie has a maximum life span of over 300 years (Loehle 1987). Thus, even in the managed stands at Pearl River WMA and Bogue Chitto NWR coarse woody debris input could be higher than a stand of comparable age at Bayou Cocodrie NWR. However, the old growth natural area at Bayou Cocodrie NWR,

despite being dominated by slower growing, longer lived trees, had a larger volume of downed woody debris than the managed stands at Pearl River WMA and, not surprisingly, the clearcut stand at Bogue Chitto NWR. Similar effects of species composition on the timing of CWD inputs have been found in other studies (Harmon et. al 1986, McGee et. al 1999, Pedlar 2002, Woodall and Nagel 2006) and clearcuts consistently have lower CWD inputs than older stands regardless of forest type (Kirby et. al 1998, Pedlar et. al 2002).

Differences in tree species compositions among the sites could have had other effects as well. *Celtis laevigata*, which occurred in the mid-story at Bayou Cocodrie NWR, had a high importance value at that site, but was absent from both Coastal Plain sites. Because their stems were small (17.77 cm + 9.45 cm), yet large enough to be tallied as trees, (as opposed to the shrubby understory found at Pearl River WMA and Bogue Chitto NWR), they could increase mean stem density, decrease mean and median live tree diameter, contribute to the volume of coarse woody debris, and decrease mean and median CWD diameter. These possible effects are underscored by the unexpectedly high stem density, the large volume of woody debris, and the preponderance of relatively small pieces of woody debris at the Bayou Cocodrie NWR old growth natural area.

Differences also occurred between the Pearl River WMA site and the Bogue Chitto NWR site. These differences between study sites are interesting, considering how close in proximity the two sites are. Again, differences in hydrology could play a role here. Stands at the Pearl River WMA were considerably wetter than those at Bogue Chitto NWR. Additionally, both of these sites were managed for timber before they were acquired as state and federal lands. The possible effects of differing management activities between the sites are difficult to address considering the lack of historical

records. But, if for instance one site was "high graded" before it was acquired as public lands, this could create a degraded forest with stand conditions much different from adjacent forested stands.

Despite the small differences in downed woody debris volumes, there were marked differences in diameter distributions of CWD between managed and unmanaged stands. At all sites there was an overall paucity of large diameter (> 30 cm) pieces of coarse woody debris. Still, at all three study sites the largest individual pieces of woody debris were in unmanaged stands. Bayou Cocodrie NWR old growth natural area did not have the largest mean volume of downed woody debris. It did, however, have a greater number of large diameter pieces of downed woody debris; and it contained the largest individual pieces of downed wood found during the study, including diameters of 50, 55, 58, 60, and 68 cm. At all stands the majority of snags had diameters less than 40 cm. This proportion ranged from 65% at the Bayou Cocodrie NWR old growth natural area to 96% at the Pearl River WMA control wet stand. However, almost 20% of the snags at the Bayou Cocodrie NWR old growth natural area were larger than 60 cm. A comparison of the number of individual pieces of CWD, standardized for sample sizes, may be the most efficient way to elucidate differences in size distributions of woody debris among different stands. Coarse woody debris volume may be helpful when comparing stands, but the density of large diameter dead wood is likely more important when addressing wildlife habitat quality.

The range and standard deviation of fine woody debris volumes among stands was much narrower than that of coarse woody debris. This pattern has been observed in at least one other study (McGee et.al 1999), and is likely because fine woody debris is more uniformly distributed in space and time. With the exception of the period

immediately following a disturbance, the input of fine woody debris to a forest stand is likely to be fairly regular throughout the life of that stand. However, these data show that more mature forests had higher mean volumes of fine woody debris. While FWD input may be less variable, FWD loading appears to increase with stand age.

Decay classes were skewed towards later stages of decay across all stands, with decay class 4 being the most common at each stand. This overall advanced state of decay could indicate a relatively high turnover rate of CWD in bottomlands. It is also possible that there is a lag in CWD decay rate at a certain point in the decay process. In other words, debris could initially decay quickly, but then slow down as carbon levels decrease and the physical properties of the wood change. Furthermore, managed stands had proportionately more pieces of CWD in advanced stages of decay than did unmanaged stands. This has been documented at least once in Swiss forests by Guby and Dobbertin (1996), but was attributed to differences in elevation, aspect, and tree species composition. That is possible in this study as well, where factors separate from forest management techniques may be causing differences in the decay class distributions among stands.

Despite these complex results, there is evidence that unmanaged stands are more likely to express some stand characteristics associated with mature forests. Perhaps more striking is the distinction that can be drawn between processes possibly occurring at the Bayou Cocodrie NWR stands and those at Pearl River WMA and Bogue Chitto NWR. These results suggest that the Bayou Cocodrie NWR old growth natural area could be undergoing or approaching a stand transition event where species composition shifts begin to take place in the canopy. In the context of the "reverse J" shaped pattern of coarse woody debris loading, this is the point where input rates are increasing due to the

mortality of large trees. In this case, the oak component of the canopy could be in excess of 100 years old. This transition event could be one of several that occur as a given stand shifts from being dominated by shade intolerant tree species to more tolerant ones. In the absence of a major disturbance, another transition event could occur at the old growth natural area when the longer lived sweetgum component begins to reach maturity.

Conversely, given the life spans of tree species in the Coastal Plain in relation to the frequency of major disturbances (namely tropical weather events), it is possible that these stands seldom or never reach a similar transitional phase. If that is the case, CWD dynamics in these stands could be characterized by long periods of relatively low loading, punctuated by infrequent events where input is extremely high. Interestingly, following this study, Hurricane Katrina made its third landfall in St. Tammany Parish, LA and severely damaged over 80% of the hardwood trees at the Pearl River site. Forty percent of the red oak species and 29% of the white oak species were blown down (Kenny Ribbeck personal comm.). Thus, predicting natural CWD inputs and managing stands to enhance CWD volumes could be particularly challenging in coastal BLH where catastrophic storms are expected to increase in frequency and intensity.

Establishing and meeting CWD goals, such as those recently put forth by the Lower Mississippi Valley Joint Venture Forest Resource Conservation Working Group (2007), could prove to be a challenge in BLH. For instance, none of the stands surveyed at Pearl River WMA and Bogue Chitto NWR met the proposed benchmark of 200 ft^3/ac (14.15 m^3/ha) of CWD. Furthermore, goals set for snag densities (> 6 stems/acre $\geq$ 10 in. dbh or > 2 stems $\geq$ 20 in. dbh) could prove difficult to meet, considering that only the Bayou Cocodrie NWR old growth natural area supported more than a small percentage of snags with dbh greater than 40 cm (15.7 in.). Further research is needed to not only

determine what are appropriate CWD characteristics for BLH, but also what methods will be most effective in creating and maintaining those goals.

Future research should more explicitly describe the processes, both natural and anthropogenic, that affect dead wood dynamics in bottomland hardwoods. For instance, at what age or size do certain tree species become more likely to contribute dead wood to the stand? What is the decay rate of this wood once it is present in a stand? What are the differences in dead wood dynamics among areas with of different elevations and with different hydrological regimes? How do differences in species composition and site productivity affect dead wood dynamics across southern forested wetlands? In order to more definitively associate forest management activities with coarse woody debris dynamics, a better understanding of the natural variation in these processes both within and among BLH with differing stand characteristics is necessary.

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