Summary of Findings

The action area includes 204 counties within the states of Alabama, Florida, Georgia, Louisiana, Mississippi, South Carolina, and Texas (see figure 1 and Appendix E of EIS). The action area is restricted by the limitations of the engineered phenotype, and the economics of silviculture. There are a total of 133 listed species and 2 proposed species within the action area (Appendix F). USDA-APHIS analyzed the possible effects that a determination of non-regulated status and the subsequent commercialization of FTE could have on these species. Of the 135 species, APHIS has determined that 43 of the listed species and the 2 proposed species have the potential to be sufficiently collocated that they may be affected by conversion of pine plantations to FTE. Of these 45 species, 26 are likely to be adversely affected, and 19 species are not likely to be adversely affected. The species likely to be adversely affected include 3 amphibians, 5 mussels, 14 plants, 3 reptiles, and 1 crustacean. These species are listed in Table 1. The species not likely to be adversely affected include 1 mammal, 5 mussels, 1 fish, 9 plants, and 3 reptiles. These species are listed in Table 2. Adoption of FTE is expected to have no effect on the remaining 90 species. These species are listed in table 3 along with a brief summary of why the action is not expected to have any effect.

Of the 135 species, 37 have designated critical habitat and two species have proposed critical habitat. There is also one plant species that is not known to occur within the action area, but has an unoccupied critical habitat unit proposed for designation within the action area. As part of its species effects analysis, APHIS considered the effects that a determination of nonregulated status of FTE and likely adoption may have on the critical habitat of these species. Twenty-six of the species with critical habitat were determined to be "no effect" species, mainly because the species are far removed from pine plantations, have specific habitat requirements, and the primary constituent elements of the species' habitat are not found in pine plantations. No effects are expected on their critical habitat either. Of the 12 "may affect" species with critical habitat (11 designated and 1 proposed), the critical habitat for most would be unlikely to be affected. Conversion of pine to FTE would be unlikely to occur within critical habitat. In the majority of cases, pine plantations are unsuitable habitat for the species and conversion from pine to FTE would be unlikely to have any effect on habitat that would be different than pine. There may be some effect on critical habitat for the 3 amphibians and 4 mussel species in locations that have been susceptible to drought. During times of drought, the lack of water will likely be exacerbated by the de-watering effects of FTE if a plantation were within the local drainage. Although such effects may make the habitat unusable, they are likely to be temporary and long term effects on the habitat are unlikely to be different than from those effects resulting from periods of drought.

May Affect, Likely to Adversely Affect Species:

Table 1: Species that may be affected, and are likely to be adversely affected.

Common Name	Scientific Name	Listing Status	States Known to Occur – (within action area)	Critical Habitat
Frosted Flatwoods	(*Ambystoma*	Threatened	FL, GA, SC	Yes - Likely to

salamander	*cingulatum*)			be adversely affected
Dusky gopher frog	(*Rana sevasa*)	Endangered	MS	Yes - Likely to be adversely affected
Reticulated flatwoods salamander	(*Ambystama bishapi*)	Endangered	FL, GA	Yes - Likely to be adversely affected
Squirrel Chimney cave shrimp	(*Palaemanetes cummingi*)	Threatened	FL	No
Gulf moccasinshell	(*Medionidus penicillatus*)	Endangered	AL, FL, GA	Yes - Likely to be adversely affected
Louisiana pearlshell	(*Margaritifera hembeli*)	Threatened	LA	No
Oval Pigtoe	(*Pleurobema pyrifarme*)	Endangered	AL, FL, GA	Yes - Likely to be adversely affected
Shinyrayed pocketbook	(*Lampsilis subangulata*)	Endangered	AL, FL, GA	Yes - Likely to be adversely affected
Southern Sandshell	(*Hamiota (=Lampsilis) australis*)	Threatened	AL, FL	Yes - Likely to be adversely affected
Louisiana quillwort	(*Isoetes lauisianensis*)	Endangered	AL, LA, MS	No
Apalachicola rosemary	(*Conradina glabra*)	Endangered	FL	No
Canby's dropwort	(*Oxypolis conbyi*)	Endangered	GA, SC	No
Chapman rhododendron	(*Rhododendran chapmanii*)	Endangered	FL	No
Cooley's meadowrue	(*Thalictrum cooleyi*)	Endangered	FL, GA, NC	No
Florida skullcap	(*Scutellaria floridana*)	Threatened	FL	No
Gentian pinkroot	(*Spigelia gentianoides*)	Endangered	AL, FL	No
Godfrey's butterwort	(*Pinguicula ionantha*)	Threatened	FL	No
Hairy rattleweed	(*Baptisia arachnifera*)	Endangered	GA	No
Harper's beauty	(*Harperocallis flavo*)	Endangered	FL	No
Pondberry	(*Lindera melissifolio*)	Endangered	AL, GA, MS, SC	No
Rugel's pawpaw	(*Deeringothamnus rugelii*)	Endangered	FL	No
Telephus spurge	(*Euphorbia telephioides*)	Threatened	FL	No

than removed because removal would be more likely to damage nearby seedlings. Presumably in some cases these stumps may be left to decay and could provide refugia for the BPS. It is quite possible that the black pine snake may use the habitat within a FTE plantation as it does pine plantations, but it is reasonable to assume that it would be less likely to do so. Activities associated with timber harvesting are cited as a threat to the species, and the shorter harvest cycle for FTE will result in harvest every six to ten years, compared to every 25 years for pine. This would make it more likely for adverse effects to occur, if the BPS were to use FTE habitat. Because of these potential negative effects on the species, APHIS has determined that adoption of FTE may affect, and is likely to adversely affect the black pine snake.

May Affect, Not Likely to Adversely Affect Species:

Table 2: Species that are likely to be affected, but are not likely to be adversely affected.

Common Name	Scientific Name	Listing Status	States Known to Occur – (within action area)	Critical Habitat
Alabama heelsplitter	(*Potamilus inflatus*)	Threatened	AL, LA, MS	No
Chipola slabsheli	(*Elliptia chipolaensis*)	Threatened	AL, FL	Yes - Not likely to be adversely affected
Choctaw bean	(*Villosa choctawensis*)	Endangered	AL, FL	Yes - Not likely to be adversely affected
Purple bankclimber	(*Elliptoideus sloatianus*)	Threatened	AL, FL, GA	Yes - Not likely to be adversely affected
Rabbitsfoot	(*Quadrula cylindrica cylindrica*)	Threatened	MS	Proposed CH - Not likely to be adversely affected
Bayou Darter	(*Etheostoma rubrum*)	Threatened	MS	No
American chaffseed	(*Schwalbea americana*)	Endangered	AL, FL, GA, LA, SC	No
Beautiful paw paw	(*Deeringothamnus pulchellus*)	Endangered	FL	No
Florida bristle fern	*Trichomanes punctatum* ssp. *floridanum*	Proposed Endangered	FL	No
Fringed campion	(*Silene polypetala*)	Endangered	FL, GA	No
Miccosukee gooseberry	(*Ribes echinellum*)	Threatened	FL	No
Navasota ladies'-tresses	(*Spiranthes parksii*)	Endangered	TX	No

Neches River rose-mallow	(*Hibiscus dasycalyx*)	Threatened	TX	Yes - Not likely to be adversely affected
Relict trillium	(*Trillium reliquum*)	Endangered	AL, GA	No
Texas trailing phlox	(*Phlox nivalis ssp. texensis*)	Endangered	TX	No
Eastern indigo snake	(*Drymarchon corois couperi*)	Threatened	AL, FL, GA	No
Bluetail mole skink	(*Eumeces egregius lividus*)	Threatened	FL	No
Sand skink	(*Neoseps reynoldsi*)	Threatened	FL	No
Northern Long-Eared Bat	(*Myotis septentrionalis*)	Endangered	AL, GA, LA, MS, SC	No

Alabama heelsplitter (*Potamilus inflatus*)

Unless otherwise noted, the following information was obtained from the species' listing rule (US-FWS, 1990d), and the FWS recovery plan for the species (US-FWS, 1993b).

Listing Status: Listed as threatened on September 28, 1990 wherever found.

Description: The Alabama heelsplitter, which is referred to as the inflated heelsplitter in the species recovery plan, is a large (sometimes reaching over 140 millimeter in length) freshwater mussel with a brown to black shell with green rays in young individuals.

Habitat: The Alabama heelsplitter prefers soft, stable substrata in slow to moderate currents. It has been found in sand, mud, silt and sandy-gravel, but not in large or armored gravel and may occur in depths over six meters (20 feet).

Life History: The life history of this species is largely unknown. Gravid females have been collected from the Amite River, Louisiana, during October. At that time, they were observed to extend a mantle margin just above the substratum surface in shallow, clear water. Indication are that the freshwater drum (*Aplodinotus grunniens*) is a suitable glochidial host for the Alabama heelsplitter.

Status and Distribution: The Alabama heelsplitter was known historically from the Amite and Tangipahoa Rivers, Louisiana; the Pearl River, Mississippi; and the Tombigbee, Black Warrior, Alabama, and Coosa Rivers, Alabama. The presently known distribution is limited to the Amite River, Louisiana, and five sites in the Tombigbee and Black Warrior Rivers, Alabama.

Critical Habitat: No critical habitat rules have been published for the Alabama heelsplitter.

Effects of Adoption of FTE on the Species: Counties within the action area where the Alabama heelsplitter is found are: Alabama: Baldwin; Louisiana: East Baton Rouge, East Feliciana, Livingston, St. Helana, and St. Tammany; Mississippi: Hancock and Pearl River.

Emerging at dusk, most hunting occurs above the understory, 1 to 3 meters (m) (3 to 10 feet (ft)) above the ground, but under the canopy on forested hillsides and ridges, rather than along riparian areas. This coincides with data indicating that mature forests are an important habitat type for foraging northern long-eared bats. Occasional foraging also takes place over forest clearings and water, and along roads. Foraging patterns indicate a peak activity period within 5 hours after sunset followed by a secondary peak within 8 hours after sunset.

Range: The northern long-eared bat ranges across much of the eastern and north central United States, and all Canadian provinces west to the southern Yukon Territory and eastern British Columbia. In the United States, the species' range reaches from Maine west to Montana, south to eastern Kansas, eastern Oklahoma, Arkansas, and east to the Florida panhandle. States within the action area where this species is found are: Alabama, Louisiana, Mississippi, South Carolina. County occurrences for northern long-eared bat within these States has not been delineated by the U.S. Fish and Wildlife Service.

Reasons for Decline: No other threat is as severe and immediate to the northern long-eared bat's persistence as the disease, white-nose syndrome. Some habitat has been lost, degraded, or fragmented, primarily through the disturbance of hibernacula and land development. Mortality caused by wind turbines is expected to increase.

Effects of Adoption of FTE on the Species:

Conversion of pine plantation to FTE could increase the disturbance of roosting northern long-eared bats because FTE is harvested more frequently than pine. Northern long-eared bats are known to roost in shortleaf pine. It is not known whether northern long-eared bats would use FTE for roosting. *Eucalyptus* is not a known roosting tree for the northern long-eared bat because the species do not naturally overlap in distribution. However, there are aspects of FTE that suggest it would not serve as a suitable roost tree for the northern long-eared bat. First, northern long-eared bats are more likely to select larger diameter trees as roosts while the diameter at breast height (dbh) of FTE at harvest is at largest, approximately 7.5 inches. Also, the bark of FTE is rather smooth. Although there is some sloughing of bark, FTE sloughs bark less than other species of *Eucalyptus*. According to the applicant, FTE trees do not have stringy bark and bark does not slough off in large strips as in some species of *Eucalyptus*; rather, the bark sloughs off in smaller bark flakes.

In addition, the program area is at the outer edge of the range of the northern long-eared bat. Once the county occurrence of the bat has been delineated, it is possible that there is little or no overlap between the counties of northern long-eared bat occurrence and the program area.

Therefore, APHIS has determined that adoption of FTE may affect, and is not likely to adversely affect the northern long-eared bat.

No Effect Species

Table 3. List of no effect species.

Group	Scientific Name	Common Name	Status	CH	State	Reason for No Effect
Birds	*Polyborus plancus audubonii*	Audubon's crested caracara	Threatened	No	FL	A predaceous bird that prefers open grasslands habitat and may use pastures. Would not likely be found in pine or Eucalyptus plantations (Federal Register, 1987c).
Birds	*Vermivora bachmanii*	Bachman's warbler (=wood)	Endangered	No	FL, SC	Presumed extinct. But used palustrine forested wetlands and longleaf pine near brackish marsh. Clearing of this breeding habitat is threat. Conversion of pine plantations to FTE would have no effect (US-FWS, 2007b).
Birds	*Rastrhamus sociabilis plumbeus*	Everglade snail kite	Endangered	Yes	FL	The principal threat to the everglade nail kite is the loss or degradation of its wetland habitat in central and southern Florida. The Everglades snail kite is a native marsh species uniquely adapted for a diet almost exclusively of freshwater apple snails *(Pomacea paludosa)*, which has been negatively impacted by man induced hydrologic changes within its Everglades habitat. Nearly half of the Everglades have been drained for agriculture and urban development (US-FWS, 2007f). The species would be unaffected by the action because it would not find plantations suitable habitat and FTE would not be planted within the wetland habitat that this species requires. Therefore, no effects are expected on the species or its designated critical habitat.
Birds	*Ammodramus savannorum floridanus*	Florida grasshopper sparrow	Endangered	No	FL	Major threat to the species is loss of dry prairie habitat, especially from conversion to pine plantations. This subspecies is extremely habitat specific, inhabiting large (greater than 50 ha) treeless, relatively poorly-drained grasslands that have a history of frequent fires (US-FWS, 2009e). Therefore, this species would not be affected by conversion of a pine plantation to a FTE plantation.
Birds	*Aphelocoma*	Florida scrub-jay	Threatened	No	FL	The major threat to the species is

	coerulescens					loss of their scrub habitat due to urban and agricultural development (US_FWS, 2006). Would not likely be found in pine or Eucalyptus plantations.
Birds	*Dendroica kirtlandii*	Kirtland's Warbler	Endangered	No	FL, SC	Nests in jack pine stands in Michigan- winters in Bahamas (US-FWS, 2008m). Would only be an incidental visitor in eucalyptus if passing through on migration.
Birds	*Sterna antillarum*	Least tern (interior pop.)	Endangered	No	AR, LA, MS, TX	Eucalyptus plantations would not be situated along beaches and sandbars along rivers and reservoirs that make up this species' habitat (US-FWS, 2008l).
Birds	*Grus canadensis pulla*	Mississippi sandhill crane	Endangered	Yes	MS	Dependent on savanna communities for year-round use. Savannas are wet grasslands predominated by wiregrass (Aristida spp.) with scattered longleaf pine (Pinus palustris), slash pine (P. elliottii), and pond cypress (Taxodium ascendens) trees. Would not likely be found in pine or Eucalyptus plantations, and there would be no conversion of pine plantations to FTE within the species' designated critical habitat (US-FWS, 1976).
Birds	*Charadrius meladus*	Piping Plover, except GL watershed	Threatened	Yes	AR, AL, FL, LA, NC, SC, TX	Shore bird. Would not likely be found in pine or Eucalyptus plantations, and there would be no conversion of pine plantations to FTE within the species' designated critical habitat (US-FWS, 2002).
Birds	*Charadrius melodus*	Piping Plover, Great Lakes watershed	Endangered	Yes	MS	Shore bird. Would not likely be found in pine or Eucalyptus plantations, and there would be no conversion of pine plantations to FTE within the species' designated critical habitat (US-FWS, 2002).
Birds	*Picoides borealis*	Red-cockaded woodpecker	Endangered	No	AL, FL, GA, LA, MS, NC, SC, TX	Require old mature pines, preferably longleaf, for nests. Suitable foraging habitat consists of mature pines with an open canopy, low densities of small pines, little or no hardwood or pine midstory, few or no overstory hardwoods, and abundant native bunchgrass and forb groundcovers. Current pine plantations are not suitable habitat, even for foraging. Loss of mature pines within pine woodlands is a threat. Even age silvicultural practices, such as is carried out on pine plantations, even with a long rotation, results

						in removal of large old trees and renders stands unsuitable for nesting. Fire management is also important to manage the understory so that it will remain suitable for foraging. There are silvicultural management practices that can be used to promote recovery of RCW, but these practices require over 100 years before harvest of at least some of the trees, very low density planting, and at least a two aged class management system. Such practices are unlikely to be used by growers interested in growing FTE, and growers interested in managing their land for the benefit of the red cockaded woodpecker would be unlikely to have an interest in growing FTE. Therefore, the conversion of pine plantations to FTE plantations will have no effect on the RCW. (US-FWS, 1979).
Birds	*Calidris conutus fufa*	Red Knot	Proposed Threatened	No	AL, GA, FL, MS, SC, TX	Primarily a shorebird that feels on molluscks and crutaceans. A migratory bird that would only be passing through briefly on migration (US-FWS, 2013d).
Birds	*Grus americana*	Whooping crane	Endangered , NE EXPN pop.	Yes	FL, TX	The major threat is habitat destruction from drainage of wetlands and development (US-FWS, 2010j). The species would not find pine or eucalyptus plantations suitable habitat, and there would be no conversion of pine plantations to FTE within the species' designated critical habitat.
Birds	*Mycteria americana*	Wood stork	Endangered	No	AL, FL, GA, MS, NC, SC	Wood storks are a wetland dependent species and loss of foraging wetlands continues to be the primary threat to this population (US-FWS, 2006c). The species would not find pine or eucalyptus plantations suitable habitat.
Clams	*Elliptio spinosa*	Altamaha spinymussel	Endangered	Yes	GA	This is a newly listed species and does not yet have a recovery plan. Information here is from the listing document (Federal Register, 2011). Requires coarse to fine grain sandbars. Sedimentation from siltation and runoff have caused decline, but mainly from row crop agriculture and roads. Host fish species are unknown.

						This species is considered a "big river" species and is found in swiftly flowing water. The historical range of the Altamaha spinymussel was restricted to the Coastal Plain portion of the Altamaha River and the lower portions of its three major tributaries, the Ohoopee, Ocmulgee, and Oconee Rivers. All known populations are in counties identified as within the action area for this species. Hydrologic impacts from adoption of FTE are only expected at the local level in small streams, not in large rivers where this species is found. Although all mussels are affected by sedimentation, the Altamaha spinymussel is unlikely to be affected by any potential increased sedimentation resulting from the adoption of FTE. Even in small waters, the effect from sedimentation related to FTE production is expected to be negligible. Any additional sediment load in the mainstem of the rivers supporting a population would be insignificant compared to the sediment loads that result from agriculture and urban development. Therefore, the determination for this species is "no effect" ", as well as a no effect on its designated critical habitat.
Clams	*Potomilus capax*	Fat pocketbook	Endangered	No	LA, MS	Within the action area this species is found only in the Lower Mississippi River. Sedimentation and turbidity have been implicated as limiting factors, however effect of FTE would be negligible in the Lower Miss. R. Likewise, hydrology not an issue. Host fish are freshwater drum (*Aplodinotus grunniens*) (US-FWS, 2007g). Because this is a "big river" species, adoption of FTE would have no effect.
Clams	*Amblema neislerii*	Fat three-ridge (mussel)	Endangered	Yes	FL, GA	Information from the recovery plan (US-FWS, 2003): The fat threeridge inhabits that main channel of small to large rivers in slow to moderate current. Substrate used by this mussel varies from gravel to cobble to a mixture of sand and sandy mud. Brim Box and Williams (2000)

						found 60 % of the specimens were located in a sandy silt substrate. The current distribution of this species is within the mainstem of the Apalachicola River and the lowermost portion of the Chipola River. Five potential host fishes: weed shiner (*Notorpis texanus*), bluegill (*Lepomis macrochirus*), redear sunfish (*L. microlophus*), largemouth bass (*Micropterus salmoides*), and blackbanded darter (*Percina nigrofasciata*). Because this species is found in the main channel of the mainstems of rivers, it is unlikely to be affected by the hydrologic affects that could occur from the adoption of FTE. Although all mussels are affected by sedimentation, the threerigde is unlikely to be affected by any potential increased sedimentation resulting from the adoption of FTE. Even in small waters, the effect from sedimentation related to FTE production is expected to be negligible. Any additional sediment load in the mainstem of the rivers supporting population would be insignificant compared to the sediment loads that result from agriculture and urban development. In addition, the fat three-ridge appears to be more tolerant of varying substrate than most mussel species and would be less likely to be adversely affected by sedimentation. Therefore, the determination for this species is "no effect", as well as a no effect on its designated critical habitat.
Clams	*Pleurabema stradeanum*	Fuzzy pigtoe	Threatened	Yes	AL, FL	This is a newly listed species and does not yet have a recovery plan. Information here is from the listing document (US-FWS, 2012). The fuzzy pigtoe is found in medium creeks to medium rivers in stable substrates of sand and silty sand with slow to moderate current. The blacktail shiner (*Cyprinella venusta*) was found to serve as a host for fuzzy pigtoe glochidia in the preliminary study trial. Considering that known populations are in medium creeks to medium rivers, it is unlikely that the potential hydrologic effects

						from the adoption of FTE would affect the species. Although all mussels are affected by sedimentation, the fuzzy pigtoe is unlikely to be affected by any potential increased sedimentation resulting from the adoption of FTE. Even in small waters, the effect from sedimentation related to FTE production is expected to be negligible. Any additional sediment load in the medium creeks to medium rivers supporting a population would be insignificant compared to the sediment loads that result from agriculture and urban development. In addition, the fuzzy pigtoe appears to prefer sand and silty sand and would be less likely to be adversely affected by sedimentation. Therefore, the determination for this species is "no effect", as well as a no effect on its designated critical habitat.
Clams	*Fusconaia escambia*	Narrow pigtoe	Threatened	Yes	AL, FL	This is a newly listed species and does not yet have a recovery plan. Information here is from the listing document (US-FWS, 2012). Little is known about the habitat requirements or life history of the narrow pigtoe. It is found in medium creeks to medium rivers, in stable substrates of sand, sand and gravel, or silty sand, with slow to moderate current. It is found in the Escambia River with 28 known occurrences, and the Yellow River drainage with 4 known occurrences. This species is unusual in that it can tolerate impoundments. The host fish for the narrow pigtoe is currently unknown. Habitat degradation is a reason for decline of this species. Drought is considered a moderate threat to the narrow pigtoe. However, considering that known populations are in medium creeks to medium rivers, it is unlikely that the potential hydrologic effects from the adoption of FTE would affect the species. Although all mussels are affected by sedimentation, the narrow pigtoe is unlikely to be affected by any potential increased sedimentation resulting from the adoption of FTE.

						Even in small waters, the effect from sedimentation related to FTE production is expected to be negligible. Any additional sediment load in the medium creeks to medium rivers supporting a population would be insignificant compared to the sediment loads that result from agriculture and urban development. In addition, the narrow pigtoe appears to prefer sand and silty sand and would be less likely to be adversely affected by sedimentation. Therefore, the determination for this species is "no effect", as well as a no effect on its designated critical habitat.
Clams	*Medionidus simpsanianus*	Ochlockonee moccasinshell	Endangered	Yes	FL, GA	Information from the recovery plan (US-FWS, 2003): Life history and host fish are unknown but may be similar to Gulf moccasinshell. The Ochlockonee moccasinshell inhabits large creeks and the Ochlockonee River main stem in areas with current. Typical substrates are sand with some gravel. Currently, the species persists in only a relatively short reach of the Ochlockonee River above Talquin Reservoir. Only three live specimens have been found since 1974. Because the species is found in the mainstem of the Ochlockonee River, it is unlikely that the potential hydrologic effects from the adoption of FTE would affect the species. Although all mussels are affected by sedimentation, the Ochlockonee moccasinshell is unlikely to be affected by any potential increased sedimentation resulting from the adoption of FTE. Even in small waters, the effect from sedimentation related to FTE production is expected to be negligible. Any additional sediment load in the mainstem of the Ochlockonee River from production of FTE would be insignificant compared to the sediment loads that result from other sources. Therefore, the determination for this species is "no effect", as well as a no effect on its designated critical habitat.
Clams	*Lampsilis abrupta*	Pink mucket	Endangered	No	LA	This species is generally found in

		(pearlymussel)				large rivers with moderate to fast flow and in depths of 0.5 to 8 meters. This mussel has a wide range throughout the mid-south and as far north as Ohio. Within the action area it was historically known to be found only in Morehouse Parish in Louisiana. However, the recovery plan does not identify current known populations anywhere near the action area. Sedimentation is a threat to this species (US-FWS, 1985). Combining the lack of known presence within the action area, with its preferred habitat of large rivers leads to a no effect determination.
Clams	*Pleurobema decisum*	Southern clubshell	Endangered	Yes	AL	Historically it was recorded within Baldwin County Alabama, the only county within the action area. Currently there are no known populations within the action area. Host fish are unknown. As for most mussel species, water quality degredation and sedimentation are threats. However, this species is found in small rivers where any increase in sedimentation from adoption of FTE would be negligible (US-FWS, 2000). . Combining the lack of known presence within the action area, with its preferred habitat of small rivers leads to a no effect determination", as well as a no effect on its designated critical habitat.
Clams	*Ptychobranchus jonesi*	Southern kidneyshell	Endangered	Yes	AL, FL	This is a newly listed species and does not yet have a recovery plan. Information here is from the listing document (US-FWS, 2012). Within the action area, the species is known to be in Holmes Creek in Washington County Florida, and the Choctawhatchee River and Pea River in Geneva County, Alabama. Little is known about this species so reasons for decline are unknown, host species are likely darters like others in its genera. It is extremely imperiled. Found in medium creeks to small rivers in firm sand substrate with slow to moderate current. Considering that known populations are in medium creeks to small rivers, it is unlikely that the hydrologic effects

						from adoption of FTE would affect the species. Although all mussels are affected by sedimentation, the southern kidneyshell is unlikely to be affected by any potential increased sedimentation resulting from the adoption of FTE. Even in very small waters, the effect from sedimentation related to FTE production is expected to be negligible. Any additional sediment load in medium creeks to small rivers from production of FTE would be insignificant compared to the sediment loads that result from other sources. Therefore, the determination for this species is "no effect", as well as a no effect on its designated critical habitat.
Clams	*Fusconaia burkei*	Tapered pigtoe	Threatened	Yes	AL, FL	This is a newly listed species and does not yet have a recovery plan. Information presented here is from the listing document (US-FWS, 2012). The tapered pigtoe is found in medium creeks to medium rivers in stable substrates of sand, small gravel, or sandy mud, with slow to moderate current. The blacktail shiner (Cyprinella venusta) has been found to serve as a host for tapered pigtoe glochidia. Habitat degradation is a reason for decline of this species. The species was not detected at 9 of the 22 historical sites examined during recent status surveys. Most of those are in the middle portion of the drainage in Alabama, and the species appears to be declining in this portion of its range. However, these are in areas outside of the action area. The tapered pigtoe is currently known from a total of 53 locations within the Choctawhatchee River drainage. Within the action area they are in the counties of Henry, Houston, and Geneva within Alabama: and Bay, Holmes, Jackson, Walton, and Washington Counties within Florida. The species persists mainly in the lower portions of the drainage and in isolated locations in Alabama. Considering that known populations are in medium creeks to small rivers, it is unlikely that the hydrologic effects from

						adoption of FTE would affect the species. Although all mussels are affected by sedimentation, the tapered pigtoe is unlikely to be affected by any potential increased sedimentation resulting from the adoption of FTE. Even in very small waters, the effect from sedimentation related to FTE production is expected to be negligible. Any additional sediment load from production of FTE in the lower reaches of the watershed where these mussels are found would be insignificant compared to the sediment loads that result from other sources. Therefore, the determination for this species is "no effect", as well as a no effect on its designated critical habitat.
Conifers and Cycads	*Torreya taxifolia*	Florida torreya	Endangered	No	FL, GA	Major decline is believed to be a result of disease caused by fungal pathogens during the 1950s and 1960s, and/ or a combination of environmental stress and native pathogens, but studies have yet to provide an explanation for this species' decline. Overcollection was a threat of high importance in the past, but at present is not of concern. The magnitude of stem damage caused by deer rubbing represents a current threat; the vascular cambium is rubbed off causing an aperture for fungal infection. Because land use of areas adjacent to ravines can affect drainage and other characteristics of the habitat, Torreya sites should include a buffer zone. This zone might consist of pine woods above the crest of a ravine and/or areas of a drainage system upstream from the Torreya site. The primary requirement for maintenance of the habitat appears to be lack of disturbances such as logging of ravines or adjacent uplands, creation of impoundments, or other alteration of hydrologic and land use patterns. (US-FWS, 2009v). Pine plantations are not typically located in ravines, and it is unlikely that FTE would be placed their either. Adoption of

						FTE will have no effect on this plant. It is not known to be present in pine plantations or pine habitat. In addition, impacts to hydrology, or from sedimentation, or more rapid canopy closure are not threats to the Florida torreya.
Fishes	*Scaphirhynchus suttkusi*	Alabama sturgeon	Endangered	Yes	AL	Water quality degradation is a threat but this species occurs in big rivers and would not be affected by FTE, and neither would its designated critical habitat (US-FWS, 2013f).
Fishes	*Acipenser oxyrinchus desotai*	Gulf sturgeon	Threatened	Yes	AL, FL, LA, MS	A big river species that would not be affected by adoption of FTE, and neither would its designated critical habitat(US-FWS, 2009l).
Fishes	*Etheostoma okaloosae*	Okaloosa darter	Threatened	No	FL	No effects are expected because 90% of its historic range is managed by Eglin AFB (98.7% of current range). Eglin AFB encompasses the headwaters of all six of these drainages, and the remainder of these streams flow out of Eglin AFB into the urban complex of the Cities of Niceville and Valparaiso (egistrar, 2011).
Fishes	*Scaphirhynchus albus*	Pallid sturgeon	Endangered	No	AR, LA, MS	A species found in larger channels of the Mississippi-Missouri river system (US-FWS, 2014d).
Flowering Plants	*Harrisia abariginum*	Aboriginal Prickly-Apple	Endangered	Proposed CH	FL	This species is not known to occur in counties within the action area for FTE, but does have one unoccupied proposed CH unit within Manatee County FL. Adoption of FTE will have no effect on this plant's CH. It is a plant only found in areas along the coast with an open canopy and a substrate of coarse sand and shells, and would not find pine plantations as suitable habitat (US-FWS, 2015a).
Flowering Plants	*Crotalaria avonensis*	Avon Park harebells	Endangered	No	FL	Endemic to the Lake Wales Ridge region of central Florida, with only 3 populations that are threatened by devlopment, and associated degredation of habitat. Prefers open sandy scrub habitat. Adoption of FTE will have no effect on this plant. It is not known to be present in pine plantations. Silviculture and timber harvest are not adversely affecting the species (US-FWS, 2006a).
Flowering Plants	*Nolina brittoniana*	Britton's beargrass	Endangered	No	FL	Found in a wide range of habitat types including relatively open

						scrub, sand pine scrub, and sandhill with almost complete canopy coverage. In all habitats where N. brittoniana occur, the soil is droughty and infertile, and all are considered upland sites. These habitats are also fire-maintained and fire-dependent ecosystems that are presumably replaced by hardwoods in the absence of fire. 72 known populations with 34 protected on public conservation lands. Adoption of FTE will have no effect on this plant. It is not known to be present in pine plantations. Silviculture and timber harvest are not adversely affecting the species. In addition, impacts to hydrology, or from sedimentation, or more rapid canopy closure are not threats to the Britton's Beargrass. (US-FWS, 2009b)
Flowering Plants	*Campanula rabinsiae*	Brooksville bellflower	Endangered	No	FL	Typically found along the margins of ponds and marshes with fluctuating water levels and moist seepage areas, both surrounded by pastures. Drought has an adverse effect. The loss of ponds and wet prairies to residential and agricultural development is a primary threat impacting the species but no mention of silviculture. There are 4-5 known sites currently occupied, 4 are protected and only one is on private land and is planned for a housing development. Adoption of FTE will have no effect on this plant. It is not known to be present in pine plantations or pine habitat, and populations are surrounded by pastures. Silviculture and timber harvest are not adversely affecting the species. Four of the five known sites are protected; the fifth site is threatened by a housing development. Therefore, FTE will not be planted in the vicinity if the Brooksville bellflower. (US-FWS, 2009c).
Flowering Plants	*Warea carteri*	Carter's mustard	Endangered	No	FL	This species is found in Turkey-oak dominated sandhills of the Lake Wales Ridge and a major threat is fire suppression. The Florida Natural Areas Inventory lists 49 occurrence records and 43 of

						these are located on protected sites. All known unprotected sites are in Highlands County (US-FWS, 2008d). Adoption of FTE will have no effect on this plant. It is not known to be present in pine plantations. Silviculture and timber harvest are not adversely affecting the species. In addition, impacts to hydrology, or from sedimentation, or more rapid canopy closure are not threats to Carter's mustard.
Flowering Plants	*Justicia cooleyi*	Cooley's water-willow	Endangered	No	FL	Would not find pine plantations as suitable habitat. Grows in rich hardwood forests, often over a limestone substrate. Threatened by habitat loss resulting from limestone mining and conversion of hardwood forest to residential and agricultural development. Adoption of FTE will have no effect on this plant. It is not known to be present in pine plantations. Silviculture and timber harvest are not adversely affecting the species. In addition, impacts to hydrology, or from sedimentation, or more rapid canopy closure are not threats to the Cooley's water willow (US-FWS, 2010b).
Flowering Plants	*Conradina etonia*	Etonia rosemary	Endangered	No	FL	Adoption of FTE will have no effect on this plant as it would not find pine plantations as suitable habitat. Habitat is Florida scrub vegetation with sand pine, shrubby evergreen oaks; in openings, edges, and disturbed areas. Also, fire managed species. No mention of pine plantations or silviculture being a threat. Of 11 known populations, only one is on unprotected private land (US-FWS, 2007e).
Flowering Plants	*Bonomia grandiflora*	Florida bonamia	Threatened	No	FL	Associated with sand pine scrub vegetation consisting of euergreen scrub oak and sand pine with openings between the trees and shrubs occupied by lichens and herbs. The openings are cleared by infrequent fires or by mechanical disturbance which greatly benefits the species. All of its known populations occur within or near scrub or on the edge of scrub habitat in the white sands associated with the ancient Pleistocene dune systems of the

						central ridge system of Florida. Can live in areas disturbed by logging (US-FWS, 2008i). The increased disturbance of FTE production in comparison with pine production would potentially benefit the species, but FTE plantations would not be expected in this habitat. Adoption of FTE will have no effect on this plant. It is not known to be present in pine plantations. Silviculture and timber harvest are not adversely affecting the species. In addition, impacts to hydrology or from sedimentation are not threats to the Florida bonamia (US-FWS, 2008i).
Flowering Plants	*Chrysopsis floridodo*	Florida golden aster	Endangered	No	FL	This plant is associated with pine scrub habitat kept open by periodic burning. The major threat is loss of habitat from usbanization. Pine plantations would not be suitable habitat. Only mention of agricultural use is livestock grazing. . Silviculture and timber harvest are not adversely affecting the species. In addition, impacts to hydrology, or from sedimentation, or more rapid canopy closure are not threats to the Florida golden aster. (US-FWS, 2009d).
Flowering Plants	*Cladonia perforoto*	Florida perforate cladonia	Endangered	No	FL	Found in xeric oak scrub habitat. Almost all known sites are on public land or on protected private land. Those sites not protected are threatened by Off-Road Vehicles and development. No mention of any presence in pine plantations (US-FWS, 2007h). It would be unlikely that this species would find tree plantations suitable because of the closed canopy. Given that nearly every known site is either protected or under management of the species, its preference for xeric scrub habitat, and lack of recording in pine plantations, there would be no effect.
Flowering Plants	*Ziziphus celato*	Florida ziziphus	Endangered	No	FL	A small perennial shrub that spreads vegetatively, this species has only a few known populations associated with old pasture and other degraded sites on the Lake Wales Ridge. Only one known population remains in natural

						scrub habitat. Requires an open canopy. (US-FWS, 2009g). Adoption of FTE will have no effect on this plant because it would not be found in pine plantations.
Flowering Plants	*Asimina tetramera*	Four petal paw paw	Endangered	No	FL	Occurs in sand pine scrub dune habitat of the ancient Atlantic coastal dunes. Most of the 21 sites with known populations are on public land or managed private land. Threats are from habitat loss, degradation, and fragmentation from development. Because of its restrictive habitat, adoption of FTE will have no effect on this plant. (US-FWS, 2009h).
Flowering Plants	*Dicerandra christmanii*	Garrett's mint	Endangered	No	FL	Found only in the yellow sand xeric oak-hickory scrub habitat of the Lake Wales Ridge, 5-8 kilometers southeast of the town of Sebring. Responds well to fire management and will be found in microhabitats with partial to no canopy cover. There are four populations, one protected, the others in areas of citrus groves and residential development. No populations reported to be in or near pine plantations. Adoption of FTE will have no effect on this plant. (US-FWS, 2009i).
Flowering Plants	*Arabis georgiana*	Georgia rockcress	Threatened	Yes	GA	A species found on steep river bluffs. Within the action area for FTE, there is one population with a proposed critical habitat unit in Clay County, GA, on a high bluff over the Chattahoochee River (Federal Register, 2013). Adoption of FTE will have no effect on this plant or its designated critical habitat because of its restrictive habitat.
Flowering Plants	*Ptilimnium nodosum*	Harperella	Endangered	No	GA	Occurs in three habitat types: rocky/gravelly shoals or cracks in bedrock outcrops beneath the water surface in clear, swift-flowing streams (usually in microsites that are sheltered from rapidly moving water); edges of intermittent pineland ponds or low, wet savannah meadows on the Coastal Plain; and granite outcrop seeps. Threats include siltation and erosion (from development), loss of riparian vegetation, poor management of logging and agriculture. Hydrologic manipulation is also a

						major threat, especially in riverine habitat because the species requires a narrow range of water depths. The only population within the action area for FTE was in Dooly County, GA and was determined to be extirpated before 1989, but at the time the recovery plan was developed (1991), the coastal pond habitat was still suitable. It is very unlikely that a FTE plantation, even planted in the vicinity of the pond, would affect the water level to the detriment of a plant not known to be present (Maryland NAtural Heritage, 1980).
Flowering Plants	*Hypericum cumulicola*	Highlands scrub hypericum	Endangered	No	FL	Limited to upland areas with well-drained, sterile, white sands. It is almost exclusively found in the sunny openings in rosemary balds. Adoption of FTE will have no effect on this plant. It is not known to be present in pine plantations. Silviculture and timber harvest are not aduersely affecting the' species. In addition, impacts to hydrology or from sedimentation are not threats to the Highlands scrub hypericum. (US-FWS, 2008k).
Flowering Plants	*Dicerandra immaculata*	Lakela's mint	Endangered	No	FL	Adoption of FTE will have no effect on this plant. The only location of this plant within the action area is an introduced population on Hobe National Wildlife Refuge. Other sites are in Indian River and St. Lucie Counties. It is threatened by urbanization with no mention in relation to pine plantations (US-FWS, 2008n).
Flowering Plants	*Polygala lewtanii*	Lewton's polygala	Endangered	No	FL	Occurs in transition area between oak scrub and in high pine. Areas are always quite dry, sparsely vegetated and have much open ground. Residential housing and citrus plantings continue to replace much of the native habitat of the Central Florida Ridge. The long-term exclusion of fire is also a problem. Adoption of FTE will have no effect on this plant. It is not known to be present in pine plantations. Silviculture and timber harvest are not aduersely affecting the species. In addition, impacts to hydrology or from sedimentation are not threats to the Lewton's polygala (US-FWS,

						2010c).
Flowering Plants	*Dicerandra carnutissima*	Longspurred mint	Endangered	No	FL	Scattered in openings (natural or artificial) in longleaf pine-turkey oak scrub/sandhill or on low rises in slash pine-palmetto scrub. Sand pine scrub habitat. Fire-maintained species. Development is main problem. Of four known occurrences, two are on private land in subdivisions, the others are on public land or right-of-ways. . Adoption of FTE will have no effect on this plant. It is not known to be present in pine plantations. Silviculture and timber harvest are not adversely affecting the species. In addition, impacts to hydrology or from sedimentation are not threats to the longspurred mint. (US-FWS, 2008o).
Flowering Plants	*Geocarpon minimum*	No Common name	Threatened	No	LA, TX	Adoption of FTE will have no effect on this plant. Populations within the action area are found in saline prairies which are harsh to most herbaceous species including Eucalyptus. (US-FWS, 2009j) .
Flowering Plants	*Cucurbita okeechobeensis ssp. okeechobeensis*	Okeechobee gourd	Endangered	No	FL	Adoption of FTE will have no effect on this plant. The species would not find a pine plantation as suitable habitat. Two natural populations, one along the shores and islands of Lake Okeechobee, the other along the St. Johns River. Most are on public land. The gourd relies on pond apple trees to support its vines above rising water levels during the wet season. Other trees and shrubs, such as willow and cypress may also provide suitable support for the vines. Along the St. Johns River the gourds are most typically found growing on elderberry and common reed. (US-FWS, 2009p).
Flowering Plants	*Paronychia chartacea*	Papery whitlow-wort	Threatened	No	FL	Occurs in sand scrub of ancient dunes, in pure, white sand clearings or blowouts on the Lake Wales Ridge. Also on the sandy shores of sinkhole lakes. An early successional species. Adoption of FTE will have no effect on this plant. It is not known to be present in pine plantations. Silviculture and timber harvest are not adversely affecting the species. In addition, impacts to hydrology or from sedimentation are not threats to the papery

						whitlow-wort. (US-FWS, 2008p).
Flowering Plants	*Clitoria fragrans*	Pigeon wings	Threatened	No	FL	Widely scattered in undisturbed clearings of xeric sandhill and scrub communities on well-drained upland soils. The well drained upland soils that it requires are rapidly being developed for residential use, golf courses and related commercial developments. Much of this land is also being or already has been converted to citrus groves. Requires undisturbed soils and fire. Adoption of FTE will have no effect on this plant. It is not known to be present in pine plantations. Silviculture and timber harvest are not aduersely affecting the species. In addition, impacts to hydrology or from sedimentation are not threats to the pigeon wings. (US-FWS, 2008q).
Flowering Plants	*Chionanthus pygmaeus*	Pygmy fringe-tree	Endangered	No	FL	Restricted to scrub habitat. Endemic to the xeric, coarse white sand scrub/oak scrub. Being converted to citrus groves and commercial use. Adoption of FTE will have no effect on this plant. It is not known to be present in pine plantations. Silviculture and timber harvest are not adversely affecting the species. In addition, impacts to hydrology or from sedimentation are not threats to the pygmy fringe-tree (US-FWS, 2010e).
Flowering Plants	*Polygonella myriophylla*	Sandlace	Endangered	No	FL	Thrives in areas of bare white or yellow sand created by moderate disturbance. In sand pine scrub of the Lake Wales Ridge. Fire maintained. Major threats are development and fire suppression. Adoption of FTE will have no effect on this plant. It is not known to be present in pine plantations. Silviculture and timber harvest are not adversely affecting the species. In addition, impacts to hydrology or from sedimentation are not threats to the sandlace (US-FWS).
Flowering Plants	*Liatris ohlingerae*	Scrub blazingstar	Endangered	No	FL	Found along the ecotone between Rosemary balds and surrounding scrub habitats on white or (rarely) on yellow sands of the Lake Wales Ridge and Winterhaven Ridge in Highlands and Polk Counties, FL.

						Fire maintained. The biggest threat is loss of habitat from commercial development, and the resulting fire suppresion. Adoption of FTE will have no effect on this plant. It is not known to be present in pine plantations. Silviculture and timber harvest are not adversely affecting the species. In addition, impacts to hydrology or from sedimentation are not threats to the scrub blazingstar (US-FWS, 2010g).
Flowering Plants	*Eriogonum longifolium var. gnaphalifolium*	Scrub buckwheat	Threatened	No	FL	Occurs in high pine and in turkey oak barrens habitats in xeric soils. Known populations are on the Lake Wales Ridge and Mount Dora Ridge. Requires active management for long term survival (prescribed fire). Habitat destruction from development is a major threat. Adoption of FTE will have no effect on this plant. It is not known to be present in pine plantations. Silviculture and timber harvest are not adversely affecting the species. In addition, impacts to hydrology or from sedimentation are not threats to the scrub buckwheat. (US-FWS, 2008t).
Flowering Plants	*Lupinus aridorum*	Scrub lupine	Endangered	No	FL	The scrub lupine grows primarily on well-drained sandy soils of the Lakewood or St. Lucie series. These soils are very dry and have very little organic accumulation. The sands are white or occasionally yellow and generally support sand pine scrub. Fire managed species. The major threat is habitat destruction due to development (US-FWS, 2007k). Adoption of FTE will have no effect on this plant. It is not known to be present in pine plantations. Silviculture and timber harvest are not adversely affecting the species. In addition, impacts to hydrology or from sedimentation are not threats to the scrub lupine.
Flowering Plants	*Dicerandra frutescens*	Scrub mint	Endangered	No	FL	Mostly restricted to excessively drained, yellow sandy soils of the Astatula and Paola soil types of the Lake Wales Ridge in Highland County, FL. In these soil types, scrub mint occurs adjacent to or within disturbed areas in sand pine scrub, oak scrub and sandhill

						habitats. It occupies sites with shallow litter layers that have an incomplete, or non-existent, tree and shrub canopy. Fire managed, the species has declined as a result of fire suppresion. Much habitat has been lost to agricultural and commercial and residential development which remain the major threat. Adoption of FTE will have no effect on this plant. It is not known to be present in pine plantations. Silviculture and timber harvest are not adversely affecting the species. In addition, impacts to hydrology or from sedimentation are not threats to the scrub mint. (US-FWS, 2009r).
Flowering Plants	*Prunus geniculata*	Scrub plum	Endangered	No	FL	Native to the high pine and oak scrub,community types. Fire managed species. Prefers dry, sunny, nutrient-poor sites that are acidic, are subject to rapid drying, and have little silt, clay, or organic matter. Adoption of FTE will have no effect on this plant. It is not known to be present in pine plantations. Silviculture and timber harvest are not adversely affecting the species. In addition, impacts to hydrology or from sedimentation are not threats to the scrub plum. (US-FWS, 2009s).
Flowering Plants	*Amaranthus pumilus*	Seabeach amaranth	Threatened	No	SC, NC	Occurs on barrier islands, mainly on coastal overwash flats at the accreting ends of the islands and lower foredunes and on ocean beaches above mean high tide. Adoption of FTE will have no effect on this plant. It is not known to be present in pine plantations. Silviculture and timber harvest are not adversely affecting the species. In addition, impacts to hydrology or from sedimentation are not threats to the seabeach amaranth. (US-FWS, 2009u).
Flowering Plants	*Conrodino brevifolia*	Short-leaved rosemary	Endangered	No	FL	Adoption of FTE will have no effect on this plant. Would not find pine plantations as suitable habitat. Inhabits white sand scrub with a scattered overstory of sand pine (Pinus clausa), interspersed with evergreen scrub oaks. Fire dependent. Habitat conversion into agriculture (citriculture), recreational, commerical and residential development result in

						habitat fragmentation (US-FWS, 1993a).
Flowering Plants	*Eryngium cuneifolium*	Snakeroot	Endangered	No	FL	Habitat is open sand gaps in xeric white sand rosemary scrub of the Lake Wales Ridge. Requires fires to maintain openings. Threats are mainly from development. Adoption of FTE will have no effect on this plant. It is not known to be present in pine plantations. Silviculture and timber harvest are not adversely affecting the species. In addition, impacts to hydrology or from sedimentation are not threats to the snakeroot (US-FWS, 1999).
Flowering Plants	*Leavenworthia texana*	Texas golden gladecress	Endangered	Yes	TX	Occurs only on the Weches outcrops of east Texas in San Augustine and Sabine counties. The Weches geologic formation consists of a layer of calcareous soils as a result of the rich marine fossil component, lying above a layer of glauconite clay up to 50 cm below the surface. The glauconite layer of the Weches is impermeable to water, making the thin upper soils seepy and wet much of the year, but often hard and dry during the summer. Conversion to cropland and invasion by non-native weedy shrubs and vines is a threat. Adoption of FTE will have no effect on this plant or its designated critical habitat. It is not known to be present in pine plantations. Silviculture and timber harvest are not adversely affecting the species. In addition, impacts to hydrology or from sedimentation are not threats to the Texas golden gladecress (US-FWS, 2013b).
Flowering Plants	*Hymenoxys texana*	Texas prairie dawn-flower	Endangered	No	TX	Endemic to the coastal plain of Texas. Poorly drained, sparsely vegetated areas ("slick spots") at the bases of small mounds in open grassland or in almost barren areas. Soils are slightly saline, sticky when wet and powdery when dry. Habitat destruction from development is the major threat. The one remaining population is on private land adjacent to a residential development at the edge of metropolitan Houston. Adoption of FTE will have no effect on this

						plant. It is not known to be present in pine plantations. Silviculture and timber harvest are not adversely affecting the species. In addition, impacts to hydrology or from sedimentation are not threats to the Texas prairie dawnflower (Federal Register, 1986).
Flowering Plants	*Polygala smallii*	Tiny polygala	Endangered	No	FL	Habitat is pine rocklands and scrub habitat. The only known site within the action area is a protected site in the Jonathan Dickinson State Park in Martin County. Adoption of FTE will have no effect on this plant. It is not known to be present in pine plantations. Silviculture and timber harvest are not adversely affecting the species. In addition, impacts to hydrology or from sedimentation are not threats to the tiny polygala (US-FWS, 2010i).
Flowering Plants	*Lesquerella pallida*	White bladderpod	Endangered	No	TX	Narrowly restricted to isolated, open, alkaline "islands" within the normally acidic soils of the Texas piney-woods. Open areas associated with exposed calcareous Weches Formation outcrops that are seepy and wet most of the year. Soils are thin, poorly drained, and alkaline. In contrast, most of the surrounding soils are acidic and sandy. Threatened (in part) by invasion of woody species. There are three populations one of 5 acres, and the others extremely small. All on private land. Adoption of FTE will have no effect on this plant. It is not known to be present in pine plantations. Silviculture and timber harvest are not adversely affecting the species. In addition, impacts to hydrology, or from sedimentation, or more rapid canopy closure are not threats to the white bladderpod (Federal Register, 1987b).
Flowering Plants	*Warea amplexifolia*	Wide-leaf warea	Endangered	No	FL	Endemic to the high pine (or sandhill) habitat. Limited to dry, open longleaf pine woods, longleaf pine/turkey oak woods, or live oak/bluejack oak woods that occur on well-drained, sterile, yellowish sands on the Lake Wales Ridge. 10 known populations on public and private lands. Populations on

						private land are threatened by development pressures for citrus and housing and by fire suppression (US-FWS, 2007m). Adoption of FTE will have no effect on this plant. It is not known to be present in pine plantations. Silviculture and timber harvest are not adversely affecting the species. In addition, impacts to hydrology or from sedimentation are not threats to the wide-leaf warea.
Flowering Plants	*Polygonella basiromia*	Wireweed	Endangered	No	FL	Most commonly found in rosemary scrub, also known as rosemary phase of sand pine scrub of the Winter Haven, Bombing Ranges, and Lake Wales Ridges of Central Florida. Endangered primarily by development of the sand pine scrub for agricultural (citrus groves) and residential purposes. Adoption of FTE will have no effect on this plant. It is not known to be present in pine plantations. Silviculture and timber harvest are not adversely affecting the species. In addition, impacts to hydrology or from sedimentation are not threats to the wireweed (US-FWS, 2010k).
Lichens	*Cladonia perforata*	Florida perforate cladonia	Endangered	No	FL	Sandy openings in stablized sand dunes with Florida scrub vegetation, of the ridges of Central Florida. Threatened by trampling, over-collection, fire, and succession. Already restricted habitat is under development pressure. Adoption of FTE will have no effect on this plant. It is not known to be present in pine plantations. Silviculture and timber harvest are not adversely affecting the species. In addition, impacts to hydrology or from sedimentation are not threats to the Florida perforate cladonia (US-FWS, 2007h).
Mammals	*Peromyscus polionotus ammobates*	Alabama beach mouse	Endangered	Yes	AL	Found only in beach dune habitat. No potential stressors have been identified from the conversion of pine to FTE that would affect the Alabama beach mouse or its designated critical habitat. (US-FWS, 2009a).
Mammals	*Peromyscus*	Anastasia Island	Endangered	No	FL	Found only on beach dune and

	polionotus phasma	beach mouse				coastal sand habitat (US-FWS, 2007a).
Mammals	*Peromyscus polionotus allophrys*	Choctawhatchee beach mouse	Endangered	Yes	FL	Found in coastal sand dunes (high primary and secondary, lower interior) with sparse vegetation, including sea oats, bluestem, and bunch grass (PANICUM) on the primary and secondary dunes, and scrubby oaks, dwarfed magnolia, and rosemary on the older dunes(US-FWS, 2007d). No potential stressors have been identified from the conversion of pine to FTE that would affect the Choctawhatchee beach mouse or its designated critical habitat.
Mammals	*Eumaps floridonus*	Florida bonneted bat	Proposed endangered	No	FL	Natural habitat has been lost, but this bat uses Spanish tile roofs for roost sites and may colonize newly installed bat houses of appropriate design (Register, 2013).
Mammals	*Puma (=Felis) concolor coryi*	Florida panther	Endangered	No	FL	No potential stressors have been identified from the conversion of pine to FTE that would affect the Florida panther. (US-FWS, 2009f).
Mammals	*Microtus pennsylvanicus dukecampbelli*	Florida salt marsh vole	Endangered	No	FL	Lives in periodically flooded high salt marsh zone where it is believed to survive high tides and storm flooding by climbing vegetation and swimming. It appears to be most common in areas vegetated by seashore saltgrass (US-FWS, 2008j).
Mammals	*Myotis grisescens*	Gray bat	Endangered	No	AL, FL	Roosts in caves. No potential stressors have been identified from the conversion of pine to FTE that would affect the gray bat (US-FWS, 2009k).
Mammals	*Herpailurus (=Felis) yagouaroundi cocomitli)*	Gulf Coast jaguarundi	Endangered	No	TX	No potential stressors have been identified from the conversion of pine to FTE that would affect the Gulf Coast jaguarondi (US-FWS, 1990e).
Mammals	*Myotis sodalis*	Indiana bat	Endangered	Yes	FL	No potential stressors have been identified from the conversion of pine to FTE that would affect the Indiana bat or its designated critical habitat (US-FWS, 2009n).
Mammals	*Ursus americanus luteolus*	Louisiana black bear	Threatened	Yes	LA, MS, TX	Silviculture is not mentioned as a threat, although timber harvest in its natural bottomland hardwoods habitat is. No potential stressors have been identified from the conversion of pine to FTE that would affect the Louisiana black bear or its designated critical habitat (Federal Register, 1992).
Mammals	*Peromyscus*	Perdido Key beach	Endangered	Yes	AL, FL	Dry, sandy, sparsely vegetated

	polionotus trissyllepsis	mouse				frontal coastal dunes of medium height, with no or very few secondary dunes lying inland; vegetation of inhabited dunes includes mainly sea oats and bluestem at moderate density (US-FWS, 2007j). No potential stressors have been identified from the conversion of pine to FTE that would affect the Perdido Key beach mouse or its designated critical habitat.
Mammals	*Puma (=Felis) concolor (all subsp. except coryi)*	Puma (=mountain lion)	Similarity of Appearance to a Threatened Taxon	No	FL	No potential stressors have been identified from the conversion of pine to FTE that would affect the Puma (US-FWS, 1991).
Mammals	*Peromyscus polionotus niveiventris*	Southeastern beach mouse	Threatened	No	FL	Found only in beach dune habitat. No potential stressors have been identified from the conversion of pine to FTE that would affect the Southeastern beach mouse (US-FWS, 2008u).
Mammals	*Peromyscus polionotus peninsularis*	St. Andrew beach mouse	Endangered	Yes	FL	Found only in beach dune habitat. No potential stressors have been identified from the conversion of pine to FTE that would affect the St. Andrew beach mouse or its designated critical habitat (US-FWS, 2010h).
Mammals	*Trichechus manatus*	West Indian manatee	Endangered	Yes	AL, FL, GA, LA, MS, NC, SC, TX	Found only in coastal waters. No potential stressors have been identified from the conversion of pine to FTE that would affect the West Indian manatee or its designated critical habitat (US-FWS, 1996a).
Reptiles	*Pseudemys alabamensis*	Alabama red-belly turtle	Endangered	No	AL, MS	Found in the marshes and bays of the Mobile River System. Threatened by human disturbances of its habitat. Water quality and quantity do not appear to be problems for this species. All of the locations where the Alabama re-bellied turtle is known to or believed to occur are within the action area for adoption of FTE. Of the numerous human activities that are threats to the Ringed map turtles, there is no mention of forestry activities. This, combined with their preference for larger bodies of water, results in a no effect determination (federal Register, 1987a).
Reptiles	*Nerodia clarkii*	Atlantic salt marsh	Threatened	No	FL	Found only in saline areas - salt

	taeniata	snake				marshes, mangrove swamps. No potential stressors have been identified from the conversion of pine to FTE that would affect the species. (US-FWS, 2008b).
Reptiles	*Chelonia mydas*	Green sea turtle	Endangered	Yes	AL, FL, GA, LA, MS, NC, SC, TX	A marine species. No potential stressors have been identified from the conversion of pine to FTE that would affect the green sea turtle or its designated critical habitat (US-FWS, 2007i).
Reptiles	*Eretmachelys imbricata*	Hawksbill sea turtle	Endangered	Yes	AL, FL, GA, LA, MS, NC, SC, TX	A marine species. No potential stressors have been identified from the conversion of pine to FTE that would affect the Hawksbill sea turtle or its designated critical habitat (US_FWS, 2007a).
Reptiles	*Lepidochelys kempii*	Kemp's ridley sea turtle	Endangered	No	AL, FL, GA, LA, MS, NC, SC, TX	A marine species. No potential stressors have been identified from the conversion of pine to FTE that would affect the Kemp's ridley sea turtle (US_FWS, 2007b).
Reptiles	*Dermochelys coriacea*	Leatherback sea turtle	Endangered	Yes	AL, FL, GA, LA, MS, NC, SC, TX	A marine species. No potential stressors have been identified from the conversion of pine to FTE that would affect the Leatherback sea turtle or its designated critical habitat (US_FWS, 2007c).
Reptiles	*Caretta caretta*	Loggerhead sea turtle	Threatened	No	AL, FL, GA, LA, MS, NC, SC, TX	A marine species. No potential stressors have been identified from the conversion of pine to FTE that would affect the Loggerhead sea turtle (US_FWS, 2007d).
Reptiles	*Graptemys aculifera*	Ringed map turtle	Threatened	No	LA, MS	Found in riverine-riparian systems and associated floodplain lakes, ponds, and sloughs. Often they nest on sandy banks or sand bars but sometimes up to about 100 m from water. The decline of the ringed map turtle has been attributed to habitat modification and water quality deterioration, reservoir construction, channelization, desnagging for navigation, siltation, and the subsequent loss of invertebrate food sources (US_FWS, 2010). Within the action area for adoption of FTE, the ringed map turtle is known to or believed to occur in the following counties or parishes: Louisiana – St. Tammany; Mississippi – Hancock, Lawrence, Marion, and Pearl River. Of the numerous human activities that are threats to the Ringed map

						turtles, there is no mention of forestry activities. This, combined with their preference for larger bodies of water, results in a no effect determination.

"US CODE TITLE 7 - AGRICULTURE CHAPTER 104—PLANT PROTECTION." 7 U.S.C. §§ 7701–7772. http://www.law.cornell.edu/uscode/text/7/chapter-104.

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APPENDIX A. SUMMARY OF COMMENTS RECEIVED ON THE NOTICE OF INTENT AND DURING THE TWO PUBLIC VIRTUAL MEETINGS

On February 22, 2013, APHIS published a notice in the Federal Register (78 FR pages 13309-13312, Docket no. APHIS-2012-0030) announcing the availability of the ArborGen petition for a 60-day public review and comment period. In this notice, APHIS announced its intention to prepare an environmental impact statement (EIS) on the action with regard to the petition for nonregulated status. Comments were required to be received on or before April 29, 2013. APHIS convened two public meetings to collect public input for this EIS. These two public meetings were convened on-line, as web-based virtual meetings. The first meeting was convened on April 17, 2013, at 7:00pm EDT, and the second public meeting was convened on April 18, 2013, at 4:00pm, EDT. Both public meetings provided an open forum for the general public to submit verbal comments on the project. All comments were carefully analyzed to identify potential environmental and interrelated economic issues and impacts that APHIS may determine should be considered in the evaluation of the petition. A total of 6,546 comments were received during the comment period[1]. Three of the comments were petitions containing a total of 30,764 signatures. The issues that were raised in the public comments which were related to the ArborGen FTE lines 427 and 435 petition included:

ISSUE 1:

A number of commenters identified similar issues related to potential increase in fire frequency and intensity from FTE plantations. Concerns were raised that the introduction of a new fuel source would change the regime of frequency and severity of fire in the southeast. Many noted that eucalyptus species are known to be highly flammable trees. Concern was raised that the highly flammable nature of the leaves may threaten surrounding forests and communities with extreme wildfires. Commenters noted incidents of fire involving eucalyptus in California and Australia, "wildfires in Oakland California in 1991 and in Australia in 2009 both fueled by eucalyptus trees-killed scores of people and caused billions in losses." It was suggested that extensive modeling be conducted to quantify the uncertainty surrounding the potential for increased fire risks.

ISSUE 2:

A number of commenters raised concerns of the effects FTE would have on water quality. Multiple commenters noted that eucalyptus leaves contain oils that are highly toxic and that their decomposition in rivers and groundwater will impact aquatic and other organisms in the surrounding communities. One commenter noted "it has been found that rain run-off from a GE eucalyptus plantation in Tasmania has poisoned the waters of the George River, causing harm to the eco-system, and decimating oyster farms in the ocean at the river's end."

ISSUE 3:

One commenter noted that other species of eucalyptus are already cold tolerant and so GE is not necessary. There are already existing cold/ snow tolerant Eucalyptus species available. These species include E. pauciflora, E. stellulata, E. viminalis, E. dalrympleana, E. amygdalina, E. gunnii, and E. ovata - and there are many more. These species naturally occur in alpine regions

[1] Comment documents may be viewed at http://www.regulations.gov/#!docketDetail;D=APHIS-2012-0030

of Australia and in Tasmania. Genetic manipulation of Eucalyptus species has not been necessary. Another commenter noted that there are native trees that could just as easily fill the niche for which FTE was developed.

ISSUE 4:

Several commenters stated that approval of FTE could result in gene flow or pollen contamination that will transmit the FTE transgene to naturalized species of eucalyptus noting that pollen is minute and can be carried inter-continentally by birds, insects, people, and even wind.

ISSUE 5:

Several commenters raised several concerns about the impacts of FTE on native species, including impacts from land conversion to FTE plantations, displacement of native species, impacts to biodiversity, and impacts on TES.

Several commenters raised the issue of decreased biodiversity within FTE plantations. Noting that "plantations of eucalyptus have been described as "green deserts" because of their total lack of biological diversity." Several commenters also noted that conversion of land from other land uses to FTE plantations would decrease "habitat amount and quality for native plants and animals throughout the prospective planting area– including threatened and endangered species – compared to natural forests or plantations of native trees, wetlands, conservation reserve lands, and other uses." Concerns were also raised that as demand for FTE increases more land will be converted to plantations.

Other issues were raised concerning the impacts related to the management of FTE plantations, specifically the use of pesticides for understory management. Both because wildlife require food and shelter provided by diverse undergrowth and because pesticides can directly and indirectly harm plants and animals.

Several issues were raised on the impacts of eucalyptus trees on native wildlife. These include the polyphenols released from the decomposition of eucalyptus leaves and concerns for native bird species from toxins and gums produced by eucalyptus trees. It was also noted that animal species will be unable to find suitable food, nest sites, germination sites and other habitat features within eucalyptus plantations.

ISSUE 6:

Several commenters raised issues concerning the increased water use and impacts on stream flow, groundwater, and on hydrology from FTE. Several commenters raised the issue that eucalyptus plantations use more water than native forests and noted this concern in light of current drought conditions in much of the South. One commenter citing that "the U.S. Forest Service has stated that large-scale plantings of eucalyptus lower water tables, and affect groundwater recharge and local stream flows, in some cases eliminating seasonal streams." Many commenters were also concerned that climate change could exacerbate these problems.

ISSUE 7:

Several commenter raised issues related to the pests and diseases of eucalyptus and whether those pests or diseases could infect native or crop species. Concerns were raised that native members of the Myrtaceae family may be susceptible to diseases that FTE plantations could

harbor. Commenters cited examples of disease infection passing from eucalyptus to Myrtaceae members in Uruguay.

ISSUE 8:

Several commenters raised concerns related to the potential invasiveness of FTE including that eucalyptus is a genus that contains many invasive species; both parent species of the FTE have been reported as invasive within similar climatic zones such as South Africa, New Zealand and Ecuador. Many commenters also note that eucalyptus has become so established in California that it is now listed as an invasive species. Concerns were raised that cold tolerant varieties grow in a wider range of areas than non-cold tolerant varieties and that this may increase the likelihood of establishment and spread of non-native species and contribute to their invasiveness. Another concern raised was that trees are long living and can live for decades to centuries in the wild, unsupported by human intervention. Their escape into the wild can be extremely difficult to eradicate.

Another issue raised with invasiveness is that propagule pressure is directly related to the size of the planting. Concerns have been raised that if given nonregulated status this crop will be planted in much larger acreages. This change in scale could significantly alter propagule pressure and could increase the potential that either or both translines might become invasive, expand the area at risk to such invasions, and expose new locations to the risk of such invasions.

ISSUE 9:

Issues related to the contamination of soil and changes to soil characteristics caused by FTE were raised by several commenters. Root exudates, decaying roots, leaf and bark litter, and other plant parts from FTE 427 and 435 will be different from those of other plants in the planting area, and may change soil dynamics in ways that impact subsequent land uses. Concerns were raised about alteration of soil characteristics (microbial communities, nutritional characteristics, secondary compound profiles) from allelopathy. Another concern raised was due to the nature of eucalyptus to draw extreme amounts of water and nutrients out of surrounding soil. Commenters noted that research conducted on the effects of Eucalyptus timber stands on soil properties and adjacent maize crops shows that Eucalyptus decreased soil nutrients and maize yields within 20 meters of the trees in Ethiopia.

ISSUE 10:

Several commenters raised concerns about the effects of agrochemical use on human health, groundwater, and soil noting that the use of GE trees, especially in industrial plantations, is likely to increase the application of dangerous chemical fertilizers, herbicides and pesticides.

ISSUE 11:

Several issues related to climate change were raised, including the effects of climate change on FTE plantations and the effects of FTE on climate change. Several commenters noted that climate change could cause or exacerbate plant pest risks and environmental impacts associated with FTE and that climate change will extend the predicted range of Eucalyptus within North America. Several commenters noted that forests play an important role in mitigating and impacting climate change and that FTE will worsen climate change through the destruction of carbon rich native forests for carbon poor plantations, noting that one study found that timber plantations contain about one-quarter the carbon of a native forest.

ISSUE 12:

One commenter raised concerns related to the stability of the inserted genes and possible pleiotropic effects stating "Trees activate and de-activate genes at different stages of their lives. An introduced gene may have minimal pleiotropic effects under "normal" field conditions. However, once climatic factors, insect pests, shifts in nutrient availability, and other stressors occur, the genetically active profile in various cells of the plant shifts. When these shifts occur, it is possible that the introduced genetic material interacts with the new active genes in ways that were not predictable before those genes became active."

ISSUE 13:

Several commenters raised concerns that FTE is a potential host for the fungal pathogen *Crytococcus gattii*. They noted that the fatal fungal pathogen, *C. gattii* has been found in the U.S., and can cause fatal fungal meningitis among people and animals that inhale its spores. They also note that although APHIS has looked at the relationship between *C. gattii* and eucalyptus in previous risk assessments the issue needs to be addressed again, given the scale-up and increase in planting range that approval of non-regulated status would trigger.

ISSUE 14:

The Nature Conservancy raised the issue that APHIS should consider use of BMP as an alternative in our analysis noting that "Best Management Practices (e.g., sufficient separation of cultivated stands from other eucalypts to preclude pollination of the GM lines), or monitoring of potential invasiveness or alterations to local hydrology would alleviate many of the potential issues associated with this specific case, and likely future proposals for deregulation of GM trees."

ISSUE 15:

Several commenters were concerned that approval of the petition would set a precedent for other GE tree approvals stating that "it would set a dangerous precedent that could enable the approval of GE poplar, pine, and other native species native to this continent. And the release of these genetically engineered versions of native species would lead to the inevitable and irreversible genetic contamination of native forests throughout the continent."

ISSUE 16:

The Center for Food Safety noted that APHIS should consider future scenarios that include non-GE freeze-tolerant eucalyptus and other lines or species of GE freeze-tolerant eucalyptus that may be expected to someday overlap the range of FTE 427 and 435, particularly when looking at cumulative and other impacts.

ISSUE 17:

Several commenters noted that ArborGen is likely under-estimating the potential range increase. Noting that "ArborGen does not include suitable regions of the Pacific Northwest." They also note that only biological-based constraints and not market-based constraints should be used because market based constraints are subject to rapid change. In addition, climate change will extend the predicted range of Eucalyptus within North America and the corresponding area where the FTE could grow.

ISSUE 18:

One comment raised concerns about the impacts of FTE on pollinators. Noting that, "honeybees may be attracted to the nectar-producing flowers but because of lack of pollen in male-sterile FTE 427 and 435, and absence of other flowering plants from undergrowth suppression, the bees may not be able to get adequate nutrition within the landscape."

ISSUE 19:

Several commenters stated that because 12 dockets for petitions were posted on the same day, that the public was not afforded enough time to review the documents.

ISSUE 20:

One commenter noted that plantings of FTE may lead to land use conflicts with wood for other purposes such as wood for building, veneer, and other products.

ISSUE 21:

One commenter raised the concern of adverse health effect associated with biofuel production. Citing that "throughout the Southeast and in the Pacific Northwest, citizens are objecting to the building of biomass energy and biofuels facilities; one of their main concerns is an increase in air and water pollution, with health impacts."

ISSUE 22:

One commenter noted that APHIS must critically analyze information from a variety of sources. Whenever possible, APHIS should consult high-quality independent peer-reviewed research, up-to-date reports in the press and extension bulletins, government studies, and other sources of relevant information. APHIS must not rely on the "Environmental Report" embedded in the Petition that was commissioned by ArborGen and is strongly biased towards finding no significant impacts. APHIS must also consult with all other federal and state agencies with relevant expertise in these issues and regarding potential impacts, such as the Fish and Wildlife Service. Another commenter noted that APHIS should consult with DOI and National Invasive Species Council to further expand the already established APHIS weed-initiated pest risk assessment.

ISSUE 23:

One commenter supports the use of bioconfinement by inclusion of a male sterility gene to reduce the risk of spread.

ISSUE 24:

Several commenters noted that FTE would fill the increased demand for wood, fiber and pulp while using land more efficiently. They also note that it offers a promising alternative to foresters and landowners interested in a fast-growing hardwood for certain areas of the South and can be a positive contribution to rural development. Commenters also note that "highly productive trees, such as the FTE hybrid can produce more wood on a smaller footprint, lessening the need to harvest from native stands of trees."

USDA APHIS Virtual Meeting on Freeze Tolerant Eucalyptus, April 17, 2013

Jennifer Wood: Good evening, I'm Jennifer Wood, your technical support for this broadcast. Welcome to the first of two virtual public meetings sponsored by the U.S. Department of Agriculture Animal and Plant Health Inspection Service.

First, I would like to go over a few housekeeping items. This virtual meeting uses audio broadcast technology. As an attendee, you will be able to hear the panelists and presenters but we are not able to hear you. If you are registered to speak today, you have received separate instructions on how to connect to the meeting so that you will be heard when it is your turn to provide your public comment. You should see a welcome sign on the left side of your screen. On the right side, you will see the panelists via webcam, the names of the panelists who will be conducting the meeting, and your name. You will not see the names of other attendees. There are several blue bars, called panels, all on the right side of the screen – participants, chat, and media viewer. You can open and close these panels by using the small half arrows next to the panel title. If you experience technical difficulties joining the WebEx session, please contact WebEx technical support at 1-866-229-3239. This number will also appear on all slides used in this meeting.

If you are registered to speak on today's call, please be sure you are dialed in via a phone line. You will see a phone icon next to your name in the participant panel. If you do not see a phone icon, please disconnect with your phone line only, and redial in. Please make sure to enter your attendee ID slowly. You must have a phone next to your name in order to provide a public comment.

If you are having difficulty during this meeting, such as with your panels, please use the chart panel located in the center of your panel to send me a communication. You can also use the green toolbar at the edge of your screen if viewing in full screen mode. Please type your question in the text field and hit "send." Please keep the send to default as all panelists. I will respond as promptly as possible. I may also contact you via the chat panel if you're speaking today and I see you are not dialed in currently.

With that, we invited you to sit back, relax, and enjoy today's presentation. Without further delay, I would like to hand the broadcast off to Dick George.

Dick George: Welcome and thank you for joining us. I'm Dick George, Communications Branch Chief of Biotechnology Regulatory Services, or BRS. BRS is part of APHIS, the Animal and Plant Health Inspection Service, an agency of the U.S. Department of Agriculture. Soliciting public comments is a very important part of our process. We value your input and are pleased that you've chosen to be with us today either to make a public comment or to listen to the comments of others. Technicians are standing by to assist anyone having difficulty in accessing this meeting. Please call 1-866-229-3239 for help. This number is at the bottom of each slide.

On the left side of your screen, you should see the slide that's currently displayed for the meeting. On the right side, you should see the projection of me and my colleague, Rebecca Stankiewicz Gabel. You will also notice that there are other panels you can navigate, such as the media viewer. To access closed captioning for this meeting, open the media viewer to the right of your screen.

USDA APHIS Virtual Meeting on Freeze Tolerant Eucalyptus, April 17, 2013

The purpose of this meeting is to solicit your comments on a notice of intent to do an environmental impact statement – or EIS – for a line of eucalyptus that has been genetically engineered to be tolerant of freezing temperatures. For more information on this eucalyptus, go to www.APHISVirtualMeeting.com. This site contains background information and also links to other documents and websites. In the past, we've traveled around the country to conduct meetings where interested parties can make public comments on our regulatory actions. Today, for the first time, we're holding an online virtual public meeting to allow more people the opportunity to comment.

Joining me is Dr. Rebecca Stankiewicz Gabel, my colleague at BRS. Rebecca is the supervisor of our Biotechnology Environmental Analysis branch.

Dr. Rebecca Stankiewicz Gabel: Before we start taking comments from our online audience, we'd like to go over some of the specifics for the virtual meeting. We will be taking only spoken comments today. If you'd prefer to make a written comment, you can do so by going to Regulations.gov. Enter the word "eucalyptus" in the search box. This will take you to a link for the freeze-tolerant eucalyptus comment site. The public comment period ends on April 29, 2013. You can go to Regulations.gov any time between now and the 29th and leave a written comment, which will become part of the public record. Or you can make a spoken comment here tonight at this meeting, which will go until 9:00 p.m. Eastern. Those of you wishing to speak will be recognized in the order in which you were registered. Today we are here to receive your input, not to answer questions about eucalyptus. For background information, please go to www.APHISVirtualMeeting.com. If you haven't already registered to speak and wish to do so, please click on the raised hand icon. This will indicate that you wish to speak and you will be placed in a queue. You will be provided with instructions on how to proceed via the chat feature.

The statements received during the public comment period, whether spoken today or submitted in writing to Regulations.gov, will be considered in the development of the draft EIS for freeze-tolerant eucalyptus. After we have published the draft EIS, we will solicit and receive comments on it. Those comments will be considered in the development of a final EIS. After the final EIS is published, there will be a decision on the regulatory status of freeze-tolerant eucalyptus.

We welcome your comments today because they will help us to determine what issues to consider as we prepare our draft Environmental Impact Statement.

Dick George: You should see a list of commenters in the order in which they will speak on your screen, so you will know when your turn is approaching. We ask that you keep your comments to three minutes or less. A recording of this meeting will be available within forty-eight hours on our site, www.APHISVirtualMeeting.com, and written transcripts will be available there within a few weeks.

At the conclusion of the virtual meeting, a survey will appear on the screen. Please complete it before you log off. Your feedback is very important to us. If you would like to be seen, as well as heard today, please turn on your webcam when it's your turn to speak and click on the camera icon next to your name on the screen. If you're experiencing technical difficulties, again, the number to call, the WebEx Technical Support team, is 1-866-229-3239. As a reminder, we're here to receive your comments only, not to answer questions on eucalyptus or to discuss or debate biotechnology.

At that, we will hear from our first commenter, who is Nancy Beecham. It may take a moment to unmute her phone so that she can speak so please bear with us just for a second. Okay, Nancy, are you there? No. In that case, we'll move ahead to our second commenter, who is William Bennington. Can we unmute his phone, please?

William Bennington: Hello.

Dick George: Yes, hello, William.

William Bennington: Yes.

Dick George: Yes, please go ahead with your comment.

William Bennington: Alright, I'll try to keep it under two minutes. It would've been good to know about that ahead of time. So my name's Will Bennington. I'm a small-scale farmer in Vermont and I have a background in forest ecology, ecological forest management. And I'm on the call today to bring up two important issues pertaining to ArborGen's petition to deregulate its freeze-tolerant GE eucalyptus.

First, I think it's a problem of widespread non-native invasive plants in this country and across the world is a serious issue that I've dealt with in my work. I think there are far too many cases of unintentional introduction of non-invasive species that has led to widespread invasion, oftentimes resulting in ecosystem level impacts. And a lot of times, these different plants and animals that are introduced are introduced under the assumption that there will be no impact and that they will not become invasive. But the reality of it is the science really can't ever dictate whether or not it's going to happen, especially when we're talking about trees, which have a much longer lifecycle than many other plants and can persist in ecosystems for a very long time.

The only way that APHIS and the USDA can do its job to serve the public and ensure the highest level of protection against highly invasive species like GE eucalyptus and to protect our forest resources is by outright banning their release. And unfortunately, the agency failed to protect the public interest several years ago when they allowed ArborGen to release several field trials of GE eucalyptus in the U.S. South. So I'm here to demand that the USDA correct their past mistakes and stop this pending ecological disaster before it's too late. And absolutely consider to be the utmost importance the fact that there is no way to tell that eucalyptus will not be invasive and that it is more likely than not that genetically engineered eucalyptus will become highly invasive.

I'm also concerned about this issue because GE eucalyptus has been likened to flammable kudzu. It's invasive and it's highly flammable. And planting vast plantations of eucalyptus in the U.S. South, which is a drought-stricken region that's very prone to wildfires, is only going to increase the risk of catastrophic wildfires, which are going to become an increasing problem as we face the impact of global warming over the coming decade.

So basically, we're looking at a highly invasive, non-native plant that is incredibly flammable, like an explosive firecracker in a drought-stricken region. So it's just about the worst combination of factors you could imagine.

And then, one final thing that I want to bring up is this, what many people call a revolving door between ArborGen and biotech giant, Monsanto. ArborGen was initially envisioned in 1999 by Fletcher Challenge Forests, International Paper, Westvaco, and biotech giant, Monsanto. Before beginning the sixty-million-dollar venture that was actually ArborGen, Monsanto backed out. However, several CEOs and other upper level management of ArborGen have come from Monsanto and ArborGen frequently cites itself as the next Monsanto and the Monsanto of the forest industry. And if what Monsanto has done to the agricultural section in the United States and across the world is any example of what ArborGen is planning to do to the forest product industry, that is a serious problem. Monsanto and their products have caused massive ecological degradation, the destruction of local agricultural systems, and the increased use of pesticides and herbicides, the privatization of genetic matter in seeds, mounting economic problems for farmers. And it's abundantly clear that this is the direction ArborGen is intending to go.

So as countries across the world are banning Monsanto's products and banning Monsanto from doing business in the country, I think it's about time that the United States follows suit. And we have a real opportunity to do that with ArborGen by saying no to their GE products today so that they cannot pursue the kind of model of economic domination and ecological destruction that Monsanto has pursued throughout the world.

And I'm sure I've gone well over three minutes, so I'll just wrap up by saying that I demand the USDA and APHIS deny ArborGen's petition to deregulate cold-tolerant genetically engineered eucalyptus, and I hope that you will consider all the concerns I brought up while preparing the environmental impact statement. Thank you.

Dick George: Thank you so much for your comment. Our next speaker is Orin Langelle. Please forgive me if I have butchered your name. Please go ahead.

Orin Langelle: Yes, hello, can you hear me?

Dick George: Yes, thank you.

Orin Langelle: Okay, yeah, you didn't butcher me. Actually, you said it in the correct way. The international pronunciation is Lon-gell. Anyway, I've worked on the study of genetically engineered trees, and written on them, since 1999. And I'm going to start out with a harsh paragraph here. "If ArborGen is allowed to sell genetically-engineered eucalyptus in the Southeastern United States, it will be potentially a criminal action that should lead to the prosecution and incarceration of ArborGen's board of directors and its parents companies of IP, – that's International Paper – MeadWestvaco, and Rubicon, Ltd. They are knowingly allowing health risks to the human and non-human inhabitants of the region, furthering global warming and decreasing the ecological sustainability of that region.

The USDA should pay attention to that scenario, in case they are not listening to all the arguments against genetically engineered trees. Traditionally, eucalyptus trees are extremely flammable and invasive. They require extreme amounts of water to grow. The U.S. South is suffering from a major drought. As Mr. Bennington stated, if they're allowed, they'll become the flammable kudzu of the South."

And now, we're going to get into some stuff by the United States Environmental Protection Agency, who stated that, "The average annual temperatures in the region are projected to increase by four to nine degrees by 2080.

Higher temperatures, longer periods between rainfall events, and greater demand for water will likely strain water resources in the Southeast. Incidents of extreme weather, increased temperatures, and flooding will likely impact human health. Higher temperatures will likely affect the growth and productivity of crops and forests in the region.

The EPA continues on the impact on water resources, stating, "Water resources scarcity can affect many sectors of the Southeast economy, as well as the region's natural ecosystems. Periodic droughts, overconsumption of water resources, and other factors can create water shortages. Managing water resources will likely become more challenging with projected climate changes and anticipated population and economic growth; higher temperatures increase in that duration and water loss from plants. Projected increases in temperature will likely increase the frequency, duration, and intensity of droughts in the area. Projected changes in the surface water runoff to the coast and groundwater recharge will likely allow saltwater to intrude and mix with shallow aquifers in sub-coastal areas in the Southeast, particularly in Florida and Louisiana. If the region increases groundwater pumping to offset water shortfalls, then aquifers will be further depleted. In the long term, the depletion of groundwater supply would place additional strain on surface water resources. Growth and demand will also likely strain water resources.

The Southeast region is attracting a great deal of people, investment, and industry. The population of Florida has more than doubled during the past thirty years. Growth rates in most other Southeastern states are forty-five to seventy-five percent over the same period. Decreased water availability will challenge future growth and the quality of lives of residents in the region."

Now, from another radical organization here, the National Wildlife Federation, whose report will, I'm going to quote the global warming and drought stage that… "The Southeast drought, as historic records show, that regular droughts are more typical through the Southeast. Global warming suggests that more is yet to come. Continued climate changes will potentially cause both more extremely dry periods and more heavy rainfall events. And sea level rise could contaminate critical underground freshwater reserves. The Southeast should take the following actions to plan for increasing variability in water supply, improved water use, efficiency, and conservation. Take global warming into account when choosing water management strategies to meet multiple demand. Maintain and restore a natural forest and wetland systems that store floodwaters and provide efficient water storage…"

Dick George: I have to ask you to please complete your thought and wrap it up, please.

Orin Langelle: Okay, I will. "…a rapidly expanding population, irrigation, and power generation have increased water demand. In the states in the National Wildlife Federation for some of the states slated for GE trees, it would be increased water (inaudible) from 1950 to (inaudible). Florida, one hundred and ninety-six percent. Alabama, a hundred and ninety-six percent. Mississippi, two hundred and twenty-three percent. Florida, two hundred and fifty-nine percent. And ArborGen's home base, South Carolina, a whopping nine hundred and forty-seven percent. And I have not even gotten into Florida's water aquifer, which is polluted and it probably will be, it's going to be a major health and economic hazard for the entire Southeastern region, especially the citizens of Florida. Thank you.

Dr. Rebecca Stankiewicz Gabel: Thank you for your comments. The next caller on the phone is Anne Peterman.

Anne Peterman: Hello, can you hear me?

Dick George: Yes, we can.

Dr. Rebecca Stankiewicz Gabel: Yes, we can.

Dick George: Please go ahead.

Anne Peterman: Okay, great. I guess I jumped the queue. I just wanted to add onto what has been reported already, that another concern that I have regarding genetically engineered eucalyptus trees – and I am, incidentally, the International Coordinator of the Stop Genetically Engineered Trees Campaign and have been working on this issue since 1999. I have spoken at United Nations meetings, including the Convention of Biological Diversity, the UN Forum on Forests, and the UN Climate Convention all over the world. One of the things that I'm additionally concerned about with regard to genetically engineered eucalyptus approval is that it would set a dangerous precedent that could enable the approval of GE poplar pine and other native species native to this continent. And the release of these genetically engineered versions of native species would lead to the inevitable and irreversible genetic contamination of native forests throughout the continent. It was for this reason, and many others, that we have been campaigning to stop the release of genetically engineered trees.

In 2008, we traveled to Bonn, Germany for the Conference of the Parties of the US Convention on Biological Diversity where we had the unanimous agreement of all of the NGOs that were there, all of the indigenous people's organizations that were there, the entire African delegation, and many countries in Latin America who agreed that the release of genetically engineered trees should be totally suspended. And they weren't just talking about commercial release, they were talking about test plots, as well. In fact, the decision that the entire conference made was that the conference of the parties recognizing the uncertainties related to potential environmental and socioeconomic impact, including long-term and transplantation-boundary impacts of genetically engineered trees on global forests, biological diversity, as well as all the livelihoods of indigenous and local communities and given the absence of reliable data and the capacity of some countries to undertake risk assessments and to evaluate those potential impacts, recommends parties to take a precautionary approach when addressing the issue of genetically modified trees.

The reason why this is so important is because these freeze-tolerant eucalyptus are not just being grown for release in the United States but they would be released all over the world. And eucalyptus plantations are already a disaster in countries like Brazil and Chile and South Africa, and many other places where they're being grown. And if they are developed to be freeze-tolerant, they will be able to spread further north, further south, higher in elevation, and spread the disaster of eucalyptus plantations to new locations that are yet untouched by them.

So this is not just about the United States. This is about what these trees could do all over the world where they would be released, endangering communities, endangering forest ecosystems, biodiversity, and so on.

So I wanted to just point out the international implications of this decision and how the US Convention on Biological Diversity recommends a precautionary approach, which means proving they're safe before they're released which clearly cannot happen with a tree as invasive and dangerous as eucalyptus. So that's good for me.

Dr. Rebecca Stankiewicz Gabel: Thank you very much for your comments.

Dick George: Our next commenter is Lillian Kui. Excuse me I've mispronounced your name. Are you there?

Lillian Kui: Hi, hello?

Dick George: Yes, hi. Please go ahead.

Lillian Kui: Okay, it's Lillian Kui, but no problem. It's not something you come across every day.

Basically, like the previous speakers before me, I'm just not even sure why genetically engineered trees are even being considered to be planted amongst natural trees, natural ecology. I mean, if USDA wants to find a cold-hardy plant, there are plenty of other natural trees that are not genetically modified or genetically engineered. We do not know the potential harm that these genetically engineered trees will potentially wreak havoc on the ecosystem of not just the United States, but around the world, like previous speakers just spoke of.

There are so many things we do not know of that can endanger hundreds of different kinds of species, wildlife, not excluding us ourselves. You know, in ecology, everything is connected. If you introduce an invasive species, everything else is going to be affected. It won't be just insects or birds or any other species that we might not think will affect us because we live in cities or whatever the idea may be. You know, genetically engineering anything should not be considered something that… I can't even get the words. Because it's so absurd for me to even consider something like this. I just want the USDA to really, really consider not approving this at all. I think it will have very, very, very dangerous effects – very, very, probably irreparable ramification if this species is released. Please consider the dangers that you are potentially putting everyone in – not just in these small forests or whatever states. It's going to affect everyone. Please, please reconsider. Thank you.

Dr. Rebecca Stankiewicz Gabel: Thank you for your comment.

Dick George: Thank you, Lillian. I'm looking for the next commenter and it doesn't look like we have another commenter ready to speak at the moment. If Nancy Beecham is there or ready, we can hear from her, and we have a couple others. So what we'll do is we'll take a pause. I will remind folks that if you're listening in on this call and you've changed your mind and would like to make a comment, you could still do so. Click on the raised-hand icon and you will receive instructions via the chat feature of what you need to do to call in and to make a comment. We welcome your comments and hope that if you do have something to say that you would call.

So until we have another person who's lined up and ready to make a comment, we're just going to take a pause. We do intend to stay here until 9:00, as advertised, so if people come onto the call late or if they're on the call and they change their mind and would like to make a comment, we're here to receive that comment. So until we have another person lined up and ready to make a comment – we're getting some notes here from our producer that there's nobody set at the moment to do so – we're going to take a pause until someone does. And again, if anybody who's listening in cares to make a comment, please use the raised-hand icon if you haven't signed up to make a comment already, and we'll be happy to receive your comment. Thanks.

Dr. Rebecca Stankiewicz Gabel: Thank you.

[Pause]

Dr. Rebecca Stankiewicz Gabel: Mr. Bennington, are you on the line?

William Bennington: I believe so.

Dr. Rebecca Stankiewicz Gabel: Okay, we can hear you.

Dick George: Please go ahead.

William Bennington: Great. Thank you so much for doing a second chance. I didn't want to leave you both hanging there for another hour and fifteen minutes. Thank you.

So I just wanted to make a couple more quick comments. First, I just want to talk about the importance that forests play in mitigating and impacting climate change and particularly, the importance that the role of native biodiverse – by biodiverse, I mean species-diverse and age class numbers for it – so not monoculture plantations, though, they're, in fact, not forest and do not serve the same function that forests do. And I'm sure you're aware, worldwide forests sequester anywhere between eleven and twelve, or more conservative, up to twenty percent of carbon is released in the atmosphere. So they're incredibly important to the global carbon cycle. And rates of deforestation that has been happening worldwide are causing serious problems with the amounts of release of C02. And one driver of this deforestation is, in fact, the increased use of forest monocultures; in particular, species like pine and eucalyptus in South America and increasingly so. If ArborGen's request to deregulate GE eucalyptus is granted, we'll start seeing that happen more in the South. And as several speakers commented on earlier, eucalyptus is incredibly flammable so that risk of forest loss is even greater.

And then, another point I wanted to make is that you both, and the USDA and APHIS, have a real opportunity here to do the right thing and to make a quite historic decision that can impact the future, all future generations on this planet. You can say no to this. The science is out there. The social, the public opposition is out there. You can say no to this and it will be okay, and it will be the right choice. And it's not very frequently that you have such an amazing opportunity to make such an important decision. And as Ms. Peterman pointed out before, this decision is going to have implications far beyond the borders of the seven states in the U.S. South. It's far beyond borders of the United States. This decision is going to have implications worldwide, and so I just hope that in making their decision to hopefully not allow the deregulation of commercial sale of genetically engineered eucalyptus that you'll consider that. And consider that this is a decision that is going to potentially negatively impact generations to come well into the future, and I certainly wouldn't want to have that on the weight of my shoulders. But I would love to be on the right side of history, and I really encourage the USDA and APHIS to stand on the right side of history and stand up to the interest that ArborGen is presenting in trying to release genetically engineered eucalyptus across the U.S. South. Thank you very much.

Dr. Rebecca Stankiewicz Gabel: Thank you for your comment. Is there anyone else that wants to make an additional comment? If anyone does, they should raise their hand. Or if any of the people that are on that haven't made a comment wish to make a comment, if you could please raise your hand, we can get you the instruction for how to call in.

Dick George: Since there are none in queue at the moment, we'll take another pause. And if there are others who change their mind or people who have spoken already and they'd like to say a little more, we certainly have time for that. So we're going to take a pause and we'll keep an eye… We're getting prompted by the producer when people become available and ready to speak, and so we'll accept those comments when and if they come. In the meantime, we'll take another pause. Thank you very much.

Dr. Rebecca Stankiewicz Gabel: Thank you.

Dick George: Well, we see that we have Orin Langelle, who already spoke and would like to say a little more. So we will get his phone unmuted and as soon as we do, we'll be happy to take more comments.

Orin Langelle: Hello?

Dick George: Yes, hello. Orin, go ahead.

Orin Langelle: Okay, thank you. Thank you for letting me finish up. I know I went a little bit longer. I want to echo what the first gentleman was just talking about, to do the right thing. And remind everybody that in a lot of indigenous cultures that people plan seven generations ahead of time. It's not just for the present, it's not just for money. It's about not just our children, our grandchildren, about their grandchildren. It's further down the line.

I was actually starting to talk about the Florida aquifer system. It's one of the most productive aquifers in the world. It underlies an area of about a hundred thousand square miles and it provides water for several large cities including Savannah and Brunswick in Georgia and Jacksonville, Tallahassee, Orlando, and St. Petersburg in Florida. It's a *(inaudible)* system and it underlies the states that I just mentioned. And one of the things about it, it's a very kind of a shallow aquifer so water gets into it very easily compared to the Ogallala Aquifer, which is really a large aquifer, elsewhere. And that means if it rains a lot or whatever, you'll get a lot of water going into the aquifer.

While it may seem good because it is shallow, you don't get the same kind of filtration you do when you have a deeper aquifer. So what's going to happen – and what's already happening – is toxic waste and runoff is already getting into Florida, and it's polluting things down… as things go further south. And there have been major studies done upon this. And I have a really bad feeling that when ArborGen and the other companies start putting more and more chemicals and whatever they're going to put on these things. It's going to get into that system and it's going to hurt people a whole lot more, including the species that need to be alive, the humans that need to be alive.

And I'll leave it like that but again, I'll ask you to do the right thing. I think a lot of us are very sad that we're in this situation of global warming and the way the world is going right now. So let's not make it worse, okay? Thank you very much.

Dr. Rebecca Stankiewicz Gabel: Thank you very much for your comment. Is there anyone else that would like to make an additional comment or anyone that is on that would like to make a comment? If you'd like to make a comment, please raise your hand.

Dick George: Well, we have no other speakers ready at the moment and so we will encourage those who are listening in who might have a comment, who might want to make a comment, to do so and we'll take another pause. Thanks.

Dr. Rebecca Stankiewicz Gabel: Thank you.

Dick George: Another speaker, apparently Lillian would like to expand her comment, which we're happy to do. So are you there?

Lillian Kui: Yes, hi.

Dick George: Hi, please go ahead.

Lillian Kui: Okay, great. Thanks for letting me speak again. Yeah, just to continue onto what I was saying. I think any time you introduce an invasive species into the environment or the ecological system that is not its native ecology, it's never good for the environment that it's being placed in and probably even for the species itself, which is not what its native environment is supposed to be. And I know these are genetically engineered trees so supposedly they're supposed to be freeze-tolerant but it's not natural. It's just not natural. And I want to stress the word "natural."

The earth has been *[inaudible]* for billions of years. It didn't need our intervention to come to where it is today which is full of life, full of diversity, full of biodiversity. It didn't need our intervention. It doesn't need our intervention now. You know, for us to intervene like this, it's just wrong. I don't think it needs any other evidence to support that creating a genetically engineered product, it's just wrong. It is playing God. It is not something that the earth has evolved. It is not something that is naturally evolved into. It did not evolve into a plant that wants to grow in the environment that ArborGen wants to place it in.

You know, it's just too many unnatural things going on. Like Mr. Bennington had said, Monsanto was a potential partner before. I mean, if ArborGen is anywhere close to Monsanto, it's not going to be good. It's not going to be good. From the GMO soybeans and corn, we don't need any more of that stuff. It's just bad for us, bad for the environment, and like my previous speaker said, the effect of this will reverberate to generation to generation to generation. You guys really do have the opportunity right now to do something right, to do something that will stop this. All these big companies out there that are just pushing these agendas for its profits. Whatever ArborGen's agenda is or Green Energy, all that stuff, it's got to stop at some point. And I think enough is enough. You know, for whatever profits, whatever industry; it's got to be enough. It's got to stop, okay? That's just, you know, I don't think it takes a rocket scientist to understand that introducing invasive species into an ecosystem that would not benefit from it. If history has taught us anything, any time an invasive species is introduced into an environment that is not native to it, it wreaks havoc. It just does. From other native species dying off from it or making it ill to toxins, pollutants. I understand that this GE eucalyptus tree is going to be herbicide resistant so that just means more herbicides would be sprayed, more polluting, more toxins.

I mean, really, do we really need to say more? I know there's only been a few speakers here but what we're saying makes a whole lot of sense and GE eucalyptus does not make any sense at all. It is completely, absolutely unnecessary. That's it for now. Maybe I'll come back.

Dr. Rebecca Stankiewicz Gabel: Thank you for your comment.

Dick George: Thank you for your comment.

Dr. Rebecca Stankiewicz Gabel: And you're welcome to come back.

Lillian Kui: Okay, thank you.

Dr. Rebecca Stankiewicz Gabel: Is there anyone else that is on the line that would like to make a comment? Please raise your hand if you'd like to make a comment.

Dick George: Since we have no other calls lined up at the moment, we'll take another pause. Again, encouraging anyone who may be having second thoughts or may decide to make a comment, please feel free to do so. Click on the raised-hand icon and we'll get instructions to you on how to do that. In the meantime, we'll take another pause. Thanks so much.

Dr. Rebecca Stankiewicz Gabel: Thank you.

[Music]

Dick George: Okay, *[music playing over speaking]*… we still have some speakers lined up to speak. We're still here. We'll be here until 9:00 and we welcome any comments. Again, encourage you, if you'd like to make a comment, to use a raised hand icon to let us know and we'll get instructions to you so that you can do so. So basically, we'll take another pause. We'll come back on every five or ten minutes or so just to let folks know that we're still here and we're glad to take any comments. So having said that, I see we still have no speakers lined up and so we shall take another pause.

Dr. Rebecca Stankiewicz Gabel: Thank you.

Dick George: Thanks so much.

Dick George: Okay, so seeing that we have no one else scheduled to speak, we're going to bring the meeting to a close. We'd like to thank everyone who participated today in our virtual meeting for freeze-tolerant eucalyptus. The PowerPoint and the audio of this virtual meeting will be available at our website, www.APHISVirtualMeeting.com within forty-eight hours. Please do not log off before completing the survey. It will appear on your screen after the… immediately following the meeting. Please fill it out and then click the submit button. We will be posting information, including dates and times of future virtual meetings, at www.APHISVirtualMeeting.com. Our next virtual meeting is tomorrow from 4:00 to 6:00 Eastern time. To register, to attend, or to speak, please go to www.APHISVirtualMeeting.com.

So having said that, for Rebecca and myself, we'd like to thank you for participating in our virtual meeting, and this meeting is now concluded. Thanks so much.

Dr. Rebecca Stankiewicz Gabel: Good night.

USDA APHIS Virtual Meeting on Freeze Tolerant Eucalyptus, April 18, 2013

Susan Wheatley: Good evening, my name is Susan Wheatley, your technical support for this podcast. Welcome to the second of two virtual public meetings, sponsored by the U.S. Department of Agriculture Animal Implant Health Inspection Service. First I would like to go over a few housekeeping items. This virtual meeting uses audio broadcast technology. As an attendee, you will be able to hear the panelists and presenters, but we are not able to hear you. If you are registered to speak today, you have been sent separate instructions on how to connect to this meeting so that you will be heard when it is your turn to provide your public comment.

You should see a welcome slide on the left side of your screen; on the right side you will see the panelists via webcam, the names of the panelists who will be conducting the meeting and your name. You will not see the names of the other attendees.

There are several blue bars called panels along the right side of your screen. (Inaudible) chat and media viewer. You can open and close these panels by using the small half arrows next to the panel title. If you experience difficulty joining the WebEx session, please contact WebEx Technical Support at 1-866-229-3239. This number will also appear on all the slides used in this meeting. If you are registered to speak on today's call, please be sure you are dialed in via a phone line. If you see a phone icon next to your name in the participant panel. If you do not see a phone icon, please disconnect with your phone only and redial in, making sure to enter the attendee ID slowly. You must have a phone next to your name in order for you to provide a public comment.

If you are having a technical difficulty during the meetings, such as with your panels, please use the chat panel located in the lower right corner of your screen to send me a communication. You can also use the green toolbar on the edge of your screen if viewing in full screen mode. Type in your questions in the text field and hit send. I will respond as promptly as possible. Please keep the send to default as all panelists. With that, we invite you to sit back, relax, and enjoy today's presentation. Without further delay, I will hand the broadcast off to Dick George.

Dick George: Thank you, welcome and thank you for joining us. I am Dick George, Communications Branch Chief at Biotechnology Regulatory Services, or BRS. BRS is part of APHIS, the Animal Plant and Health Inspection Service, an agency of the U.S. Department of Agriculture. Soliciting public comments is a very important part of our process. We value your input and are pleased that you have chosen to be with us today, either to make a public comment or to listen to the comments of others. Technicians are standing by to assist anyone having difficulties in accessing this virtual meeting. Please call 1-866-229-3239 for help. This number is at the bottom of each slide. On the left side of your screen you should see the slide that is currently displayed for the meeting. On the right side you should see the projection of me and my colleague, Rebecca Stankiewicz Gabel. You will also notice that there are other panels that you can navigate such as the media viewer. To access closed captioning for this meeting, open the media viewer to the right of your screen. I will repeat that, to access closed captioning, open the media viewer to the right of your screen.

The purpose of this meeting is to solicit your comments on a notice of intent to do an Environmental Impact Statement or EIS for a line of eucalyptus that has been genetically engineered to be tolerant of freezing temperatures. For more information on this eucalyptus go to www.APHISVirtualMeetings.com. This slide contains background information, and also links to other documents and websites.

In the past, we have traveled around the country to conduct meetings where interested parties can make public comments on our various regulatory actions. Now, for the first time, we are holding online virtual public meetings to allow more people the opportunity to comment. Joining me is Dr. Rebecca Stankiewicz Gabel my colleague at BRS. Rebecca is the supervisor of our Biotechnology Environmental Analysis Branch.

Dr. Rebecca Stankiewicz Gabel: Before we start taking comments from our online audience, we would like to go over some of the specifics for the virtual meeting. We are taking only spoken comments today. If you prefer to make a written comment, you can do so by going to www.regulations.gov. Enter the word "eucalyptus" in the search box. This will take you to a link for the freeze tolerant eucalyptus comment site. The public comment period ends on April 29, 2013. You can go to regulations.gov anytime between now and the 29th and leave a written comment, which will become part of the public record. Or you can make a comment here at our meeting which will go until 6:00 p.m. tonight eastern time.

Those of you wishing to speak today will be recognized in the order in which you were registered. Today we are here to receive your input, not to answer questions about eucalyptus. For background information, please go to www.APHISVirtualMeeting.com. If you did not already register to speak and you wish to do so, please click on the raised hand icon. This will indicate that you wish to speak and you will be placed in the queue. You will be provided with instructions on how to proceed through the chat feature.

The statements received during the public comment period, whether spoken here today, or provided in writing to regulations.gov, will be considered in the development of the draft EIS for freeze tolerant eucalyptus. After we have published the draft EIS, we will solicit and receive comments on it. Those comments will be considered in the development of the final EIS. After the final EIS is published, there will be a decision on the regulatory status of freeze tolerant eucalyptus. We welcome your comments today because they will help us to determine what issues to consider as we prepare our draft and environmental impact statement.

Dick George: You should see a list of commenters and the order in which they will speak on your screen so you will know when your turn is approaching. We ask that you keep your comments to three minutes or less. Once everyone who wants to speak has done so, if we have extra time and you would like to say more, we will glad to afford you that opportunity. A recording of this meeting will be available within 48 hours on our site which is www.APHISVirtualMeeting.com. And written transcripts will be available there within a few weeks.

At the conclusion of the meeting, a survey will appear on the screen. Please complete it before you log off. Your feedback is very important to us. If you would like to be seen as well as heard today, please turn on your webcam when it is your turn to speak, and click on the camera icon next to your name. If you are having technical difficulties call the technical support team at 1-866-229-3239. As a reminder, we are here to receive your comments only, not to answer questions on eucalyptus or to discuss or debate biotechnology. With that, we are ready to hear from any commenter who is ready to speak and the first person on our list I think, I am looking at the screen here to get a queue as to whether we have a commenter who is ready quite yet to speak. Do we have Madelynn Frazier or Michael Portereiko. If we could – Michael Portereiko, if your mic is open, you can go ahead. It may take a moment to unmute his phone.

Dr. Rebecca Stankiewicz Gabel: Michael, are you on the line?

Dick George: Michael Portereiko, are you there?

Michael Portereiko: Yes we are here actually, we were just on the list to listen. We do not have any prepared comments at this time.

Dick George: Okay, thank you. Is there anyone else who would like to comment? Ann Peterman, are you there, if so let us know.

Ann Peterman: Yes, can you hear me?

Dick George: Yes, we certainly can.

Dr. Rebecca Stankiewicz Gabel: Yes we can.

Dick George: If you would like to go ahead with your comment, please do.

Ann Peterman: Okay, just one moment. Alright, I guess I would like to point out that this environmental impact statement for this genetically engineered eucalyptus represents the first time that APHIS has prepared a full environmental impact statement on a genetically engineered plant without being forced to by litigation. And it is only the fourth time that APHIS has prepared an environmental impact statement for any GE plant. Previously the agency was forced by litigation to prepare an environmental impact statement for alfalfa, beets and bent grass. And I think what that means is that APHIS is aware that this genetically engineered eucalyptus is potentially very dangerous and could have severe environmental impacts, and that is the fact that there is overwhelming public opposition to them. So I hope that that means that APHIS will take this very seriously and not rubber stamp these genetically engineered eucalyptus.

They are not native to the United States, eucalyptus of any kind, and they are also a documented invasive species. They are highly flammable, they are known to deplete ground water, and the freeze tolerant eucalyptus will be able to escape into ecosystems that previously have been too cold for them. So that makes them very dangerous in addition to the very – the other impacts that eucalyptus plantations already have as we know from the impacts that eucalyptus plantations have had elsewhere in the world, which all the impacts include clear cutting of bio-diverse forests for conversion to industrial eucalyptus plantations in Brazil. These are called green deserts because they have no bio-diversity at all. In Chile they are called green soldiers because they are constantly increasing and on the march forward, taking over more and more land. In South Africa they are called green cancer because people cannot control their spread, they are constantly being found in ecosystems where they were not planted.

They are documented as invasive in Florida and California. They increase the danger of firestorms. They contain a highly volatile oil and are explosively flammable. They displace wildlife that cannot use the eucalyptus trees for habitat or food and in addition, some eucalyptus trees are known to actually glue the beaks of birds together and kill them. They contaminate soil and ground water with the toxic agro chemicals that are used on them. And they are worse in droughts, they have deep tap roots and monopolize ground water and dry up soils. And all of this put together means that they will worsen climate change through the destruction of carbon rich native forests for carbon poor plantations. One study found that timber plantations actually contain about one-quarter the carbon of a native forest. So that is good for my comments for now.

Dr. Rebecca Stankiewicz Gabel: Thank you for your comments.

Dick George: Thank you, we have Keith Brunner on the line, Keith, are you there.

Keith Brunner: Hello Dick, can you hear me?

Dick George: I sure can, please go ahead.

Keith Brunner: Great, so my name is Keith Brunner, I am here today to call on the USDA to deny this permit from ArborGen. Eucalyptus trees are introduced organisms here in the U.S. and they are documented as invasive pests in parts of California and Florida. This cold tolerant trait that we are discussing today, would vastly expand the range of GE eucalyptus trees. And so hence it would enhance its ability to invade native ecosystems which is seriously problematic for bio-diversity as well as for ecosystem resiliency in the face of catastrophic climate change that we are facing.

Our experience in California and other parts of the world has shown that when eucalyptus escapes it is near impossible to eradicate them. And I wanted to include a quote from the renowned geneticist David Suzuki, I quote. "We have no control over the movement of insects, birds and mammals, wind and rain that carry pollen and seeds, genetically engineered trees with the potential to transfer pollen for hundreds of miles carrying genes for tracing, including insect resistance, herbicide resistance, sterility and released lignin, thus have the potential to wreak ecological havoc throughout the world's native forests." And as was mentioned, approval of GE eucalyptus would open the door for other GE tree species.

Also as was mentioned, GE trees are green deserts. They are an industrial plantation of trees, tree plantation, especially of GE trees, is like an industrial army of trees that will wipe out all of the life around them. These have major impacts on bio-diversity, particularly, these trees the cold-tolerant eucalyptus trees are being targeted for the forests of the southern U.S., and these are some of the most bio-diverse forests in the world. They have species found nowhere else including the Louisiana Black Bear, the Golden Cheeked Warbler, and the Red-Cockaded Woodpecker. These are species that could be pushed over the edge if millions of acres of GE Eucalyptus plantations are developed. They are also – eucalyptus trees are known to soak up more water than the forest that evolves naturally here, which threatens creeks and rivers. And the endangered freshwater species that live in them.

I also wanted to talk about the fact that there is enormous public opposition, not only in the United States, but internationally, to genetically engineered trees as well as to eucalyptus plantations. The last time that APHIS took comments on the test plots, there were tens of thousands of comments opposed to the field trials, and there were only 50 in favor. So that tells if it is something about where the public stands, and in this democracy of course, it should be a participatory process and it should be absolutely included in our decision making. I also wanted to highlight in 2006 this sort of, this story sort of encapsulates some of their resistance to eucalyptus plantations that occurs internationally. In 2006, on March 8, 2000 women from La Via Campesina, occupied the plantation of Aracruz Celulose which is now Fibria in Brazil, and Rio Grande do Sul on a Wednesday, and they occupied this plantation to denounce the social and environmental impacts of these green deserts created by eucalyptus monoculture. Now this was a massive even in Brazilian politics caused by the expansion of eucalyptus monocultures. And I quote from La Via Campesina from the women, "We are against green deserts, the enormous plantations of eucalyptus that cover thousands of hectáreas in Brazil and Latin America when the green desert advances, bio-diversity is destroyed, soil deteriorates, and rivers dry up. Moreover, these plants pollute air and water and threaten human health." So that is what we will see here in the U.S. South is what has happened internationally, and that is why I am calling on APHIS to not submit – to deny this permit to Arbor Gen Corp cold tolerant eucalyptus trees. Thank you, I am done.

Dr. Rebecca Stankiewicz Gabel: Thank you for your comments. Do we have anyone else on the line?

Dick George: We have no one else lined up at the moment to speak. I would mention to those who are listening in if perhaps you have decided that you would like to make a comment, you could still do so. You need to click on the raised hand icon on your screen, and you will receive instructions through the chat feature on how to make a comment. So since we have no others signed up at the moment, we do receive a signal from our WebEx producer when someone is on the line and ready to speak. So what we will do, we will take a pause. We encourage those listening, if you have a comment, please do so the way I just described. And in the meantime, we will take a pause, and if we have no others who come on, we will come back on every five minutes or so just to let folks know that we are still here. We plan on being here until 6:00 p.m. today, so if someone comes on this meeting late, they will still have the opportunity to make a comment.

So having said that, I will take a pause and if we get a signal that we have someone else who is ready to speak, we will come back on and receive that comment. So we will take a pause right here, thank you.

Dr. Rebecca Stankiewicz Gabel: Thank you.

Dick George: Okay, we have someone who would like to make a comment. It is Rachel Smolker, please forgive me if I have mispronounced your name, Rachel are you there?

Rachel Smolker: Hi, I am here.

Dick George: Terrific, go ahead with your comment.

Rachel Smolker: Okay. I had a little trouble getting onto the call so I am not sure what had already been said or not. But I wanted to comment on two things. First of all, the organization that I work with does a lot of work on the impacts of large scale bio-energy on climate and on human rights and on food and we do not support the position that was in this petition that this is – that large scale bio energy is a great socio-economic benefit to people. Because in fact the demand for land, to produce enough biomass to make any kind of significant contribution to our energy demand as it is right now, is astronomical. And we cannot meet more than a very small portion of our energy demand from trees or any other source that requires large amount of land and water like eucalyptus would. So that is one point, the other point I would like to bring up, in the petition, the issue of Cryptococcus, which is a fungal pathogen that causes fungal meningitis and is becoming global epidemic at this point. It is a major cause of death for a lot of patients with AIDS. It also infects people who are immunocompetent that does not have any compromised immune system in different places.

It was initially discovered in Australia associated with eucalyptus species, and we brought this up in the process where decision about field testing these eucalyptus, and it was dismissed because it was found that there are other trees that also host this Cryptococcus fungus. That is not a good basis for dismissing it in my opinion because just because there are other trees that are also host, Cryptococcus is not a plant of favored host over wide swathes of the United States. It is rather foolhardy actually.

In a letter to the USDA at that time, Dr. Heitman who is from Duke University, wrote, in summary there is a possibility that exporting or planting large numbers of eucalyptus trees could create a novel environmental niche for human pathogen that causes infections of the lungs and the central nervous system that can be difficult to treat, exhibit drug resistance and can be fatal. So I think it is immature to be dismissing the issue of Cryptococcus setting the possibility of setting up widespread habitat for that fungal pathogen by planting eucalyptus over a much extended range with these genetically engineered trees.

The other issue I wanted to bring up was is around pests, having looked a little bit at what was here in the petition about the various test species. I just want to say that I really want to say that it was really quite impossible to predict what kinds of pests will be attracted to massive plantings of eucalyptus in the United States. Plantings elsewhere are not necessarily indicative because there are different plants and plant pests traveling around in different parts of the world. I just want to read a brief portion from an abstract of a paper that was published in 2010 which was about the introduction of pests to eucalyptus in California. The paper that this was from was published in the journal of economical entomology, accumulation of pest insect on eucalyptus in California, random process or smoking gun. Timothy Paine, Jocelyn Millar, and Kent, M. Daane. These are folks from the University of California. The main point is that between 1983 and 2008, an additional 16 Australian insect pests of eucalyptus have become established in that state. Others prior to that. The modes or routes of introduction have never been established, and I just highlight that. We do not know, we cannot tell, there is no way of controlling the travel and transport of these pests. However, examinations, different temporal spatial patterns suggest the introductions were non random processes. And it goes on to say that the precautionary approach to these things and the risks associated with large scale planting of something like that.

And so, one of my questions is what are the environment impacts going to be of having large areas planted with this eucalyptus if we have no idea really what kinds of pests, we cannot really pretend that we know, and what kinds of controls are going to be used, what kinds of chemicals will have to be sprayed in order to control those pests when they inevitably do arrive. So that is my comments, thank you.

Dick George: Thank you so much for your comment. We do not have another speaker scheduled to speak at the moment, but we will, as I said before, we are here until 6:00 so if anyone else would like to speak, perhaps someone who is on the line who has been listening in, just click on the raised hand icon to do so, you will get instructions on the chat feature. And if someone does decide they would like to make a comment, we will come back online as quickly as we can to receive that comment. So otherwise, we will see you, if we do not hear from anyone else, we will close the meeting right before 6:00, so we will see you in about 15 minutes if not before. And if we have someone who wants to speak in the meantime, we will be back on as quickly as we can. Thank you so much.

We would like to thank everyone who participated today in our virtual meeting on freeze tolerant eucalyptus. Our PowerPoint and audio of this virtual meeting will be available on our website, www.APHISVirtualMeeting.com within 48 hours. Please do not log off before completing our survey, it will appear on your screen following the meeting. Please fill it out and then click the submit button. We will be posting information, including dates and times of future virtual meetings at our website, www.APHISVirtualMeeting.com. Thanks again for joining us for this virtual meeting. For Rebecca and myself, we appreciate you being here and your comments. And also those who just attended. As of now, this virtual meeting is now concluded, thanks so much.

Dr. Rebecca Stankiewicz Gabel: Good night.

APPENDIX B. USDA-FS TECHNIAL REPORT ON THE POTENTIAL ADOPTION OF FREEZE-TOLERANT EUCALYPTUS IN THE UNITED STATES

Projecting potential adoption of genetically engineered freeze-tolerant Eucalyptus plantations

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Executive Summary

1. The recent development of genetically engineered clones of a *Eucalyptus* hybrid: *Eucalyptus grandis X Eucalyptus urophylla,* with genetic modifications targeting freeze tolerance and male sterility raises questions about the potential for landowners to plant *Eucalyptus* and the potential extent of *Eucalyptus* plantations in the U.S. This study examines the economics of freeze tolerant (FT)-*Eucalyptus* plantations and projects the potential extent of adoption.

2. While APHIS defines the potential range of FT-Eucalyptus as plant hardiness zones 8b and greater based on anticipated freeze tolerance, other environmental factors may limit the viability of commercial plantings. We used a survey of the literature on the range of *Eucalyptus grandis* and *E. grandis x E. urophylla* in Asia, Australia, and South America to further define the viable range of FT-*Eucalyptus* based on annual precipitation, temperature, and solar insolation. This effectively eliminated the western U.S. from consideration and limits the viable range to a portion of the Southeastern U.S. from eastern Texas to South Carolina.

3. We used the best available data to assess the potential returns to FT-*Eucalyptus* and existing forest and agricultural land uses within the viable range. We compiled detailed area and return data on individual crops from USDA sources at the finest scale available and developed aggregate return estimates based on implied crop rotations. We estimated the present net value of pine plantations and FT-Eucalyptus plantations using a management simulation approach based on estimates of productivity, management costs, and historical stumpage prices. Annualized returns were developed from the present values. Results were reported at a substate scale using the price-reporting zones of Timber Mart South. A comparison of the returns to FT-*Eucalyptus* and other rural land uses indicates a potential for the commercial adoption of freeze-tolerant FT-*Eucalyptus* in the southeastern United States. FT-*Eucalyptus* could provide comparable returns to planted pine forests especially in the western part of the southeast (Texas, Louisiana, and Mississippi). This competitive position derives from strong growth in real hardwood pulpwood prices over the past two decades. In contrast, high returns to cropland would generally preclude transition to FT-*Eucalyptus*—current crop returns exceed FT-*Eucalyptus* returns by an order of 3-5 times.

4. Projecting the potential adoption of FT-*Eucalyptus* in the viable range required a model that addresses return risk and uncertainty as well as expected values of returns. We developed a real options model to simulate land use choices by risk-neutral landowners using estimates of future returns and return variance (based on time series of historical returns) and the costs of land use

conversions. We examined a range of assumptions regarding return risks, price levels, and productivity.

5. Our analysis indicates that FT-*Eucalyptus* is potentially competitive with planted pine management over a range of future conditions. Results further indicate that while FT-*Eucalyptus* may be competitive in terms of expected returns, its higher return variance and conversion costs may limit the degree to which land is actually converted. Two models of return variance under base case conditions (i.e., based on historical price trends and variance), project between 0.8 million acres and 1.4 million acres of FT-*Eucalyptus* by year 30. These models are consistent with a scenario with mild expansion in demands for hardwood material (perhaps for a bioenergy market). However, under such a scenario, we might also expect the return variance for hardwoods to decrease as demand strengthened. If this were the case, then a more substantial switching to Eucalyptus could result.

6. Our analysis assumes that transitions between forest and FT-*Eucalyptus* uses would be limited to the current area of planted pine because this is the portion of the region's forests that has demonstrated economic feasibility for tree plantations. This is likely to be a conservative estimate of available area. If we assume instead that the eligible area also includes the area of naturally regenerated pine, then the total eligible area would shift from about 16 million acres to about 27 million acres. Applying the proportion of switching from our two base models would shift the projected area of adoption from a range of 0.8-1.4 million acres to between 1.35 and 2.75 million acres.

7. Our analysis is based on several assumptions about market futures and risk. One especially important assumption is that the freeze tolerance conferred by the FT-*Eucalyptus* will be successful in preventing substantial freeze damage to planted trees throughout the viable range (plant hardiness zone 8b and higher). Mortality and productivity are however important stochastic elements of overall return estimates which could influence return risk differentially across the study area. Other uncertainties unaddressed by our analysis include the actual cost of the FT-*Eucalyptus* seedlings and the risk of some public backlash against the planting of genetically modified trees. Societal and economic risks could affect investment choices in the same fashion as biophysical risk—i.e., increased risk would reduce the rate of adoption.

8. While our projections are not meant to be precise predictions of the area of FT-*Eucalyptus* adoption, they do demonstrate that under current conditions, a risk-neutral and profit maximizing land owner could choose to adopt some amount of FT-*Eucalyptus* as a preferred land use. The extent of that adoption will depend on the future of market prices for various timber products, including new bioenergy products, and on the demonstrated productivity and certainty of production from available FT-*Eucalyptus* seedlings. It is important to note that this work is based on the assumption that the behavior of returns for each of the land uses will remain unchanged into the future. We also did not explicitly address the effects of shifting timber supply on future market equilibrium.

Projecting potential adoption of genetically engineered freeze-tolerant Eucalyptus plantations

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Abstract

Development of Eucalyptus plantations has been limited in the United States due mainly to the species' sensitivity to freezing temperatures. Recently developed genetically engineered clones of a Eucalyptus hybrid which confer freeze tolerance could expand the range of commercial plantations. This study asks whether and to what degree the freeze tolerant Eucalyptus might be adopted as a preferred land use based on comparative returns and a real options land use switching model. Climate factors other than freezing (rainfall and average temperatures) are assumed to limit potential adoption to the southeastern region of the United States. Comparison of returns indicates that Eucalyptus would not likely compete with cropland in this region but could be competitive with forest uses, especially planted pine. Real options analysis, using both geometric Brownian motion and mean reverting models of stochastic returns indicates that switching could be expected on a portion of planted pine forest land. Models predict about .8 to 1.4 million acres of Eucalyptus plantations or 5 to 9 percent of the current area of planted pine. Extending the analysis to also consider the current area of naturally regenerated pine results in as much as 2.8 million acres of Eucalyptus. Actual adoption will likely depend on uncertain future markets for cellulose, especially for bioenergy feedstock, and a set of model variants explore the potential range of responses.

Introduction

Planted forests provide an increasing share of fiber supply throughout the world and their area expanded at a rate of 5 million ha yr^{-1} between 2000 and 2010 (FAO 2012). *Eucalyptus*, a highly productive genus native to Australia and Indonesia, has been planted across large areas of Asia, Africa, and Brazil but its application in the United States has been limited by environmental factors, especially sensitivity to freezing temperatures. In the southeastern United States, the 16 million ha of planted forests are almost exclusively pines (*Pinus spp.*) and are an important source of softwood forest products. Hardwood forest products in the region are mostly sourced from natural stands and have become somewhat scarce, especially in some localized markets (Wear et al. 2007). As a result, a freeze-tolerant *Eucalyptus* established in plantations could have commercial application in the region for industries currently using hardwood forest products as an input and may make novel industrial applications economically viable.

Recent efforts to modify the genetics of *Eucalyptus* hybrids to confer freeze tolerance could expand the range of *Eucalyptus* in the United States. In particular, ArborGen LLC has developed two genetically engineered clones of a *Eucalyptus* hybrid: *Eucalyptus grandis X Eucalyptus urophylla,* with genetic modifications targeting freeze tolerance and male sterility. The company has petitioned the USDA Animal and Plant Health Inspection Service (APHIS) for a determination of nonregulated status of this freeze tolerant (FT) *Eucalyptus* under regulations 7 CFR part 340 under the authority of the Plant Protection Act of 2000 (Public Law 106-224—June 20, 2000). In response to the ArborGen petition, USDA APHIS has decided to prepare an Environmental Impact Statement (EIS) to consider the potential environmental effects of an agency determination of nonregulated status consistent with Council of Environmental Quality's (CEQ) National Environmental Policy Act of 1969 and subsequent amendments (NEPA) regulations and the USDA and USDA-APHIS NEPA implementing regulations and procedures (40 CFR Parts 1500-1508, 7 CFR Part 1b, and 7 CFR Part 372). If the petition is granted, it would allow ArborGen to plant these freeze-tolerant clones without permit in unconfined conditions. Our assignment, in support of the EIS conducted by APHIS, is to explore the potential adoption of these clones in light of anticipated productivity and economics. The overarching question is how much land area might be occupied by FT-*Eucalyptus* plantations if these clones receive nonregulated status. The answer would necessarily derive from the willingness of landowners to adopt this new land use in lieu of existing land uses. This paper compares returns to existing land uses with those accruing to potential FT-

Eucalyptus management regimes within an anticipated viable range in the United States to determine where returns to *Eucalyptus* management could compete with existing land uses.

The analysis starts by examining the production technology and economics of *Eucalyptus* plantations to estimate potential returns and present net values of *Eucalyptus* adoption. These estimates depend on a full accounting of the costs, biophysical productivity, and revenues of management and are based largely on estimates from management of non-FT *Eucalyptus*. We construct implied historical returns by linking simulated profit functions to historical prices and compare these returns with returns to other land uses. Adoption of *Eucalyptus* would depend not only on expected returns but also on the relative return risk associated with all land uses. A real options land use switching model compares FT-*Eucalyptus* with existing major land uses to estimate adoption under modeled return and risk conditions. The use of disaggregated county and sub-regional data allows for the mapping of potential land use changes. The analysis of several model variants allows us to explore how the expansion of Eucalyptus plantations could develop under various market futures.

This document is organized as follows: The next section of this paper describes land use theory, first in a deterministic setting and then with a consideration of risk and uncertainty using real options and includes specifics regarding estimation of the land use switching models. The data section describes the geographic region viable for FT-*Eucalyptus* and the compilation of data on the extent and net returns for the existing agriculture and forest land uses within this region, as well as the predicted returns for *Eucalyptus* management. The third section describes the results of model estimation, comparisons of *Eucalyptus* returns with returns to existing land uses, and projections of potential *Eucalyptus* adoption in the future for a set of scenarios. The concluding section describes key findings and discusses important uncertainties associated with the analysis.

Land Use Theory

Understanding the potential expansion of FT-*Eucalyptus* plantations requires a model of switching between different possible land uses. For example, under a deterministic land use switching model, the existing distribution of land uses is assumed to reflect profit-maximizing behavior on the part of private landowners so that the quasi-rent accruing to the selected land use exceeds the quasi-rents accruing to all other possible uses (e.g., Hardie et al 2000):

$$R^* = \max\left(R^{*1}, \ldots, R^{*J}\right) \quad (1)$$

where j=1, ..., J represents the possible land use categories. These quasi-rents are defined by profit functions which account for all the relevant costs of management as well as the returns to harvest for different rural land uses—we treat urban land uses as fixed. Anticipated rents therefore vary across demand futures—i.e., they depend on the prices of known and anticipated products—but also depend on the qualities of the site that determine productivity and operating costs. If land is of homogenous quality then we would expect one land use to dominate all others everywhere; heterogeneous land quality accounts for a diversity of land use outcomes within an analysis area. A more explicit accounting follows:

$$R^{*j}(P,Q)=Px^{*j}(P,Q)' \quad (2)$$

Where quasi-rent for land use j depends on a vector of input and output prices (P) and the quality of the parcel indexed by Q. The product of prices with the vector of input/output quantities (which likewise depend on P and Q) define the profit associated with land use j. Equation (2) indicates that the rent accruing to any land use would change in response to exogenous changes in input (energy, labor, or capital) prices or in output (corn, wheat, other crops, timber) prices and also implies that the ranking of rents for a given parcel may change in response. Rent reordering explains rural land use changes in this formulation.

Introduction of a new land use alternative—for example, *Eucalyptus* plantations—would require a reevaluation of relationship (1) with J+1 (rather than J) alternatives. Because the current distribution of land uses across an analysis area represents the optimal allocation of land across economic and land quality conditions, the potential for reallocation depends on comparing the quasi-rent for *Eucalyptus* plantations with the quasi-rent accruing to each land use currently occurring within the analysis area. With a deterministic model, once the returns to *Eucalyptus* have been estimated, this reduces to evaluating the following inequality:

$$R^{*J+1} - C > R^* = \max(R^{*1}, \cdots, R^{*J}) \quad (3)$$

Where C accounts for the one-time cost of converting to a *Eucalyptus* plantation. If the inequality holds, then the land use would be expected to switch from the current optimal alternative to a *Eucalyptus* plantation.

Landowners face uncertainty regarding future returns and the structure of that uncertainty along with costs of conversion have been shown to influence switching decisions (e.g., Schatzki 2003). To address uncertainty and conversion costs we apply real options methods to estimate the potential for adoption of *Eucalyptus*. In general, the inclusion of uncertainty and conversion costs into the decision model tends to reduce the likelihood of conversion compared to the predictions of the deterministic model (Dixit and Pindyk 1994). The approach changes the switching calculus from an "all or nothing" proposition to one which accounts for portfolio balancing among uses.

A real options land use switching model

Our switching model anticipates that a risk-neutral decision maker chooses between retaining a current land use or (reversibly) adopting a new land use (*Eucalyptus*) based on a comparison of returns, conversion costs, and uncertainty regarding future returns. Modern investment theory highlights the limitations of discounted cash flow as a decision rule where returns are not known with certainty and investments are at least costly to reverse (Dixit and Pindyck 1994). The ability to switch land use is an option which is lost when the decision is made—i.e., the landowner foregoes the option to further delay the timing of the investment and therein benefit from future information. The costs (as well as the benefits) of exercising the option factor into the decision, therein defining a real options problem. We adopt the modeling approach of Song et al. (2011) to define switching models to compare the *Eucalyptus* land use with current land uses. Their analysis addresses the potential adoption of perennial switchgrass over a corn-soybean land use in the Midwest US and allows for two-way switching, a question directly analogous to our research question.

Following Song et al. (2011), assume that a risk-neutral landowner is considering the current use of a unit of land, denoted by i, that can be converted to another use, j, at a lump sum cost of C_{ij}. The return to the current land use i ($\pi_i[t]$) in a given time period t is assumed to evolve by a stochastic process of the form:

$$d\pi_i(t) = \alpha_i \pi_i dt + \sigma_i \pi_i dz_i \qquad (4)$$

where α_i, the drift term, and σ_i, the variance term, are both constants and dz_i is the increment to a Wiener process. Equation (4) defines a geometric Brownian motion model of the returns to the land use which is nonstationary—a positive α indicates an upward drift in revenues.

To compare returns between two land uses requires estimating a GBM model for each and accounting for the correlation of the return series due to the influence of common factors (for example, all land based returns in a region may be similarly influenced by drought). The joint GBM models for both land uses can be expressed as follows:

$$d\pi_1(t) = \alpha_1(\pi_1, t)dt + \sigma_i(\pi_1, t)dz_1$$

$$d\pi_2(t) = \alpha_2(\pi_2, t)dt + \sigma_2(\pi_2, t)(\rho dz_1 + \sqrt{1-\rho^2}dz_2) \quad (5)$$

where ρ is the correlation coefficient between the two return series and other variables are defined as above.

The GBM model with positive drift implies increasing scarcity. In the case of renewable resources a long term stability in commodity returns may be more consistent with theory. Accordingly, we also examine a mean-reverting stochastic return model that allows for short run fluctuations but anticipates a tendency for prices to be drawn back to a long run mean value, consistent with a stock adjustment process (i.e., planting more or less crops) that responds to increasing or decreasing scarcity. This model is defined as:

$$d\pi_i(t) = \eta(\bar{\pi}_i - \pi_i)\pi_i dt + \sigma_i \pi_i dz_i \quad (6)$$

where n is the speed of reversion back to the mean (and is expected to be positive) and the other parameters are as defined for the GBM model. While the GBM is more tractable and is the standard form applied to the real options analysis of financial instruments, the mean reverting (MR) model may be preferable for describing returns to land-based commodity production. It is difficult to select mean reversion or to allow for drift *a priori*. We instead investigate the implications of both formulations.

The expected present-value payoff in time period t due to the landowner following optimal conversion is a function of the returns to both possible land uses and is denoted as $V^i(\pi_{cur}(t), \pi_{alt}(t))$, with cur and alt denoting the current and *alternative (e.g.,Eucalyptus)* land use respectively. Letting r be the landowner's discount rate, the conversion decision is defined by:

$$V^i(\pi_{cur}(t), \pi_{alt}(t)) = \max\begin{Bmatrix} \pi_{cur}(t)dt + e^{-rdt}EV^{cur}(\pi_{cur}(t+dt), \pi_{alt}(t+dt)), \\ V^{alt}(\pi_{cur}(t), \pi_{alt}(t)) - C_{cur,alt} \end{Bmatrix}. \quad (7)$$

The first term in the maximum operator is the return to the landowner from staying in the current land

Figure .1 Idealized switching boundaries for a real options based land use switching model.

use $i$and is the sum of the immediate profits from the current land use and the discounted value of the expected profits at the end of the time period $[t + dt]$. The second term in the maximum operator is the return from converting to *the alternative use* net of the switching cost $C_{cur,alt}$.

This present value function can be redefined to describe optimal decision rules incorporating the option value of the current land use based on different realizations of relative returns in the two possible land uses. Figure 1 shows a graphical representation of idealized switching boundaries for the current problem (equation 7) with returns to current use and *Eucalyptus* use on the horizontal and vertical axes respectively. Where relative returns occur above the upper switching boundary, returns to *Eucalyptus* exceed returns to the current use enough to justify switching from the current land use to *Eucalyptus*. Where relative returns occur below the lower switching boundary, returns to the current land use exceed *Eucalyptus* returns enough to justify switching from *Eucalyptus* back to the original use.

The region where relative returns fall between the two lines corresponds to the condition in which it is not optimal for the landowner to make a switch, even if current returns for the existing land use are lower than the alternative (due to conversion costs and/or risk). Note that land use hysteresis is expected with this model specification—i.e., following a land use switch a return to a pre-switch price pair may not induce switching back to the original land use. More information about the mathematical procedure and proofs underlying the conversion of the present value function to the optimality conditions can be found in Song et al. (2011) and Brekke and Øksendal (1994).

Model Specification

The land use switching model described above is too complex to be solved analytically and is instead solved by numerical approximation. In this procedure, the model is reformulated as a series of piecewise linear basis functions and then solved for a subset of possible values by a process called collocation. This produces an approximation of the location of the switching boundaries between the two land uses demonstrated in Figure 1 (Fackler 2004; Miranda and Fackler 2002). The probability of conversions through time may be estimated by simulating switching behavior over a large set of simulations for the return paths determined by equations (5) and the correlation between returns. For each year in each simulation, switches to and from *Eucalyptus* are tallied to predict the total proportion of land that would be allocated to *Eucalyptus*. We construct pairwise comparisons of existing rural land uses with *Eucalyptus* management in each of several sub-regions where distinct estimates of revenue time series can be constructed.

For each pairing between a current land use and the *Eucalyptus* land use, we use OSSOLVER, a MATLAB utility developed by Fackler (2004) for solving switching problems (to and from Eucalyptus) by numerical approximation, to solve for the optimality conditions and develop the conversion boundaries between land uses for each county. The switching boundaries estimated in this step define a mapping between revenue pairs and the optimal decision, incorporating the option value of the current land use and conversion costs between all pairs of land uses.

Monte Carlo simulations were done in the Python programming language, applying 100,000 realizations of equations (4) over a 30 year time period and calculating the switching between the *Eucalyptus* and alternate land use based on the OSSOLVER switching boundaries. *Eucalyptus* adoption is examined initially for the existing market situation, that is, with the estimated stochastic revenue functions for existing land uses and a constructed *Eucalyptus* revenue function based on production of

hardwood pulpwood. To address altered demands for cellulosic fiber, for example, from anticipated thermal and biochemical bioenergy uses, we also consider scenarios with higher initial prices for both *Eucalyptus* and other wood producing land uses.

Study Area and Data

The study area is limited initially by USDA plant hardiness zones 8b and higher as shown in Figure 2. This is defined by the parameters of the environmental analysis conducted by USDA APHIS and implicitly assumes that an effective frost tolerance is conferred upon the Eucalyptus hybrid through genetic modification[1]. This zone encompasses a large area of the southeastern United States, but also includes much of the southwestern US and California along with coastal areas of Oregon and Washington. Intolerance to cold (freeze damage) has restricted the small area of commercial plantings of non-FT *Eucalyptus* to zone 9 (generally zone 9a) and FT hybrids could expand the range to this broader area. USDA plant hardiness zones are defined by bands of average annual minimum temperatures and can be useful for defining limits based on frost or cold tolerance. Commercial *Eucalyptus* plantings would be limited not only by cold sensitivity, but also by potential productivity, which is influenced by availability of water inputs and solar insolation. We define the areas where Eucalyptus could be a viable crop by screening out areas based on the plants minimum requirements for water and solar inputs. First we screen out areas based on rainfall limitations. While vapor pressure deficit, seasonal rainfall distribution, and other factors affecting water balance play a role, total rainfall is used to summarize water availability. Schonau (1984) cites 800 mm/year as a threshold for E. *grandis* plantations around the globe (900 mm/year for commercial success). Stape et al. (2004) observe productive *E. grandis* x *urophylla* plantations in Brazil on sites where precipitation ranges from 853-1164 mm/year, while Gonçalves et al. (2012) cite a range of 1000-3000 mm/year for *Eucalyptus* plantations in Brazil. A global climate envelop for E. *grandis*, based on data from Austrailia and Africa (Booth 1989), includes a mean annual rainfall requirement of 700-2500 mm yr^{-1}. We screen out areas with average annual precipitation of less than 800 mm/year as unsuitable for plantings in the U.S. This eliminates the southwestern United

[1] This is clearly a strong assumption given that freeze damage is influenced by minimum temperatures and the time of year at which the stand is subjected to freezing temperatures (e.g., before or after hardening).

States, from central Texas westward and much of California—and also assumes that irrigation would not be used to grow *Eucalyptus* in arid regions of the southwestern United States (Figure 3)[2].

Figure 2A. Plant hardiness zones 8b and higher intersected with precipitation zones for the South.

[2] Assuming that Eucalyptus would need the equivalent of 900 mm of rainfall to produce a viable crop equates to about 3 ac. ft. of water input from irrigation, a quantity that is consistent with irrigation delivery in Arizona (average of 5.4 ac. ft.) and California (average of 3.1 ac. ft.; USDA 2009). However, the costs of irrigation would be prohibitive: the average costs of irrigation from off-farm suppliers in 2008 was $140/ac/year and $143/ac/year in Arizona and California respectively. As demonstrated later in this paper, these costs far exceed potential returns from Eucalyptus.

Figure 3B. Plant hardiness zones 8b and higher intersected with precipitation zones for (A) the South (showing Timber Mart-South Zones) and (B) the West

Figure 3A. Earth temperature intersected with plant hardiness zones 8b and higher for the South. Timber Mart-South zones are defined within each State.

We also limit our analysis to areas with solar insolation comparable to the current distribution of productive *Eucalyptus* plantations. We consider two metrics of solar input, mean annual daily temperatures and total solar radiation measured as annual kilowatt hours per square meter per day (Kwh/m^{-2} per day). In Brazil, Stape (2004) finds productive *Eucalyptus* plantations over a range of average daily temperatures from 19.4 – 23.6º C and Gonçalves et al (2012) reports a range of 13-26º C. Booth's climate envelop for E. *grandis* identifies a mean annual temperature range of 14-25° C. Also in Brazil, Almeida et al. (2004) observe productive *Eucalyptus* across a solar radiation range of 4.5-5.1 kwh/year. We define the mean annual daily temperature cutoff as greater than 15 degrees Celsius (about 60 degrees F) and a solar insolation cutoff as 4 Kwh/m^{-2} per day. These screens eliminate from consideration the small section of plant hardiness zone 8b contained in Oregon and Washington (see

Figure 3B. Earth temperature intersected with plant hardiness zones 8b and higher for the West.

Figures 3 and 4). Our study area is therefore limited to the southeastern United States from east-central Texas to South Carolina as shown by the areas with green shading in Figure 2. [3]

[3] For the most part, these literature-derived environmental constraints define clear boundaries for commercial viability. However, a small area of northern California while excluded from our analysis by these constraints, is close to the margins for rainfall and solar insolation.

Figure 4A. Solar radiation intersected with plant hardiness zones 8b and higher for the South.

To examine the potential adoption of *Eucalyptus* plantations in zone 8b requires data on the current rural land use distributions across forest management types and crop types, net returns accruing to each of these existing land uses, the costs of converting from existing land uses to *Eucalyptus* and vice versa, and the potential rents accruing to *Eucalyptus*. Data were compiled at county and sub-regional levels. Returns data are organized by the one or two Timber Mart-South (TMS) sub-regions within each state (see Figure 2). Crop returns are compiled across broader regions defined by the USDA and crop were linked to TMS sub-regions. Where more than one crop return region is associated with the TMS sub-region an average return is constructed by weighting the respective crop returns by crop acreage. Data (land uses, conversion costs, and returns) are assembled for each sub-region in the study area from the following sources:

Figure 4B. Solar radiation intersected with plant hardiness zones 8b and higher for the South.

Area of Land Uses: Cropland by crop type and pastureland area are taken from the 1997, 2002, and 2007 Census of Agriculture (USDA 2007) as reported in the National Agricultural Statistics Service,[4] forest areas by forest management type are taken from the Forest Service FIA data bases for each state (e.g., Miles et al. 2001; Smith et al. 2009). Because farmers use a variety of crop rotation patterns (which we cannot identify *a priori*) and rarely employ monocultures, we treat cropland as a single use and

[4] Accessed at http://www.nass.usda.gov/ January 29, 2013.

assign the portfolio of six major crops produced within the sub-region based on cropland acreages. Forests are divided between intensively managed planted pine and all other, naturally regenerated forest types. We consider switching options for the former but not for the latter because currently planted forests have demonstrated economic feasibility for tree plantations. This logic limits our analysis to areas already identified as "operational" in terms of drainage and access and we revisit the implications of this assumption in the conclusions section by considering naturally regenerated pine.

Returns to land uses: Net returns to land uses are derived from annual return and cost estimates or from secondary sources and expressed in real terms using the implicit GDP price deflator with a base year of 2005. Forest land returns are developed for each county using sub-state timber (stumpage) prices linked to simulated outputs and costs associated with a specified management regime. For cropland returns we use reports of annual net returns to each major crop type for each subregion. For the historical time series of crop returns, years 1975-1995/6, we defined the net return as the gross value of production net of variable cash expenses. To most closely match the definition of crop returns between the historical and recent time series (years 1995/6-2011), we defined recent crop returns to be the value of production less operating costs and hired labor and excluded interest on operating capital. We construct an acreage weighted average return to cropland for each subregion using individual crop acreages for 1997, 2002, and 2007. We assume that the 1997 acreages apply to years prior to 1997 and then interpolate between data points to estimate acreages for 1997-2007. Acreages are held at 2007 levels for 2007-2011. Comparable data were not available for pasture and we have not included this land use in our analysis.

Net returns accruing to *Eucalyptus* plantations are inferred using cost and productivity data from recent published work related to Eucalypts grown in the southeastern United States (especially Gonzalez et al. 2011). These are linked to historical hardwood pulpwood prices to simulate the historical revenue series used to estimate the stochastic revenue functions. The same approach is used to construct a return series for planted pine forests. To produce return data comparable to annual crop returns, we calculate an equal annual return for both forestry uses based on a valuation using each year's stumpage prices for a given region. This approach is consistent with the landowner basing the decision to switch on anticipated returns for woody crops and that switching from the current woody crop would occur only following a harvest. That is, we do not directly address the issue of changing the harvest timing for existing woody crops in response to other options.

Estimates of land use switching are based on return processes (GBM or MR) estimated for the various land uses. We start with base scenarios that use the estimated models applied to starting conditions defined by 2011 prices. Alternative futures are constructed by adjusting the rates of return growth in the GBM models, adjusting the variability and correlations of returns in the MR or GBM models, or changing the starting conditions. We also construct sensitivity analysis of these models to examine the influence of *Eucalyptus* establishment costs and starting prices on eventual adoption of Eucalyptus across the southeastern U.S.

Figure 5. Distribution of rural land uses in the study area for (A) crop types in 1997, 2002, and 2007 and (B) for forest types in 2010 (Sources: USDA Census of Agriculture and FIA).

Results

Rural land in the region reflects a diversity of uses (Figure 5). The 2007 Census of Agriculture (USDA 2007) indicates that 7.7 million acres of land was dedicated to six major crop uses, down from 9.3 million acres in 1997.[5] Most of the decline between 1997 and 2007 is explained by declines in cotton acreage (-0.85 million acres) and soybean acreage (-0.98 million acres) coupled with a moderate expansion in corn acreage (+0.43 million acres). Peanut and wheat acreages are relatively small (0.5 million acres) but stable over this period. Forest uses dominate the rural landscape in the study area shown in Figure 2 at 59.3 million acres. Forest uses similarly show strong diversity in this region (Figure 2B). Pine forest types account for 27 million acres or 46 percent of total forest area, with 16 million acres (27 percent) in a planted forest condition. Hardwood forest types account for 25 million acres (42 percent) with a majority (15 million acres) in lowland hardwood forest types.

Table 1. Eucalyptus management regime for producing hardwood pulpwood.

Description	Timing	Value	Unit	Value	Unit
Mechanical site prep	Establishment	247	$/ha	99.96	$/ac
Chemical site prep	Establishment	116	$/ha	46.94	$/ac
Planting density	Establishment	1250	trees/ha	505.86	trees/ac
Planting cost	Establishment	133	$/ha	53.82	$/ac
Seedling cost	Establishment	0.25	$/seedling	0.25	$/seedling
Fertilizer	Mid-rotation (years 2 and 10)	247	$/ha	99.96	$/ac
Herbicide	Mid-rotation (years 1 and 9)	124	$/ha	50.18	$/ac
Management	Yearly	25	$/ha	9.98	$/ac
Growth rate	Yearly	30	ton/ha/year	12	tons/ac/year
Discount rate		0.08	-	0.08	-
Harvest age		8	years	8	years

[5] The percentage change (-17 percent) is roughly consistent with the 12 percent drop in cropland area reported for the entirety of these seven states by the NRI for 1997-2007 (NRI 2011).

Returns to Eucalyptus management

To estimate returns to *Eucalyptus* management we start by assuming removals will be sold in a hardwood pulpwood market and simulate management using a 16 year management regime (based on Gonzalez et al. 2011, Dougherty and Wright 2012). Conversion costs include mechanical and chemical site preparation, seedlings, and planting. An initial harvest occurs at age 8 followed by coppice regeneration and a final harvest at age 16. Management costs include fertilization applied at year 2 and at year 10, herbicide treatments at years 1 and 9, and annual management costs (generally consistent with management regimes described in Dougherty and Wright 2012). All cost estimates are shown in Table 1. Revenues depend on biophysical production and prices. FT-*Eucalyptus* productivity is uncertain, so we consider three different levels of productivity based on the published literature (see Table 2). We define a baseline level of expected productivity (mean annual increment) as 12 green tons/acre/yr and examine returns at 8 and 16 green tons/acre/year as lower and upper cases.

Table 2. Estimates of *Eucalyptus* productivity from various published studies.

Author	**Region**	**Productivity (Green tons $ac^{-1}yr^{-1}$)**	**Methods**
Dougherty And Wright (2012)	Southern United States	High: 15[1] Medium: 11 Low: 8	Assumption
Gonzalez et al. (2011)	Southern United States	Range for pulpwood management: 8-16 Range for energy crops: 10-18	Assumption
Kline and Coleman (2010)	Southeastern United States	Range: 8-11 Most likely: 9.8	Survey of forest industry experts
Stape et al. (2010)	Brazil	Average (current silviculture): 11[1] Irrigated: 14 Maximum: 19	Measured plots across 1000+km gradient
Langholtz et al.	Central Florida	Range: 15-28[1]	Model fit to field trial data

1- Converted from Mg ha^{-1} yr^{-1} assuming 1.1023 tons/Mg and 2.47 acres/ha.

Figure 6. Implied bareland values for Eucalyptus management with a pulpwood management regime for (A) low, (B) baseline, and (C) high productivity scenarios, by Timber Mart-South zones within States, 1977-2012 (for example AL-2 refers to TMS zone 2 in the State of Alabama; see figure 3A for a map of zones).

Throughout this study we adopt a discount rate of 8 percent.

To simulate what the returns to the *Eucalyptus* management regime would have been over the historical period, we apply historical hardwood pulpwood prices to *Eucalyptus* output and calculate the net present value of perpetual management of *Eucalyptus* using the cost and revenue components described above.[6] This is the bareland value (BLV) for *Eucalyptus* management. Figure 6 shows the inferred *Eucalyptus* BLV for each subregion between 1977 and 2011. Reflecting a sustained growth in hardwood pulpwood prices over this period, *Eucalyptus* BLV increased from exclusively negative values between 1977 and the early 1990s to strongly positive values in the latter part of the series (2005-2011). Values are highly variable across the region ($173-$698/acre in 2011) with the highest values in 2011 found in the western part of the region (Texas, Mississippi, and Louisiana) and lowest values found in Florida. The ranking of values by State have not been constant over time.

We also constructed an annualized return series based on the discounted cash flow described above, excluding the conversion costs (initial site prep and planting), which are incorporated directly in the switching decision. The annualized return series is used to construct the stochastic returns. Consistent with the BLV estimates, annualized returns to *Eucalyptus* have trended upward since the late 1980s. In 2011, they ranged from between $16/acre and $66/acre across the subregions with an average return of about $48 for the entire region (Figure 7).

[6] An OLS regression between net annual revenues and hardwood pulpwood prices was developed using revenue estimates generated for a sequence of hardwood pulpwood prices between minimum and maximum historical values. These are forward looking NPV estimates and define return expectations for landowners.

Figure 7. Returns estimates for Eucalyptus management, pulpwood management regime for baseline productivity (a) by by Timber Mart-South zones within States, 1977-2012 (for example AL-2 refers to TMS zone 2 in the State of Alabama; see figure 3A for a map of zones and (b) for regional averages (1977-2012).

Returns to pine management

Jones et al. 2010 conducted a financial analysis of intensive loblolly pine plantation management and our pine plantation management regime is based on their work. To obtain yield by product class, we reproduced a portion of their study using the simulation model LobDSS. Table 3A lists all of the

management activities and costs. Regional averages of annual management costs and herbaceous weed control are from Barlow 2011. Table 3B lists the assumed yields by product class by harvest event.

Table 3. Planted pine management regime.

A) Costs and timings:

	Year	Value	Unit	Value	Unit
Mechanical site prep	0	370.65	$/ha	150.00	$/ac
Chemical site prep	0	286.31	$/ha	115.87	$/ac
Planting and seedlings	0	156.66	$/ha	63.40	$/ac
Weed control, banded	0	89.57	$/ha	36.25	$/ac
Weed control, broadcast	1	84.51	$/ha	34.20	$/ac
Fertilizer	1	74.13	$/ha	30.00	$/ac
Management costs	1 - 24	25	$/ha	9.98	$/ac
Discount rate	-	0.08	-	-	-

B) Harvest events and yields:

Event	Year	Pulpwood	CNS	Sawtimber	Unit
First thinning	11	35.5	-	-	Tons/acre
Second thinning	18	7.4	17	-	Tons/acre
Final harvest	24	18	9.4	61.3	Tons/acre

To examine the returns to planted pine over the historical period, we apply this management and cost regime and calculate implied bareland values in each year for the observed pine pulpwood and sawtimber prices. Bareland values (Figure 8) have been positive throughout the region except for five sub-regions in the western part of the region during a short period (1985-1988) and for Texas sub-regions in 1990 and 2009. Bareland values reached peak values in the late 1990s, but then fell substantially between 1998 and 2001 and have trended slightly downward since. The variability of bareland values across sub-regions fell along with the level of values during the latter period. The annualized return series (Figure 9) follows the same pattern. The average bareland values and returns to planted pine were at historically low values between 2009 and 2012.

Figure 8. Implied bareland values for planted pine management, pulpwood management regime by Timber Mart-South zones within States, 1977-2012 (for example AL-2 refers to TMS zone 2 in the State of Alabama; see figure 3A for a map of zones).

Returns to cropland management

Returns to individual crops have been quite variable across the regions since the 1970s (see Figure 10 for an example from Alabama). The returns to peanuts for example trended downward between 1977 and 2005, but increased between 2005 and 2011. Returns to all crops have trended upward since 2005 and this is reflected in the returns to the composite crop index for each sub-region (Figure 11). For most regions, the real return to cropland nearly tripled between 2005 and 2011, reflecting increased returns to corn as well as shifts in crop acreages toward corn and other higher valued crops.

Figure 9. Returns estimates for planted pine management regime (a) by Timber Mart-South zones within States, 1977-2012 (for example AL-2 refers to TMS zone 2 in the State of Alabama; see figure 3A for a map of zones) and (b) for regional averages (1977-2012).

Figure 10. Returns estimates for individual crops (corn, peanuts, cotton, sorghum, wheat) in Alabama.

Figure 11. Returns estimates for composite of crops (a) by Timber Mart-South zones within States, 1977-2012 (for example AL-2 refers to TMS zone 2 in the State of Alabama; see figure 3A for a map of zones) and (b) for regional averages (1977-2011).

Return Comparisons

Figure 12 compares annual returns between *Eucalyptus*, planted pine, and crops for the years 1977-2011. Crop returns dominate the other two uses across the time series with the exception of 2003, where returns to crops were slightly less that the annualized returns to planted pine. Returns to pine peaked in the late 1990s and have declined to about $40/acre, while implied returns to *Eucalyptus* have increased over the period, becoming positive in the early 1990s and are now comparable to pine returns (slightly exceeding average returns to pine in the last year of the time series). Returns to pine are linked to the progression of real prices for pine pulpwood, sawtimber, and "chip-n-saw." Pulpwood prices

moved upward from the 1970s through the late 1990s and then dropped substantially, consistent with a strong expansion in pine pulpwood supplies (see Wear and others 2007). Sawtimber prices are generally cyclical and strongly affected by demands from the housing sector—recent declines in returns are strongly influenced by the post-2007 recession. Returns to Eucalyptus are driven by the dynamics of hardwood pulpwood prices and strong price increases are consistent with an overall tightening of hardwood pulpwood supplies (see Wear and others 2007). Because crop returns in 2010 and 2011 were about 5 times higher than both the *Eucalyptus* and pine returns, we assume that land use switching from crops to Eucalyptus would be highly unlikely. We focus exclusively on switching between planted pine and Eucalyptus.

Figure 12. Southeast-wide regional average returns for Eucalyptus, planted pine, and crop composite (1977-2011).

Figure 13. Difference between bareland values for Eucalyptus (base productivity) and planted pine management by Timber Mart-South zones within States, 1977-2012 (for example AL-2 refers to TMS zone 2 in the State of Alabama; see figure 3A for a map of zones).

To examine the possibility of land use switching between *Eucalyptus* and planted pine we first examine the difference between their respective bareland values (Figure 13). The differences have changed from a range of -$1300 to -$800 acre in the 1970s to a range of -$400 to +$200 /acre in 2012 (based on moderate Eucalyptus productivity) again reinforcing the observation that returns to the two technologies have become comparable in the recent past and supporting a careful analysis of potential switching. Note as well that the most positive differences are found for the western part of the study area (Texas, Louisiana, and Mississippi).

Stochastic Return Models

The geometric Brownian motion (GBM) model of returns as described by equation 4,

$$d\pi_i(t) = \alpha_i \pi_i dt + \sigma_i \pi_i dz_i$$

requires estimates of the drift parameter (α) and the variance parameter (σ) for each return series. After discretizing the series and rearranging terms, the parameters can be derived as functions of the first difference of the ln(π) series: $\alpha = m + 0.5s^2$ and σ=s where m and s are the mean and standard deviation of the series $\ln(\pi_t) - \ln(\pi_{t-1})$ and ρ defines the simple correlation coefficient between the differenced return series for *Eucalyptus* and the alternative land use. Because the GBM estimates derive from the logarithm of the returns, the parameters are undefined when revenues are negative. In addition, in the context of the switching problem described in equation 7, explosive returns result when the drift parameter exceeds the discount rate (0.08 in this case).

As shown in Figure 7, returns to *Eucalyptus* are negative until the last 10-15 years of the time series (depending on the sub-region) leaving only a short time period over which to calculate the parameters of the GBM. During this period, *Eucalyptus* returns rose steadily to the point where they have converged with pine returns and this is reflected in high drift parameters (ranging from 0.07 to 0.592; Table 4), with a variance parameter ranging from 0.27 to 0.90. In nearly all cases, the growth in *Eucalyptus* returns would exceed the discount rate. In contrast, returns to planted pine exhibited relatively small drift rates ranging from negative (-0.02) to slightly positive (0.008) and fairly consistent variance parameters (from 0.09 to 0.16). The high drift parameters for *Eucalyptus* may indicate (1) a transition period where the scarcity of hardwood products increased substantially and then stabilizes or (2) that the short time series of positive *Eucalyptus* returns does not provide enough information to precisely discern drift from variance from the data.

A mean reverting model described by equation 6 provides a plausible alternative to the GBM for describing stochastic returns:

$$d\pi_i(t) = \eta_i(\bar{\pi}_i - \pi_i)\pi_i dt + \sigma_i \pi_i dz_i$$

where n is the speed of reversion back to the mean (and is expected to be positive), $\bar{\pi}$ is the mean return, and the variance parameter (σ) is directly comparable to the value from the GBM model. Following Dixit and Pindyck (1994), the mean reverting models were estimated in pairwise fashion using seemingly unrelated regression (SUR) model of differenced returns:

$$\pi_{i,t} - \pi_{i,t-1} = a_i + b_i \pi_{i,\ t-1} + \sigma_i \epsilon_i, \quad i = pine,\ eucalyptus \qquad (7)$$

Estimates for reversion speed are defined as $\eta_i = -b_i$, the long run revenue mean of revenue is defined as $\pi_i = -a_i / b_i$, and σ_i is defined as the standard error of the regression. The model anticipates a positive reversion speed (otherwise the revenue series would be explosive). The correlation coefficients between return series is defined using the cross equation covariance from the SUR estimation. Inspection of product price and return values for forest products indicates a structural break at the end of the 1990s—prior to this time, softwood pulpwood prices grew steadily and afterward dropped substantially. After examining MR models for a variety of time frames, only the post-1999 series provided significant positive reversion speeds across all commodities (Table 5). Model estimates indicate that reversion speeds are higher for *Eucalyptus* than for other commodities—i.e., there is a stronger tendency to return to the mean for Eucalyptus—and the correlation between pine and *Eucalyptus* returns is estimated at 0.17.

Table 5. Estimates of mean-reverting stochastic return processes for *Eucalyptus* versus crop and *Eucalyptus* versus planted pine returns using data for 2000-2011.

	Eucalyptus versus crop composite				**Eucalyptus versus planted pine**			
	Eucalyptus		Crops		Eucalyptus		Pine	
Long-run production profit	π_e	32.66	π_c	146.14	π_e	34.15	π_p	39.84
Reverting speed	η_e	0.0467*	η_c	0.021*	η_e	0.036*	η_p	0.0059*
Variance parameter	σ_e	0.40	σ_c	1.48	σ_e	0.404	σ_p	0.064
Correlation parameter	ρ	0.81			ρ	0.17		

* - significant at 5% level.

Table 4. Estimates of parameters of the geometric Brownian Motion (GBM) model of pine and *Eucalyptus* returns by Timber Mart-South zone. Estimates of pine returns are based on the full times series (1977-2012), while estimates for *Eucalyptus* returns are based on the series over the period where returns are positive (1993-2012).

	Pine		Eucalyptus		
Timber Mart-South zone	Drift term	Variance term	Drift term	Variance term	Correlation coefficient
AL2	-0.005	0.102	0.150	0.370	0.610
FL1	-0.020	0.090	0.007	0.432	-0.300
FL2	-0.011	0.095	0.332	0.784	0.480
GA2	-0.009	0.103	0.056	0.309	0.340
LA1	0.008	0.139	0.080	0.267	0.210
LA2	0.005	0.164	0.401	0.454	0.070
MS2	0.007	0.143	0.592	0.895	0.420
SC2	-0.012	0.088	0.024	0.281	0.140
TX1	0.006	0.104	0.074	0.326	0.84
TX2	0.003	0.098	na	na	na
Minimum	-0.020	0.088	0.007	0.267	-0.300
Maximum	0.008	0.164	0.592	0.895	0.840
Mean	-0.004	0.114	0.191	0.458	0.312
Median	-0.005	0.103	0.080	0.370	0.340
Southeast (SE)	-0.007	0.100	0.139	0.494	0.260
TX-LA-MS (TLM)	0.006	0.134	0.191	0.458	0.410
AL-FL-GA-SC (AFGS)	-0.013	0.088	0.049	0.334	0.380

Real options land use switching

To construct the real options model for land use switching using the GBM model, we start with the parameter estimates in Table 4 and modify them to reflect a set of scenarios. We adopt the average estimate of return variance parameter from the estimated models (0.11 for pine and 0.46 for *Eucalyptus*) showing substantially higher return variance for *Eucalyptus*. The drift parameter is set at zero for pine returns assuming that markets have adjusted to the point where plantation returns will no longer drift downward—recall that the estimated mean value for the drift parameter was slightly negative. We assume that *Eucalyptus* returns continue to drift upward but at a more moderate rate of

0.02. The correlation coefficient is set at the mean value for the TMS zones (0.31) reflecting a positive but relatively low correlation between the returns to these two forestry options.

Figure 14. Switching boundaries for Eucalyptus and pine for A) the base model and B) with the variation in Eucalyptus returns reduced by 50%.

The base model, with drift parameters of 0.00 and 0.02 for pine and *Eucalyptus* respectively, yield the switching boundaries displayed in Figure 14A. Landowners are motivated to switch from pine to *Eucalyptus* only where the latter's returns are substantially higher than those for pine (the upper switching boundary in Figure 14A). For example, with pine returns at $50.00/acre, *Eucalyptus* returns would need to exceed about $200.00/acre to result in switching. Hysteresis is clearly indicated with these switching boundaries. For example, if land use switched to *Eucalyptus* at the *Eucalyptus*:Pine return pair of $210:$50, a subsequent reversal of land use would only result if *Eucalyptus* returns fell to nearly zero (Figure 14A). When the return variance term for Eucalyptus is decreased to 0.11 (the value of the pine return variance term), the switching boundaries are much closer as shown in Figure 14B, indicating that higher return certainty would lead to more frequent switching to Eucalyptus.

Figure 15. Projected proportion of planted pine land that switches to Eucalyptus from year 1 through year 30 for several scenarios of the GBM model.

Switching simulations based on 100,000 Monte Carlo simulations of the stochastic return series are played out against the switching boundaries in Figure 14A and land use switches are recorded for each realization. A summary of switching for all 100,000 realizations yields the proportion of land managed for *Eucalyptus* at each time step. We constructed simulations across several alternative GBM models: A) the base case described above, B) higher initial returns for *Eucalyptus consistent with the* high Eucalyptus productivity case shown in Figure 6, C) increased correlation between *Eucalyptus* and planted pine returns, D) reduced variance term for *Eucalyptus* returns (equal to the variance term for planted pine), and E) a 50 percent reduction in the drift term for *Eucalyptus* returns (0.01). Cases A and B can be simulated based on the switching boundaries from the base model while cases C, D, and E require estimating alternative models (i.e., parameters of the switching model are altered by these scenarios). *Eucalyptus* proportion of the planted pine area is shown in Figure 15, while total area

Figure 16. Projected area of Eucalyptus plantations by GBM scenario: a) base, b) higher initial returns for Eucalyptus, c) increased correlation between Eucalyptus and planted pine returns, d) reduced variance term for Eucalyptus returns (equal to variance term for planted pine), and e) 50 percent reduced drift term for Eucalyptus returns.

converted is shown in Figure 16 for these five scenarios.

Switching results, summarized in Figure 15, show that for the base case (Scenario A), the area of *Eucalyptus* grows steadily to about 5 percent of planted pine area in year 10 (2022) and remains between 4 and 5 percent through year 30 (2042). The percentage of *Eucalyptus* remains low in spite of the upward drift in returns. The low percentage reflects the high upper switching boundary in Figure 14A which reflects the high return variance associated with *Eucalyptus*. With a higher starting price for *Eucalyptus* (Scenario B), switching occurs earlier in the time series, peaks at about 10 percent at year 8 and then drifts back toward levels simulated under the base case. Higher early adoption reflects the higher likelihood of observing price pairs above the upper switching boundary but the higher return variance for *Eucalyptus* dominates over time. A higher correlation between the two return series (Scenario C) causes simulated price pairs to be closer to the 45 degree line in Figure 14A, thereby reducing the probability of price pairs being outside the switching boundaries. By year 30, only about 2 percent of pine land is planted in *Eucalyptus* under this scenario. Lowering the variance term for the *Eucalyptus* returns (Scenario D) results in a strong upward trend in the area of *Eucalyptus*, exceeding 15 percent by year 30. Recalling that *Eucalyptus* is modeled with a positive drift term (0.02) while the pine trend term is set to zero, lowering the variance term for *Eucalyptus* returns allows the trend—i.e., an increasing spread between *Eucalyptus* and pine returns—to be more dominant in the projected return series, resulting in an increasing rate of land use switching. Reducing the drift term by 50 percent lowers adoption of *Eucalyptus* by about 20 percent.

Figure 17. Projected proportion of planted pine land that switches to Eucalyptus from year 1 through year 30 using the GBM model for the Base scenario, a case with 25 percent higher conversion costs, and a case with 25 percent lower conversion costs.

To explore the sensitivity of the projections to conversion costs we rerun the base model for cases where Eucalyptus conversion costs are 25 percent higher or lower. The results indicate an inelastic response to conversion costs (see Figure 17) but do demonstrate that the costs of FT-Eucalyptus seedlings would influence the area of plantations. To examine differences across space we apply the regional models to prices observed in each of the ten Timber Mart-South zones. The resulting switching proportions (Figure 18) range from less than 2 percent in Florida zones and to a high of 7-10 percent for Alabama, Mississippi, Louisiana, and Texas zones.

Figure 18. Projected proportion of planted pine land that switches to Eucalyptus from year 1 through year 30 by Timber Mart-South zones within States, 1977-2012 (for example AL-2 refers to TMS zone 2 in the State of Alabama; see figure 3A for a map of zones), using the GBM base model with TMS specific starting returns.

We also simulated switching with the mean reverting (MR) model, first using the base case defined by parameters in Table 5 and then for a set of model variants. Switching behavior is much less variable with the MR model (Figure 19). Using average return values (pine= $40 and Eucalyptus=$34) and parameters from Table 5, about 9 percent of planted pine area converts to Eucalyptus and this proportion is maintained throughout the simulation period. When the Eucalyptus average return is increased to $40 (the same as for pine), about 30 percent of the planted pine forest area switches to Eucalyptus. Model variants with higher return correlations do not lead to substantial departures from the Base MR model in terms of total area converted.

A mapping of potential adoption which is based on the conversion proportions from the GBM

Figure 19. Projected proportion of planted pine land that switches to Eucalyptus from year 1 through year 30 for several scenarios of the mean reverting model.

switching model and the current distribution of prices and land uses (see Figure 18) indicates that conditions are most favorable for Eucalyptus in the western part of the study area Figure 20. The projected area of Eucalyptus exceeds 20 thousand acres for several counties stretching from coastal Alabama through Louisiana. Another area of high adoption is projected for the upper coastal plain in Georgia.

Figure 20. Forecasted area of Eucalyptus in the southeastern United States at year 10 using the Base GBM model and separate starting returns of each Timber Mart-South region.

Discussion and Conclusions

Our analysis of returns to *Eucalyptus* and other rural land uses indicates a potential for the commercial adoption of freeze-tolerant *Eucalyptus* in the southeastern United States. A comparison of bareland values indicates that FT-*Eucalyptus* could provide comparable returns to planted pine forests especially in the western part of the southeast (Texas, Louisiana, and Mississippi). This competitive position derives from strong growth in real hardwood pulpwood prices over the past two decades. In contrast, high returns to cropland would generally preclude transition to *Eucalyptus*—current crop returns currently exceed *Eucalyptus* returns by an order of 3-5 times.

While hardwood prices and returns to *Eucalyptus* plantations have grown, real softwood pulpwood prices and returns to pine plantations declined from peak levels in the late 1990s and have leveled off

where returns to the two uses are comparable. A choice to convert from pine to *Eucalyptus* would depend on these return comparisons but also on the conversion costs and the return risk associated with the two land uses. The implied return variance for Eucalyptus has been higher than for pine and our real options analysis indicates that land use switching estimates are sensitive to the model used to describe these stochastic returns series.

Simulations based on the geometric Brownian motion (GBM) model, which allows for a continued upward drift in Eucalyptus returns, results in a conversion of about 5 percent of planted pine forest area (about 0.8 million acres) to Eucalyptus in year 30. Reflecting differences in its formulation, the mean reverting (MR) model generates different projections--for the base case, about 9 percent of planted pine area would switch to Eucalyptus (roughly 1.4 million acres). The MR model defines a higher degree of certainty regarding the range of future returns and this is reflected in the higher rates of land use switching over time. Variants of both models indicate that adoption of Eucalyptus is sensitive to return variance—lowering return variance parameters for Eucalyptus strongly increases adoption, especially with the GBM formulation—but is less sensitive to estimates of return correlations between pine and Eucalyptus.

How should these results be interpreted in terms of plausible future conditions? First, our analysis indicates that Eucalyptus is potentially competitive with planted pine management over a range of future conditions. Results further indicate that while Eucalyptus may be competitive in terms of expected returns, return variance and conversion costs will limit the degree to which land is actually converted. Our two empirical models which simulate future returns under base case conditions, project between 0.8 million acres (the GBM model) and 1.4 million acres (the MR model) of Eucalyptus in year 30. The GBM base model describes a case where returns to Eucalyptus drift upward while returns to planted pine follow a random walk, consistent with a future where the demand for hardwood material continued to grow relative to supply (i.e., hardwood scarcity increased). This could be consistent with a scenario where mild expansion in demands for bioenergy feedstocks steadily increased the demand for hardwoods. However, under such a scenario, we might also expect the return variance for hardwoods to decrease as demand strengthened. If this were the case, then a more substantial switching to Eucalyptus could result. This is clearly demonstrated in the variant of the GBM model where the return variance for Eucalyptus is reduced by 50 percent w doubling of the projected area of Eucalyptus. These and other variants of the models that adjust starting prices and variance indicate that conceivable shifts in key market parameters could lead to strong shifts in land use outcomes.

Our analysis assumes that forest areas likely to switch would be limited to the current area of planted pine because this is the portion of the region's forests that has demonstrated economic feasibility for tree plantations. This is likely to be a conservative estimate of available area. If we assumed instead that the eligible area also included the area of naturally regenerated pine—Wear and others (2013) find high probabilities of planting following harvests of this forest type—then the total eligible area would shift from about 16 million acres to about 27 million acres. Applying the proportion of switching from our two base models would shift the projected area of adoption from a range of 0.8-1.4 million acres to between 1.35 and 2.75 million acres.

The analysis is based on several assumptions about market futures and risk. One especially important assumption is that the freeze tolerance conferred by the FT-*Eucalyptus* will be successful in preventing substantial freeze damage to planted trees within the study area (plant hardiness zone 8b and higher). Mortality and productivity are however important stochastic elements of overall return estimates which would influence return risk. In general, higher return variance would reduce adoption of Eucalyptus as demonstrated by our sensitivity analyses. In addition, this study assumes that productivity is essentially uniform across the southeastern United States. This seems appropriate given the lack of data regarding these factors, but incorporating location specific productivity and damage functions could provide additional insights into the likely location of future Eucalyptus plantations. Another unknown is the actual cost of the FT-*Eucalyptus* seedlings. According to our analysis, the conversion costs between land uses could have an appreciable impact on the area that would ultimately switch. An additional source of risk and one that extends beyond the scope of this study, is the risk of some public backlash against the planting of genetically modified trees. This societal risk could affect investment choices in the same fashion as biophysical risk—i.e., increased risk would reduce the rate of adoption.

While our projections are not meant to be precise predictions of the area of Eucalyptus adoption, they do demonstrate that under current conditions, a risk-neutral and profit maximizing land owner could choose to adopt Eucalyptus as a preferred land use. The extent of that adoption will depend on the future of market prices for various timber products, including new bioenergy products, and on the demonstrated productivity and certainty of production from available Eucalyptus seedlings. It is important to note that this work is based on the assumption that the behavior of returns for each of the land uses will remain unchanged into the future and that we did not explicitly address the effects of shifting timber supply on future market equilibrium.

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Appendix. Key Assumptions and Uncertainties

This study represents a normative simulation analysis of potential land owner behavior and depends on a set of critical assumptions. Most fundamental is the set of behavioral assumptions behind the analysis. That is we assume that private landowners behave as maximizing entities. To quote from the theory section: "Our switching model anticipates that a risk-neutral decision maker chooses between retaining a current land use or (reversibly) adopting a new land use (Eucalyptus) based on a comparison of returns, conversion costs, and uncertainty regarding future returns." Intertemporal value comparisons depend on time preferences which we approximate with a discount rate set at 8 percent.

The analysis of land use data requires processing a large amount of data, often with incongruent boundaries. Nearly all land use and production data were organized by counties. We considered counties to be a part of plant hardiness zone 8B and higher if a majority of their land area was within the zonal boundary. What's more our restriction of the study area based on the environmental range of *Eucalyptus grandis* represents an important assumption and source of uncertainty. The relationship between environmental variables and productivity and commercial viability for the modified hybrid is not fully knowable prior to field experience.

Our analysis also assumes that the forest land base that would be plausible for transition to Eucalyptus is limited to planted pine. This is based on the assumption that these lands have already been selected or deemed suitable for intensive forest management. The managed condition of these forests also defines lower conversion costs compared to those associated with naturally regenerated forests. Analysis by Wear et al (2013) also indicates that rates of tree planting following harvest are very high for natural pine in this region but are low for upland and lowland hardwoods. Accordingly we explore the possibility that naturally regenerated pine could be a source in the future (see Conclusions) but do not consider hardwoods as a potential source based on current and anticipated economics. This set of assumptions deserves further study.

The analysis is also based on several assumptions about market futures and risk. One especially important assumption is that the freeze tolerance conferred by the FT-Eucalyptus will be successful in

preventing substantial freeze damage to planted trees within the study area (plant hardiness zone 8b and higher). Mortality and productivity are however important stochastic elements of overall return estimates which would influence return risk. In general, higher return variance would reduce adoption of Eucalyptus as demonstrated by our sensitivity analyses. In addition, this study assumes that productivity is essentially uniform across the southeastern United States. This is a necessary assumption given the lack of data regarding these factors in the southeastern U.S., but incorporating location specific productivity and damage functions could provide additional insights into the likely location of future Eucalyptus plantations. Another unknown is the actual cost of the FT-Eucalyptus seedlings. According to our analysis, the conversion costs between land uses could have an appreciable impact on the area that would ultimately switch. An additional source of risk that extends beyond the scope of this study is the risk of some public backlash against the planting of genetically modified trees. This societal risk could affect investment choices in the same fashion as biophysical risk—i.e., increased risk would reduce the rate of adoption.

APPENDIX C. USDA-FS TECHNIAL REPORT ON THE POTENTIAL IMPACTS TO HYDROLOGY FROM FREEZE-TOLERANT EUCALYPTUS

Implications for Expansion of Freeze-Tolerant Eucalyptus Plantations on Water Resources in the Southern U.S.

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Executive Summary

1. The potential expansion of freeze-tolerant (FT) *Eucalyptus* plantations in the U.S. has raised questions about the implications for a variety of environmental and biological factors including fire risk, biodiversity, and water resources. Concerns about the effects of *Eucalyptus* plantations on water resources are based on numerous studies of evapotranspiration (ET = transpiration + interception evaporation) and stand level water balance (*Q* = precipitation – ET, where a positive *Q* results in streamflow and/or groundwater recharge) from across the world.

2. We used a modeling approach with the best available data to assess the potential implications of expanding the distribution of FT *Eucalyptus* plantations in USDA plant hardiness zones 8b and greater on water balance (*Q*) and the resulting impacts on groundwater recharge. We focused our analyses at two spatial scales: the local scale (or stand level) and the 12-digit Hydrologic Unit Code (HUC) watershed scale. At the local scale, we used a leaf-level model to predict plant water loss and climate data from five southern states to estimate ET across a full rotation of the crop. At the 12-dgit HUC scale, we used a parsimonious water balance model (WaSSi). Quantifying ET and *Q* required a modeling approach because to our knowledge, no data quantifying ET or streamflow changes from planting FT *Eucalyptus* in the U.S. are available.

3. Predictions of annual *Eucalyptus* ET rates ranged from about 900 mm of water in Florida to over 1200 mm in Mississippi and Alabama. When comparing our predictions for FT *Eucalyptus* to published values for other land covers and species, our estimated ET values were 1.5 to 2-fold greater than estimates for old fields (460–650 mm), mature deciduous hardwoods forests (480–640 mm), loblolly pine plantations in the piedmont (560–740) and crops, such as cotton (386–397 for no irrigation, 739–775 for irrigated); but comparable to some slash and loblolly pine plantations in the Coastal Plain where soil water is relatively plentiful (676–1226 mm). When soil moisture controls on stomatal conductance were removed by assuming an unlimited supply of soil water, ET values were on average about 20% higher overall, with the highest ET exceeding 1400 mm yr^{-1} in year 7 (the last year of rotation) at the Alabama location. These wet soil conditions would likely be comparable to areas where high ET (*e.g.*, > 1000 mm yr^{-1}) has been observed for loblolly and slash pine plantations. In these cases, the energy available to drive transpiration is the primary limiting factor.

4. Simulations indicated that the stand-level implications of planting FT *Eucalyptus* on *Q* could vary by location, the land cover type prior to *Eucalyptus* establishment, and the hydrological conditions of the planting site and surrounding area. Contributions to streamflow/recharge

could be reduced by as much as to 180 mm yr^{-1} (relative to conifer forests) near the end of the rotation on sites when leaf area is high (leaf area index, LAI = 4). At LAI = 5, streamflow/recharge could be reduced by as much as 300 mm yr^{-1}.

5. The implications for these reductions in streamflow or groundwater recharge depend on the hydrologic setting and the amount of land area planted in FT *Eucalyptus*. Conditions that could result in a substantial negative impact at the local scale would include: (1) planting in areas where precipitation (*P*) is limited or where droughts are likely, (2) planting in areas where the ratio of *P*/potential ET is low, and (3) planting in headwater areas or planting large acreages in close proximity to streams that have low annual baseflow.

6. At the scale of conversion indicated by an economic analysis (*e.g.*, <20% conversion of conifer cover to FT *Eucalyptus*), our analysis suggests that the impacts on either *Q*, percent change in *Q*, or groundwater recharge at the scale of the 12-digit HUC will be negligible.

7. Our model-based analysis of the potential impacts of the expansion of FT *Eucalyptus* represents our best approximation based on currently available data. Biophysical models at all scales are limited by imperfect knowledge and simplifications of processes, parameters, and driving variables; and by limits to the accuracy and precision of climate driving variables such as precipitation and air temperature. Our models were not appropriate for simulating the potential impacts of extreme drought due to a lack of model sophistication and data on physiological and structural responses from FT *Eucalyptus*. These assumptions and uncertainties reinforce the need to obtain empirical measurements to validate (or reject) model projections.

Implications for Expansion of GE Freeze-Tolerant Eucalyptus Plantations on Water Resources in the Continental U.S.

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Abstract

The potential expansion of freeze-tolerant (FT) *Eucalyptus* plantations in the U.S. has raised questions about the implications for a variety of environmental and biological factors including fire risk, biodiversity, and water resources. Concerns about the effects of *Eucalyptus* plantations on water resources are based on numerous studies of evapotranspiration (ET = transpiration + interception evaporation) and stand level water balance (*Q* = precipitation – ET, where a positive *Q* results in streamflow and/or groundwater recharge) from across the world. We used a modeling approach to assess the potential implications of expanding the distribution of FT *Eucalyptus* plantations in plant hardiness zones 8b and greater on water balance (*Q*) and the resulting impacts on groundwater recharge. We focused our analyses at two scales: the local scale (or stand level) and the 12-digit Hydrologic Unit Code (HUC) watershed scale. Quantifying ET and *Q* required a modeling approach because to our knowledge, no data quantifying ET or streamflow changes from planting FT Eucalyptus are available. Our simulations indicated that the stand-level implications of planting FT *Eucalyptus* on *Q* could vary by location, the land cover type prior to *Eucalyptus* establishment, and the hydrological conditions of the planting site and surrounding area. Stand water budgets indicated that contributions to streamflow/recharge could be equal to or reduced by as much as to 180 mm yr^{-1} (relative to conifer forests) near the end of the rotation or on sites when leaf area index (LAI)LAI = 4 and reduced by as much as 300 mm yr^{-1} when LAI = 5. The implications for these reductions in streamflow or groundwater recharge depend on the hydrologic setting and the amount of land area planted in FT *Eucalyptus*. Conditions that could result in a substantial negative impact at the local scale would include: (1) planting in areas where precipitation (*P*) is limited or where dry years are likely, (2) planting in areas where the ratio of *P*/potential ET is low, and (3) planting in headwater areas or planting large acreages in close proximity to streams that have low annual baseflow. In contrast, at the scale of conversion indicated by an economic analysis (e.g., <20% conversion of conifer cover to FT *Eucalyptus*), our analysis suggests that the impacts on either *Q*, percent change in *Q*, or groundwater recharge at the scale of the 12-digit HUC will be negligible.

Introduction

Expansion of *Eucalyptus* plantations offers great potential for increasing wood-fiber production in the United States. The range of suitable environmental conditions, especially air temperature below freezing, has limited the extent of *Eucalyptus* primarily to central and southern Florida. The development of more freeze-tolerant (FT) *Eucalyptus* through genetic engineering (GE) has the potential to expand the range of GE FT *Eucalyptus* to climate zones 8b and greater (Hinchee *et al.* 2011) (Figure 1). The expansion of FT *Eucalyptus* plantations in the U.S. has raised questions about implications for a variety of environmental and biological factors including fire risk, biodiversity, and water resources (especially, water supply) (Stanturf *et al.* 2013). This analysis focuses on the potential impacts of FT *Eucalyptus* expansion on water resources.

Figure 1. USDA Plant hardiness map. Dark solid line denotes approximate northern limit (zone 8b and greater) for GE FT *Eucalyptus* in the continental United States. Hawaii and Puerto Rico were not included in our analyses as climatic conditions would likely not require planting FT *Eucalyptus* for survival.

Concerns about the effects of *Eucalyptus* plantations on water resources are based on numerous studies of evapotranspiration (ET = transpiration + interception evaporation) and stand water balance from across the world (*e.g.*, Farley *et al.* 2005, Ferraz *et al.* 2013, King *et al.* 2013); however, to our knowledge, no published studies have been conducted in the southern U.S. Based on these international studies, it is well accepted that *Eucalyptus* has among the highest ET rates of tree species (Whitehead and Beadle 2004, Farley *et al.* 2005), driven by high stomatal conductance, evergreen leaf habit, physiological characteristics that increase drought tolerance, and rooting characteristics that can exploit deep soil water reserves (Cavaleri and Sack 2008). *Eucalyptus* is also extremely fast growing and has a high water use efficiency (WUE = kg biomass produced/kg water transpired) (Stape *et al.* 2004) even in the fastest growing stands (Binkley 2012). High WUE could offset some of the potential negative impacts of high ET on water resources (King *et al.* 2013); however, this offset would only be realized if less land area was planted relative to species with a lower WUE. Regardless of higher WUE, substantial reductions or elimination of streamflow from greater absolute water use could have detrimental impacts on water resources and associated aquatic ecosystems, especially at local scales.

Assessing the potential impacts of FT *Eucalyptus* on water resources requires an analysis of all of the water budget components at multiple spatial levels. Evaluating water budgets requires quantification of the effects of changes in ET within the context of climate and other site characteristics that regulate soil water availability and storage. In its most basic form, the water budget of a forest watershed can be described as:

Surface Runoff + Groundwater Recharge = Precipitation – Evapotranspiration +/- Soil Water Storage.

At an annual time scale, water balance (Q) of *Eucalyptus* can be estimated as:

$$Q = P - \mathrm{ET} \qquad (1)$$

Here, Q is an estimate of excess water that goes into streamflow, groundwater recharge, or soil water storage. Q is also termed water yield in the hydrology literature and over long time periods (e.g., annual), the net soil water storage term is typically assumed to be zero. Depending on local topography, soils, and the geomorphic setting, a positive Q could contribute to streamflow or deep soil water storage and recharge, while a negative water balance implies a cessation of streamflow and groundwater recharge. Expansion of FT *Eucalyptus* plantations would not be expected to impact local P or net soil water storage at annual time scales; hence, our focus will be primarily on how changes in ET impact Q. As a result, analyses of the potential impacts of FT *Eucalyptus* culture will first require either direct measurements of changes in Q (*e.g.,* from gauged watersheds), scaled measurements of transpiration (*e.g.,* sapflow or canopy conductance) and predictions of impacts on Q, or modeled estimates of changes in ET and Q. For this analysis, we were constrained by a lack of available empirical data for *any* approach to estimating how changes in ET from planting FT *Eucalyptus* affect Q. Hence, our results should be considered a first approximation until empirical data are available for direct measurement or better model parameterization.

Three factors require consideration when evaluating the potential impacts of FT *Eucalyptus* on ET or water resources. First, because large-scale *Eucalyptus* plantations are not present over most of the U.S., the context for interpreting changes in ET and *Q* will vary based on what land cover serves as a reference. For example, among alternative forest covers, ET varies considerably, ranging from 480 mm yr^{-1} in hardwoods (Stoy *et al.* 2006) to ~1200 mm yr^{-1} in slash and loblolly pine plantations (Sun *et al.* 2010). Different interpretations of potential impacts are likely when comparing *Eucalyptus* ET to a "high ET" vs. a "low ET" land cover type reference. Second, the relative impact on *Q* depends in large part on the balance between precipitation and ET. Assuming that ET is comparable among areas of high and low precipitation, the *relative impacts* (*i.e.,* as a percentage of flow under reference conditions) of higher ET on *Q* are lower in areas where precipitation is higher (Table 1).

Table 1. Hypothetical example of the influence of annual precipitation levels on absolute *versus* relative impacts of *Eucalyptus* on *Q*.

	Initial Vegetation		*Eucalyptus*		Absolute	Relative
Rainfall (mm)	ET (mm)	*Q* (mm)	ET (mm)	*Q* (mm)	ΔQ (mm)	ΔQ (%)
1400	600	800	800	600	-200	-25%
1000	600	400	800	200	-200	-50%

Third, potential impacts are scale and location dependent. For example, small (*e.g.*, < 20 ha), infrequent, and well dispersed plantations over a large land area may limit impacts to the local scale, such as first order streams draining the *Eucalyptus* stand, while impacts at larger spatial scales would likely be minor and undetectable. Predicting the configuration of plantations to support end uses (*e.g.,* fiber or bioenergy) is beyond the scope of this analysis; however, factors such as minimizing transportation costs will likely influence the size and spatial distribution of plantations. For example, we would expect a greater concentration of plantations in areas where financial returns are likely to be highest (Wear *et al.* 2013 – APHIS report). Impacts on aquatic species and habitats at the local scale could still be significant, especially if plantations are established in or near areas where aquatic species and habitats are vulnerable to changes in *Q* (*e.g.*, Threatened and Endangered (T&E) species). In contrast, large plantations occupying large land area could have measurable, and perhaps undesirable, impacts at larger spatial scales. In short, the scale and location of *Eucalyptus* plantations is a critical consideration when evaluating potential impacts. Ultimately, business decisions on the size and location of *Eucalyptus* plantations will be driven by a combination of economic (are markets available to provide a return on investment?), technological (are site conditions suitable for using efficient establishment and harvesting technologies?), and environmental (can *Eucalyptus* survive and grow here?), considerations.

Questions Addressed in this Technical Document

1. **What are the potential impacts of FT *Eucalyptus* plantations on overall local stand water balance in areas where it is most likely to be grown?**

    a. How does this vary in space and time (*i.e.,* are some potential planting locations more sensitive than others and how does this change with stand age)?
    b. What are the environmental and biological factors that determine response patterns?
    c. How do reference conditions and climate regimes influence the interpretation of potential impacts?

2. **How does the size and distribution of FT *Eucalyptus* plantations influence impacts on water balance at varying spatial scales (e.g., local *vs*. 12-digit Hydrologic Unit Code (HUC)?**

II. Methods

Question 1 *- What are the potential impacts of FT Eucalyptus plantations on overall local stand water balance in areas where it is most likely to be grown?*

Plantation Scale Impacts on Water Balance

For estimating the plantation scale effects on the local water balance, we used a process-based transpiration model to estimate transpiration (*Ec*), then estimated canopy interception (Ic) to derive total evapotranspiration (ET) by a *Eucalyptus* stand at five locations (Figure 4) representing a range of potential land use changes, adoption rates, and climatic conditions (Table 2). Our expectation was that a detailed process model would provide the best estimate of actual ET. To our knowledge, no physiological data are available for FT *Eucalyptus* so we relied on physiological data and relationships from the published literature. Where possible, we used data for *Eucalyptus grandis* (*e.g.,* Mielke *et al.* 1999). The *Ec* model is based on the physiological processes of leaves in a tall canopy, and can be used to estimate hourly water use by the stand. Model components include:

$$E_c = \frac{1}{\lambda} \cdot \frac{sR_n + \rho c_p D g_a}{s + \gamma(1 + \frac{g_a}{g_c})} \cdot t, \quad (2)$$

$$1/g_a = \{ln[(z-d)/z_0]\}^2/(k^2u), \quad (3)$$

$$g_s = -0.024 + 0.00008PPFD - 0.156D + 0.129\Psi_{pd} + 0.016T_a, \quad (4)$$

$$\Psi_{pd} = 0.33\ (\theta/\theta_{max})^{-0.57} \quad (5)$$

where, E_c is canopy transpiration (mm hour^{-1}), s is the slope of the saturation vapor pressure curve (mbar °C^{-1}), at air temperature T_a (°C). R_n is average daylight canopy net radiation (W m^{-2}), ρ is air density (kg m^{-3}), γ is the psychometric constant (mbar °C^{-1}), c_p is the specific heat of the air (J kg^{-1} °C^{-1}), D is vapor pressure deficit of the air (mbar), g_a is canopy aerodynamic conductance (m s^{-1}), g_c is canopy conductance to water vapor (m s^{-1}), λ is the latent heat of vaporization of water (J kg^{-1}), and t is the

number of seconds in an hour (s $hour^{-1}$). Canopy conductance, g_c, is given by $g_c = g_s*LAI_{max}*fLAI$, where g_s is the stomatal conductance (converted into m s^{-1} units), LAI_{max} is the maximum annual Leaf Area Index (m^2 m^{-2}) for each year of the rotation, and fLAI is the fraction of maximum annual LAI (range 0–1). This latter term changes on a monthly basis and simulates the seasonal dynamics of leaf phenology (described below). The equation for g_s (mol m^{-2} s^{-1}) was taken from Mielke *et al.* (1999), where *PPFD* is photosynthetically active photon flux density (μmol m^{-2} s^{-1}) and Ψ_{PD} is predawn water potential (MPa) estimated from the ratio of soil moisture content (θ, % v/v) and maximum annual soil moisture content (θ_{max}, % v/v). The soil moisture limitation on Ψ_{PD} does not incorporate changes in soil moisture resulting from soil water uptake by *Eucalyptus* tree roots. Instead, θ reflects the net effects of climate, soils, and vegetation in the location of the open-field climate station (described below). Boundary layer conductance (g_a) was fixed at 0.083 m s^{-1}, based on a study by Hatton *et al.* (1992) on *Eucalyptus maculata* trees. The hourly estimates of E_c are then summed for all 24 hours in a day to estimate daily transpiration, summed for all days in a month to estimated monthly transpiration, and summed for all months in a year to estimate annual transpiration.

We applied this model to a hypothetical *Eucalyptus* plantation from initial planting through a full rotation. Maximum leaf area for *Eucalyptus* hybrid plantations is a function of precipitation and tree age and typically ranges from 3–5 m^2 m^{-2} (Stape *et al.* 2004, le Maire *et al.* 2011), although values as high as 8 have been reported in irrigated and fertilized *E. grandis* plantations (Meyers et al. 1976) To model the dynamics associated with a developing stand, we began with an initial LAI = 2 at year one and then incrementally increased LAI by 0.5 m^2m^{-2} per year, until the end of the rotation at age seven when LAI = 5.0. Intra-annual variation in LAI was simulated based on maximum annual LAI and the monthly dynamics of two plantations in Brazil (Hubbard *et al.* 2010).

Climate data used in the *Ec* model were obtained from five open-field climate stations maintained by the Natural Resources Conservation Service (NRCS 2008–2012) as part of the Soil Climate Analysis Network (SCAN, http://www.wcc.nrcs.usda.gov/scan/). Climate data at each station were available for a variable number of years; we used data from five sites across five states that had at 18 months of data available to run the model. Sites were located across the southeastern gulf Coastal Plain in Texas, Alabama, Georgia, Florida, and Mississippi (NRCS SCAN stations 2016, 2180, 2027, 2009, and 2082, respectively) as shown in Figure 4. Data consisted of hourly measurements of standard climate variables (*e.g.*, air temperature, relative humidity, solar radiation, wind speed) used to estimate plant water use, as well as soil moisture measured in a vertical array over five depths (depths 2–40 inches) at the climate station. To obtain an upper limit for ET, we also simulated ET without soil moisture constraints on g_s by setting θ to θ_{max} for all time periods; in other words, predawn water potential was always equal to 0.33 MPa (see equations 4–5). This would represent a well-watered soil such as what might occur in areas with high and well distributed rainfall, with irrigation, or where roots have access to groundwater.

To estimate I_C, we used an interception model ($I_C = 0.11*P$) developed for a *E. grandis* hybrid plantation (Soares and Almeida 2001), where *P* is annual precipitation in mm. Evapotranspiration was estimated for all years at each site and a mean for each year of stand development was calculated.

Question 2 - *How does the size and distribution of FT Eucalyptus plantations influence impacts on water balance at larger spatial scales?*

Simulating the Impacts on Water Balance at Larger Spatial Scales

While a process-based model is often a better approach for simulating complex hydrologic processes and estimating actual ET, the intensive data requirements of process-based models preclude this approach at larger spatial scales (such as USDA plant hardiness zone 8b and warmer). Hence, we used a parsimonious large-scale monthly water balance model (WaSSI; Sun *et al*. 2011; Caldwell *et al*., 2012) to evaluate the potential impacts of planting *Eucalyptus* at the larger watershed scale. This model was chosen because of its ease of use and performance in similar applications assessing the implications of changing land cover on water balance. Complete WaSSI model details are available in Sun *et al*. (2011) and Caldwell *et al*. (2012); so, only a brief explanation of the modifications required to use WaSSI to assess *Eucalyptus* ET is presented here.

WaSSI simulates actual ET, soil water storage, water yield, and streamflow at the watershed outlet at a monthly time step. WaSSI predicts ET of various land covers from empirical relationships between actual ET (AET) *vs*. climate variables, stand LAI, and potential ET (PET) (Figure 2). Accurate predictions of AET for the various land uses are a critical component of the overall model; however, no models are available for *Eucalyptus* growing in the southern U.S. Instead, for this evaluation, AET values for *Eucalyptus* were estimated by a revised WaSSI with a *Eucalyptus grandis* specific empirical AET model using data acquired from an eddy covariance study site in Brazil (Cabral *et al*., 2010).

Figure 2. Structural diagram of the WaSSI water balance model (Sun *et al*., 2011, Caldwell *et al*. 2012).

The empirical AET model using the data from Cabral *et al.* (2010) has the following form:

$$AET = -270.3 + LAI^* (116.6 + 0.056\ PET - 0.455^* P_i) + 0.168^* P_{i-1} + 1.374^* P_i \quad (6)$$

Adj. $R^2 = 0.81$; $P < 0.001$; RMSE = 21 mm month^{-1}

Where, PET is estimated using a formulation published by Hamon (1963) based on mean air temperature (T) and sunshine hours; and P_i and P_{i-1} are current and previous month's total precipitation, respectively. All units are in mm per month. Within the the WaSSi model, AET modeled from this equation is further reduced if soil water stress occurs (Caldwell *et al*. 2012).

Based on the results from sensitivity analyses, the version of the empirical AET model described above was not particularly sensitive to variation in air temperature, most likely because (1) the range of air temperature data from the Brazil site used to develop the empirical relationship was narrow and generally warmer than observed across the SE region, and (2) the model only indirectly accounts for T through impacts on PET. As a result, AET estimates in the winter months were over-estimated, especially when T_a was $\leq$ 18 °C and P was large. To adjust for this, we applied a correction such that when predicted AET > PET and $T_a \leq$ 18°C, then AET = 1.6*PET, where a correction factor of 1.6 is within the range (*e.g.*, 1.4–2.0) of previous studies examining PET/AET relationships in the southern U.S. forests (Rao *et al.* 2011, Lu *et al.* 2009). We also compared monthly AET predictions generated with the stand level process-based model to the WaSSI large scale empirical model and found that they were well correlated with no obvious biases (Figure 3). This adds confidence to our AET estimates derived from the empirical model and subsequent evaluations of potential implications on large scale water balance.

Figure 3. Comparison of ET based stand-level model and WaSSI large scale model.

To assess the watershed scale implications of planting *Eucalyptus* at the five study locations (Figure 4) where we conducted the process-modeling, we identified the associated 12-digit Hydrologic Unit Code (henceforth HUC 12) watersheds where they reside. HUC 12 is the watershed classification system that has the highest spatial resolution currently available for the continental U.S. There are about 17,000 HUC 12 watersheds in the 8b zone within the southeastern U.S. We applied WaSSI under current land cover conditions to calculate watershed-level *Q* (weighted by current land cover and driven by a climate for the time period from 1999–2010) and generated baseline monthly and annual water balances for the watershed. Next, we replaced varying proportions (ranging from 1% to 100%; Table 2) of current land cover (*i.e.*, crop, conifer forest, deciduous forest, mixed forest) with *Eucalyptus* and re-calculated water yield. Scenarios 2, 14, 15, and 16 (Table 2) bracket the range of potential land use changes identified in the economic analysis (Wear *et al.* 2013 - APHIS report). The other scenarios examine the implications of wider, but far less likely, ranges of possible land use switching to Eucalyptus. Potential impacts were evaluated by quantifying the absolute (mm yr^{-1}) and percentage change in *Q* from baseline. In all cases, we used an LAI value for *Eucalyptus* of 4.0 to represent an older stand with moderate productivity. Water balance calculations for other land cover types are reported in Sun *et al.* (2011) and Caldwell *et al*. (2012). Additional data sets required for the model include land cover, climate (monthly mean precipitation and air temperature), and soil properties. Those data sets were obtained from various national sources and applied following the standard methods described in Sun *et al*. (2011) and Caldwell *et al*. (2012).

Table 2. Land Cover Change Scenarios

Scenario Number	Simulated Land Cover Change
1	Replace all vegetation with *Eucalyptus*
2	Replace 10% of the conifer forest cover with *Eucalyptus*
3	Replace 50% of the conifer forest cover with *Eucalyptus*
4	Replace 10% of the deciduous forest cover with *Eucalyptus*
5	Replace 50% of the deciduous forest cover with *Eucalyptus*
6	Replace 10% of the crop cover with *Eucalyptus*
7	Replace 50% of the crop cover with *Eucalyptus*
8	Replace 10% of the grass and shrub cover with *Eucalyptus*
9	Replace 50% of the grass and shrub cover with *Eucalyptus*
10	Replace 10% of mixed forest with *Eucalyptus*
11	Replace 50% of mixed forest with *Eucalyptus*
12	Replace 1% of all vegetation with *Eucalyptus*
13	Replace 10% of all vegetation with *Eucalyptus*
14	Replace 1% of the conifer forest cover with *Eucalyptus*
15	Replace 3% of the conifer forest cover with *Eucalyptus*
16	Replace 20% of the conifer forest cover with *Eucalyptus*

Figure 4. Locations of stand-level studies overlain on the 12-digit HUC watersheds. The expanded view provides a visual context for the scale of a 12-digit HUC.

Using the same approach, we expanded the analysis to include all areas in Plant Hardiness zone 8b and greater, excluding areas identified as highly unlikely to support *Eucalyptus* as a result of biophysical or socioeconomic constraints (Figure 5). In this case, we replaced 1%, 3%, 10%, and 20% of conifer land cover with *Eucalyptus*, as these span the most likely scenarios identified in the economic analysis (Wear

et al. 2013 – APHIS report). Potential impacts were evaluated by quantifying the absolute (mm yr^{-1}) and relative (%) change in *Q* from baseline.

Figure 5. Forecasted area of *Eucalyptus* in the southeastern United States at year 10. For a detailed description of methods and assumptions, see Wear *et al*. 2013 APHIS report entitled "Projecting potential adoption of genetically engineered freeze-tolerant *Eucalyptus* plantations".

Impacts on Groundwater Recharge

When *P* exceeds ET, *Q* is distributed as streamflow soil water storage or groundwater recharge. Groundwater recharge is a critical part of the overall water budget and is one of the most difficult components to quantify, particularly at large spatial scales. We used Wolock's (2003a, 2003b) approach (below) to estimate long term potential impact of vegetation change on groundwater recharge (GWr) at a broad scale. GWr is a qualitative indicator of groundwater available to supply water in low flow seasons.

GWr = Base flow index * Q (7)

Watershed Q was modeled using the WaSSI model as described above under reference and altered landuse conditions. The baseflow index, the percentage of natural ground-water discharge in streamflow, is derived from historic streamflow records using a flow separation technique (Wolock, 2003b, 2003c).

Results

Question 1: What are the potential impacts of FT Eucalyptus plantations on overall local site water balance in areas where it is most likely to be grown?

Variation Among Locations

Climate - The five locations used to simulate the potential impacts of FT *Eucalyptus* on stand scale water balance represented a wide range of climatic conditions (Table 3). For example, mean annual precipitation (averaged over the years used for simulation) ranged from about 780 mm yr^{-1} for the site in Texas to about 1550 mm yr^{-1} for the site in Mississippi. Indeed, the low precipitation value for the Texas location is slightly below the precipitation limit (*i.e.,* 800 mm yr^{-1}) where FT *Eucalyptus* plantations would be expected to be viable (Figure 5) and clearly reflects the driest potential site for a FT *Eucalyptus* plantation. The nearly two-fold variation in precipitation influences soil θ and available water for transpiration; however, θ is also affected by soil textural characteristics that influence water holding capacity. As result, measured soil moisture ranged from 5.1% (by volume) to 25.3% and was lowest at the Florida location and greatest at the Mississippi location. Mean annual air temperature ranged from 18.1 to 20.6 °C and net solar radiation ranged from 155 to 201 W m^{-2}.

Table 3. Environmental conditions at the five study sites. Data are annual daily means (soil moisture, temperature, and net radiation) and annual total (precipitation) obtained from the NRCS field sites described in the methods.

Location	Soil Moisture (%)	Precipitation (mm)	Air T (°C)	Net Radiation (w m^{-2})
Alabama	15.6	1479	20.6	201
Florida	5.1	1375	20.5	155
Georgia	13.1	1063	19.7	190
Mississippi	25.3	1553	18.1	183
Texas	21.2	779	19.9	196

ET Estimates - Because assumptions about leaf area and stand development patterns (*i.e.*, an increase in LAI from 2.0 to 5.0 by 0.5 increments from age 1 to age 7) were consistent across the five study locations, variation in ET only reflects differences in climatic conditions and soil moisture (Figure 6A). Ranking locations, the highest ET was predicted for the Mississippi and Alabama locations, the lowest ET was predicted for the Florida location, and Texas and Georgia locations were intermediate. As would be expected, stand-level ET increased with stand age and assumed patterns of leaf area development.

By the end of the rotation (age 7; LAI = 5), our predictions of annual ET rates (ranging from about 900 in Florida to over 1200 in Mississippi and Alabama). Because a large number of stand scale ET estimates already existed for alternative land covers in the SE U.S. (Table 4), we did not develop land cover specific physically based ET models. In addition, developing a full suite of species-specific physically based models would be especially challenging for stands with mixed species composition; an effort beyond the scope of this analysis. When comparing our predictions for FT *Eucalyptus* to published values for other land covers and species, our estimated ET values were 1.5 to 2-fold greater than estimates for old fields (460–650 mm, Stoy *et al.* 2006), mature deciduous hardwoods forests (480–640 mm, Stoy *et al.* 2006), loblolly pine plantations in the piedmont (560-740, Stoy *et al.* 2006) and crops, such as cotton (386–397 for no irrigation, 739–775 for irrigated; data not shown in Table 4) (Howell *et al.* 2004); but comparable to some slash and loblolly pine plantations in the coastal plain (676 to-1226 mm, Gholz and Clark 2002, Powell *et al.* 2005, Stoy *et al.* 2006, Sun *et al.* 2010). We are aware of only one study where *Eucalyptus* ET has been quantified in the U.S. Here, Abichou *et al.* (2012) estimated an average annual ET of 1086 mm (81% of precipitation) for *Eucalyptus amplifolia* in the Florida panhandle using weighing lysimeters and a constructed soil system. If site conditions (*e.g.*, soil nutrients, disturbances, precipitation; Stape *et al.*, 2006) preclude attainment of LAI = 5, and lower maximum LAI values (*e.g.*, 3 to 4) result, ET estimates range from about 600 (Florida) to 850 (Alabama and Mississippi), well within the range of what has been observed for late-rotation pine plantations in the SE U.S (Sun *et al.* 2010). When soil moisture controls on stomatal conductance were removed by assuming an unlimited supply of soil water, ET values were on average about 20% higher overall, with the highest ET exceeding 1400 mm yr^{-1} in year 7 at the Alabama location (Figure 7). These wet soil conditions would likely be comparable to areas where high ET (*e.g.*, > 1000 mm yr^{-1}) has been observed for loblolly and slash pine plantations (Gholz and Clark 2002, Sun *et al.* 2010). In these cases, the energy available to drive transpiration is the primary limiting factor.

Stand Water Balance - Estimates of stand water balance ($Q = P - ET$), declined as ET increased over time (Figure 6B). For three of the locations, Q remained positive over the full rotation. However, at the Texas site, estimates of Q reached zero by age 3 (LAI = 3) and Q reached zero at the Georgia site at age 7 (LAI = 5.0). In reality, if ET exceeds precipitation, trees would experience considerable water stress and physiological adjustments would occur that would reduce ET such that Q would not be less than zero (as shown in Figure 6B). For example, trees would either need to access water not supplied through precipitation (i.e., access deep water sources) to maintain ET, reduce ET through shedding leaves, or adjust stomatal and hydraulic properties (Whitehead and Beadle 2004). Leaf area reduction could occur through tree mortality or fewer leaves per tree, a likely result during drought conditions or when planted in low rainfall areas. These drought avoidance adjustments to limitations were too complex (and unknown for FT *Eucalyptus*) to be included in our modeling; however, the ability of *Eucalyptus* to survive sudden or prolonged drought is well recognized (Whitehead and Beadle 2004) and provides a mechanism for persistence in the driers regions of hardiness zone 8b and higher. If our model and assumptions are correct, these results indicate the potential for the complete elimination of groundwater recharge or surface water flows in areas with low annual precipitation or possibly during drought years in areas with higher average annual rainfall. It should be noted that predicting Q with a simple water balance approach (*i.e.*, P-ET) would also suggest complete elimination of flow for many of

the forest types listed in Table 4 under low rainfall conditions (e.g., ~800 mm yr^{-1}). However, this assumes that those species could tolerate or avoid drought and continue to transpire under low soil moisture conditions. In contrast, temporal patterns in areas with higher rainfall suggest that while *Q* declines as stand develop (Figure 6B), site water balance remained positive and complete elimination of *Q* would not be expected, although *Q* may decrease significantly.

Table 4. Annual evapotranspiration for *Eucalyptus* in Brazil and for major forest ecosystems in southeastern United States (U.S. values are adapted from Sun et al., 2010). Values in parentheses = range.

Ecosystems	Evapotranspiration (mm)	Precipitation (*P*, mm)	ET/*P*	References
Eucalyptus Plantation (clonal *Eucalyptus grandis* x *Eucalyptus Urophylla*), 2-4 years old, São Paulo State, Brazil	1179 (1124–1235)	1329 (1280–1377)	0.88 (0.82–0.96)	Cabral et al. 2010
Eucalyptus Plantation (hybrid of *E. urophylla* and *E. grandis*), 2-6 years old, spacing of 3.00 × 2.75m, São Paulo State, Brazil	1101 (943–1364)	1308 (1150–1601)	0.84 (0.81–0.89)	Lima et al. 2012
Eucalyptus Plantation (hybrid of *E. urophylla* and *E. grandis*, different clone), 0-2 years old, spacing of 6.00 × 1.40 m. São Paulo State, Brazil	1099 (949–1240)	1601 (1537–1716)	0.69 (0.55–0.80)	Lima et al. 2012
Loblolly pine plantation (LP) 16 year old, North Carolina	1087 (1011-1226)	1238	0.88	Sun et al. 2010
Loblolly pine plantation (CC), 4 year old, coastal North Carolina	838 (755-885)	1274	0.66	Sun et al. 2010
Loblolly pine plantation, 4 year old, Parker Track, North Carolina	895 (702–1078)	1152	0.78 (0.73–	Diggs 2004

			0.94)	
Loblolly pine plantation, 15 year old, Parker Track, North Carolina	988 938 (after thinning 1/3 of basal area)	1098	0.9	Grace et al. 2006a, 2006b
Loblolly pine plantation, 14-30 year old, Parker Track, North Carolina	997 (763–1792)	1538 (947–1346)	0.65	Amayta et al. 2006
Loblolly pine plantation (PP), 25 year old, Piedmont North Carolina	658 (560–740)	1092 (930–1350)	0.60	Stoy et al. 2006
Mature deciduous hardwoods (HW), Duke Forest, Piedmont North Carolina	573 (460–640)	1092 (930–1350)	0.52	Stoy et al. 2006
Grass-cover old field (OL), Duke Forest, Piedmont North Carolina	508 (360–650)	1092 (930–1350)	0.46	Stoy et al. 2006
Slash pine (*Pinus taeda* L.) plantation, clearcut, Florida	958 (869–1048)	959 (869–1048)	0.85 (0.84–0.86)	Gholz and Clark 2002
Slash pine (*Pinus taeda* L.) plantation, 10-year old, Florida	1058 (994–1122)	1062 (877–1247)	1.0 (0.9–1.1)	Gholz and Clark 2002
Slash pine (*Pinus taeda* L.) plantation, full-rotation, Florida	1193 (1102–1284)	1289 (887–1014)	0.93 (0.92–0.93)	Gholz and Clark 2002
Slash pine (*Pinus taeda* L.) plantation, full-rotation, Florida (extreme drought years)	754 (676–832)	883 (811–956)	0.85	Powell et al. 2005
Pine flatwoods, Bradford Forest, Florida	1077	1261	0.87	Sun et al. 2002

Deciduous hardwoods, Coweeta, North Carolina	779	1730	0.47	Sun et al. 2002
Mixed Pine and hardwoods, Santee Exp. Forest, South Carolina	1133	1382	0.82	Lu et al. 2003
White pine (*Pinus strobus* L.), Coweeta, North Carolina	1291	2241	0.58	Ford et al. 2007
Deciduous hardwoods, Oak Ridge, Tennessee	567 (537–611)	1372 (1245–1682)	0.41	Wilson and Baldocchi 2000
Deciduous hardwoods, Oak Ridge, Walker Branch watershed, Tennessee	575	1244	0.45	Updated data from Lu et al. 2003; Hanson et al. 2004

Figure 6A&B. Annual ET (A) and Runoff (B) predicted from process based model for the five intensive study locations. The model does not incorporate physiological or structural adjustments that occur when annual ET exceeds P (*i.e.*, leaf area reduction, access to deep soil water, etc.) so predicted runoff is negative for the Texas site when LAI > 3.0. Because "negative runoff" is not possible, these data should be interpreted as runoff = 0.

Figure 7. Estimates of FT *Eucalyptus* evapotranspiration without soil moisture limitations on stomatal conductance.

Intra-annual Patterns - At the monthly scale, ET estimates showed a distinct seasonal pattern. Across all sites, peak ET occurred in either June or July (Figure 8A-E). This is to be expected as this pattern coincides with the timing of maximum stand LAI and when climatic driving variables are most favorable to drive ET. These peak values are well within the range of what has been observed for other *Eucalyptus* species across the globe (Whitehead and Beadle 2004). Estimating *Q* by *P*-ET is not applicable at sub-annual time scales so we are unable to quantify seasonal variation in streamflow using this approach. However, these seasonal patterns in predicted ET suggest that depending on seasonal precipitation patterns, *Q* likely would be most impacted during the summer months.

Figure 8A-E: Monthly total evapotranspiration (error bars denote standard error of the mean) simulated across all years of climate and over seven years of stand development for five sites. Stand development is represented as increases in leaf area index (LAI) from 2–5 m^2 m^{-2}.

Implications

The stand-level implications of planting FT *Eucalyptus* on *Q* will vary by location, the land cover type prior to *Eucalyptus* establishment, and the hydrological conditions of the planting site and surrounding area. To illustrate, we can compare ET values of *Eucalyptus* to alternative options for wood fiber production such as pine plantations. As noted above, estimates of planted pine ET range from about 650 to 1200 mm yr^{-1}; with the latter being observed in areas where soil water is plentiful (Gholz and Clark 2002, Powell *et al*. 2005, Stoy *et al*. 2006, Sun *et al*. 2010). At LAI = 4, predicted *Eucalyptus* ET ranges from 790 mm yr^{-1} at the Florida site, to 980 mm yr^{-1} at the Mississippi site, within the range for pine stands. This suggests that contributions to streamflow/recharge could be equal to or reduced by as much as to 180 mm yr^{-1} relative to pine near the end of the rotation or on sites where LAI is below the maximum. Aat *Eucalyptus* LAI = 5, ET ranges from 909 mm yr^{-1} (Florida) to 1229 mm yr^{-1} (Mississippi) as compared to pine plantations with annual ET of about 900 mm yr^{-1} (the average of the low and high estimates from Sun *et al.* 2010). Under these conditions, reductions in contributions to streamflow or groundwater recharge of about 0 to 300 mm yr^{-1} are possible. The implications for these reductions in streamflow or groundwater recharge depend on the hydrologic setting and the amount of land area planted in FT *Eucalyptus*. For example, conditions that might result in a negative impact would include:

1. Planting in areas where precipitation is limited or where dry years are likely,
2. Planting in areas where the ratio of *P*/potential evapotranspiration is low, and
3. Planting in headwater areas or planting large acreages in close proximity to streams that have low annual baseflow.

These implications must be viewed in the context of an incomplete understanding of the rooting characteristics, leaf phenology, and ecophysiology of FT *Eucalyptus* that could potentially affect the model-base estimates of ET. For example, we don't know aspects such as how g_s in FT *Eucalyptus* will recover after a freeze event and the implications for growing season length. Also, deep rooting could allow tree to maintain high leaf water potentials and g_s under dry conditions relative to pine or native species.

Question 2. ***How does the size and distribution of FT Eucalyptus plantations impact water balance at larger spatial scales?***

Scaling from the Stand to the Watershed

The impact of planting FT *Eucalyptus* at larger spatial scales will vary depending upon the hydrologic setting (e.g., high rainfall *vs*. low rainfall) and the type and amount land cover being replaced. To include the influence of land cover, one of our tasks was to quantify current land cover types across the region. As an example, at the five locations used for process based modeling, current land cover within the associated 12-digit HUC varied greatly (Figure 9 A-E). To characterize how different land covers influence water balance at the 12-digit HUC, land cover specific LAI data were derived from Moderate

Resolution Imaging Spectroradiometer (MODIS) remote sensing products (1000 m spatial resolution) and water use was driven by land cover based variation in LAI (Sun *et al*. 2011). Although the WaSSI model does not use land cover specific ET models to estimate ET for each land cover in a watershed, the ET model does consider the effects of LAI (magnitude and seasonal dynamics) on water use.

A

B

Georgia (HUC 31102040105)
urban
(LAI=3.8)
21%
crop
(LAI=2.8)
34%
wetlands
(LAI=4.7)
14%
grassland
(LAI=3.8)
7%
evergreen
(LAI=3.6)
14%

C

Alabama (HUC 31300040801)
Water
2%
Barren
0%
Urban
4%
Wetlands
9%
Shrubland
7%
Grassland
3%
Mixed forest
2%
Crop
49% (LAI=1.8)
Evergreen
17%
Deciduous
7%

D

Florida (HUC 31200010702)
Barren
0%
Deciduous
1%
Water
0%
Urban
7%
Crop
4%
Evergreen
(LAI=4.2)
35%
Wetlands (LAI=4.5)
39%
Mixed forest
4%
Shrubland
5%
Grassland
5%

E

Figure 9A-E. Current land cover (2006) for the 12–digit HUC associated with the five study locations. Landcover sources: 2006 National Land Cover Database for the Conterminous U.S. (Fry et al., 2011).

The interactions among hydrologic setting, current land cover, and the amount of land cover changed were examined by predicting changes in absolute and relative water yield described in the case study scenarios (Table 2). Not surprisingly, the largest changes in *Q* (amount and %) were predicted when all of the vegetation within the watershed was converted to FT *Eucalyptus* (Scenario 1 - Figure 10 A&B). However, there were substantial differences in the magnitude of response among locations. For absolute changes in flow, responses varied from about -250 mm yr^{-1} (-48%) at the Alabama location, to about -100 mm yr^{-1} (-18%) at the Florida location (Figures 10 A&B). These changes are comparable to changes predicted at the stand scale. Based on the economic analysis (Wear *et al*. 2013 APHIS report), it is highly unlikely that FT *Eucalyptus* would be planted at this scale and much smaller changes are more realistic. For example, if only 1% of the vegetative cover in the watersheds were converted to FT *Eucalyptus* (Scenario 12 – Figure 10 A&B), changes in *Q* (amount or %) would be very small (e.g., < 5 mm and <1%) across all study areas. In short, responses of this magnitude would likely not be measurable with streamflow gauges at a large scale, are unlikely to negatively impact streamflow or groundwater

recharge, and are well within the errors associated with this type of model-based approach. However, as noted in the previous section, measurable local scale impacts may still occur immediately downstream of FT *Eucalyptus* plantations. At intermediate levels of change (e.g., 10% *vs*. 50%), impacts varied depending upon the land cover being replaced. For example, on average, the next largest change occurs when 50% of crop land cover (Scenario 7) is converted to FT *Eucalyptus* (S7; Figure 10A-B).

Based on the results of the socioeconomic analyses, projections suggest that FT *Eucalyptus* plantations could replace 3 to 20% of conifer land cover depending on economic assumptions, with the most likely scenario being an overall 10% conversion (Wear et al. 2013 APHIS report). The potential implications of 10%, 20%, or 50% conversion from conifer to FT *Eucalyptus* and a 100% conversion of all vegetation across climate zone 8b and higher is shown in Figure 11 A-H. At these larger scales, major changes in *Q* (absolute or %) were projected only when all of the vegetation was replaced with FT *Eucalyptus*. Simulations assuming either a 10% (scenario 2 – Figure 11 C&D) or 20% (scenario 3 – Figure 11 E&F) replacement of conifer land cover with FT *Eucalyptus* suggested that the impacts on Q would be minimal (*i.e.*, > 24 mm of absolute *Q*; < 10% change in percent *Q*). At a 50% replacement of conifer cover with FT *Eucalyptus* (scenario 16 – Figure 11 G&H), simulations suggested reduction in *Q* of ~100 mm were possible, especially in the Florida panhandle region and parts of Louisiana, Alabama, and Texas.

We emphasize that these results are based on LAI = 4.0, which is representative of an older stand nearing the end of the rotation (assumed to be 7 years). As a result, our analyses and interpretations reflect what might occur under a near "maximum impact" scenario. At lower LAI's (reflective of factors such as younger stands, lower density, or poor quality sites), the projected effects would even less.

Impacts on Groundwater Recharge

Groundwater recharge rate in a watershed is controlled mainly by the water balance (precipitation and ET) and geological properties of the watershed as illustrated by Equation 4. Impacts of vegetation changes will affect water yield and thus the amount of groundwater recharge. Similar to water yield impact results, converting all vegetation to FT *Eucalyptus* is projected to have a large impact on regional groundwater recharge (*e.g.*, decrease as high as 200 mm/yr in some watersheds); however, a 10% conversion (the most likely scenario) of conifer forests to FT *Eucalyptus* may have negligible effects on groundwater recharge rate on average, especially in the wet regions in the coastal plains (Figure 12A-B).

Implications

Assessing the impacts at larger spatial scales is an extremely challenging task because it is a function of the hydrologic setting, current land cover and its water use, and how much of the land cover is converted. Our modeling approach attempts to account for all of these variables and represents a "best approximation" based on the available data. At the scale of conversion indicated by the economic analysis (*e.g.*, <20% conversion of conifer cover to FT *Eucalyptus*; Wear *et al*. 2013 – APHIS report), our analysis (using LAI = 4) suggests that the regional impacts on either *Q*, percent change in *Q*, or

groundwater recharge at the scale of the 12-digit HUC will be negligible. At lower LAI's, impacts would be even lower. Again, local scale impacts may occur immediately downstream of FT *Eucalyptus* plantations even at low land cover conversion rates. In contrast, if economic conditions promoted large scale conversion of existing land cover (e.g., 50% of current conifer cover) to FT *Eucalyptus*, then regional impacts on *Q* could be observable in many areas of zone 8b and higher. Areas where changes are anticipated to be the greatest include the Florida panhandle, south Alabama, southwest Georgia, Louisiana, and southern Mississippi (Figure 11).

Assumptions and Uncertainties

Our model-based analysis of the potential impacts of the expansion of FT *Eucalyptus* represents our best approximation based on currently available data. Because physiological and structural data for FT *Eucalyptus* do not exist, we assumed that:

1. Physiological (*e.g.*, stomatal conductance) and stand structure data (*e.g.*, leaf area index amount, season dynamics, and development over time) from *Eucalyptus grandis* (and other *Eucalyptus* species) growing in other regions of the world are applicable to FT *Eucalyptus* growing in USDA plant hardiness zone 8b and higher.
2. The stand level model was a sufficient representation of how FT *Eucalyptus* would respond to climatic and soil driving variables at the five study locations.
3. The empirical AET model (equation 7) developed from an eddy covariance tower in Brazil was applicable to FT *Eucalyptus* growing in USDA plant hardiness zone 8b and higher.
4. A stand LAI = 4 is a reasonable value for commercial stands of FT *Eucalyptus* growing in USDA plant hardiness zone 8b and higher.

In addition to these assumptions, biophysical models at all scales are limited by imperfect knowledge and simplifications of processes, parameters, and driving variables; and by limits to the accuracy and precision of climate driving variables such as precipitation and air temperature. Furthermore, these results must be viewed in the context of the hydrologic setting of the area of the plantation. Key physical features such as soil texture, topography, existing drainage networks and road systems, and groundwater depth can either mitigate or exacerbate responses. Future climate variability, especially an increased frequency and severity of drought may make some areas much more sensitive to the effects of higher ET in the future. Our models were not appropriate for simulating the potential impacts of extreme drought due to a lack of model sophistication and data on physiological and structural responses from FT *Eucalyptus*. These assumptions and uncertainties reinforce the need to obtain empirical measurements to validate (or reject) model projections.

A

Modeled Mean (1999-2010 climate) Effects of Eucalyptus on Streamflow under Mutiple Scenarios
50
0
-50
-100
-150
-200
-250
-300
Effects on Q (mm/year)
S1
S2
S3
S4
S5
S6
S7
S8
S9
S10
S11
S12
S13
S14
S15
S16
TX P=1128 mm
GA P=1183 mm
FL P=1507 mm
AL P=1361 mm
MS P=1724 mm
Scenarios

Figure 10A-B. Effect of planting *Eucalyptus* water yield where (A) is absolute change, and (B) is relative change in water yield. Scenario runs (labeled S1 through S16) by WaSSI for the 5 watersheds where the stand-level modeling sites are located (see Table 2 for scenario label definitions).

A
Scenario 1
Impact on Q (mm/yr.)
-301 - -200
-199 - -150
-149 - -100
-99 - -50
-49 - -25
-24 - 0
B
Scenario 1
Impact on Q%
-100 - -80
-79 - -60
-59 - -40
-39 - -20
-19 - -10
-9 - 1
C
Scenario 2
Impact on Q (mm/yr.)
-301 - -200
-199 - -150
-149 - -100
-99 - -50
-49 - -25
-24 - 0
D
Scenario 2
Impact on Q%
-100 - -80
-79 - -60
-59 - -40
-39 - -20
-19 - -10
-9 - 1

Figure 11A-H Regional analysis simulating the impact on Q (absolute change in mm yr^{-1} and percent change in) of replacing 100% of all vegetation (Scenario 1), 10% of the conifer cover (Scenario 2), 50% of the conifer cover (Scenario 3), and 20% of the conifer cover (Scenario 16) with FT *Eucalyptus* for all of the 12-digit HUCS in the southern region of hardiness zones 8b and greater.

A

Scenario 1
Impact on GWR (mm/yr.)
-198 - -100
-99 - -80
-79 - -60
-59 - -30
-29 - -15
-14 - 0
0
250
500
1,000 Kilometers

B

Figure 12A-B Spatial distribution of modeled impacts on groundwater recharge across 17,000 watersheds (A) Scenario 1 = Converting all vegetation to FT *Eucalyptus* (B) Scenario 2 = 10% of conversion of conifer forests to FT E*ucalyptus*.

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APPENDIX D. USDA-FS TECHNICAL REPORT ON THE POTENTIAL FIRE RISK OF FREEZE-TOLERANT EUCALYPTUS

Evaluation of Potential Fire Behavior in Genetically Engineered Freeze-Tolerant (FTE) Plantations of the Southern United States

September 2013

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Executive Summary

Andreu, A., Ottmar, R.D. and Prichard, S.J. 2013. Evaluation of Potential Fire Behavior in Genetically Engineered Freeze-Tolerant (FTE) Plantations of the Southern United States.

The United States Department of Agriculture's Animal and Plant Health Inspection Service (USDA-APHIS) is preparing an Environmental Impact Statement (EIS) to assess plantings of genetically-engineered freeze-tolerant *Eucalyptus* (FTE *Eucalyptus x urograndis*, FTE) in the United States. If approved for commercial production, some pine plantations mixed hardwood forests and agricultural lands in the Southern United States may be converted to FTE plantations. Since FTE plantations could pose an increase in risk of fire hazard relative to existing vegetation, a fire risk assessment is needed and will be addressed in the EIS. APHIS asked the Fire and Environmental Research Applications Team (FERA) of the Pacific Northwest Research Station to conduct the fire risk assessment using the Fuel Characteristic Classification System (FCCS).

The objective of this project was to model potential fire behavior in FTE plantations in the southern United States and assess fire risk compared to existing vegetation, including southern pine, mixed hardwoods, and post-harvest agricultural fields. To meet this objective, the FERA team of the Pacific Northwest Research Station developed detailed fuelbed pathways that represent current and potential fuelbeds of FTE and loblolly pine plantations. Each fuelbed in the pathways were constructed and used to generate FCCS outputs under a range of fuel moisture and weather scenarios. Potential fire behavior was compared between the FTE and loblolly pine plantation fuelbeds and compared with mixed hardwood forest and agricultural field fuelbeds already in existence.

Additional fuelbeds were constructed to evaluate potential fuel conditions that might contribute to fire hazard in FTE fuelbeds. These included:
1) Evaluating tree regeneration as a shrub stratum in FCCS calculations,
2) Replacing neutral shrub species in FTE and loblolly fuelbeds that do not influence predicted surface fire behavior with accelerant shrubs,
3) Examining potential fire behavior with cured herbaceous stratum to represent dormant season fuel conditions, and
4) Frost damage including canopy kill and leaf-off conditions.

Based on FCCS predictions, we conclude that in general, FTE fuelbeds do not pose a substantially higher fire risk than southern pine plantations, other forest types common to the southern United States, or agricultural lands. Potential fire behavior in the agricultural and mixed hardwood fuelbeds that we evaluated was actually higher in general than the FTE fuelbeds.

In their first year, plantations may pose a short-term fire risk, particularly under high wind scenarios and in the dormant season when the majority of herbaceous biomass is dead.

Treating first-year FTE plantations as a shrub layer provides the most conservative estimate of potential surface fire behavior. In addition, if FTE is planted in areas that typically have flammable shrubs in their understories (e.g., wax myrtle or gallberry), effective site preparation may be required to reduce the risk of shrub development and associated fire hazard. If such plantations do not receive effective site preparation, understory herbaceous vegetation may moderately increase the surface fire behavior potential. Frost damage would likely result in a short-term increase in surface fire potential associated with leaf-fall and resulting litter accumulations.

Due in part to low to moderate surface fire behavior potential, FTE plantations generally had low crown fire initiation potential. However, if a crown fire starts, there is a high risk of it spreading. Active management to reduce surface fuel loads, including flammable shrub layers and herbaceous fuels, would be important measures to reduce the risk of crown fire initiation.

Potential fire behavior generally increases over time in FTE biomass, pulpwood and coppice pathways as litter and woody fuels accumulate. We evaluated fuelbeds that represented over-mature or abandoned FTE and loblolly plantations that were 20-30 years old. Under these conditions, potential fire hazard is only moderate and does not markedly differ between FTE and loblolly pine plantations. However, if plantations were allowed to continue to grow, we would expect that ladder fuels could develop and lead to a high potential for crown fire initiation and spread.

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Introduction

The United States Department of Agriculture's Animal and Plant Health Inspect Service (USDA-APHIS) is preparing an Environmental Impact Statement (EIS) to assess plantings of genetically engineered freeze-tolerant *Eucalyptus x urograndis* (FTE) in the United States. If FTE is adopted for commercial production in the United States, pine plantations, mixed hardwood forests and agricultural lands in the southern United States may be converted to FTE (see other APHIS technical reports appended to this EIS for more information). Since FTE may pose an increased risk of fire hazard relative to existing vegetation, a fire risk assessment of these potential plantations is needed and will be addressed in the EIS and this technical report.

Because native *Eucalyptus* forests in Australia and other parts of the world have been associated with extreme surface and crown fire events (Cruz et al. 2012, McCaw et al. 2012) and firebrand spotting potential (Ellis 2011) a fire risk assessment for introduced FTE plantations is warranted. A preliminary analysis by Goodrick and Stanturf (2012) indicated little difference in potential fire behavior between young FTE plantations relative to existing southern pine plantations. However, the authors cautioned that flammable shrub layers could pose substantial surface fire risk and if crown fires were allowed to initiate, older FTE plantations had a high potential for crown fire spread.

This study was developed to further assess surface and crown fire hazard in FTE plantations by developing fuelbeds to represent different life stages and management scenarios for FTE plantations and predicting potential fire behavior under a range of wildfire scenarios. Predicted fire behavior was compared to common vegetation types that currently exist in the southern United States and could be replaced by FTE plantations. This assessment did not address firebrand spotting potential because FCCS does not evaluate spotting potential and FTE trees do not have stringy bark, a key fuelbed component needed for creating firebrands.

Fuel Characteristics Classification System

Assessments of fire risk, fire effects, fire emissions, and carbon have demonstrated the need for a system to quantify and classify wildland fuels and be able to adequately characterize the inherent variability of fuel characteristics across geographic regions, under various management scenarios, and over time. The Fire and Environmental Research Applications team (FERA) of the Pacific Northwest Research Station's Pacific Wildland Fire Sciences Laboratory (U.S Department of Agriculture, Forest Service) has developed the Fuel Characteristic Classification System (FCCS) (Ottmar et al. 2007, Riccardi et al. 2007, Sandberg et al. 2007a, Sandberg et al. 2007b, Schaaf et al. 2007, Prichard et al. *in press*) to meet this need. The system offers consistently organized fuels data and fire behavior models that can be used to assess fuelbeds for fire risk. Users can access fuelbeds from 500 reference FCCS fuelbeds contained in the database, modify or customize any of the 300 fuelbed input variables and calculate surface fire behavior, crown fire, and available fuel potentials (index between 0- 9) for each FCCS fuelbed. FCCS also predicts surface fire behavior, including reaction intensity (BTU ft^{-2} min^{-1}), flame length (ft), and rate of spread (ft min^{-1}), under specified environmental conditions.

The FCCS fuelbeds include characteristics for all strata, categories and sub-categories of a fuelbed that have a potential to burn including trees, snags, ladder fuels, shrubs, herbaceous fuels (herbs), sound and rotten woody fuels, stumps, piles, litter, and duff. The refinement of fuels into categories and subcategories allows specific attributes to be captured that contribute to fire behavior such as accelerant shrubs, stringy or fuzzy bark, or deep, fluffy litter composed of leaves and bark. Each strata, category, and subcategory may be modified to capture variability in fuels, and to create customized fuelbed(s) particular to a fuelbed type and applied at a management unit, forest, state, region, or any other scale of choice. This design can also be used to capture complexity and variability of fuels across time and space. For example, modification of height, percentage cover, and density of trees (overstory, midstory, or understory) can be used to represent the effects of a thinning operation on fuels. Changes to the values of the percentage live and live foliar moisture in either the shrubs or grass fuels can be used to represent a temporal change of season (i.e., growing vs. dormant). Many possibilities exist because every variable can be edited. Extensive data within, and produced by, FCCS can be used for fuel operation and management activities, fire behavior, emissions analysis, fire effects, and ecological analysis.

Project Objectives

The objective of this project was to model potential fire behavior in FTE plantations in the southern United States and assess fire risk compared to existing vegetation, including southern pine, mixed hardwoods, and post-harvest agricultural fields. To meet this objective, the FERA team of the Pacific Northwest Research Station developed detailed fuelbed pathways that represent current and potential fuelbeds of FTE and loblolly pine plantations. Pathway fuelbeds were constructed and used to generate FCCS outputs under a range of fuel moisture and weather scenarios. Potential fire behavior was compared between the FTE and loblolly pine plantation fuelbeds and compared with mixed hardwood forest, pine hardwood forest, and agricultural field fuelbeds already in existence.

Methods

Fuelbed pathways were constructed based on knowledge of local successional patterns and modeling and consultation with FTE experts. FERA performed a literature search and consulted with FTE experts (Pat Minogue, University of Florida, and José Stape, North Carolina State University) to develop FTE pathways and fuelbeds. Michael Andreu, University of Florida was consulted for loblolly pine pathway and fuelbed development.

Three main pathways were developed to represent typical management and harvest scenarios for commercial FTE plantations including

1) A biomass pathway that represents short FTE rotations for biomass and energy production
2) A pulpwood pathway that represents longer FTE rotations for pulpwood and chip harvests

3) A Coppice pathway that represents harvested plantations that have been allowed to sprout (*see FTE Pathway Handbook*).

Specific characteristics of the FTE plantations were incorporated, including standard stocking, height, height to live crown, and crown closure. A comparative pathway was developed for intensively-managed loblolly pine plantations. Loblolly pine fuelbed pathways were constructed in order to provide consistent comparisons between southern pine plantations and potential FTE plantations over similar management trajectories and successional stages.

The following paragraphs describe key assumptions made for each pathway.

FTE Biomass Pathway

The FTE biomass pathway represents fuelbeds across time, starting with dense (~1200 trees/acre) FTE plantations that established following: 1) intensive chemical and mechanical site preparation including bedding, fertilizer within tree rows and herbicide applications to increase tree growth and reduce competing vegetation and 2) incomplete or unsuccessful site preparation (Couto et al. 2011, Zalesny et al. 2011, Hinchee et al. 2009, Rockwood and Peter 1997). The incomplete site preparation is assumed to have resulted in lower stand vigor and delayed canopy closure, which would allow for competing vegetation (e.g., grasses, other herbaceous vegetation, shrubs and mixed hardwood trees) to become established (Couto, 2012, Rockwood and Peter 1997, José Stape, North Carolina State University, personal communication, 2013). Biomass harvests are generally conducted at 3-4 years and often are coppiced, so harvested fuelbeds from the FTE biomass pathway would be converted to early-stage coppice fuelbeds. FTE fuelbeds over 4 years old represent FTE biomass plantations that have been abandoned (José Stape, North Carolina State University, personal communication, 2013).

FTE Pulpwood Pathway

The FTE pulpwood pathway represents FTE pulpwood plantations over time, starting with a planting density of 625 trees/acre that established following: 1) intensive chemical and mechanical site preparation including bedding, fertilizer within tree rows and herbicide applications to increase tree growth and reduce competing vegetation and 2) incomplete or unsuccessful site preparation (Patrick Minogue, University of Florida, personal communication, 2013). Pulpwood plantations are considered harvestable at 7-8 years. Pulpwood FTE plantations are often coppiced; harvested pulpwood plantations would then be converted to early-stage coppice fuelbeds. Two older fuelbeds (16-30 years) are included to represent abandoned pulpwood plantations.

FTE Coppice Pathway

The coppice pathway represents biomass or coppice pathway fuelbeds that have been harvested and have been left to sprout following: 1) fertilizer and herbicide applications and 2) no application of herbicides or fertilizer. Effectively managed, coppiced fuelbeds are assumed to be thinned to one stem per stump within the first year, resulting in a density of 1200 stems per acre. Ineffectively managed coppiced fuelbeds are not thinned to one stem per stump and

are assumed to have 3 sprouts per stem, resulting in a starting density of 3600 stems per acre. Fuelbeds past the typical age of harvest (3-4 years) are included to represent FTE coppice stands that have been abandoned. A coppice pathway that represents pulpwood densities was not included because fuelbeds would have been intermediate between pulpwood and biomass coppice and would not have added appreciably to the range of conditions modeled in this assessment.

Loblolly Pathway

The loblolly pathway represents loblolly pine plantations across time under intensive management for pulpwood and saw timber harvest following: 1) intensive chemical and mechanical site preparation including application of herbicide to increase tree growth and reduce competing vegetation, and 2) incomplete or unsuccessful site preparation. Frequent application of fertilizer is typical in intensively managed, commercial loblolly plantations, and saw timber stands are also thinned to improve stand vigor and tree growth. Pulpwood harvests are generally conducted at 12-15 years, and saw timber harvests are conducted at 20-30 years. Ineffectively managed fuelbeds and fuelbeds beyond the normal pulpwood harvesting age (e.g., fuelbeds 1347 and 1348) are also included to represent loblolly stands that have been abandoned (Moorhead et al. 1998, Zalesny et al. 2011, Michael Andreu, University of Florida, personal communication, 2013).

Fuelbed development

FCCS fuelbeds were developed using scientific literature, datasets, local plant guides, and expert opinion from local and foreign colleagues familiar with stand structures, species composition, and fuel characteristics. Due to a lack of actual field data for FTE plantations (e.g., surface fuels inventories to systematically quantify live and dead biomass across fuelbeds representative of pathway intervals), assumptions were made during this process. The fuelbeds are intended to be template fuelbeds that can be updated with more current and specific datasets as they become available. Key assumptions are listed by fuelbed stratum.

Canopy

Most FTE fuelbeds are assumed to reach canopy closure at 2 to 3 years (Campoe et al. 2013, Nutto et al. 2006). However, fuelbeds with incomplete site preparation (e.g., herbicide and/or fertilizer application) or lacking site preparation have partial canopy closure at 2-3 years with some grass and herbaceous cover (Rockwood and Peter 1997, Fox 2012). Height to live crown was estimated based on photos of very young stands and calculated for older stands based on crown ratios in the literature for various stand ages and interpolated for ages/heights that fell between those values (Campoe et al. 2013, Nutto et al. 2006). We assumed that snags would begin to occur in fuelbeds at 2-3 years. Snags were assumed to remain standing through time, moving through the three decay classes within FCCS (Prichard et al. *in press*), eventually falling and contributing to coarse woody debris in 9 to 15 years. Data on snag recruitment were lacking for *Eucalyptus* plantations, so we used loblolly plantation snag recruitment data (Samuelson et al. 2008, Zhao et al. 2011). Loblolly pine canopy data were taken from long-term studies in intensively managed pine stands (Samuelson et al. 2008, Zhao et al. 2011)

Shrubs

Shrub layers are expected to be sparse in most fuelbeds due to rapid canopy closure and herbicide applications. In ineffectively managed stands, shrubs are assumed to become established with a moderate increase in biomass and cover as the stand ages and canopy openings develop through tree mortality. Because few *Eucalyptus* plantations currently exist in the southern United States, an assumption was made that shrub vegetation would be similar in species composition, percentage cover, height and fuel loading to that of similarly managed pine plantations with comparable planting densities and cover (Miller et al. 1995, Martin and Jokela 2004, Jones et al. 2012). Shrub strata were assigned height values from 0.5 to 3.5 feet based on photos and typical heights of species included in the fuelbeds.

Shrub species typical of loblolly fuelbed understories (e.g., hollies, blueberries, blackberries, oaks, and woody vines such as greenbrier and muscadine) do not affect surface fire behavior or contribute to predicted reaction intensity. Because flammable shrub layers (e.g., wax myrtle and gallberry) have the potential to contribute to much higher reaction intensities than the neutral species assigned to the FTE and loblolly pathway fuelbeds, fuelbeds were also constructed with these species to evaluate differences in fire hazard between shrub understories common to loblolly pine plantations and scenarios in which flammable shrub understories were allowed to develop (see Additional Fuelbeds section below).

Herbs

Grasses and other herbaceous vegetation are the primary competing vegetation in young (less than 2 years old) loblolly plantations. Fuelbeds that lacked effective site preparation have substantial herbaceous cover. Species included in the *Eucalyptus* and loblolly fuelbeds were selected based on literature review of loblolly pine plantations managed at different intensities. As with the shrub stratum, an assumption was made that herbaceous vegetation would be similar in species composition, percentage cover, height and fuel loading to that of similarly managed pine plantations with comparable planting densities and percentage cover (Miller et al. 1995, Martin and Jokela 2004, Jones et al. 2012). Herbaceous vegetation was assigned a height of 8 inches, based on photos and typical heights of species included in the fuelbeds.

Downed Wood

There are no published estimates of woody fuel loads in FTE plantations. Fuel loads are expected to be negligible in new plantations. Coppice fuelbeds were assumed to inherit the same woody fuel loads as 3-4 year old biomass plantations with an estimated 10% recruitment of new woody fuels from harvest activities. Two- to three-year old plantations have an estimated 1 ton per acre of fine wood, and no coarse wood. However, pulpwood plantations with a lower stocking density were assumed to have 0.5 tons/acre of fine wood. Downed wood is assumed to increase by 20% to 4-6 year old and 7-8 year old plantations, 80% for 9-15 year old plantations and 200% in 16 to 30 year old plantations. However, fuelbeds with lower productivity associated with incomplete or ineffective site preparation, were assumed to have lower rates of woody fuel recruitment. Canopy depth, which is defined as tree height minus tree height to live crown of the overstory canopy layer, was used to inform differences in

expected rates of woody fuel recruitment. For loblolly fuelbeds, we used loblolly photo plot data for downed wood estimates (Scholl and Waldrop 1999, Reeves 1988).

Litter

Estimates of litter depth and percentage cover are lacking for FTE fuelbeds. Litter is defined as the uppermost layer of the forest floor, composed of fallen leaves and decomposing organic matter. In the literature from other regions, litterfall estimates and current litter loads are available (Cunha et al. 2005, Turner and Lambert 2002, Bernhard-Reversat 2001, Lamb 1985, Ferreira 1984). However, we were not confident in their applicability to the southern United States because reported litter decomposition rates are highly variable, ranging from a few months to 2 years with differences due to climate, *Eucalyptus* species, plantation or forest age, soil type and origin (coppice vs. seedling) (Adair et al. 2008, Moorhead et al. 1999, Ferreira 1984). José Stape (personal communication) indicated that the half-life of *Eucalyptus* litter in the southern United States is approximately 3 to 4 months, but accurate information on *Eucalyptus* litterfall for the southern United States is not available. Due to the lack of reliable data, we did not focus on decomposition rates, but rather on the characteristics of the canopy and a range of litter loads. We used our expert opinion to assign initial litter inputs for young plantations and assigned a maximum of 3.5 inches for abandoned 20-30 year-old plantations based on measures taken from the *Eucalyptus globulus* East Bay Photo Series (Wright and Vihnanek *in press*). Midpoint values were interpolated based on assumed litter accumulation rates as well as differences in canopy depth (as described in downed wood).

Duff

Duff is defined as organic soil (Oe and Oa soil horizons) and is composed of decaying organic matter. It is generally found below a litter layer in forest floors. We set a range of duff loads (0-3.5 tons/acre) based on literature from southern United States hardwood forests and *Eucalyptus* stands in other regions and interpolated midpoint values based on relationships among values used for the litter layer (Ottmar and Vihnanek 2000, Ottmar et al. 2003, Ottmar and Andreu 2007, Scholl and Waldrop 1999, Reeves 1988). FTE and loblolly pine fuelbeds are both assumed to have shallow duff layers (less than three inches). We assumed there was no duff in mechanically site prepared fuelbeds and assumed young coppice stands retained duff from pre-harvest fuelbeds.

Figure 1: Genetically engineered freeze-tolerant *Eucalyptus x urograndis* (FTE) fuelbed pathways for the southern United States. Blue highlights represent high-density stands, and red highlights represent low-density stands. Vertical arrows indicate points at which biomass or pulpwood harvests may reset pathways to stand initiation. Wildfire or coppice harvests are possible at any stage of the fuelbed pathways.

Figure 2: Loblolly pine fuelbed pathways. Vertical arrows indicate points at which pulpwood or saw timber harvests may reset pathways to stand initiation. Wildfires are possible at any stage of the fuelbed pathways.

FCCS model scenarios

Fuelbeds were calculated in FCCS version 3.0 using 18 combinations of three moisture scenarios, three mid-flame wind speeds and two slope gradients (Table 1). Environmental variables were selected to provide results at a wide range of fuel moisture and fire weather conditions that likely capture the actual variations in fuel moisture, wind speed, and slope gradients that could occur during wildfires. Further wind scenarios were tested to evaluate potential fire behavior under 10-mph, 15-mph and 20-mph winds under very dry, dry and moist fuel moisture scenarios.

Table 1: Environmental scenarios and descriptions. Midflame wind speeds include 0, 3 and 7 miles per hour (mph) and slope gradients include 0% and 15%. Moisture scenarios include very dry (1hr = 3%, 10hr = 4%, 100hr = 5%, Herb = 30%, Shrub = 60%), dry (1hr = 6%, 10hr = 7%, 100hr = 8%, Herb = 60%, Shrub = 90%), and moist (1hr = 12%, 10hr = 13%, 100hr = 14%, Herb = 60%, Shrub = 90%). Gray highlighted scenarios are most likely to occur in the Southern United States depending on season (moisture/wind) and terrain (slope) (Hollingsworth et al. 2007).

Scenario #	**Fuel moisture scenario**	**Midflame wind speed** (mph)	**Slope gradient** (%)
1	Very dry	0	0
2	Dry	0	0
3	Moist	0	0
4	Very dry	3	0
5	Dry	3	0
6	Moist	3	0
7	Very dry	7	0
8	Dry	7	0
9	Moist	7	0
10	Very dry	0	15
11	Dry	0	15
12	Moist	0	15
13	Very dry	3	15
14	Dry	3	15
15	Moist	3	15
16	Very dry	7	15
17	Dry	7	15
18	Moist	7	15

Additional fuelbeds

A set of existing fuelbeds in the potential FTE planting zone was compiled to provide a comparison to vegetation types other than pine plantations that might be converted to FTE plantations (see 1 below). We also constructed additional fuelbeds to evaluate potential fuel conditions that might contribute to fire hazard in FTE fuelbeds. These include 2-5 below:

1) Agricultural and mixed hardwood fuelbeds. Fuelbeds from the FCCS reference library were selected to represent agricultural crops and mixed hardwood forests common to the

southern United States. The mixed hardwood forests are generally 40- to 100-years old and are composed of mixed hardwoods, oak, and pine/oak/mixed hardwood.

2) Tree regeneration as a shrub stratum. Regardless of age, trees are typically included in the FCCS canopy stratum. However, young plantations of FTE and loblolly pine could be considered flammable shrublands. To evaluate the effect of modeling 0-1 year old plantations as shrublands, we created test fuelbeds that assigned all plantation trees to the shrub stratum. Due to rapid tree growth in the southern United States, resulting in distinct gaps between surface and canopy fuels, it would not be appropriate to assign young plantations to a shrub stratum in any other stage.

3) Accelerant shrubs. All FTE and loblolly pine pathway fuelbeds were constructed with flammable shrub species (*Ilex glabra*) in the shrub stratum to evaluate potential fire behavior on sites and management scenarios that support the growth of highly flammable shrub species. This evaluation is particularly applicable to pine flatwood sites that contain flammable palmetto/gallberry understories.

4) Cured (Senesced) herbaceous stratum. Dormant-season fuelbeds with dead grass in their understories were constructed to evaluate the difference in potential fire behavior between the growing season, when herbaceous biomass is mostly living, and the dormant season when herbaceous biomass is mostly dead.

5) Frost-damage. Fuelbeds were constructed to evaluate the effects of a hard freeze on FTE plantations and included leaf-on fuelbeds immediately following frost damage and leaf-off fuelbeds in which leaves had contributed to deeper litter layers.

Results and Discussion

Information from each fuelbed pathway is summarized in a table including a description, the age class, and any management actions or natural change agents associated with each fuelbed (*see TFE Pathway Handbook*). Outputs from FCCS fire behavior and potential calculations (Sandberg et al. 2007a, Sandberg et al. 2007b) were summarized in a data table for each pathway and include:

1) Surface fire behavior outputs: rate of spread (ft min^{-1}), flame length (ft) and reaction intensity (BTU $ft^{-2}min^{-1}$);
2) FCCS crown fire, surface fire and available fuel potentials (each is an index from 0-9); and
3) Fuel model crosswalks to the original Fire Behavior Prediction System (Rothermel 1972; Albini 1976) and standard fuel models (Scott and Burgan 2005).

In order to provide a comparison of a range of wildfire scenarios, outputs are provided for 18 different environmental scenarios (Table 1; see FTE Pathway Handbook for outputs). Graphical comparisons between fuelbeds were made under benchmark environmental conditions (dry fuel moisture scenario, 4 mph midflame wind speed, no slope) for consistency between predicted surface fire behavior and crown fire potentials. FCCS surface fire, crown fire and available fuel potentials for each pathway fuelbed are shown in Appendix A. Tabular outputs are provided in Appendix B. Outputs from the three additional wind scenarios (10, 15, and 20 mph) are listed in Appendix C. While these wind speeds aren't typical in the Southeast, they were included to model fire behavior in potential high wind conditions which can occur during fire season in the Southeast, most commonly during dry cold fronts.

The FCCS surface fire behavior predictions are based on a modified version of the Rothermel fire spread model (Sandberg et al. 2007a). They include:

1) Rate of spread (ft min^{-1}), defined as the predicted rate of spread of the flaming front of a surface fire under an input environmental scenario,
2) Flame length (ft), generally defined as the distance from the ground to flame tip,
3) Reaction intensity (BTU ft^{-2} min^{-1}), defined as the rate of heat release per area of the flaming front of a surface fire, expressed as heat energy per area per time.

The FCCS fire potentials are defined as indexed values (0-9) that rate the intrinsic physical capacity of a wildland fuelbed to release energy, spread, crown, consume, and smolder under benchmark dry fuel conditions, 4 mph wind speeds, and flat ground (Prichard et al. *in press*). The three fire potentials can be used to compare the potential fire behavior among fuelbeds. For example, an FCCS fire potential of 469 represents a fuelbed with a modest surface fire potential, above-average crown fire potential, and extreme potential for biomass consumption (Sandberg et al. 2007a). Comparing a FCCS potential of 469 to a FCCS potential of 222 would indicate that the second fuelbed is predicted to have lower surface fire potential, much lower

potential for crown fire and also much lower potential for biomass consumption than the first fuelbed.

- **Surface fire behavior potential** is a relative index (0-9) based on the potential maximum flame length or rate of spread. Predicted surface fire behavior is influenced by the loading, flammability, fuel moisture, and arrangement of surface fuels, including shrubs, herbaceous vegetation, fine woody fuels (< 3 inches in diameter) and litter.

- **Crown fire potential** is a relative index based on a weighted average of three crown fire subpotentials, including:
  - Crown fire initiation potential – an index (0-9) of the likelihood a surface fire will reach individual tree crowns,
  - Crown-to-crown transmissivity potential – an index (0-9) of the likelihood that a crown fire will spread through forest canopies, and
  - Crown fire spreading potential - an index (0-9) of the rate of crown fire spread.

- **Available fuel potential** represents the relative amount of combustible biomass available during the flaming, smoldering, and residual combustion stages. The available fuel potential tends to be highest in fuelbeds with high total biomass. However, a fuelbed with higher loading of finer fuels might have a higher available fuel potential than a fuelbed with higher loading of coarse fuels, because the fine fuels are more likely to be consumed. The three subpotentials (flaming, smoldering and residual smoldering) are scaled to 10 tons/acre (tpa).

The FTE, loblolly, mixed hardwood and agricultural fuelbed outputs are part of the project deliverables. Additional outputs can be calculated in FCCS using the fuelbed files provided in the final project deliverable and include fuel loading, total carbon, and summaries of fuel characteristics by stratum.

The following sections present results for each fuelbed within a pathway. Histogram comparisons are made to compare surface fire behavior (rate of spread, flame length, and reaction intensity by stratum) and crown fire potentials within and between FTE and loblolly pine pathways under benchmark environmental conditions (dry fuel moisture scenario, 4 mph midflame wind speed (wind), and no slope). FTE and loblolly pathways are presented with three-digit FCCS fire potential codes in Appendix C. Additional outputs including fuel model crosswalks are provided in the FTE Fuelbed Pathways Handbook.

<u>FTE Biomass pathway fuelbed outputs</u>

Predicted surface fire behavior is generally low for the FTE biomass pathway with rates of spread ranging from 2-5 ft min^{-1}, flame lengths ranging from 0.5 to 3 ft and reaction intensity below 3800 BTU ft^{-2} min^{-1} (Figure 3). Shrub reaction intensity is predicted to be zero in all FTE pathway fuelbeds because they contain neutral shrub species (as opposed to accelerant species) and do not contribute to predicted surface fire intensity (Prichard et al. *in press*).Under

benchmark environmental conditions (4 mph wind, no slope, and dry fuel moistures), potential surface fire behavior does not substantially differ from the loblolly pine saw timber or pulpwood pathways.

Although crown fire initiation potential is low throughout the duration of the pathway, these dense FTE stands do have the maximum crown-to-crown transmissivity and spread potential, suggesting that if a crown fire initiation does start, it could spread quickly through plantation areas. There is little difference in crown fire potential between the effective versus ineffective site preparation pathways, likely because both pathways exhibit maximum crown-to-crown transmissivity and crown fire rate of spread potentials.

Compared to ineffective site preparation, the effective site preparation pathway prevents herbaceous undergrowth and results in lower predicted surface fire behavior in early stages. Due to lower tree density and cover, herbaceous vegetation remains a dominant fuel in the ineffective site preparation pathway, reflecting lower tree growth and more grassy openings in the forest floor.

FTE Pulpwood pathway fuelbed outputs

Potential surface fire behavior is low for the FTE pulpwood pathway with results similar to the FTE biomass pathway (Figure 4). Predicted rates of spread range from 2 to 7 ft min^{-1}, flame lengths range from 0.5 to 3 ft, and reaction less than 3400 BTU ft^2 min^{-1}. Ineffective site preparation has much higher predicted rate of spread and flame length than the effective site prep fuelbed at 0-1 yr. Herbaceous fuels remain a dominant fuel type throughout the ineffective site prep pathway.

The effective site preparation pathway for the FTE pulpwood plantations has similar crown fire potentials to the biomass pathway with low crown fire initiation potential but high spread potential if crown fires were to occur. The ineffective site preparation pathway has somewhat lower crown fire potentials, reflecting the lower tree density and cover in these plantations. However, crown fire initiation potential is higher due to the contribution of the herbaceous layer to surface reaction intensity.

FTE Coppice pathway fuelbed outputs

Although the coppice fuelbeds inherit litter from biomass and pulpwood plantations, litter is not a major contributor to predicted surface reaction intensity (Figure 5) compared to other strata. Predicted surface fire behavior is very similar to the biomass and pulpwood pathways with rates of spread ranging from 2.5 to 6 ft min^{-1}, flame lengths ranging from 1.2 to 3.6 ft, and reaction intensity values ranging from 700 to 3300 BTU ft^2 min^{-1}.

Coppice pathway fuelbeds have similar crown fire potential to the biomass and pulpwood pathway fuelbeds, reflecting similar canopy characteristics of high stocking but relatively low crown fire initiation potential.

Ineffective site preparation (i.e., herbicide application) of coppice plantations allows for herbaceous fuels to be a dominant fuel type and contributes to higher predicted reaction intensities. However, predicted rates of spread and flame lengths are actually higher in the effective site preparation pathway because woody fuel and litter depths are higher in effectively managed stands due to assumption of crown depth relationship to those strata. That is, more vigorous stands were assumed to have larger crowns that could contribute more branches and leaves to those fuelbed strata.

Figure 3: FTE biomass pathway including A) effective site preparation and B) ineffective site preparation. Fert. = fertilization, Herb. = herbicide treatment.

Figure 4: FTE pulpwood including A) effective site preparation and B) ineffective site preparation. Fert. = fertilization, Herb. = herbicide treatment.

Figure 5: FTE coppice pathway A) effective site preparation and B) ineffective site preparation. Fert. = fertilization, Herb. = herbicide treatment, Thin = mechanical thinning.

Loblolly Saw timber pathway fuelbed outputs

The loblolly saw timber fuelbeds are dominated by litter and woody fuels with only a minor component of herbaceous fuels (Figure 6). Surface fire behavior predictions are only fractionally lower than FTE pathway fuelbeds with rates of spread between 0.5 to 5 ft min^{-1}, flame lengths less than 2.5 ft, and reaction intensity values less than 1700 BTU ft^2 min^{-1}. Surface fire behavior generally increases over the life of the stands but is not considerably different between harvest age (16-19 yr) and over-mature stands (20-30 yr).

Although the crown-to-crown transmissivity potential of loblolly saw timber plantations is high, they have a relatively low probability of crown fire initiation and only moderate potential for spread, reflecting relatively low surface fire behavior potential and that plantations are regularly thinned.

Loblolly Pulpwood pathway fuelbed outputs

The loblolly pulpwood pathway has somewhat higher predicted fire behavior than the loblolly saw timber pathway (Figure 7). Surface fire behavior is somewhat higher than FTE pathway fuelbeds with rates of spread between 0.5 and 5 ft min^{-1}, flame lengths between 0.3 and 4 ft, and reaction intensity values between 100 and 3500 BTU ft^2 min^{-1}. Ineffective site prep leaves a legacy of more herbaceous vegetation, which contributes to higher predicted reaction intensities but no corresponding increase in ROS and FL. Loblolly pulpwood plantations also have high crown-to-crown transmissivity potential but low crown fire initiation potentials and only moderate spreading potential.

Loblolly Sawtimber
Effective site prep

Figure 6: Loblolly saw timber pathway. Fert. = fertilization, Herb. = herbicide treatment, Thin = mechanical thinning.

Figure 7: Loblolly pathway including A) effective site preparation and B) ineffective site preparation. Fert. = fertilization, Herb. = herbicide treatment.

Additional fuelbeds and environmental scenarios

Additional fuelbeds were created to evaluate conditions that could potentially lead to increased fire hazard and had mixed effects on potential surface and crown fire behavior.

1) Agricultural and mixed hardwood fuelbeds

Agricultural fuelbeds vary widely in their potential surface fire behavior under benchmark environmental inputs (Figure 8). All agricultural fuelbeds represent post-harvest crop residues. Growing season fuelbeds were not constructed because croplands are not considered flammable while they are green and regularly irrigated. The most flammable crop is the rice residue with extremely high rate of spread predictions (159 ft min^{-1}) and flame lengths (32 ft). Other major crops include corn, cotton and soybeans, with predicted rates of spread ranging from 20 to 55 ft min^{-1} and flame lengths ranging from 2.0 to 7.3 ft. Although these results suggest that replacement of crop residues with FTE plantations would not lead to higher surface fire behavior, the risk of fire spread through continuous forest canopies could be possible if FTE plantations replaced croplands adjacent to existing forestlands.

The mixed hardwood, oak and mixed hardwood/pine fuelbeds were selected from the FCCS library of reference fuelbeds. They generally range in age from 40-100 years old and have more developed woody fuel and litter layers than the younger FTE and loblolly pine pathway fuelbeds. Predicted rates of spread range from 1 to 12 ft min^{-1}, and flame lengths less than 5 ft (Figure 9). Crown fire potentials are low in all mixed hardwood fuelbeds because broadleaf deciduous canopies are mostly composed of neutral species that do not contribute to predicted crown fire potential (Appendix A). These results suggest that replacement of mixed hardwood forests with FTE fuelbeds would not lead to increased fire risk.

2) Tree regeneration as a shrub stratum

Comparison of FCCS predictions between treating young plantations as a canopy versus shrub layer produce markedly different surface fire behavior predictions. When FTE trees less than a year old are entered as a canopy layer, FCCS predicts only low surface fire behavior (e.g., with surface fire potential index of 2 or 3). Predicted ROS ranges between 2.5 and 7 ft min^{-1} and flame lengths range from 0.5 to 3 ft, depending on whether fuelbeds received effective site preparation or not (Figure 9).

In contrast, when FTE trees less than a year old are input into the shrub stratum, FCCS predicts much higher surface fire behavior. Predicted ROS and FL are at least five times higher when FTE is input as a shrub layer in FCCS. For the most conservative estimate of potential surface fire behavior (e.g., rates of spread, flame length and reaction intensity), young, 0-1 year old FTE should be considered as a shrub stratum for FCCS calculations.

Figure 8: Predicted surface fire behavior for agricultural and mixed hardwood fuelbeds from the FCCS reference fuelbed library.

Figure 9: Predicted surface fire behavior for recent (0-1 year old) FTE and loblolly pulpwood plantations with FTE input as a shrub (ROS_shrub, FL_shrub, and RI_shrub) and as a typical canopy layer (ROS, FL, and RI). Initial fuelbeds from each of the six FTE pathways are represented, including biomass with effective site prep (BioPrep), biomass with ineffective site prep (Bio), pulpwood with effective site prep. (PulpPrep), pulpwood with ineffective site prep (Pulp), coppice with effective site prep (Coppice_Prep), and coppice with ineffective site prep (Coppice).

3) Accelerant shrubs

Because the shrub species in FTE and loblolly pathway fuelbeds are considered neutral species and do not contribute to predicted surface reaction intensity, we evaluated the potential effect of accelerant species on predicted fire behavior. Replacement of shrub species with accelerant species increased predicted surface fire behavior in young plantations, which are more open grown and support more shrub cover than older stages (Figure 10).

Figure 10: Comparison of predicted rates of spread (ROS) and flame lengths (FL) in FTE biomass and pulpwood pathway fuelbeds with regular shrub species (ROS/FL) and accelerant species (ROS_accelShrub and FL_accelShrub). Only ineffective site prep pathways are displayed because effective site prep pathways do not contain a developed shrub stratum.

4) Cured herbaceous stratum

We examined the potential influence of cured herbaceous fuels on predicted rates of spread and flame lengths. In some locations, grasses and other herbaceous fuels may be mostly composed of dead biomass during the dormant (winter) season. Because dead grasses have lower fuel moistures than living grasses, predicted surface fire behavior is indeed higher in fuelbeds with a 100% dead herbaceous stratum, suggesting that potential fire behavior may be greater during dormant season wildfires (Figure 11).

Figure 11: Comparison of predicted rates of spread (ROS) and flame lengths (FL) in FTE biomass and pulpwood pathway fuelbeds with regular herbaceous fuels (ROS/FL) and cured herbaceous fuels (ROS_deadHerb and FL_deadHerb). Only ineffective site prep pathways are displayed because effective site prep pathways do not contain a developed herbaceous stratum.

5) Freeze damage

We compared normal FTE pathway fuelbeds to fuelbeds at stand ages that had been damaged by a hard freeze. Recent, freeze-damaged with retained leaves have no difference in predicted surface fire behavior, which would be expected given that surface fuel characteristics remain unchanged (Figure 12). However, there is a sharp increase in predicted surface fire behavior in the leaf-off fuelbed, resulting from the large increase in litter fuels. The pronounced drop in crown fire potentials is likely an artifact of the FCCS crown fire model; trees with dead foliage were reassigned to snags and were not considered flammable.

Figure 12: Comparison of FTE biomass and pulpwood fuelbeds under normal conditions (normal), immediately after frost damage in which the canopy has been killed (freeze), and following leaf-drop (leaf off).

6) Extreme wind scenarios.

Examination of predicted rates of spread and flame lengths under high winds (10, 15, and 20 mph) relative to the FCCS benchmark 4 mph wind speed demonstrates a close relationship between fire behavior and wind speed (Figure 13). There is a potential for high rates of spread, particularly in young plantations with high herbaceous cover following ineffective site preparation and also in abandoned plantations. Trends are markedly similar between FTE and loblolly plantations. Loblolly pulpwood plantations with ineffective site prep have the highest predicted rates of spread and flame lengths, suggested greater fire risk in loblolly pine plantations than the FTE plantations.

Figure 13: Influence of wind speed scenario on predicted rate of spread (ROS, left column) and flame lengths (FL, right column) for FTE and loblolly pulpwood fuelbeds.

Conclusions

We evaluated potential fire behavior for FTE fuelbeds and compared to fuelbeds that are common in the southern United States. Overall, we conclude that FTE fuelbeds do not pose a substantially higher fire risk than southern pine plantations. Predicted fire behavior in agricultural and mixed hardwood fuelbeds was generally higher than the FTE fuelbeds.

Young (0-1 year-old) FTE plantations may pose a short-term fire risk, particularly under high wind scenarios and if a fire occurs in the dormant season when the majority of herbaceous biomass is dead. If FTE plantations do not receive effective site preparation, understory herbaceous vegetation may contribute to moderate surface fire behavior potential. In addition, if FTE is planted on sites that typically have flammable shrubs in their understories (e.g., wax myrtle or gallberry), effective site preparation may be required to reduce the risk of shrub development and associated fire hazard (Goodrick and Stanturf 2012). Frost damage would likely result in a short-term increase in surface fire potential associated with leaf-fall and an increased litter layer.

Due in part to low to moderate surface fire behavior potential, FTE plantations generally had low crown fire initiation potential. However, in the event that crown fire initiation did occur, FTE plantations have a high risk of crown fire spread. Active management to reduce surface fuels, including flammable shrub layers and herbaceous fuels, would be important to reduce the risk of crown fire initiation.

Potential fire behavior generally increases over time in each FTE pathway as litter and woody fuels accumulate. We evaluated fuelbeds that represent abandoned FTE and loblolly plantations that were 20 to 30 years old. Under these conditions, potential fire hazard is only moderate and does not markedly differ between FTE and loblolly pine plantations. However, if plantations were allowed to continue to grow, we would expect that ladder fuels could develop and lead to a high potential for crown fire initiation and spread.

Assumptions and limitations

Because we lacked actual stand exam and surface fuel survey data for the FTE fuelbeds, our results and interpretations should be considered preliminary. The fuelbeds are intended to provide a logical and systematic exploration of potential fire risks in FTE plantations in the southern United States. The following are key assumptions made in fuelbed construction that could have substantial impacts on our fire hazard assessment for FTE plantations.

1) Understory species composition was assumed to be comparable to typical southern pine plantations. However, if individual sites have flammable understory shrubs such as gallberry or wax myrtle predicted surface fire behavior would be considerably higher (Figure 11).
2) To remain consistent with standard FCCS fuelbed development, 0-1 year old FTE and loblolly pine plantations are represented as short tree canopy layers in this report. However, if trees less than a year old are considered as shrubs, they are treated as flammable shrub layers by FCCS and the predicted surface fire behavior increases dramatically (Figure 9). For the most

conservative estimate of fire risk, we recommend using the fuelbeds constructed with 0-1 year FTE as a shrub layer.

3) Decomposition rates are assumed to be high in the southern United States, so accumulations of litter over time is considered to be low.

4) Although FTE bark does not slough off in large strips as in some species of *Eucalyptus*, we did notice substantial sloughing of bark flakes in photographs of FTE plantations. The contribution of FTE bark to litter reaction intensity has not been fully accounted for in our fuelbeds. Incorporation of a litter and/or bark layer would require some field sampling to accurately reflect the bulk density and decomposition rates of the fuels.

5) Fine woody fuel surveys would be required to more accurately represent this fuelbed component. Because we assumed that FTE plantations would have similar woody fuel loads as loblolly plantations, we didn't expect any difference in predicted surface fire behavior.

Data gaps

The following data would be needed to improve characterization of FTE fuels and provide more reliable predictions of fire hazard:

1) Forest inventory plots to provide important canopy inputs including tree height, height to live crown, tree density and forest cover across management scenarios and plantation ages.
2) Understory vegetation surveys including shrub and herbaceous species, relative cover, height, percent cover by ground projection, and fuel loading.
3) Downed woody fuel inventories by size class with particular emphasis on fine wood (1-hr, 10-hr, and 100-hr fuels for surface fire behavior prediction).
4) Forest floor inventories to measure litter depth, bark slough, percent cover and bulk density.

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Appendix A

Figure A1: Pathway diagram for genetically-engineered freeze-tolerant *Eucalyptus x urograndis* fuelbeds with 3-digit FCCS summary codes. The 3-digit code presents predicted surface fire behavior (red), crown fire behavior (blue) and available fuel potentials respectively (green) as a 0-9 index value.

Figure A2: Pathway diagram for loblolly pine fuelbeds with 3-digit FCCS summary codes. The 3-digit code presents predicted surface fire behavior (red), crown fire behavior (blue) and available fuel potentials respectively (green) as a 0-9 index value.

Appendix B: FCCS outputs for FTE and loblolly pine pathways under benchmark environmental conditions

Table B1: FCCS fire behavior predictions at default environmental conditions for genetically engineered freeze-tolerant *Eucalyptus x urograndis* pathway fuelbeds. Default environmental conditions are 4 mph midflame wind speed, 0% slope gradient and dry fuel moisture scenario (Table 1). Surface fire behavior outputs include reaction intensity (BTU $ft^{-2}min^{-1}$), shrub, herbaceous vegetation, woody fuel, and litter reaction intensities (BTU $ft^{-2}min^{-1}$), flame length (m), and rate of spread (ft min^{-1}). Suggested crosswalks to the original 13 fire behavior fuel models (Rothermel 1972, Albini 1976) and standard 40 fire behavior fuel models (Scott and Burgan 2005) are also included, along with the percentage difference between the fuel model-defined and FCCS-predicted rates of spread and flame lengths.

Fuelbed #	Age Class	Rate of Spread	Flame Length	Reaction Intensity	Shrub RI	Herb RI	Woody RI	Litter RI	Crosswalk FBPS FMs	Percent Difference ROS	Percent Difference FL	Crosswalk Standard Fuel Models	Percent Difference ROS	Percent Difference FL
	yr	ft/min	ft	---------- BTU/ft2/min ----------						%	%		%	%
1301	0-1	2.5	0.5	161.8	0.0	161.8	0.0	0.0	8	151.2	45.7	183	191.9	50.7
1302	0-1	5.1	2.1	2180.5	0.0	2136.2	0.0	44.3	9	75.2	84.1	183	394.4	233.6
1303	0-1	2.5	0.5	161.8	0.0	161.8	0.0	0.0	8	151.2	45.7	183	191.9	50.7
1304	0-1	7.0	2.8	3032.6	0.0	2978.5	0.0	54.1	9	102.9	113.1	189	101.7	65.7
1305	0-1	2.7	1.2	796.6	0.0	201.6	187.1	407.9	8	161.1	121.1	185	78.2	63.7
1306	2-3	3.7	2.1	2719.9	0.0	2299.4	147.7	272.7	9	53.8	84.2	183	282.3	233.8
1307	2-3	2.3	0.9	524.5	0.0	0.0	116.5	407.9	8	138.6	92.4	183	175.9	102.6
1309	2-3	3.5	2.0	2514.9	0.0	2108.4	133.8	272.7	8	212.7	198.5	186	79.8	86.3
1310	2-3	2.8	1.1	752.9	0.0	222.6	122.4	407.9	8	167.6	113.7	185	81.3	59.8
1312	2-3	3.6	2.1	3141.5	0.0	2820.6	48.2	272.7	9	53.1	85.8	183	278.7	238.4
1313	2-3	2.9	1.3	665.8	0.0	0.0	257.9	407.9	8	177.7	128.8	185	86.2	67.8
1314	2-3	2.4	1.6	2109.5	0.0	1639.5	197.3	272.7	8	148.5	161.3	186	55.7	70.1
1315	4-6	2.8	1.1	546.7	0.0	0.0	138.7	407.9	8	168.4	105.4	184	146.3	87.8
1316	4-6	5.7	2.1	1574.0	0.0	0.0	138.7	1435.2	9	84.0	83.6	183	440.5	232.2
1317	4-6	2.8	1.1	546.7	0.0	0.0	138.7	407.9	8	168.4	105.4	184	146.3	87.8
1318	4-6	2.6	1.7	2266.4	0.0	1809.6	184.1	272.7	8	158.6	169.9	186	59.5	73.9
1319	4-6	2.9	0.8	417.9	0.0	0.0	10.0	407.9	8	177.7	78.2	183	225.5	86.9
1320	4-6	2.9	1.8	2665.5	0.0	2329.6	63.2	272.7	8	176.7	181.5	186	66.3	78.9
1349	4-6	3.5	1.5	724.3	0.0	0.0	316.4	407.9	8	210.0	148.7	185	101.9	78.3

Fuelbed #	Age Class	Rate of Spread	Flame Length	Reaction Intensity	Shrub RI	Herb RI	Woody RI	Litter RI	Crosswalk FBPS FMs	Percent Difference ROS	Percent Difference FL	Crosswalk Standard Fuel Models	Percent Difference ROS	Percent Difference FL
1321	4-6	2.6	1.7	2038.9	0.0	1495.6	270.6	272.7	8	158.6	169.6	186	59.5	73.7
1322	7-8	3.3	0.8	419.6	0.0	0.0	11.7	407.9	8	200.8	83.2	183	254.8	92.5
1323	7-8	3.1	1.9	2708.7	0.0	2358.7	77.2	272.7	8	187.5	188.9	186	70.3	82.1
1324	9-15	4.0	1.9	1269.9	0.0	422.4	439.6	407.9	8	241.7	194.8	186	90.7	84.7
1325	9-15	4.2	2.4	2904.6	0.0	2291.1	340.9	272.7	9	61.3	97.9	186	95.0	106.4
1350	9-15	5.7	2.5	1419.8	0.0	415.7	596.2	407.9	9	84.0	101.2	188	124.5	84.3
1326	9-15	2.7	1.9	2316.7	0.0	1568.2	475.8	272.7	8	162.7	193.3	186	61.0	84.1
1327	16-30	5.2	3.0	2086.1	0.0	627.2	1050.9	407.9	9	75.9	120.6	189	75.0	70.1
1328	16-30	3.8	3.0	3727.9	0.0	2480.5	974.7	272.7	9	55.9	118.1	189	55.2	68.6
1329	16-30	5.9	2.2	1188.5	0.0	431.4	349.2	407.9	9	86.1	87.3	183	451.5	242.6
1330	16-30	5.2	2.8	3355.3	0.0	2822.2	260.4	272.7	9	76.2	111.5	188	113.0	92.9
1351	16-30	5.5	3.6	2643.0	0.0	620.7	1614.4	407.9	9	80.2	145.2	189	79.3	84.4
1331	16-30	3.3	2.6	3270.4	0.0	2048.2	949.5	272.7	9	47.8	105.5	188	70.8	87.9

Table B2: FCCS fire behavior predictions at default environmental conditions for loblolly pine (*Pinus taeda*) pathway fuelbeds. Default environmental conditions are 4 mph midflame wind speed, 0% slope gradient and dry fuel moisture scenario (Table 1). Surface fire behavior outputs include reaction intensity (BTU $ft^{-2}min^{-1}$), shrub, herbaceous vegetation, woody fuel, and litter reaction intensities (BTU $ft^{-2}min^{-1}$), flame length (m), and rate of spread (ft min^{-1}). Suggested crosswalks to the original 13 fire behavior fuel models (Rothermel 1972, Albini 1976) and standard 40 fire behavior fuel models (Scott and Burgan 2005) are also included, along with the percentage difference between the fuel model-defined and FCCS-predicted rates of spread and flame lengths.

Fuelbed #	Age Class	Rate of Spread	Flame Length	Reaction Intensity	Shrub RI	Herb RI	Woody RI	Litter RI	Crosswalk FBPS FMs	Percent Difference ROS	Percent Difference FL	Crosswalk Standard Fuel Models	Percent Difference ROS	Percent Difference FL
	yr	ft/min	ft	---------- BTU/ft2/min ----------						%	%		%	%
1352	0-1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2	0.0	0.0	121	0.0	0.0
1353	0-1	14.6	3.6	2466.3	0.0	2466.3	0.0	0.0	6	52.1	66.8	142	635.2	189.8
1332	2-3	0.4	0.3	99.0	0.0	0.0	99.0	0.0	8	26.0	28.9	181	61.4	57.7
1333	2-3	4.4	2.2	2695.7	0.0	2601.9	39.2	54.5	9	63.9	87.5	183	335.0	243.0
1334	4-6	1.3	0.7	447.0	0.0	0.0	97.6	349.4	8	80.1	70.2	183	101.6	78.0
1335	4-6	1.3	0.7	447.0	0.0	0.0	97.6	349.4	8	80.1	70.2	183	101.6	78.0
1336	4-6	5.0	2.7	3427.6	0.0	2905.4	214.5	307.7	9	73.0	109.0	188	108.3	90.9
1337	7-11	3.2	1.9	1408.3	0.0	363.6	419.9	624.8	8	195.8	185.0	186	73.4	80.4
1338	7-11	3.2	1.9	1408.3	0.0	363.6	419.9	624.8	8	195.8	185.0	186	73.4	80.4
1340	7-11	2.5	2.0	2636.9	0.0	1813.2	516.1	307.7	8	150.7	197.2	186	56.5	85.7
1341	12-15	3.3	1.1	681.5	0.0	54.8	2.0	624.8	8	201.4	111.4	184	174.9	92.8
1342	12-15	4.2	1.2	651.3	0.0	26.3	0.2	624.8	8	255.7	121.9	185	124.1	64.2
1344	12-15	2.2	1.7	1816.7	0.0	1012.8	496.2	307.7	8	135.5	167.2	186	50.8	72.7
1345	16-19	4.9	2.5	1637.5	0.0	372.6	640.2	624.8	9	71.3	100.7	188	105.7	84.0
1346	20-30	4.9	2.4	1581.7	0.0	372.9	584.1	624.8	9	71.3	98.0	186	110.4	106.5
1347	20-30	4.8	2.4	1581.7	0.0	372.9	584.1	624.8	9	70.0	97.2	186	108.4	105.6
1348	20-30	2.8	2.1	2682.7	0.0	1821.3	553.8	307.7	9	40.5	84.1	183	212.6	233.7

Table B3: FCCS predicted fire potentials (0-9 index) for genetically-engineered freeze tolerant *Eucalyptus x urograndis* pathway fuelbeds. The surface fire potential summary potential has three sub-potentials (reaction potential, spread potential, and flame length potential). The crown fire summary potential has three sub-potentials (crown initiation potential, crown to crown transmissivity potential, and crown fire spread potential). The available fuel summary potential three sub-potentials (flame available potential, smolder available potential, and residual smolder potential).

Fuelbed #	Age Class	Surface fire summary potential	Reaction potential	Spread potential	Flame length potential	Crown fire summary potential	Crown initiation potential	Crown-crown transmissivity potential	Crown fire spread potential	Available fuel summary potential	Flame available potential	Smolder available potential	Residual smolder potential
1301	0-1	3.16	1.02	3.16	1.35	5.87	3.94	8.85	6.81	0.48	0.48	0.00	0.00
1302	0-1	4.53	3.74	4.53	2.90	2.12	0.00	4.75	3.36	0.58	0.58	0.00	0.00
1303	0-1	3.16	1.02	3.16	1.35	4.25	3.94	4.75	4.41	0.32	0.32	0.00	0.00
1304	0-1	5.30	4.41	5.30	3.36	1.27	0.00	0.00	2.96	0.58	0.58	0.00	0.00
1305	0-1	3.26	2.26	3.26	2.20	5.54	5.28	9.00	4.65	1.19	1.04	0.15	0.00
1306	2-3	3.83	4.17	3.83	2.90	2.45	0.00	6.60	3.51	0.78	0.64	0.15	0.00
1307	2-3	3.02	1.83	3.02	1.92	5.63	2.26	9.00	7.87	2.24	2.09	0.15	0.00
1309	2-3	3.75	4.01	3.75	2.82	4.81	5.30	6.60	3.74	0.89	0.74	0.15	0.00
1310	2-3	3.33	2.20	3.33	2.13	4.24	2.38	8.85	4.56	2.05	1.91	0.15	0.00
1312	2-3	3.81	4.48	3.81	2.93	4.43	4.59	6.60	3.54	0.88	0.74	0.15	0.00
1313	2-3	3.42	2.06	3.42	2.27	5.94	2.50	9.00	8.36	2.57	2.42	0.15	0.00
1314	2-3	3.13	3.67	3.13	2.54	4.93	4.29	8.85	4.27	1.03	0.89	0.15	0.00
1317	4-6	3.33	1.87	3.33	2.05	4.98	1.40	9.00	7.23	1.74	1.58	0.15	0.02
1318	4-6	3.23	3.81	3.23	2.61	4.02	1.91	8.51	4.65	1.17	1.02	0.15	0.00
1319	4-6	3.42	1.64	3.42	1.77	5.64	1.16	9.00	9.00	1.98	1.82	0.15	0.02
1320	4-6	3.42	4.13	3.42	2.69	3.86	1.87	8.12	4.43	1.21	1.06	0.15	0.00
1349	4-6	3.72	2.15	3.72	2.44	5.21	1.55	9.00	7.61	1.99	1.84	0.15	0.00
1321	4-6	3.24	3.61	3.24	2.60	4.40	1.90	9.00	5.36	1.33	1.18	0.15	0.00
1322	7-8	3.64	1.64	3.64	1.82	5.57	1.00	9.00	9.00	4.71	4.34	0.20	0.17
1323	7-8	3.52	4.16	3.52	2.75	4.27	1.56	8.12	5.70	2.52	2.28	0.19	0.05
1324	9-15	3.99	2.85	3.99	2.79	5.71	1.46	9.00	8.86	4.88	4.33	0.24	0.31
1325	9-15	4.09	4.31	4.09	3.13	4.84	1.75	8.12	6.84	3.00	2.51	0.24	0.25
1350	9-15	4.79	3.01	4.79	3.18	5.81	1.56	9.00	9.00	5.63	5.06	0.25	0.32
1326	9-15	3.28	3.85	3.28	2.78	4.96	1.73	9.00	6.84	2.94	2.44	0.24	0.26

Fuelbed #	Age Class	Surface fire summary potential	Reaction potential	Spread potential	Flame length potential	Crown fire summary potential	Crown initiation potential	Crown-crown transmissivity potential	Crown fire spread potential	Available fuel summary potential	Flame available potential	Smolder available potential	Residual smolder potential
1327	16-30	4.55	3.65	4.55	3.47	5.88	1.71	9.00	9.00	9.00	5.82	0.35	4.27
1328	16-30	3.90	4.88	3.90	3.44	4.80	1.85	7.69	6.78	5.43	3.30	0.35	1.79
1329	16-30	4.85	2.76	4.85	2.96	5.75	1.40	9.00	9.00	7.68	6.29	0.34	1.06
1330	16-30	4.56	4.63	4.56	3.34	5.02	1.70	7.69	7.45	4.43	3.43	0.34	0.67
1351	16-30	4.68	4.11	4.68	3.81	5.90	1.77	9.00	9.00	9.00	7.02	0.37	6.52
1331	16-30	3.61	4.58	3.61	3.25	5.24	1.91	9.00	7.31	4.69	3.18	0.35	1.16

Table B4: FCCS predicted fire potentials (0-9 index) for loblolly pine (*Pinus taeda*) pathway fuelbeds. The surface fire summary potential has three sub-potentials (reaction potential, spread potential, and flame length potential). The crown fire summary potential has three sub-potentials (crown initiation potential, crown to crown transmissivity potential, and crown fire spread potential). The available fuel summary potential has three sub-potentials (flame available potential, smolder available potential, and residual smolder potential).

Fuelbed #	Age Class	Surface fire summary potential	Reaction potential	Spread potential	Flame length potential	Crown fire summary potential	Crown initiation potential	Crown-crown transmissivity potential	Crown fire spread potential	Available fuel summary potential	Flame available potential	Smolder available potential	Residual smolder potential
1352	0-1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.10	0.00	0.00
1353	0-1	7.64	3.97	7.64	3.80	0.86	0.00	0.00	2.00	0.44	0.44	0.00	0.00
1332	2-3	1.31	0.80	1.31	1.07	1.17	1.44	0.00	1.29	0.29	0.21	0.05	0.04
1333	2-3	4.17	4.15	4.17	2.96	2.32	3.79	0.00	1.61	0.37	0.28	0.05	0.04
1334	4-6	2.30	1.69	2.30	1.68	3.46	1.70	8.85	3.43	1.16	1.07	0.05	0.04
1335	4-6	2.30	1.69	2.30	1.68	3.48	1.67	8.85	3.50	1.19	1.10	0.05	0.04
1336	4-6	4.46	4.68	4.46	3.30	2.38	3.50	0.00	2.06	1.13	0.74	0.37	0.02
1337	7-11	3.59	3.00	3.59	2.72	3.84	2.12	9.00	3.84	1.52	1.37	0.11	0.05
1338	7-11	3.59	3.00	3.59	2.72	3.86	2.08	9.00	3.91	1.59	1.44	0.11	0.05
1340	7-11	3.15	4.11	3.15	2.81	3.12	2.53	7.19	2.35	1.07	0.86	0.18	0.03
1341	12-15	3.65	2.09	3.65	2.11	4.66	1.65	9.00	6.21	2.33	1.98	0.27	0.09
1342	12-15	4.11	2.04	4.11	2.21	5.14	1.73	9.00	7.27	2.75	2.14	0.14	0.46
1344	12-15	2.99	3.41	2.99	2.59	3.43	2.30	8.85	2.76	1.63	1.28	0.20	0.15
1345	16-19	4.41	3.24	4.41	3.17	4.18	2.27	9.00	4.48	2.33	1.96	0.32	0.06
1346	20-30	4.41	3.18	4.41	3.13	4.39	2.12	9.00	5.13	2.72	2.35	0.31	0.07

Appendix C: FCCS fire behavior predictions for high wind scenarios (10, 15 and 25 mph)

Table C1: FCCS fire behavior predictions at 10 mph midflame wind speed for genetically engineered freeze-tolerant *Eucalyptus x urograndis* pathway fuelbeds. FCCS predictions are calculated at 10 mph midflame wind speed, 0% slope gradient and dry fuel moisture scenario (Table 1). Surface fire behavior outputs include reaction intensity (BTU $ft^{-2}min^{-1}$), shrub, herbaceous vegetation, woody fuel, and litter reaction intensities (BTU $ft^{-2}min^{-1}$), flame length (ft), and rate of spread (ft min^{-1}). Suggested crosswalks to the original 13 fire behavior fuel models (Rothermel 1972, Albini 1976) and standard 40 fire behavior fuel models (Scott and Burgan 2005) are also included, along with the percentage difference between the fuel model-defined and FCCS-predicted rates of spread and flame lengths.

Fuelbed #	Age Class	Rate of Spread	Flame Length	Reaction Intensity	Shrub	Herb	Woody	Litter	Crosswalk FBPS FMs	Percent Difference ROS	Percent Difference FL	Crosswalk Standard FMs	Percent Difference ROS	Percent Difference FL
	yr	ft/min	ft	---------- BTU/ft^2/min ----------						%	%		%	%
1301	0-1	9.5	0.8	161.8	0.0	161.8	0.0	0.0	2	30.9	14.8	121	84.6	30.1
1302	0-1	19.3	3.9	2180.5	0.0	2136.2	0.0	44.3	6	68.9	71.7	142	840.9	203.7
1303	0-1	9.5	0.8	161.8	0.0	161.8	0.0	0.0	2	30.9	14.8	121	84.6	30.1
1304	0-1	26.5	5.2	3032.6	0.0	2978.5	0.0	54.1	6	94.3	96.4	144	127.2	89.7
1305	0-1	6.9	1.9	796.6	0.0	201.6	187.1	407.9	8	417.1	187.6	186	156.4	81.6
1306	2-3	13.7	3.9	2719.9	0.0	2299.4	147.7	272.7	6	48.7	71.3	142	593.6	202.7
1307	2-3	5.4	1.4	524.5	0.0	0.0	116.5	407.9	8	328.0	137.3	185	159.2	72.3
1309	2-3	13.1	3.6	2514.9	0.0	2108.4	133.8	272.7	6	46.6	67.3	142	568.6	191.4
1310	2-3	7.3	1.8	752.9	0.0	222.6	122.4	407.9	8	442.8	177.7	186	166.0	77.3
1312	2-3	13.6	3.9	3141.5	0.0	2820.6	48.2	272.7	6	48.4	72.9	142	589.7	207.3
1313	2-3	6.9	1.9	665.8	0.0	0.0	257.9	407.9	8	420.6	191.4	186	157.7	83.2
1314	2-3	8.3	2.8	2109.5	0.0	1639.5	197.3	272.7	9	122.0	113.2	164	92.4	57.8
1317	4-6	6.6	1.6	546.7	0.0	0.0	138.7	407.9	8	398.7	156.6	186	149.5	68.1
1318	4-6	9.7	3.1	2266.4	0.0	1809.6	184.1	272.7	11	179.6	100.0	202	84.9	58.5
1319	4-6	6.9	1.2	417.9	0.0	0.0	10.0	407.9	8	420.6	116.2	185	204.1	61.2
1320	4-6	10.8	3.3	2665.5	0.0	2329.6	63.2	272.7	11	201.3	107.2	202	95.2	62.7
1349	4-6	8.2	2.2	724.3	0.0	0.0	316.4	407.9	11	152.2	71.3	201	170.9	81.9
1321	4-6	9.2	3.0	2038.9	0.0	1495.6	270.6	272.7	11	171.3	97.7	201	192.4	112.2
1322	7-8	7.8	1.2	419.6	0.0	0.0	11.7	407.9	2	25.6	21.7	121	70.0	44.2
1323	7-8	10.3	3.3	2708.7	0.0	2358.7	77.2	272.7	11	191.7	106.1	202	90.6	62.1

Fuelbed #	Age Class	Rate of Spread	Flame Length	Reaction Intensity	Shrub	Herb	Woody	Litter	Crosswalk FBPS FMs	Percent Difference ROS	Percent Difference FL	Crosswalk Standard FMs	Percent Difference ROS	Percent Difference FL
1324	9-15	10.5	3.0	1269.9	0.0	422.4	439.6	407.9	11	195.1	98.2	201	219.0	112.7
1325	9-15	15.4	4.5	2904.6	0.0	2291.1	340.9	272.7	6	55.0	82.7	142	671.0	234.9
1350	9-15	15.0	3.9	1419.8	0.0	415.7	596.2	407.9	6	53.4	72.9	142	651.1	207.2
1326	9-15	8.8	3.3	2316.7	0.0	1568.2	475.8	272.7	9	129.5	133.7	164	98.1	68.2
1327	16-30	13.4	4.7	2086.1	0.0	627.2	1050.9	407.9	10	179.0	99.3	164	148.8	95.2
1328	16-30	13.9	5.4	3727.9	0.0	2480.5	974.7	272.7	10	186.1	114.0	163	70.0	85.0
1329	16-30	15.5	3.4	1188.5	0.0	431.4	349.2	407.9	6	55.4	63.3	142	675.4	179.8
1330	16-30	19.3	5.1	3355.3	0.0	2822.2	260.4	272.7	6	68.9	94.5	144	92.9	87.9
1351	16-30	14.0	5.6	2643.0	0.0	620.7	1614.4	407.9	10	186.5	118.8	163	70.1	88.6
1331	16-30	11.8	4.8	3270.4	0.0	2048.2	949.5	272.7	10	158.2	101.5	163	59.5	75.8

Table C2: FCCS fire behavior predictions at 10 mph midflame wind speed for loblolly pine (*Pinus taeda*) pathway fuelbeds. FCCS predictions are calculated at 10 mph midflame wind speed, 0% slope gradient and dry fuel moisture scenario (Table 1). Surface fire behavior outputs include reaction intensity (BTU $ft^{-2}min^{-1}$), shrub, herbaceous vegetation, woody fuel, and litter reaction intensities (BTU $ft^{-2}min^{-1}$), flame length (ft), and rate of spread (ft min^{-1}). Suggested crosswalks to the original 13 fire behavior fuel models (Rothermel 1972, Albini 1976) and standard 40 fire behavior fuel models (Scott and Burgan 2005) are also included, along with the percentage difference between the fuel model-defined and FCCS-predicted rates of spread and flame lengths.

Fuelbed #	Age Class	Rate of Spread	Flame Length	Reaction Intensity	Shrub	Herb	Woody	Litter	Crosswalk FBPS FMs	Percent Difference ROS	Percent Difference FL	Crosswalk Standard FMs	Percent Difference ROS	Percent Difference FL
	yr	ft/min	ft	---------- BTU/ft^2/min ----------						%	%		%	%
1352	0-1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2	0.0	0.0	121	0.0	0.0
1353	0-1	55.1	6.6	2466.3	0.0	2466.3	0.0	0.0	1	82.5	174.8	109	43.4	23.8
1332	2-3	1.6	0.5	99.0	0.0	0.0	99.0	0.0	8	94.5	52.2	183	120.0	58.0
1333	2-3	16.4	4.0	2695.7	0.0	2601.9	39.2	54.5	6	58.4	74.5	142	712.0	211.7
1334	4-6	3.5	1.1	447.0	0.0	0.0	97.6	349.4	8	213.7	110.3	184	185.6	91.9
1335	4-6	3.5	1.1	447.0	0.0	0.0	97.6	349.4	8	213.7	110.3	184	185.6	91.9
1336	4-6	18.5	5.0	3427.6	0.0	2905.4	214.5	307.7	6	66.0	92.3	144	88.9	85.9
1337	7-11	8.6	2.9	1408.3	0.0	363.6	419.9	624.8	9	125.8	116.0	164	95.3	59.2
1338	7-11	8.6	2.9	1408.3	0.0	363.6	419.9	624.8	9	125.8	116.0	164	95.3	59.2
1340	7-11	9.1	3.6	2636.9	0.0	1813.2	516.1	307.7	9	133.4	143.2	164	101.1	73.1
1341	12-15	8.6	1.7	681.5	0.0	54.8	2.0	624.8	8	520.6	172.4	186	195.2	74.9
1342	12-15	10.9	1.9	651.3	0.0	26.3	0.2	624.8	8	661.5	188.8	186	248.0	82.1
1344	12-15	5.9	2.6	1816.7	0.0	1012.8	496.2	307.7	9	87.2	104.9	188	129.3	87.4
1345	16-19	13.2	4.0	1637.5	0.0	372.6	640.2	624.8	6	47.2	73.9	142	575.1	210.0
1346	20-30	13.2	3.9	1581.7	0.0	372.9	584.1	624.8	6	47.1	71.9	142	574.3	204.2
1347	20-30	12.9	3.8	1581.7	0.0	372.9	584.1	624.8	6	45.8	71.0	142	559.1	201.7
1348	20-30	10.2	3.8	2682.7	0.0	1821.3	553.8	307.7	9	149.3	153.3	146	54.7	46.7

Table C3: FCCS fire behavior predictions at 15 mph midflame wind speed for genetically engineered freeze-tolerant *Eucalyptus x urograndis* pathway fuelbeds. FCCS predictions are calculated at 15 mph midflame wind speed, 0% slope gradient and dry fuel moisture scenario (Table 1). Surface fire behavior outputs include reaction intensity (BTU $ft^{-2}min^{-1}$), shrub, herbaceous vegetation, woody fuel, and litter reaction intensities (BTU $ft^{-2}min^{-1}$), flame length (ft), and rate of spread (ft min^{-1}). Suggested crosswalks to the original 13 fire behavior fuel models (Rothermel 1972, Albini 1976) and standard 40 fire behavior fuel models (Scott and Burgan 2005) are also included, along with the percentage difference between the fuel model-defined and FCCS-predicted rates of spread and flame lengths.

Fuelbed #	Age Class	Rate of Spread	Flame Length	Reaction Intensity	Shrub	Herb	Woody	Litter	Crosswalk FBPS FMs	Percent Difference ROS	Percent Difference FL	Crosswalk Standard FMs	Percent Difference ROS	Percent Difference FL
	yr	ft/min	ft	---------- BTU/ft^2/min ----------						%	%		%	%
1301	0-1	17.3	1.1	161.8	0.0	161.8	0.0	0.0	2	56.4	19.5	121	154.4	39.8
1302	0-1	35.3	5.1	2180.5	0.0	2136.2	0.0	44.3	2	114.9	89.5	103	96.1	83.7
1303	0-1	17.3	1.1	161.8	0.0	161.8	0.0	0.0	2	56.4	19.5	121	154.4	39.8
1304	0-1	48.3	6.9	3032.6	0.0	2978.5	0.0	54.1	1	72.3	180.6	109	38.0	24.6
1305	0-1	11.6	2.4	796.6	0.0	201.6	187.1	407.9	11	215.5	77.0	201	242.0	88.4
1306	2-3	24.8	5.1	2719.9	0.0	2299.4	147.7	272.7	6	88.5	93.9	144	119.4	87.4
1307	2-3	8.9	1.7	524.5	0.0	0.0	116.5	407.9	8	540.3	172.7	186	202.6	75.1
1309	2-3	23.8	4.8	2514.9	0.0	2108.4	133.8	272.7	6	84.9	88.7	144	114.4	82.6
1310	2-3	12.4	2.3	752.9	0.0	222.6	122.4	407.9	6	44.2	42.0	142	538.9	119.3
1312	2-3	24.7	5.2	3141.5	0.0	2820.6	48.2	272.7	6	88.1	96.1	144	118.8	89.5
1313	2-3	11.4	2.4	665.8	0.0	0.0	257.9	407.9	11	212.1	77.7	201	238.1	89.2
1314	2-3	15.1	3.7	2109.5	0.0	1639.5	197.3	272.7	6	53.9	69.0	142	657.3	196.1
1317	4-6	10.8	2.0	546.7	0.0	0.0	138.7	407.9	8	656.7	197.0	186	246.3	85.7
1318	4-6	17.6	4.1	2266.4	0.0	1809.6	184.1	272.7	6	62.7	75.6	142	765.1	214.9
1319	4-6	11.4	1.5	417.9	0.0	0.0	10.0	407.9	2	37.2	25.7	121	102.1	52.2
1320	4-6	19.8	4.4	2665.5	0.0	2329.6	63.2	272.7	6	70.4	81.0	142	858.9	230.3
1349	4-6	13.5	2.8	724.3	0.0	0.0	316.4	407.9	6	48.2	51.5	142	587.4	146.3
1321	4-6	16.8	4.0	2038.9	0.0	1495.6	270.6	272.7	6	59.8	73.8	142	729.0	209.7
1322	7-8	12.9	1.6	419.6	0.0	0.0	11.7	407.9	2	42.1	27.3	121	115.3	55.6
1323	7-8	18.8	4.3	2708.7	0.0	2358.7	77.2	272.7	6	67.1	80.3	142	817.9	228.1
1324	9-15	17.8	3.9	1269.9	0.0	422.4	439.6	407.9	6	63.6	71.8	142	775.1	204.2
1325	9-15	28.0	5.9	2904.6	0.0	2291.1	340.9	272.7	6	100.0	108.8	144	134.8	101.3
1350	9-15	25.3	5.0	1419.8	0.0	415.7	596.2	407.9	6	90.3	92.8	144	121.8	86.4

Fuelbed #	Age Class	Rate of Spread	Flame Length	Reaction Intensity	Shrub	Herb	Woody	Litter	Crosswalk FBPS FMs	Percent Difference ROS	Percent Difference FL	Crosswalk Standard FMs	Percent Difference ROS	Percent Difference FL
1326	9-15	16.0	4.4	2316.7	0.0	1568.2	475.8	272.7	6	57.1	81.4	142	696.6	231.4
1327	16-30	22.6	5.9	2086.1	0.0	627.2	1050.9	407.9	6	80.6	109.9	144	108.6	102.4
1328	16-30	25.2	7.0	3727.9	0.0	2480.5	974.7	272.7	5	116.5	128.1	147	86.5	61.3
1329	16-30	26.4	4.4	1188.5	0.0	431.4	349.2	407.9	2	85.9	76.4	101	219.7	256.3
1330	16-30	35.2	6.7	3355.3	0.0	2822.2	260.4	272.7	5	162.3	122.1	145	79.2	55.5
1351	16-30	23.5	7.1	2643.0	0.0	620.7	1614.4	407.9	5	108.2	128.9	147	80.3	61.7
1331	16-30	21.4	6.3	3270.4	0.0	2048.2	949.5	272.7	5	99.0	114.1	147	73.4	54.6

Table C4: FCCS fire behavior predictions at 15 mph midflame wind speed for loblolly pine (*Pinus taeda*) pathway fuelbeds. FCCS predictions are calculated at 15 mph midflame wind speed, 0% slope gradient and dry fuel moisture scenario (Table 1). Surface fire behavior outputs include reaction intensity (BTU $ft^{-2}min^{-1}$), shrub, herbaceous vegetation, woody fuel, and litter reaction intensities (BTU $ft^{-2}min^{-1}$), flame length (ft), and rate of spread (ft min^{-1}). Suggested crosswalks to the original 13 fire behavior fuel models (Rothermel 1972, Albini 1976) and standard 40 fire behavior fuel models (Scott and Burgan 2005) are also included, along with the percentage difference between the fuel model-defined and FCCS-predicted rates of spread and flame lengths.

Fuelbed #	Age Class	Rate of Spread	Flame Length	Reaction Intensity	Shrub	Herb	Woody	Litter	Crosswalk FBPS FMs	Percent Difference ROS	Percent Difference FL	Crosswalk Standard FMs	Percent Difference ROS	Percent Difference FL
	yr	ft/min	ft	---------- BTU/ft^2/min ----------						%	%		%	%
1352	0-1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2	0.0	0.0	121	0.0	0.0
1353	0-1	100.5	8.8	2466.3	0.0	2466.3	0.0	0.0	3	102.5	74.2	104	194.0	116.8
1332	2-3	2.8	0.7	99.0	0.0	0.0	99.0	0.0	8	171.3	68.7	183	217.4	76.3
1333	2-3	29.8	5.3	2695.7	0.0	2601.9	39.2	54.5	6	106.4	98.2	144	143.5	91.4
1334	4-6	6.1	1.4	447.0	0.0	0.0	97.6	349.4	8	367.3	141.6	185	178.3	74.5
1335	4-6	6.1	1.4	447.0	0.0	0.0	97.6	349.4	8	367.3	141.6	185	178.3	74.5
1336	4-6	33.7	6.6	3427.6	0.0	2905.4	214.5	307.7	5	155.3	119.3	145	75.8	54.2
1337	7-11	14.6	3.7	1408.3	0.0	363.6	419.9	624.8	6	52.0	68.5	142	633.8	194.8
1338	7-11	14.6	3.7	1408.3	0.0	363.6	419.9	624.8	6	52.0	68.5	142	633.8	194.8
1340	7-11	16.5	4.7	2636.9	0.0	1813.2	516.1	307.7	6	58.8	87.2	142	717.4	247.8
1341	12-15	14.5	2.2	681.5	0.0	54.8	2.0	624.8	2	47.2	38.5	121	129.4	78.3
1342	12-15	18.4	2.4	651.3	0.0	26.3	0.2	624.8	2	60.0	42.1	121	164.4	85.8
1344	12-15	10.1	3.3	1816.7	0.0	1012.8	496.2	307.7	11	187.5	107.9	202	88.6	63.1
1345	16-19	22.6	5.1	1637.5	0.0	372.6	640.2	624.8	6	80.6	94.5	144	108.6	88.0
1346	20-30	22.6	5.0	1581.7	0.0	372.9	584.1	624.8	6	80.4	91.9	144	108.5	85.6
1347	20-30	21.9	4.9	1581.7	0.0	372.9	584.1	624.8	6	78.2	90.7	144	105.4	84.5
1348	20-30	18.5	5.0	2682.7	0.0	1821.3	553.8	307.7	6	65.9	93.4	144	88.9	87.0

Table C5: FCCS fire behavior predictions at 20 mph midflame wind speed for genetically engineered freeze-tolerant *Eucalyptus x urograndis* pathway fuelbeds. FCCS predictions are calculated at 20 mph midflame wind speed, 0% slope gradient and dry fuel moisture scenario (Table 1). Surface fire behavior outputs include reaction intensity (BTU $ft^{-2}min^{-1}$), shrub, herbaceous vegetation, woody fuel, and litter reaction intensities (BTU $ft^{-2}min^{-1}$), flame length (ft), and rate of spread (ft min^{-1}). Suggested crosswalks to the original 13 fire behavior fuel models (Rothermel 1972, Albini 1976) and standard 40 fire behavior fuel models (Scott and Burgan 2005) are also included, along with the percentage difference between the fuel model-defined and FCCS-predicted rates of spread and flame lengths.

Fuelbed #	Age Class	Rate of Spread	Flame Length	Reaction Intensity	Shrub	Herb	Woody	Litter	Crosswalk FBPS FMs	Percent Difference ROS	Percent Difference FL	Crosswalk Standard FMs	Percent Difference ROS	Percent Difference FL
	yr	ft/min	ft	---------- BTU/ft^2/min ----------						%	%		%	%
1301	0-1	26.6	1.4	161.8	0.0	161.8	0.0	0.0	2	86.5	23.8	121	237.1	48.4
1302	0-1	54.1	6.2	2180.5	0.0	2136.2	0.0	44.3	1	81.1	163.6	109	42.7	22.3
1303	0-1	26.6	1.4	161.8	0.0	161.8	0.0	0.0	2	86.5	23.8	121	237.1	48.4
1304	0-1	74.1	8.4	3032.6	0.0	2978.5	0.0	54.1	1	110.9	219.9	109	58.4	30.0
1305	0-1	17.2	2.9	796.6	0.0	201.6	187.1	407.9	2	56.1	50.2	101	143.5	168.3
1306	2-3	38.1	6.2	2719.9	0.0	2299.4	147.7	272.7	1	57.0	162.5	109	30.0	22.1
1307	2-3	13.1	2.1	524.5	0.0	0.0	116.5	407.9	2	42.6	36.1	121	116.6	73.5
1309	2-3	36.5	5.8	2514.9	0.0	2108.4	133.8	272.7	1	54.7	153.4	109	28.8	20.9
1310	2-3	18.4	2.7	752.9	0.0	222.6	122.4	407.9	2	60.0	47.7	121	164.5	97.1
1312	2-3	37.9	6.3	3141.5	0.0	2820.6	48.2	272.7	5	174.9	114.9	145	85.3	52.2
1313	2-3	16.7	2.9	665.8	0.0	0.0	257.9	407.9	6	59.7	53.2	142	728.2	151.1
1314	2-3	23.2	4.5	2109.5	0.0	1639.5	197.3	272.7	6	82.6	84.0	142	1007.4	238.6
1317	4-6	15.9	2.3	546.7	0.0	0.0	138.7	407.9	2	51.7	41.2	121	141.8	83.9
1318	4-6	27.0	5.0	2266.4	0.0	1809.6	184.1	272.7	6	96.2	92.0	144	129.7	85.7
1319	4-6	16.7	1.7	417.9	0.0	0.0	10.0	407.9	2	54.6	30.6	121	149.5	62.2
1320	4-6	30.3	5.3	2665.5	0.0	2329.6	63.2	272.7	6	108.0	98.7	144	145.7	91.9
1349	4-6	19.8	3.3	724.3	0.0	0.0	316.4	407.9	6	70.6	61.4	142	860.7	174.5
1321	4-6	25.7	4.8	2038.9	0.0	1495.6	270.6	272.7	6	91.6	89.8	144	123.5	83.6
1322	7-8	18.9	1.9	419.6	0.0	0.0	11.7	407.9	2	61.7	32.6	121	169.0	66.3
1323	7-8	28.9	5.3	2708.7	0.0	2358.7	77.2	272.7	6	102.9	97.7	144	138.7	91.0
1324	9-15	26.5	4.7	1269.9	0.0	422.4	439.6	407.9	6	94.4	86.2	142	1151.6	245.0
1325	9-15	43.0	7.1	2904.6	0.0	2291.1	340.9	272.7	1	64.4	188.1	109	33.9	25.6
1350	9-15	37.6	6.0	1419.8	0.0	415.7	596.2	407.9	1	56.3	158.2	109	29.6	21.6

1326	9-15	24.5	5.3	2316.7	0.0	1568.2	475.8	272.7	6	87.5	99.1	144	118.0	92.2
1327	16-30	33.5	7.1	2086.1	0.0	627.2	1050.9	407.9	5	154.6	129.4	145	75.4	58.8
1328	16-30	38.7	8.6	3727.9	0.0	2480.5	974.7	272.7	5	178.4	155.8	145	87.1	70.8
1329	16-30	39.2	5.2	1188.5	0.0	431.4	349.2	407.9	1	58.7	137.6	107	50.7	32.7
1330	16-30	53.9	8.2	3355.3	0.0	2822.2	260.4	272.7	1	80.7	215.2	109	42.5	29.3
1351	16-30	34.7	8.5	2643.0	0.0	620.7	1614.4	407.9	5	160.2	154.4	145	78.2	70.2
1331	16-30	32.8	7.6	3270.4	0.0	2048.2	949.5	272.7	5	151.5	138.7	145	73.9	63.1

Table C6: FCCS fire behavior predictions at 20 mph midflame wind speed for loblolly pine (*Pinus taeda*) pathway fuelbeds. FCCS predictions are calculated at 20 mph midflame wind speed, 0% slope gradient and dry fuel moisture scenario (Table 1). Surface fire behavior outputs include reaction intensity (BTU $ft^{-2}min^{-1}$), shrub, herbaceous vegetation, woody fuel, and litter reaction intensities (BTU $ft^{-2}min^{-1}$), flame length (ft), and rate of spread (ft min^{-1}). Suggested crosswalks to the original 13 fire behavior fuel models (Rothermel 1972, Albini 1976) and standard 40 fire behavior fuel models (Scott and Burgan 2005) are also included, along with the percentage difference between the fuel model-defined and FCCS-predicted rates of spread and flame lengths.

Fuelbed #	Age Class	Rate of Spread	Flame Length	Reaction Intensity	Shrub	Herb	Woody	Litter	Crosswalk FBPS FMs	Percent Difference ROS	Percent Difference FL	Crosswalk Standard FMs	Percent Difference ROS	Percent Difference FL
	yr	ft/min	ft	---------- BTU/ft^2/min ----------						%	%		%	%
1352	0-1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2	0.0	0.0	121	0.0	0.0
1353	0-1	154.3	10.7	2466.3	0.0	2466.3	0.0	0.0	3	157.4	90.4	106	295.0	93.5
1332	2-3	4.3	0.8	99.0	0.0	0.0	99.0	0.0	8	262.1	83.5	183	332.7	92.8
1333	2-3	45.8	6.5	2695.7	0.0	2601.9	39.2	54.5	1	68.6	169.9	109	36.1	23.1
1334	4-6	9.1	1.7	447.0	0.0	0.0	97.6	349.4	8	549.3	170.3	186	206.0	74.1
1335	4-6	9.1	1.7	447.0	0.0	0.0	97.6	349.4	8	549.3	170.3	186	206.0	74.1
1336	4-6	51.6	8.0	3427.6	0.0	2905.4	214.5	307.7	1	77.3	210.2	109	40.7	28.6
1337	7-11	21.7	4.4	1408.3	0.0	363.6	419.9	624.8	6	77.3	82.3	142	942.6	233.8
1338	7-11	21.7	4.4	1408.3	0.0	363.6	419.9	624.8	6	77.3	82.3	142	942.6	233.8
1340	7-11	25.3	5.7	2636.9	0.0	1813.2	516.1	307.7	6	90.1	106.1	144	121.5	98.8
1341	12-15	21.5	2.6	681.5	0.0	54.8	2.0	624.8	2	70.0	46.1	121	191.8	93.8
1342	12-15	27.3	2.9	651.3	0.0	26.3	0.2	624.8	2	89.0	50.5	102	107.1	71.9
1344	12-15	15.0	4.0	1816.7	0.0	1012.8	496.2	307.7	6	53.6	74.4	142	653.5	211.4
1345	16-19	33.7	6.1	1637.5	0.0	372.6	640.2	624.8	5	155.5	111.5	145	75.9	50.7
1346	20-30	33.6	6.0	1581.7	0.0	372.9	584.1	624.8	6	119.9	110.5	146	180.9	72.7
1347	20-30	32.7	5.9	1581.7	0.0	372.9	584.1	624.8	6	116.4	109.0	146	175.6	71.8
1348	20-30	28.3	6.1	2682.7	0.0	1821.3	553.8	307.7	5	130.8	111.6	165	388.2	93.0

Fuelbed Pathways Handbook

Evaluation of potential fire behavior in genetically engineered freeze-tolerant *Eucalyptus x urograndis* (FTE) plantations of the Southern United States

September 2013

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Introduction

The United States Department of Agriculture's Animal and Plant Health Inspection Service (APHIS) is preparing an Environmental Impact Statement (EIS) to assess plantings of genetically engineered freeze-tolerant *Eucalyptus x urograndis* (FTE) in the United States. If approved for production, FTE plantations may replace some pine plantations, mixed hardwood forests and agricultural lands in the Southern United States. As part of the EIS process, the potential for FTE plantations to alter fire hazard relative to existing vegetation was investigated. APHIS requested that the Fire and Environmental Research Applications Team (FERA) of the Pacific Northwest Research Station conduct the fire risk assessment using the Fuel Characteristic Classification System (FCCS). The FERA team compiled information from the literature and consulted with experts to create FCCS fuelbeds (Ottmar et al. 2007; Riccardi et al. 2007) representing FTE plantation developmental stages and anticipated management activities between those stages (Table 1; Figures 1 and 2). Information from each fuelbed pathway is summarized in a table including a description, the age class, stocking, and any management actions or natural change agents associated with each fuelbed (Tables 2 and 3).

Table 1. Descriptions of harvest types, fuel treatments and natural change agents in the FTE and loblolly pine fuelbeds.

Harvest / Fuel Treatment	Description
Biomass harvest	Full-tree harvest of trees for bioenergy or chip material.
Clearcut harvest and site prep	Harvest of all or nearly all trees in a forest stand with herbicide application to kill existing trees
Coppice harvest	Harvest of all or nearly all trees, leaving stumps to sprout
Thin	Thinning harvest in which small trees are removed throughout a forest stand to increase growth and decrease ladder fuels
Fertilize	Fertilizer application to enhance tree growth
Herbicide	Herbicide application to remove or inhibit understory plant growth and competition from grasses, other herbaceous vegetation, hardwood trees and shrubs
Effective site preparation	Chemical and mechanical site preparation including bedding, fertilizer within tree rows and herbicide applications to reduce competition
Ineffective site preparation	Incomplete or ineffective herbicide treatment, leading to reduced stocking density and/or tree growth
Pulpwood harvest	Clearcut harvest for pulpwood
None	No recent harvest or fuel treatment
Natural Change Agent	**Description**
Wildfire	An unplanned, stand-replacing wildland fire including unauthorized human-caused fires, escaped wildland fire use events, escaped prescribed fire projects, and all other wildland fires where the objective is to put the fire out
None	No recent natural change agent for a specific pathway interval

FTE fuelbed pathways

Figure 1. FTE fuelbed pathways for the southern United States. Blue highlights represent high-density stands, and red highlights represent low-density stands. Vertical arrows indicate points at which biomass or pulpwood harvests may reset pathways to stand initiation. Wildfire or coppice harvests are possible at any stage of the fuelbed pathways.

Table 2. FTE fuelbed descriptions. FTE may be planted throughout much of the outer Coastal Plain of South Carolina, Georgia, Florida, Alabama, Mississippi, Louisiana and Texas.

FuelbedID	Age class	Harvest / fuel treatment	Change agent	Stocking (planted trees per acre)	Fuelbed name / description
FB_1301	0-1 yr	Clearcut harvest	Herbicide Mechanical site prep	1200 tpa	FTE plantation. This fuelbed represents a young, dense (~1200 trees/acre) biomass plantation that was established following intensive chemical and mechanical site preparation including bedding, fertilizer and herbicide applications to increase tree growth and reduce competing vegetation.
FB_1302	0-1 yr	Clearcut harvest	Mechanical site prep	1200 tpa	FTE plantation. This fuelbed represents a young, dense (~1200 trees/acre) biomass plantation that was established following ineffective chemical and mechanical site preparation; therefore, fairly dense competing vegetation is present and tree growth is limited.
FB_1303	0-1yr	Clearcut harvest	Herbicide Mechanical site prep	625 tpa	FTE plantation. This fuelbed represents a young pulpwood plantation (~625 trees/acre) that was established following intensive chemical and mechanical site preparation including bedding, fertilizer and herbicide applications to increase tree growth and reduce competing vegetation.
FB_1304	0-1yr	Clearcut harvest	Mechanical site prep	625 tpa	FTE plantation. This fuelbed represents a young pulpwood plantation (~625 trees/acre) that was established following ineffective chemical and mechanical site preparation; therefore, fairly dense competing vegetation is present and tree growth is limited.
FB_1305	0-1 yr	Coppice harvest	Fertilize Herbicide	1200 tpa	FTE plantation. This fuelbed represents a newly coppiced stand with ~1200 stumps per acre. Fertilizer and herbicide have been applied to the site to increase tree growth and reduce competing vegetation.
FB_1306	0-1 yr	Coppice harvest	None	1200 tpa	FTE plantation. This fuelbed represents a newly coppiced stand with ~1200 stumps per acre. Neither herbicide nor fertilizer was applied or was ineffective; therefore, fairly dense competing vegetation is present and tree growth is limited.
FB_1307	2-3 yr	None	Fertilize Herbicide	1200 tpa	FTE plantation. This fuelbed represents a 2 to 3 year old biomass plantation which has had periodic herbicide and fertilizer applications to reduce competing vegetation and increase tree growth. Canopy closure also limits understory vegetation. The stand is ready for harvest.
FB_1309	2-3 yr	None	None	1200 tpa	FTE plantation. This fuelbed represents a 2 to 3 year old biomass plantation which had ineffective site preparation at planting and has not been actively

FuelbedID	Age class	Harvest / fuel treatment	Change agent	Stocking (planted trees per acre)	Fuelbed name / description
					managed to eliminate competing vegetation; therefore, trees are not growing vigorously.
FB_1310	2-3 yr	None	None	625 tpa	FTE plantation. This fuelbed represents a 2 to 3 year old pulpwood plantation which has had periodic herbicide and fertilizer applications to reduce competing vegetation and increase tree growth. Canopy closure will also limit understory vegetation.
FB_1312	2-3 yr	None	None	625 tpa	FTE plantation. This fuelbed represents a 2 to 3 year old pulpwood plantation which had ineffective site preparation at planting and has not been actively managed to eliminate competing vegetation; therefore, trees are not growing vigorously.
FB_1313	2-3 yr	None	None	1200 tpa	FTE plantation. This fuelbed represents a 2 to 3 year old coppiced stand which has been thinned to one stem per stump. The stand has been actively managed and is ready for harvest.
FB_1314	2-3 yr	None	None	3600 tpa	FTE plantation. This fuelbed represents a 2 to 3 year old coppiced stand that was not thinned to one stem per stump. The stand was ineffectively site prepped and has not been managed to reduce competing vegetation, therefore, trees are not growing vigorously.
FB_1317	4-6 yr	Biomass harvest	None	1200 tpa	FTE plantation. This fuelbed represents a 4 to 6 year old biomass plantation that has had periodic herbicide and fertilizer applications in the past to reduce competing vegetation and increase tree growth. Canopy closure also limits understory vegetation. The stand is past optimal harvest age and should be harvested.
FB_1318	4-6 yr	None	None	1200 tpa	FTE plantation. This fuelbed represents a 4 to 6 year old abandoned plantation that was ineffectively site prepped and has not been managed to reduce competing vegetation, therefore, trees are not growing vigorously.
FB_1319	4-6 yr	None	Fertilize	625 tpa	FTE plantation. This fuelbed represents a 4 to 6 year old pulpwood plantation that has been effectively managed. Due to the use of herbicide in the past and canopy closure, there is very little vegetation in the understory. Periodic fertilizer applications have maintained vigorous tree growth.
FB_1320	4-6 yr	None	None	625 tpa	FTE plantation. This fuelbed represents a 4 to 6 year old abandoned pulpwood plantation that has not been properly managed; therefore,

FuelbedID	Age class	Harvest / fuel treatment	Change agent	Stocking (planted trees per acre)	Fuelbed name / description
					grasses and forbs are well established and the trees are not growing vigorously.
FB_1349	4-6 yr	None	None	1200 tpa	FTE plantation. This fuelbed represents a 4 to 6 year old coppiced stand that has been effectively managed. Due to the use of herbicide in the past and canopy closure, there is very little vegetation in the understory. The stand is past optimal harvest age and should be harvested.
FB_1321	4-6 yr	None	None	3600 tpa	FTE plantation. This fuelbed represents a 4 to 6 year old coppiced stand that has not been managed to reduce competing vegetation. The stand has not been thinned to reduce stems per stumps, resulting in a "wolfy" stand structure.
FB_1322	7-8 yr	None	None	625 tpa	FTE plantation. This fuelbed represents a 7 to 8 year old pulpwood plantation that has been actively managed and is ready for harvest.
FB_1323	7-8 yr	None	None	625 tpa	FTE plantation. This fuelbed represents a 7 to 8 year old pulpwood plantation that was abandoned before canopy closure. This allowed grasses and shrubs to become established, and trees are not growing vigorously due to competing vegetation.
FB_1324	9-15 yr	None	None	1200 tpa	FTE plantation. This fuelbed represents a 9 to 15 year old biomass plantation that was abandoned after canopy closure so very little other vegetation is present. However, competition among the dense trees has led to snags and downed wood accumulations.
FB_1325	9-15 yr	None	None	1200 tpa	FTE plantation. This fuelbed represents a 9 to 15 year old biomass plantation that was abandoned before canopy closure. This allowed dense grasses and shrubs to become established within the stand. Trees are somewhat stunted, and snags and downed wood are present.
FB_1350	9-15 yr	None	None	1200 tpa	FTE plantation. This fuelbed represents a 9 to 15 year old coppiced biomass stand that was abandoned after canopy closure so very little other vegetation is present. However, competition among the dense trees has led to snags and downed wood accumulations.
FB_1326	9-15 yr	None	None	3600 tpa	FTE plantation. This fuelbed represents a 9 to 15 year old coppiced biomass stand that has not been managed to reduce competing vegetation. The stand has not been thinned to reduce stems per stumps, resulting in a

FuelbedID	Age class	Harvest / fuel treatment	Change agent	Stocking (planted trees per acre)	Fuelbed name / description "wolfy" stand structure.
FB_1327	16-30 yr	None	None	1200 tpa	FTE plantation. This fuelbed represents a 16 to 30 year old biomass plantation that was abandoned after canopy closure and has had no subsequent management. Competition among the dense trees has led to snags and downed wood accumulations.
FB_1328	16-30 yr	None	None	1200 tpa	FTE plantation. This fuelbed represents a 16 to 30 year old biomass plantation that was abandoned before canopy closure and has had no subsequent management. This allowed dense grasses and shrubs to become established within the stand. Trees are somewhat stunted, and snags and downed wood are present.
FB_1329	16-30 yr	None	None	625 tpa	FTE plantation. This fuelbed represents a 16 to 30 year old pulpwood plantation that was actively managed but was abandoned after canopy closure. Competition among the canopy trees has led to snags and downed woody accumulations. Some grasses, forbs and shrubs are becoming established in the understory.
FB_1330	16-30 yr	None	None	625 tpa	FTE plantation. This fuelbed represents a 16 to 30 year old pulpwood plantation that was not actively managed and was abandoned before canopy closure. The understory is dense and trees are somewhat stunted due to the competition. Snags and downed wood are present.
FB_1351	16-30 yr	None	None	1200 tpa	FTE plantation. This fuelbed represents a 16 to 30 year old coppiced biomass stand that was abandoned after canopy closure so very little other vegetation is present. However, competition among the dense trees has led to snags and downed wood accumulations. Grasses, forbs and shrubs are becoming established in the understory.
FB_1331	16-30 yr	None	None	3600 tpa	FTE plantation. This fuelbed represents a 16 to 30 year old coppiced biomass stand that has not been managed to reduce competing vegetation. The stand has not been thinned to reduce stems per stumps, resulting in a "wolfy" stand structure with a well developed understory of grasses and shrubs.

Loblolly pine pathways

Figure 2. Loblolly pine fuelbed pathways. Vertical arrows indicate points at which pulpwood or saw timber harvests may reset pathways to stand initiation. Wildfires are possible at any stage of the fuelbed pathways.

Table 3. Loblolly pine fuelbed descriptions. Intensively managed loblolly pine plantations are common throughout the Coastal Plain of the southern United States.

FuelbedID	Age class (yr)	Harvest / fuel treatment	Change agent	Stocking (planted trees per acre)	Fuelbed name / description
FB_1352	0-1 yr	Clearcut harvest or Wildfire/salvage	Site prep (chemical and mechanical)	750 tpa	Loblolly pine forest. This fuelbed represents a 0 to 1 year old plantation with 750 trees/acre that was established following intensive chemical and mechanical site preparation including bedding and herbicide applications to reduce competing vegetation.
FB_1353	0-1 yr	Clearcut harvest or Wildfire/salvage	Site prep (chemical and mechanical)	750 tpa	Loblolly pine forest. This fuelbed represents a 0 to 1 year old plantation with 750 trees/acre that was established following ineffective chemical and mechanical site preparation; therefore, fairly dense competing vegetation is present.
FB_1332	2-3 yr	None	Herbicide	750 tpa	Loblolly pine forest. This fuelbed represents a 2 to 3 year old plantation with 750 trees/acre that had intensive site preparation, including bedding and herbicide application. This stand is actively managed to reduce competing vegetation and has had a recent herbicide application.
FB_1333	2-3 yr	None	None	750 tpa	Loblolly pine forest. This fuelbed represents a 2 to 3 year old plantation with 750 trees/acre that had ineffective site preparation and no subsequent management, allowing establishment of competing vegetation.
FB_1334	4-6 yr	None	Herbicide	750 tpa	Loblolly pine forest. This 4 to 6 year old stand has been actively managed with effective site preparation and subsequent herbicide applications to release pines from competing vegetation.
FB_1335	4-6 yr	None	Fertilize Herbicide	750 tpa	Loblolly pine forest. This 4 to 6 year old stand has been actively managed with effective site preparation and subsequent fertilizer and herbicide applications to release pines from competing vegetation and promote tree growth.
FB_1336	4-6 yr	None	None	750 tpa	Loblolly pine forest. This 4 to 6 year old stand had ineffective site preparation and is not being actively managed. Therefore, the trees are not growing vigorously due to competing vegetation.
FB_1337	7-11 yr	None	Fertilize	750 tpa	Loblolly pine forest. This fuelbed represents a 7 to 11 year old stand that has been properly managed to reduce competing vegetation. The

					stand was recently fertilized to increase tree growth.
FB_1338	7-11 yr	None	Fertilize	7500	Loblolly pine forest. This 7 to 11 year old stand has been actively managed to reduce competing vegetation. The stand was recently fertilized to increase growth.
FB_1340	7-11 yr	None	None	750	Loblolly pine forest. This fuelbed represents a 7 to 11 year old stand that has not been actively managed and allowed establishment of competing vegetation.
FB_1341	12-15 yr	None	Thin Fertilize	560 (post-thin)	Loblolly pine forest. This 12 to 15 year old stand has been actively managed and was recently thinned and fertilized to promote tree growth.
FB_1342	12-15 yr	None	None	750	Loblolly pine forest. This fuelbed represents a 12 to 15 year old stand that has been managed to reduce competing vegetation and promote tree growth. The stand ready for pulpwood harvest.
FB_1344	12-15 yr	None	None	750	Loblolly pine forest. This fuelbed represents a 12 to 15 year old stand that has not been actively managed, allowing establishment of competing vegetation.
FB_1345	16-19 yr	None	Thin Fertilize	450 (post-thin)	Loblolly pine forest. This 16 to 19 year old stand has been actively managed and was recently thinned and fertilized to promote tree growth.
FB_1346	20-30 yr	None	None	450 (post-thin)	Loblolly pine forest. This fuelbed represents a 20 to 30 year old stand that has been actively managed throughout its development. The stand is ready for saw timber harvest.
FB_1347	20-30 yr	None	None	750	Loblolly pine forest. This fuelbed represents a 20 to 30 year old over-mature pulpwood stand that has had no recent management. Competition among the canopy trees has led to mortality and woody fuel accumulations.
FB_1348	20-30 yr	None	None	750	Loblolly pine forest. This 20 to 30 year old stand has not been actively managed, allowing establishment of competing vegetation. Competition among canopy trees has led to mortality and woody fuel accumulations.

Mixed hardwood and agriculture fuelbeds

Table 4. Mixed hardwood and agriculture fuelbed descriptions.

Fuelbed number	Fuelbed name	Fuelbed description
FB_0129	Green ash -- American elm forest	Bottomland hardwood forests dominated by green ash and American elm and other mixed hardwoods including oak species, black walnut, hackberry or sugarberry, and maples. These forests occur throughout the southeastern and central United States.
FB_0157	Loblolly pine -- shortleaf pine -- mixed hardwoods forest	Maturing (45+ years old), second growth, predominantly loblolly and shortleaf pine forests occurring throughout the interior of the southeastern coastal plain. Scattered slash pine and longleaf pine possible, depending on geographic location. Various hardwood species are co-dominant in the canopy; with longer time since disturbance (fire, logging, etc.), hardwoods make up more of the canopy cover.
FB_0158	Loblolly pine -- shortleaf pine -- mixed hardwoods forest	Maturing (45+ years old), second growth, predominantly loblolly and shortleaf pine forests occurring throughout the interior of the southeastern coastal plain. Scattered slash pine and longleaf pine possible, depending on geographic location. Various hardwood species are co-dominant in the canopy. Approximately 10-12 years after southern pine beetle infestation.
FB_0186	Turkey oak -- bluejack oak forest	Oak scrub community developing in dry pine - oak forest regions throughout southeast coastal plain (similarly structured types occur in the midwest with different species assemblages) after long-term fire suppression or removal of overstory pine species or as a edaphic climax on xeric sites. Depending on the geographic location of the type, many oak species may occur, including blackjack (*Q. marilandica*), sand live oak, sand post oak, myrtle oak, Arkansas oak, post oak and live oak.
FB_0276	Oak -- pine -- magnolia forest	Mesic forests dominated by a mixture of American beech, southern magnolia, and oaks, often with pines in the overstory, that generally occur in small stands throughout the southeastern coastal plain. This forest type occurs on protected sites including ravines and coves or in mesic upland forests that were previously dominated by pines where fire has been excluded.

Fuelbed number	Fuelbed name	Fuelbed description
FB_0281	Shortleaf pine -- post oak -- black oak forest	Dry, open to closed forests dominated by shortleaf pine and mixed oak species, usually post oak and black oak. Other oaks such as blackjack oak, southern red oak, scarlet oak, and white oak may also be present depending on geographic location and soil type. These forests occur mainly in the West Gulf coastal plain and Interior Highlands of the southern United States from OK, MO and TX east to MS; also occur farther east in the southern Appalachians and Piedmont on dry, low elevation ridges, generally under 2000 ft.
FB_0283	Willow oak -- laurel oak -- water oak forest	Oak dominated bottomland forests are common alluvial forest types throughout the southeastern and central United States. The canopy species composition varies with length of inundation and geographic region. This fuelbed represents stands between 25-70 years old.
FB_0402	Pine / holly -- privet forest	Recently logged timberland. Can occur throughout the eastern United States on sites managed for wood products. Established following clearcut harvest less than 10 years ago. Stand composed of open overstory with moderate shrub and nonwoody cover.
FB_0406	American beech -- southern magnolia -- oak forest	West Gulf Coastal Plain mesic hardwood forest. Mesic forests occurring in Louisiana, Texas and Arkansas. Stands are dominated by a mixture of American beech, southern magnolia, and oaks. Scattered pines may be present in the canopy. These forests generally occur in small stands on sites that are topographically protected from fire.
FB_0407	Darlington oak forest	Southern Coastal Plain dry upland hardwood forest. Occurs in the East Gulf Coastal Plain in Alabama, Florida, Georgia and Mississippi. Stands are typically dominated by Darlington oak, but may be dominated by white oak, post oak, or southern red oak. Scattered pines may be present in the canopy.
FB_1201	Corn	Corn crop field. Fuelbed represents post-harvest field with crop residue.
FB_1202	Cotton	Cotton crop field. Fuelbed represents post-harvest field with crop residue.
FB_1203	Rice	Rice crop field. Fuelbed represents post-harvest field with crop residue.
FB_1205	Soybeans	Soybean crop field. Fuelbed represents post-harvest field with crop residue.

Fuelbed number	Fuelbed name	Fuelbed description
FB_1223	Wheat	Wheat crop field Fuelbed represents post-harvest field with crop residue.
FB_1273	Tree fruits	Tree fruit field. Species may include cherry, peach, apple, citrus, pear, prune, orange, pomegranate, nectarine, plum, or apricot trees or grapes. Fuelbed represents row planted trees or vines with very little groundcover

Fire Behavior Outputs

Fuelbeds were calculated in FCCS version 3.0 using eighteen combinations moisture scenarios, midflame windspeeds and slope gradients (Table 5) to provide results at a wide range of potential wildfire conditions. Outputs from the calculations (Sandberg et al. 2007a; Sandberg et al. 2007b) were summarized in a data table for each pathway and include (1) the surface fire behavior outputs rate of spread (ft/min), flame length (ft) and reaction intensity (BTU/ft^2/min); (2) FCCS crown fire, surface fire and available fuel potentials (each is an index from 0-9) and (3) suggested crosswalks to the original Fire Behavior Prediction System (Rothermel 1972; Albini 1976) and standard fuel models (Scott and Burgan 2005).

Table 5: Environmental scenarios and descriptions. Midflame wind speeds include 0, 3 and 7 miles per hour (mph) and slope gradients include 0% and 15%. Moisture scenarios include very dry (1hr = 3%, 10hr = 4%, 100hr = 5%, Herb = 30%, Shrub = 60%), dry (1hr = 6%, 10hr = 7%, 100hr = 8%, Herb = 60%, Shrub = 90%), and moist (1hr = 12%, 10hr = 13%, 100hr = 14%, Herb = 60%, Shrub = 90%).

Scenario #	**Fuel moisture scenario**	**Midflame wind speed** (mph)	**Slope gradient** (%)
1	Very dry	0	0
2	Dry	0	0
3	Moist	0	0
4	Very dry	3	0
5	Dry	3	0
6	Moist	3	0
7	Very dry	7	0
8	Dry	7	0
9	Moist	7	0
10	Very dry	0	15
11	Dry	0	15
12	Moist	0	15
13	Very dry	3	15
14	Dry	3	15
15	Moist	3	15
16	Very dry	7	15
17	Dry	7	15
18	Moist	7	15

The FCCS fire potentials are defined "as a set of relative values that rate the intrinsic physical capacity of any wildland fuelbed to release energy, spread, crown, consume, and smolder under extremely dry conditions. These potentials are calculated from the loading, heat content, bulk density, and characteristic thickness of fuel elements without consideration of moisture content or environmental conditions" (Prichard et al. 2008). The surface fire potential is a relative index based on the potential maximum flame length or rate of spread. Crown fire potential is a relative index based on a weighted average of the likelihood that a fire will reach the tree crowns, spread through the canopy and, if so, how fast it will spread. The available fuel potential represents the relative amount of combustible biomass available during the flaming, smoldering, and residual combustion stages. In general, the crown fire potential takes into account the predicted surface fire behavior, whether the canopy height to live crown or ladder fuels are sufficient to carry fire into the tree crowns, and finally, whether the tree crowns are closely spaced enough to carry fire through the canopy. So fuelbeds with higher than average surface fire behavior and dense canopies with either low live crowns or ladder fuels are likely to have a high crown fire potential. The surface fire potential considers the loading and arrangement of surface fuels including shrubs, herbs, downed wood <3 inches in diameter and litter, in addition to the shrub species composition - specifically, whether highly flammable species are present. The available fuel potential tends to be highest in fuelbeds with high total biomass. However, a fuelbed with higher loading of finer fuels might have a higher available fuel potential than a fuelbed with higher loading of coarse fuels, because the fine fuels are more likely to be consumed.

The three fire potentials can be used to compare the potential fire behavior among fuelbeds. For example, an FCCS fire potential of 469 represents a fuelbed with modest surface fire potential, above-average crown fire potential, and extreme potential for biomass consumption (Sandberg et al. 2007b). A fuelbed with a fire potential of 222 is predicted to have lower surface fire potential and much lower potentials for crown fire and biomass consumption than the first fuelbed. Potentials are calculated from the loading, heat content, bulk density, and characteristic thickness of fuel elements without consideration of moisture content or environmental conditions.

The FTE and loblolly fuelbeds are included as project deliverables and can be input into the FCCS, allowing additional outputs not included in the results tables presented here to be calculated. Additional outputs include fuel loading, total carbon, and summaries of fuel characteristics by stratum.

Table 6. FCCS fire behavior predictions for FTE fuelbeds. Windspeed = input midflame windspeed (mph), Slope = input slope gradient. Surface fire behavior outputs include reaction intensity (BTU $ft^{-2}min^{-1}$), flame length (ft), and rate of spread (ft min^{-1}). The 3-digit FCCS fire potential code is a combined index (0-9) of surface fire behavior, crown fire behavior, and available fuel potentials. Suggested crosswalks to the original 13 fire behavior fuel models (Rothermel 1972, Albini 1976) and standard 40 fire behavior fuel models (Scott and Burgan 2005) are also included. To convert rate of spread to ch/hr multiply ft/min by 0.9091.

		FCCS Fire Behavior Predictions Genetically engineered freeze-tolerant *Eucalpytus x urograndis* fuelbeds in the Southern United States																	
		D4L4C1 Moisture Scenario						D2L2C3 Moisture Scenario						D1L1C4 Moisture Scenario					
	Windspeed mph	0	0	3	3	7	7	0	0	3	3	7	7	0	0	3	3	7	7
	Slope %	00	15	00	15	00	15	00	15	00	15	00	15	00	15	00	15	00	15
FB_1301	Reaction Intensity (1,000 BTU/ft²/min)	0.00	0.00	0.00	0.00	0.00	0.00	0.16	0.16	0.16	0.16	0.16	0.16	0.19	0.19	0.19	0.19	0.19	0.19
	Flame Length (ft)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.38	0.40	0.66	0.67	0.00	0.00	0.55	0.58	0.96	0.97
	Rate of Spread (ft/min)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.67	1.89	5.60	5.83	0.00	0.00	3.11	3.53	10.48	10.89
	FCCS Fire Potentials	360	360	360	360	360	360	360	360	360	360	360	360	360	360	360	360	360	360
	Crosswalk – FBPS FMs	2	2	8	8	8	8	2	2	8	8	2	2	2	2	8	2	2	2
	Crosswalk – Standard FMs	121	121	181	181	181	181	121	121	181	181	121	121	121	121	183	121	121	121
FB_1302	Reaction Intensity (1,000 BTU/ft²/min)	0.04	0.04	0.04	0.04	0.04	0.04	2.18	2.18	2.18	2.18	2.18	2.18	2.59	2.59	2.59	2.59	2.59	2.59
	Flame Length (ft)	0.00	0.00	0.06	0.07	0.09	0.10	0.00	0.00	1.75	1.80	3.04	3.07	0.00	0.00	2.34	2.40	4.07	4.10
	Rate of Spread (ft/min)	0.00	0.00	0.18	0.20	0.39	0.42	0.00	0.00	3.44	3.66	11.46	11.68	0.00	0.00	5.43	5.78	18.09	18.43
	FCCS Fire Potentials	521	521	521	521	521	521	521	521	521	521	521	521	521	521	521	521	521	521
	Crosswalk – FBPS FMs	2	2	8	8	8	8	2	2	8	8	11	11	2	2	9	9	6	6
	Crosswalk – Standard FMs	121	121	181	181	181	181	121	121	186	186	202	202	121	121	186	186	142	142

		FCCS Fire Behavior Predictions Genetically engineered freeze-tolerant *Eucalpytus x urograndis* fuelbeds in the Southern United States																	
		D4L4C1 Moisture Scenario						D2L2C3 Moisture Scenario						D1L1C4 Moisture Scenario					
	Windspeed mph	0	0	3	3	7	7	0	0	3	3	7	7	0	0	3	3	7	7
	Slope %	00	15	00	15	00	15	00	15	00	15	00	15	00	15	00	15	00	15
FB_1303	Reaction Intensity (1,000 BTU/ft²/min)	0.00	0.00	0.00	0.00	0.00	0.00	0.16	0.16	0.16	0.16	0.16	0.16	0.19	0.19	0.19	0.19	0.19	0.19
	Flame Length (ft)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.38	0.40	0.66	0.67	0.00	0.00	0.55	0.58	0.96	0.97
	Rate of Spread (ft/min)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.67	1.89	5.60	5.83	0.00	0.00	3.11	3.53	10.48	10.89
	FCCS Fire Potentials	340	340	340	340	340	340	340	340	340	340	340	340	340	340	340	340	340	340
	Crosswalk – FBPS FMs	2	2	8	8	8	8	2	2	8	8	2	2	2	2	8	2	2	2
	Crosswalk – Standard FMs	121	121	181	181	181	181	121	121	181	181	121	121	121	121	183	121	121	121
FB_1304	Reaction Intensity (1,000 BTU/ft²/min)	0.05	0.05	0.05	0.05	0.05	0.05	3.03	3.03	3.03	3.03	3.03	3.03	3.61	3.61	3.61	3.61	3.61	3.61
	Flame Length (ft)	0.00	0.00	0.08	0.08	0.11	0.12	0.00	0.00	2.35	2.42	4.09	4.12	0.00	0.00	3.14	3.23	5.47	5.51
	Rate of Spread (ft/min)	0.00	0.00	0.22	0.25	0.48	0.51	0.00	0.00	4.71	4.98	15.68	15.95	0.00	0.00	7.44	7.87	24.76	25.19
	FCCS Fire Potentials	511	511	511	511	511	511	511	511	511	511	511	511	511	511	511	511	511	511
	Crosswalk – FBPS FMs	2	2	8	8	8	8	2	2	9	9	6	6	2	2	9	9	6	6
	Crosswalk – Standard FMs	121	121	181	181	181	181	121	121	186	186	142	142	121	121	189	164	144	144

		FCCS Fire Behavior Predictions Genetically engineered freeze-tolerant *Eucalpytus x urograndis* fuelbeds in the Southern United States																	
		D4L4C1 Moisture Scenario						D2L2C3 Moisture Scenario						D1L1C4 Moisture Scenario					
	Windspeed mph	0	0	3	3	7	7	0	0	3	3	7	7	0	0	3	3	7	7
	Slope %	00	15	00	15	00	15	00	15	00	15	00	15	00	15	00	15	00	15
FB_1305	Reaction Intensity (1,000 BTU/ft²/min)	0.52	0.52	0.52	0.52	0.52	0.52	0.80	0.80	0.80	0.80	0.80	0.80	0.96	0.96	0.96	0.96	0.96	0.96
	Flame Length (ft)	0.00	0.00	0.82	0.88	1.16	1.20	0.00	0.00	1.10	1.17	1.55	1.60	0.00	0.00	1.38	1.47	1.94	2.00
	Rate of Spread (ft/min)	0.00	0.00	1.56	1.80	3.29	3.53	0.00	0.00	2.16	2.48	4.54	4.87	0.00	0.00	2.91	3.35	6.13	6.57
	FCCS Fire Potentials	361	361	361	361	361	361	361	361	361	361	361	361	361	361	361	361	361	361
	Crosswalk – FBPS FMs	2	2	8	8	8	8	2	2	8	8	8	8	2	2	8	8	8	8
	Crosswalk – Standard FMs	121	121	183	183	185	185	121	121	184	185	186	186	121	121	185	185	186	186
FB_1306	Reaction Intensity (1,000 BTU/ft²/min)	0.37	0.37	0.37	0.37	0.37	0.37	2.72	2.72	2.72	2.72	2.72	2.72	3.24	3.24	3.24	3.24	3.24	3.24
	Flame Length (ft)	0.00	0.00	0.65	0.68	0.93	0.95	0.00	0.00	1.76	1.78	3.03	3.04	0.00	0.00	2.25	2.28	3.88	3.89
	Rate of Spread (ft/min)	0.00	0.00	1.32	1.47	2.90	3.05	0.00	0.00	2.49	2.56	8.12	8.19	0.00	0.00	3.56	3.66	11.62	11.72
	FCCS Fire Potentials	421	421	421	421	421	421	421	421	421	421	421	421	421	421	421	421	421	421
	Crosswalk – FBPS FMs	2	2	8	8	8	8	2	2	8	8	9	9	2	2	9	9	9	11
	Crosswalk – Standard FMs	121	121	183	183	183	183	121	121	186	186	164	164	121	121	186	186	148	202

		FCCS Fire Behavior Predictions Genetically engineered freeze-tolerant *Eucalpytus x urograndis* fuelbeds in the Southern United States																	
		D4L4C1 Moisture Scenario						D2L2C3 Moisture Scenario						D1L1C4 Moisture Scenario					
	Windspeed mph	0	0	3	3	7	7	0	0	3	3	7	7	0	0	3	3	7	7
	Slope %	00	15	00	15	00	15	00	15	00	15	00	15	00	15	00	15	00	15
FB_1307	Reaction Intensity (1,000 BTU/ft²/min)	0.46	0.46	0.46	0.46	0.46	0.46	0.52	0.52	0.52	0.52	0.52	0.52	0.63	0.63	0.63	0.63	0.63	0.63
	Flame Length (ft)	0.00	0.00	0.69	0.74	0.93	0.97	0.00	0.00	0.85	0.92	1.15	1.20	0.00	0.00	1.07	1.15	1.44	1.50
	Rate of Spread (ft/min)	0.00	0.00	1.39	1.62	2.67	2.90	0.00	0.00	1.92	2.24	3.68	4.00	0.00	0.00	2.58	3.02	4.96	5.40
	FCCS Fire Potentials	362	362	362	362	362	362	362	362	362	362	362	362	362	362	362	362	362	362
	Crosswalk – FBPS FMs	2	2	8	8	8	8	2	2	8	8	8	8	2	2	8	8	8	8
	Crosswalk – Standard FMs	121	121	183	183	183	183	121	121	183	183	185	185	121	121	184	185	185	185
FB_1309	Reaction Intensity (1,000 BTU/ft²/min)	0.36	0.36	0.36	0.36	0.36	0.36	2.51	2.51	2.51	2.51	2.51	2.51	3.00	3.00	3.00	3.00	3.00	3.00
	Flame Length (ft)	0.00	0.00	0.65	0.68	0.93	0.96	0.00	0.00	1.66	1.68	2.86	2.87	0.00	0.00	2.11	2.14	3.65	3.66
	Rate of Spread (ft/min)	0.00	0.00	1.42	1.59	3.13	3.30	0.00	0.00	2.37	2.44	7.77	7.84	0.00	0.00	3.37	3.47	11.02	11.12
	FCCS Fire Potentials	451	451	451	451	451	451	451	451	451	451	451	451	451	451	451	451	451	451
	Crosswalk – FBPS FMs	2	2	8	8	8	8	2	2	8	8	9	9	2	2	9	9	11	11
	Crosswalk – Standard FMs	121	121	183	183	183	184	121	121	186	186	164	164	121	121	183	183	202	202

		FCCS Fire Behavior Predictions Genetically engineered freeze-tolerant *Eucalpytus x urograndis* fuelbeds in the Southern United States																	
		D4L4C1 Moisture Scenario						D2L2C3 Moisture Scenario						D1L1C4 Moisture Scenario					
	Windspeed mph	0	0	3	3	7	7	0	0	3	3	7	7	0	0	3	3	7	7
	Slope %	00	15	00	15	00	15	00	15	00	15	00	15	00	15	00	15	00	15
FB_1310	Reaction Intensity (1,000 BTU/ft²/min)	0.47	0.47	0.47	0.47	0.47	0.47	0.75	0.75	0.75	0.75	0.75	0.75	0.91	0.91	0.91	0.91	0.91	0.91
	Flame Length (ft)	0.00	0.00	0.75	0.80	1.07	1.10	0.00	0.00	1.03	1.10	1.46	1.51	0.00	0.00	1.29	1.37	1.83	1.89
	Rate of Spread (ft/min)	0.00	0.00	1.61	1.85	3.47	3.71	0.00	0.00	2.23	2.55	4.79	5.11	0.00	0.00	3.00	3.44	6.46	6.90
	FCCS Fire Potentials	342	342	342	342	342	342	342	342	342	342	342	342	342	342	342	342	342	342
	Crosswalk – FBPS FMs	2	2	8	8	8	8	2	2	8	8	8	8	2	2	8	8	8	8
	Crosswalk – Standard FMs	121	121	183	183	184	184	121	121	184	184	185	186	121	121	185	185	186	186
FB_1312	Reaction Intensity (1,000 BTU/ft²/min)	0.28	0.28	0.28	0.28	0.28	0.28	3.14	3.14	3.14	3.14	3.14	3.14	3.74	3.74	3.74	3.74	3.74	3.74
	Flame Length (ft)	0.00	0.00	0.49	0.52	0.71	0.73	0.00	0.00	1.79	1.81	3.10	3.11	0.00	0.00	2.26	2.29	3.92	3.93
	Rate of Spread (ft/min)	0.00	0.00	1.37	1.54	3.04	3.20	0.00	0.00	2.44	2.51	8.05	8.12	0.00	0.00	3.42	3.51	11.25	11.35
	FCCS Fire Potentials	441	441	441	441	441	441	441	441	441	441	441	441	441	441	441	441	441	441
	Crosswalk – FBPS FMs	2	2	8	8	8	8	2	2	8	8	9	9	2	2	9	9	9	9
	Crosswalk – Standard FMs	121	121	181	183	183	183	121	121	186	186	164	164	121	121	186	186	148	148

		FCCS Fire Behavior Predictions Genetically engineered freeze-tolerant *Eucalpytus x urograndis* fuelbeds in the Southern United States																	
		D4L4C1 Moisture Scenario						D2L2C3 Moisture Scenario						D1L1C4 Moisture Scenario					
	Windspeed mph	0	0	3	3	7	7	0	0	3	3	7	7	0	0	3	3	7	7
	Slope %	00	15	00	15	00	15	00	15	00	15	00	15	00	15	00	15	00	15
FB_1313	Reaction Intensity (1,000 BTU/ft²/min)	0.58	0.58	0.58	0.58	0.58	0.58	0.67	0.67	0.67	0.67	0.67	0.67	0.80	0.80	0.80	0.80	0.80	0.80
	Flame Length (ft)	0.00	0.00	0.96	1.04	1.30	1.35	0.00	0.00	1.19	1.28	1.60	1.67	0.00	0.00	1.49	1.60	2.01	2.09
	Rate of Spread (ft/min)	0.00	0.00	1.78	2.08	3.42	3.72	0.00	0.00	2.46	2.87	4.72	5.13	0.00	0.00	3.31	3.88	6.36	6.93
	FCCS Fire Potentials	363	363	363	363	363	363	363	363	363	363	363	363	363	363	363	363	363	363
	Crosswalk – FBPS FMs	2	2	8	8	8	8	2	2	8	8	8	8	2	2	8	8	11	11
	Crosswalk – Standard FMs	121	121	183	184	185	185	121	121	161	185	186	186	121	121	185	186	185	185
FB_1314	Reaction Intensity (1,000 BTU/ft²/min)	0.41	0.41	0.41	0.41	0.41	0.41	2.11	2.11	2.11	2.11	2.11	2.11	2.52	2.52	2.52	2.52	2.52	2.52
	Flame Length (ft)	0.00	0.00	0.74	0.78	1.06	1.09	0.00	0.00	1.45	1.53	2.23	2.24	0.00	0.00	1.81	1.91	2.84	2.86
	Rate of Spread (ft/min)	0.00	0.00	1.42	1.59	3.12	3.29	0.00	0.00	1.96	2.19	4.95	5.00	0.00	0.00	2.64	2.95	7.02	7.09
	FCCS Fire Potentials	351	351	351	351	351	351	351	351	351	351	351	351	351	351	351	351	351	351
	Crosswalk – FBPS FMs	2	2	8	8	8	8	2	2	8	8	9	9	2	2	8	8	9	9
	Crosswalk – Standard FMs	121	121	183	183	184	184	121	121	161	186	186	186	121	121	186	186	189	189

		FCCS Fire Behavior Predictions Genetically engineered freeze-tolerant *Eucalpytus x urograndis* fuelbeds in the Southern United States																	
		D4L4C1 Moisture Scenario						D2L2C3 Moisture Scenario						D1L1C4 Moisture Scenario					
	Windspeed mph	0	0	3	3	7	7	0	0	3	3	7	7	0	0	3	3	7	7
	Slope %	00	15	00	15	00	15	00	15	00	15	00	15	00	15	00	15	00	15
FB_1317	Reaction Intensity (1,000 BTU/ft²/min)	0.48	0.48	0.48	0.48	0.48	0.48	0.55	0.55	0.55	0.55	0.55	0.55	0.66	0.66	0.66	0.66	0.66	0.66
	Flame Length (ft)	0.00	0.00	0.79	0.85	1.06	1.11	0.00	0.00	0.97	1.04	1.31	1.36	0.00	0.00	1.22	1.31	1.64	1.71
	Rate of Spread (ft/min)	0.00	0.00	1.69	1.97	3.24	3.53	0.00	0.00	2.33	2.72	4.47	4.87	0.00	0.00	3.14	3.68	6.03	6.57
	FCCS Fire Potentials	352	352	352	352	352	352	352	352	352	352	352	352	352	352	352	352	352	352
	Crosswalk – FBPS FMs	2	2	8	8	8	8	2	2	8	8	8	8	2	2	8	8	8	8
	Crosswalk – Standard FMs	121	121	183	183	184	184	121	121	183	184	185	185	121	121	185	185	186	186
FB_1318	Reaction Intensity (1,000 BTU/ft²/min)	0.40	0.40	0.40	0.40	0.40	0.40	2.27	2.27	2.27	2.27	2.27	2.27	2.70	2.70	2.70	2.70	2.70	2.70
	Flame Length (ft)	0.00	0.00	0.73	0.77	1.05	1.08	0.00	0.00	1.51	1.59	2.44	2.45	0.00	0.00	1.88	1.98	3.12	3.13
	Rate of Spread (ft/min)	0.00	0.00	1.47	1.64	3.23	3.41	0.00	0.00	2.03	2.27	5.76	5.82	0.00	0.00	2.73	3.06	8.18	8.26
	FCCS Fire Potentials	341	341	341	341	341	341	341	341	341	341	341	341	341	341	341	341	341	341
	Crosswalk – FBPS FMs	2	2	8	8	8	8	2	2	8	8	9	9	2	2	8	8	9	9
	Crosswalk – Standard FMs	121	121	183	183	184	184	121	121	186	186	186	186	121	121	186	186	164	164

		FCCS Fire Behavior Predictions Genetically engineered freeze-tolerant *Eucalpytus x urograndis* fuelbeds in the Southern United States																	
		D4L4C1 Moisture Scenario						D2L2C3 Moisture Scenario						D1L1C4 Moisture Scenario					
	Windspeed mph	0	0	3	3	7	7	0	0	3	3	7	7	0	0	3	3	7	7
	Slope %	00	15	00	15	00	15	00	15	00	15	00	15	00	15	00	15	00	15
FB_1319	Reaction Intensity (1,000 BTU/ft²/min)	0.37	0.37	0.37	0.37	0.37	0.37	0.42	0.42	0.42	0.42	0.42	0.42	0.50	0.50	0.50	0.50	0.50	0.50
	Flame Length (ft)	0.00	0.00	0.59	0.63	0.79	0.82	0.00	0.00	0.72	0.77	0.97	1.01	0.00	0.00	0.90	0.97	1.22	1.27
	Rate of Spread (ft/min)	0.00	0.00	1.78	2.08	3.42	3.72	0.00	0.00	2.46	2.87	4.72	5.13	0.00	0.00	3.31	3.88	6.36	6.93
	FCCS Fire Potentials	362	362	362	362	362	362	362	362	362	362	362	362	362	362	362	362	362	362
	Crosswalk – FBPS FMs	2	2	8	8	8	8	2	2	8	8	8	8	2	2	8	8	8	8
	Crosswalk – Standard FMs	121	121	183	183	183	183	121	121	183	183	184	184	121	121	184	184	185	185
FB_1320	Reaction Intensity (1,000 BTU/ft²/min)	0.29	0.29	0.29	0.29	0.29	0.29	2.67	2.67	2.67	2.67	2.67	2.67	3.18	3.18	3.18	3.18	3.18	3.18
	Flame Length (ft)	0.00	0.00	0.57	0.60	0.83	0.85	0.00	0.00	1.64	1.72	2.61	2.62	0.00	0.00	2.04	2.14	3.30	3.31
	Rate of Spread (ft/min)	0.00	0.00	1.69	1.89	3.72	3.92	0.00	0.00	2.33	2.60	6.44	6.49	0.00	0.00	3.14	3.51	8.94	9.02
	FCCS Fire Potentials	341	341	341	341	341	341	341	341	341	341	341	341	341	341	341	341	341	341
	Crosswalk – FBPS FMs	2	2	8	8	8	8	2	2	8	8	9	9	2	2	9	9	9	9
	Crosswalk – Standard FMs	121	121	183	183	183	183	121	121	186	186	188	188	121	121	183	183	164	164

		FCCS Fire Behavior Predictions Genetically engineered freeze-tolerant *Eucalpytus x urograndis* fuelbeds in the Southern United States																	
		D4L4C1 Moisture Scenario						D2L2C3 Moisture Scenario						D1L1C4 Moisture Scenario					
	Windspeed mph	0	0	3	3	7	7	0	0	3	3	7	7	0	0	3	3	7	7
	Slope %	00	15	00	15	00	15	00	15	00	15	00	15	00	15	00	15	00	15
FB_1321	Reaction Intensity (1,000 BTU/ft²/min)	0.48	0.48	0.48	0.48	0.48	0.48	2.04	2.04	2.04	2.04	2.04	2.04	2.43	2.43	2.43	2.43	2.43	2.43
	Flame Length (ft)	0.00	0.00	0.85	0.90	1.22	1.25	0.00	0.00	1.53	1.61	2.39	2.40	0.00	0.00	1.91	2.01	3.07	3.08
	Rate of Spread (ft/min)	0.00	0.00	1.52	1.70	3.33	3.51	0.00	0.00	2.09	2.34	5.51	5.57	0.00	0.00	2.82	3.16	7.93	8.02
	FCCS Fire Potentials	341	341	341	341	341	341	341	341	341	341	341	341	341	341	341	341	341	341
	Crosswalk – FBPS FMs	2	2	8	8	8	8	2	2	8	8	9	9	2	2	8	9	9	9
	Crosswalk – Standard FMs	121	121	183	183	185	185	121	121	186	186	186	186	121	121	186	183	164	164
FB_1322	Reaction Intensity (1,000 BTU/ft²/min)	0.37	0.37	0.37	0.37	0.37	0.37	0.42	0.42	0.42	0.42	0.42	0.42	0.51	0.51	0.51	0.51	0.51	0.51
	Flame Length (ft)	0.00	0.00	0.62	0.67	0.84	0.87	0.00	0.00	0.77	0.82	1.04	1.08	0.00	0.00	0.96	1.03	1.30	1.35
	Rate of Spread (ft/min)	0.00	0.00	2.01	2.35	3.86	4.21	0.00	0.00	2.77	3.25	5.33	5.80	0.00	0.00	3.74	4.38	7.19	7.83
	FCCS Fire Potentials	465	465	465	465	465	465	465	465	465	465	465	465	465	465	465	465	465	465
	Crosswalk – FBPS FMs	2	2	8	8	8	8	2	2	8	8	8	8	2	2	8	8	8	8
	Crosswalk – Standard FMs	121	121	183	183	183	183	121	121	183	183	184	184	121	121	184	184	185	185

		FCCS Fire Behavior Predictions Genetically engineered freeze-tolerant *Eucalpytus x urograndis* fuelbeds in the Southern United States																	
		D4L4C1 Moisture Scenario						D2L2C3 Moisture Scenario						D1L1C4 Moisture Scenario					
	Windspeed mph	0	0	3	3	7	7	0	0	3	3	7	7	0	0	3	3	7	7
	Slope %	00	15	00	15	00	15	00	15	00	15	00	15	00	15	00	15	00	15
FB_1323	Reaction Intensity (1,000 BTU/ft²/min)	0.31	0.31	0.31	0.31	0.31	0.31	2.71	2.71	2.71	2.71	2.71	2.71	3.23	3.23	3.23	3.23	3.23	3.23
	Flame Length (ft)	0.00	0.00	0.62	0.65	0.89	0.91	0.00	0.00	1.70	1.79	2.59	2.60	0.00	0.00	2.12	2.23	3.27	3.28
	Rate of Spread (ft/min)	0.00	0.00	1.79	2.00	3.95	4.16	0.00	0.00	2.47	2.76	6.14	6.18	0.00	0.00	3.33	3.73	8.55	8.62
	FCCS Fire Potentials	443	443	443	443	443	443	443	443	443	443	443	443	443	443	443	443	443	443
	Crosswalk – FBPS FMs	2	2	8	8	8	8	2	2	8	8	9	9	2	2	9	9	9	9
	Crosswalk – Standard FMs	121	121	183	183	184	184	121	121	186	186	188	188	121	121	183	186	164	164
FB_1324	Reaction Intensity (1,000 BTU/ft²/min)	0.74	0.74	0.74	0.74	0.74	0.74	1.27	1.27	1.27	1.27	1.27	1.27	1.53	1.53	1.53	1.53	1.53	1.53
	Flame Length (ft)	0.00	0.00	1.31	1.39	1.86	1.92	0.00	0.00	1.76	1.88	2.51	2.58	0.00	0.00	2.21	2.35	3.13	3.23
	Rate of Spread (ft/min)	0.00	0.00	2.33	2.67	5.00	5.34	0.00	0.00	3.21	3.69	6.89	7.37	0.00	0.00	4.34	4.97	9.30	9.94
	FCCS Fire Potentials	465	465	465	465	465	465	465	465	465	465	465	465	465	465	465	465	465	465
	Crosswalk – FBPS FMs	2	2	8	8	8	8	2	2	8	8	9	9	2	2	9	9	9	11
	Crosswalk – Standard FMs	121	121	161	185	186	186	121	121	186	186	162	162	121	121	186	186	164	202

		FCCS Fire Behavior Predictions Genetically engineered freeze-tolerant *Eucalpytus x urograndis* fuelbeds in the Southern United States																	
		D4L4C1 Moisture Scenario						D2L2C3 Moisture Scenario						D1L1C4 Moisture Scenario					
	Windspeed mph	0	0	3	3	7	7	0	0	3	3	7	7	0	0	3	3	7	7
	Slope %	00	15	00	15	00	15	00	15	00	15	00	15	00	15	00	15	00	15
FB_1325	Reaction Intensity (1,000 BTU/ft²/min)	0.54	0.54	0.54	0.54	0.54	0.54	2.90	2.90	2.90	2.90	2.90	2.90	3.47	3.47	3.47	3.47	3.47	3.47
	Flame Length (ft)	0.00	0.00	1.00	1.05	1.43	1.47	0.00	0.00	2.05	2.08	3.52	0.00	0.00	0.00	2.65	2.68	4.54	4.56
	Rate of Spread (ft/min)	0.00	0.00	1.77	1.99	3.89	4.10	0.00	0.00	2.84	2.92	9.19	0.00	0.00	0.00	4.14	4.25	13.37	13.48
	FCCS Fire Potentials	453	453	453	453	453	453	453	453	453	453	453	453	453	453	453	453	453	453
	Crosswalk – FBPS FMs	2	2	8	8	8	8	2	2	9	9	9	2	2	2	9	9	10	10
	Crosswalk – Standard FMs	121	121	183	184	185	185	121	121	183	183	164	121	121	121	188	188	164	164
FB_1326	Reaction Intensity (1,000 BTU/ft²/min)	0.66	0.66	0.66	0.66	0.66	0.66	2.32	2.32	2.32	2.32	2.32	2.32	2.77	2.77	2.77	2.77	2.77	2.77
	Flame Length (ft)	0.00	0.00	1.07	1.13	1.54	1.58	0.00	0.00	1.74	1.84	2.64	2.65	0.00	0.00	2.18	2.29	3.39	3.40
	Rate of Spread (ft/min)	0.00	0.00	1.56	1.74	3.40	3.59	0.00	0.00	2.15	2.41	5.27	5.33	0.00	0.00	2.90	3.25	7.58	7.65
	FCCS Fire Potentials	353	353	353	353	353	353	353	353	353	353	353	353	353	353	353	353	353	353
	Crosswalk – FBPS FMs	2	2	8	8	8	8	2	2	8	8	9	9	2	2	9	9	9	9
	Crosswalk – Standard FMs	121	121	184	187	186	186	121	121	186	186	188	188	121	121	183	185	189	189

		FCCS Fire Behavior Predictions Genetically engineered freeze-tolerant *Eucalpytus x urograndis* fuelbeds in the Southern United States																	
		D4L4C1 Moisture Scenario						D2L2C3 Moisture Scenario						D1L1C4 Moisture Scenario					
	Windspeed mph	0	0	3	3	7	7	0	0	3	3	7	7	0	0	3	3	7	7
	Slope %	00	15	00	15	00	15	00	15	00	15	00	15	00	15	00	15	00	15
FB_1327	Reaction Intensity (1,000 BTU/ft²/min)	1.28	1.28	1.28	1.28	1.28	1.28	2.09	2.09	2.09	2.09	2.09	2.09	2.51	2.51	2.51	2.51	2.51	2.51
	Flame Length (ft)	0.00	0.00	2.08	2.22	2.93	3.03	0.00	0.00	2.74	2.92	3.85	3.98	0.00	0.00	3.42	3.65	4.82	4.98
	Rate of Spread (ft/min)	0.00	0.00	3.04	3.50	6.40	6.86	0.00	0.00	4.20	4.83	8.83	9.47	0.00	0.00	5.67	6.52	11.92	12.78
	FCCS Fire Potentials	569	569	569	569	569	569	569	569	569	569	569	569	569	569	569	569	569	569
	Crosswalk – FBPS FMs	2	2	9	9	9	9	2	2	9	9	9	9	2	2	9	9	10	10
	Crosswalk – Standard FMs	121	121	183	186	189	189	121	121	188	189	146	146	121	121	189	189	163	163
FB_1328	Reaction Intensity (1,000 BTU/ft²/min)	1.09	1.09	1.09	1.09	1.09	1.09	3.73	3.73	3.73	3.73	3.73	3.73	4.46	4.46	4.46	4.46	4.46	4.46
	Flame Length (ft)	0.00	0.00	1.70	1.80	2.44	2.50	0.00	0.00	2.66	2.81	4.23	4.24	0.00	0.00	3.33	3.51	5.42	5.44
	Rate of Spread (ft/min)	0.00	0.00	2.21	2.48	4.81	5.08	0.00	0.00	3.05	3.42	8.31	8.39	0.00	0.00	4.12	4.62	11.88	12.00
	FCCS Fire Potentials	455	455	455	455	455	455	455	455	455	455	455	455	455	455	455	455	455	455
	Crosswalk – FBPS FMs	2	2	8	8	9	9	2	2	9	9	10	10	2	2	9	9	10	10
	Crosswalk – Standard FMs	121	121	186	186	186	186	121	121	188	188	164	164	121	121	189	189	163	163

		FCCS Fire Behavior Predictions Genetically engineered freeze-tolerant *Eucalpytus x urograndis* fuelbeds in the Southern United States																	
		D4L4C1 Moisture Scenario						D2L2C3 Moisture Scenario						D1L1C4 Moisture Scenario					
	Windspeed mph	0	0	3	3	7	7	0	0	3	3	7	7	0	0	3	3	7	7
	Slope %	00	15	00	15	00	15	00	15	00	15	00	15	00	15	00	15	00	15
FB_1329	Reaction Intensity (1,000 BTU/ft²/min)	0.66	0.66	0.66	0.66	0.66	0.66	1.19	1.19	1.19	1.19	1.19	1.19	1.43	1.43	1.43	1.43	1.43	1.43
	Flame Length (ft)	0.00	0.00	1.44	1.53	2.05	2.11	0.00	0.00	1.98	2.10	2.81	2.90	0.00	0.00	2.47	2.63	3.51	3.62
	Rate of Spread (ft/min)	0.00	0.00	3.42	3.92	7.37	7.87	0.00	0.00	4.72	5.41	10.17	10.86	0.00	0.00	6.37	7.30	13.73	14.66
	FCCS Fire Potentials	568	568	568	568	568	568	568	568	568	568	568	568	568	568	568	568	568	568
	Crosswalk – FBPS FMs	2	2	8	8	11	11	2	2	8	9	11	11	2	2	9	9	6	6
	Crosswalk – Standard FMs	121	121	185	186	185	185	121	121	186	183	201	202	121	121	186	162	142	142
FB_1330	Reaction Intensity (1,000 BTU/ft²/min)	0.47	0.47	0.47	0.47	0.47	0.47	3.36	3.36	3.36	3.36	3.36	3.36	4.00	4.00	4.00	4.00	4.00	4.00
	Flame Length (ft)	0.00	0.00	1.06	1.11	1.52	1.56	0.00	0.00	2.33	2.43	4.02	4.03	0.00	0.00	2.99	3.03	5.16	5.17
	Rate of Spread (ft/min)	0.00	0.00	2.51	2.81	5.51	5.81	0.00	0.00	3.52	3.87	11.49	11.56	0.00	0.00	5.08	5.22	16.57	16.67
	FCCS Fire Potentials	554	554	554	554	554	554	554	554	554	554	554	554	554	554	554	554	554	554
	Crosswalk – FBPS FMs	2	2	8	8	8	8	2	2	9	9	10	10	2	2	9	9	6	6
	Crosswalk – Standard FMs	121	121	184	184	186	186	121	121	186	186	162	162	121	121	189	189	144	144

		FCCS Fire Behavior Predictions Genetically engineered freeze-tolerant *Eucalpytus x urograndis* fuelbeds in the Southern United States																	
		D4L4C1 Moisture Scenario						D2L2C3 Moisture Scenario						D1L1C4 Moisture Scenario					
	Windspeed mph	0	0	3	3	7	7	0	0	3	3	7	7	0	0	3	3	7	7
	Slope %	00	15	00	15	00	15	00	15	00	15	00	15	00	15	00	15	00	15
FB_1331	Reaction Intensity (1,000 BTU/ft²/min)	1.07	1.07	1.07	1.07	1.07	1.07	3.27	3.27	3.27	3.27	3.27	3.27	3.91	3.91	3.91	3.91	3.91	3.91
	Flame Length (ft)	0.00	0.00	1.47	1.55	2.10	2.15	0.00	0.00	2.23	2.35	3.77	3.79	0.00	0.00	2.86	2.94	4.85	4.87
	Rate of Spread (ft/min)	0.00	0.00	1.64	1.84	3.57	3.77	0.00	0.00	2.27	2.54	7.08	7.15	0.00	0.00	3.23	3.43	10.19	10.30
	FCCS Fire Potentials	455	455	455	455	455	455	455	455	455	455	455	455	455	455	455	455	455	455
	Crosswalk – FBPS FMs	2	2	8	8	9	9	2	2	9	9	9	9	2	2	9	9	10	10
	Crosswalk – Standard FMs	121	121	187	188	183	183	121	121	185	185	189	189	121	121	189	189	163	163
FB_1349	Reaction Intensity (1,000 BTU/ft²/min)	0.64	0.64	0.64	0.64	0.64	0.64	0.72	0.72	0.72	0.72	0.72	0.72	0.87	0.87	0.87	0.87	0.87	0.87
	Flame Length (ft)	0.00	0.00	1.11	1.20	1.50	1.56	0.00	0.00	1.37	1.47	1.85	1.92	0.00	0.00	1.72	1.84	2.32	2.41
	Rate of Spread (ft/min)	0.00	0.00	2.10	2.46	4.04	4.40	0.00	0.00	2.90	3.40	5.57	6.07	0.00	0.00	3.92	4.58	7.52	8.19
	FCCS Fire Potentials	452	452	452	452	452	452	452	452	452	452	452	452	452	452	452	452	452	452
	Crosswalk – FBPS FMs	2	2	8	8	8	8	2	2	8	8	8	8	2	2	8	8	11	11
	Crosswalk – Standard FMs	121	121	184	161	186	186	121	121	185	185	186	186	121	121	186	186	185	201

		FCCS Fire Behavior Predictions Genetically engineered freeze-tolerant *Eucalpytus x urograndis* fuelbeds in the Southern United States																	
		D4L4C1 Moisture Scenario						D2L2C3 Moisture Scenario						D1L1C4 Moisture Scenario					
	Windspeed mph	0	0	3	3	7	7	0	0	3	3	7	7	0	0	3	3	7	7
	Slope %	00	15	00	15	00	15	00	15	00	15	00	15	00	15	00	15	00	15
FB_1350	Reaction Intensity (1,000 BTU/ft²/min)	0.88	0.88	0.88	0.88	0.88	0.88	1.42	1.42	1.42	1.42	1.42	1.42	1.71	1.71	1.71	1.71	1.71	1.71
	Flame Length (ft)	0.00	0.00	1.74	1.85	2.46	2.53	0.00	0.00	2.29	2.45	3.25	3.35	0.00	0.00	2.87	3.06	4.06	4.19
	Rate of Spread (ft/min)	0.00	0.00	3.36	3.86	7.14	7.64	0.00	0.00	4.63	5.32	9.85	10.54	0.00	0.00	6.25	7.18	13.29	14.22
	FCCS Fire Potentials	566	566	566	566	566	566	566	566	566	566	566	566	566	566	566	566	566	566
	Crosswalk – FBPS FMs	2	2	8	8	9	11	2	2	9	9	11	11	2	2	9	9	6	6
	Crosswalk – Standard FMs	121	121	186	186	186	185	121	121	186	186	202	202	121	121	189	189	142	142
FB_1351	Reaction Intensity (1,000 BTU/ft²/min)	1.77	1.77	1.77	1.77	1.77	1.77	2.64	2.64	2.64	2.64	2.64	2.64	3.18	3.18	3.18	3.18	3.18	3.18
	Flame Length (ft)	0.00	0.00	2.57	2.74	3.59	3.71	0.00	0.00	3.31	3.53	4.62	4.78	0.00	0.00	4.13	4.42	5.78	5.98
	Rate of Spread (ft/min)	0.00	0.00	3.23	3.73	6.70	7.20	0.00	0.00	4.46	5.15	9.25	9.94	0.00	0.00	6.02	6.95	12.48	13.41
	FCCS Fire Potentials	569	569	569	569	569	569	569	569	569	569	569	569	569	569	569	569	569	569
	Crosswalk – FBPS FMs	2	2	9	9	9	9	2	2	9	9	10	10	2	2	10	10	10	10
	Crosswalk – Standard FMs	121	121	188	188	189	189	121	121	189	189	164	163	121	121	162	162	163	163

Table 7. FCCS fire behavior predictions for loblolly pine fuelbeds. Windspeed = input midflame windspeed (mph), Slope = input slope gradient. Surface fire behavior outputs include reaction intensity (BTU $ft^{-2}min^{-1}$), flame length (ft), and rate of spread (ft min^{-1}). The 3-digit FCCS fire potential code includes a combined index (0-9) of surface fire behavior, crown fire behavior, and available fuel potentials. Suggested crosswalks to the original 13 fire behavior fuel models (Rothermel 1972, Albini 1976) and standard 40 fire behavior fuel models (Scott and Burgan 2005) are also included. To convert rate of spread to ch/hr multiply ft/min by 0.9091.

		FCCS Fire Behavior Predictions Loblolly pine fuelbeds																	
		D4L4C1 Moisture Scenario						D2L2C3 Moisture Scenario						D1L1C4 Moisture Scenario					
	Windspeed mph	0	0	3	3	7	7	0	0	3	3	7	7	0	0	3	3	7	7
	Slope %	00	15	00	15	00	15	00	15	00	15	00	15	00	15	00	15	00	15
FB_1332	Reaction Intensity (1,000 BTU/ft²/min)	0.09	0.09	0.09	0.09	0.09	0.09	0.10	0.10	0.10	0.10	0.10	0.10	0.12	0.12	0.12	0.12	0.12	0.12
	Flame Length (ft)	0.00	0.00	0.20	0.20	0.33	0.34	0.00	0.00	0.24	0.25	0.41	0.42	0.00	0.00	0.30	0.31	0.52	0.52
	Rate of Spread (ft/min)	0.00	0.00	0.21	0.22	0.68	0.69	0.00	0.00	0.30	0.31	0.93	0.95	0.00	0.00	0.40	0.42	1.26	1.28
	FCCS Fire Potentials	110	110	110	110	110	110	110	110	110	110	110	110	110	110	110	110	110	110
	Crosswalk – FBPS FMs	2	2	8	8	8	8	2	2	8	8	8	8	2	2	8	8	8	8
	Crosswalk – Standard FMs	121	121	181	181	181	181	121	121	181	181	181	181	121	121	181	181	183	183
FB_1333	Reaction Intensity (1,000 BTU/ft²/min)	0.08	0.08	0.08	0.08	0.08	0.08	2.70	2.70	2.70	2.70	2.70	2.70	3.21	3.21	3.21	3.21	3.21	3.21
	Flame Length (ft)	0.00	0.00	0.14	0.14	0.20	0.20	0.00	0.00	1.82	1.84	3.16	3.17	0.00	0.00	2.39	2.42	4.15	4.16
	Rate of Spread (ft/min)	0.00	0.00	0.18	0.20	0.39	0.42	0.00	0.00	2.93	3.01	9.71	9.79	0.00	0.00	4.44	4.56	14.71	14.83
	FCCS Fire Potentials	420	420	420	420	420	420	420	420	420	420	420	420	420	420	420	420	420	420
	Crosswalk – FBPS FMs	2	2	8	8	8	8	2	2	8	8	11	11	2	2	9	9	6	6
	Crosswalk – Standard FMs	121	121	181	181	181	181	121	121	186	186	202	202	121	121	186	186	142	142

		FCCS Fire Behavior Predictions Loblolly pine fuelbeds																	
		D4L4C1 Moisture Scenario						D2L2C3 Moisture Scenario						D1L1C4 Moisture Scenario					
	Windspeed mph	0	0	3	3	7	7	0	0	3	3	7	7	0	0	3	3	7	7
	Slope %	00	15	00	15	00	15	00	15	00	15	00	15	00	15	00	15	00	15
FB_1334	Reaction Intensity (1,000 BTU/ft²/min)	0.39	0.39	0.39	0.39	0.39	0.39	0.45	0.45	0.45	0.45	0.45	0.45	0.54	0.54	0.54	0.54	0.54	0.54
	Flame Length (ft)	0.00	0.00	0.52	0.57	0.73	0.76	0.00	0.00	0.64	0.70	0.90	0.93	0.00	0.00	0.81	0.88	1.13	1.17
	Rate of Spread (ft/min)	0.00	0.00	0.79	0.95	1.65	1.77	0.00	0.00	1.09	1.32	2.27	2.44	0.00	0.00	1.47	1.78	3.06	3.29
	FCCS Fire Potentials	231	231	231	231	231	231	231	231	231	231	231	231	231	231	231	231	231	231
	Crosswalk – FBPS FMs	2	2	8	8	8	8	2	2	8	8	8	8	2	2	8	8	8	8
	Crosswalk – Standard FMs	121	121	183	183	183	183	121	121	183	183	183	183	121	121	183	183	185	185
FB_1335	Reaction Intensity (1,000 BTU/ft²/min)	0.39	0.39	0.39	0.39	0.39	0.39	0.45	0.45	0.45	0.45	0.45	0.45	0.54	0.54	0.54	0.54	0.54	0.54
	Flame Length (ft)	0.00	0.00	0.52	0.57	0.73	0.76	0.00	0.00	0.64	0.70	0.90	0.93	0.00	0.00	0.81	0.88	1.13	1.17
	Rate of Spread (ft/min)	0.00	0.00	0.79	0.95	1.65	1.77	0.00	0.00	1.09	1.32	2.27	2.44	0.00	0.00	1.47	1.78	3.06	3.29
	FCCS Fire Potentials	231	231	231	231	231	231	231	231	231	231	231	231	231	231	231	231	231	231
	Crosswalk – FBPS FMs	2	2	8	8	8	8	2	2	8	8	8	8	2	2	8	8	8	8
	Crosswalk – Standard FMs	121	121	183	183	183	183	121	121	183	183	183	183	121	121	183	183	185	185

		FCCS Fire Behavior Predictions Loblolly pine fuelbeds																	
		D4L4C1 Moisture Scenario						D2L2C3 Moisture Scenario						D1L1C4 Moisture Scenario					
	Windspeed mph	0	0	3	3	7	7	0	0	3	3	7	7	0	0	3	3	7	7
	Slope %	00	15	00	15	00	15	00	15	00	15	00	15	00	15	00	15	00	15
FB_1336	Reaction Intensity (1,000 BTU/ft²/min)	0.46	0.46	0.46	0.46	0.46	0.46	3.43	3.43	3.43	3.43	3.43	3.43	4.09	4.09	4.09	4.09	4.09	4.09
	Flame Length (ft)	0.00	0.00	0.71	0.76	1.03	1.06	0.00	0.00	2.28	2.30	3.92	3.94	0.00	0.00	2.93	2.96	5.04	5.06
	Rate of Spread (ft/min)	0.00	0.00	1.18	1.33	2.62	2.77	0.00	0.00	3.38	3.45	11.00	11.08	0.00	0.00	4.87	4.98	15.88	15.99
	FCCS Fire Potentials	421	421	421	421	421	421	421	421	421	421	421	421	421	421	421	421	421	421
	Crosswalk – FBPS FMs	2	2	8	8	8	8	2	2	9	9	9	9	2	2	9	9	6	6
	Crosswalk – Standard FMs	121	121	183	183	184	184	121	121	185	186	148	148	121	121	189	189	144	144
FB_1337	Reaction Intensity (1,000 BTU/ft²/min)	0.92	0.92	0.92	0.92	0.92	0.92	1.41	1.41	1.41	1.41	1.41	1.41	1.69	1.69	1.69	1.69	1.69	1.69
	Flame Length (ft)	0.00	0.00	1.27	1.35	1.81	1.86	0.00	0.00	1.67	1.78	2.39	2.46	0.00	0.00	2.09	2.23	2.98	3.08
	Rate of Spread (ft/min)	0.00	0.00	1.88	2.16	4.07	4.34	0.00	0.00	2.59	2.97	5.61	5.99	0.00	0.00	3.50	4.01	7.58	8.09
	FCCS Fire Potentials	442	442	442	442	442	442	442	442	442	442	442	442	442	442	442	442	442	442
	Crosswalk – FBPS FMs	2	2	8	8	8	8	2	2	8	8	9	9	2	2	9	9	9	9
	Crosswalk – Standard FMs	121	121	161	161	186	186	121	121	186	186	186	186	121	121	183	186	189	164

		FCCS Fire Behavior Predictions Loblolly pine fuelbeds																	
		D4L4C1 Moisture Scenario						D2L2C3 Moisture Scenario						D1L1C4 Moisture Scenario					
	Windspeed mph	0	0	3	3	7	7	0	0	3	3	7	7	0	0	3	3	7	7
	Slope %	00	15	00	15	00	15	00	15	00	15	00	15	00	15	00	15	00	15
FB_1338	Reaction Intensity (1,000 BTU/ft²/min)	0.92	0.92	0.92	0.92	0.92	0.92	1.41	1.41	1.41	1.41	1.41	1.41	1.69	1.69	1.69	1.69	1.69	1.69
	Flame Length (ft)	0.00	0.00	1.27	1.35	1.81	1.86	0.00	0.00	1.67	1.78	2.39	2.46	0.00	0.00	2.09	2.23	2.98	3.08
	Rate of Spread (ft/min)	0.00	0.00	1.88	2.16	4.07	4.34	0.00	0.00	2.59	2.97	5.61	5.99	0.00	0.00	3.50	4.01	7.58	8.09
	FCCS Fire Potentials	442	442	442	442	442	442	442	442	442	442	442	442	442	442	442	442	442	442
	Crosswalk – FBPS FMs	2	2	8	8	8	8	2	2	8	8	9	9	2	2	9	9	9	9
	Crosswalk – Standard FMs	121	121	161	161	186	186	121	121	186	186	186	186	121	121	183	186	189	164
FB_1340	Reaction Intensity (1,000 BTU/ft²/min)	0.72	0.72	0.72	0.72	0.72	0.72	2.64	2.64	2.64	2.64	2.64	2.64	3.15	3.15	3.15	3.15	3.15	3.15
	Flame Length (ft)	0.00	0.00	1.05	1.11	1.52	1.55	0.00	0.00	1.73	1.82	2.82	2.84	0.00	0.00	2.15	2.27	3.61	3.64
	Rate of Spread (ft/min)	0.00	0.00	1.35	1.51	2.99	3.15	0.00	0.00	1.86	2.08	5.43	5.51	0.00	0.00	2.51	2.81	7.74	7.85
	FCCS Fire Potentials	331	331	331	331	331	331	331	331	331	331	331	331	331	331	331	331	331	331
	Crosswalk – FBPS FMs	2	2	8	8	8	8	2	2	8	8	9	9	2	2	9	9	9	9
	Crosswalk – Standard FMs	121	121	184	184	186	186	121	121	186	186	189	189	121	121	183	185	164	164

		FCCS Fire Behavior Predictions Loblolly pine fuelbeds																	
		D4L4C1 Moisture Scenario						D2L2C3 Moisture Scenario						D1L1C4 Moisture Scenario					
	Windspeed mph	0	0	3	3	7	7	0	0	3	3	7	7	0	0	3	3	7	7
	Slope %	00	15	00	15	00	15	00	15	00	15	00	15	00	15	00	15	00	15
FB_1341	Reaction Intensity (1,000 BTU/ft²/min)	0.55	0.55	0.55	0.55	0.55	0.55	0.68	0.68	0.68	0.68	0.68	0.68	0.82	0.82	0.82	0.82	0.82	0.82
	Flame Length (ft)	0.00	0.00	0.80	0.85	1.12	1.16	0.00	0.00	1.01	1.08	1.42	1.47	0.00	0.00	1.27	1.35	1.78	1.84
	Rate of Spread (ft/min)	0.00	0.00	1.96	2.26	4.11	4.41	0.00	0.00	2.70	3.11	5.67	6.08	0.00	0.00	3.64	4.20	7.65	8.21
	FCCS Fire Potentials	452	452	452	452	452	452	452	452	452	452	452	452	452	452	452	452	452	452
	Crosswalk – FBPS FMs	2	2	8	8	8	8	2	2	8	8	8	8	2	2	8	8	8	8
	Crosswalk – Standard FMs	121	121	183	183	184	185	121	121	184	184	185	185	121	121	185	185	186	186
FB_1342	Reaction Intensity (1,000 BTU/ft²/min)	0.55	0.55	0.55	0.55	0.55	0.55	0.65	0.65	0.65	0.65	0.65	0.65	0.79	0.79	0.79	0.79	0.79	0.79
	Flame Length (ft)	0.00	0.00	0.83	0.89	1.16	1.20	0.00	0.00	1.11	1.18	1.56	1.61	0.00	0.00	1.42	1.52	2.00	2.07
	Rate of Spread (ft/min)	0.00	0.00	2.16	2.49	4.47	4.81	0.00	0.00	3.42	3.95	7.20	7.72	0.00	0.00	4.89	5.63	10.28	11.02
	FCCS Fire Potentials	453	453	453	453	453	453	453	453	453	453	453	453	453	453	453	453	453	453
	Crosswalk – FBPS FMs	2	2	8	8	8	8	2	2	8	8	8	8	2	2	8	8	11	11
	Crosswalk – Standard FMs	121	121	183	183	185	185	121	121	184	185	186	186	121	121	185	186	201	201

		FCCS Fire Behavior Predictions Loblolly pine fuelbeds																	
		D4L4C1 Moisture Scenario						D2L2C3 Moisture Scenario						D1L1C4 Moisture Scenario					
	Windspeed mph	0	0	3	3	7	7	0	0	3	3	7	7	0	0	3	3	7	7
	Slope %	00	15	00	15	00	15	00	15	00	15	00	15	00	15	00	15	00	15
FB_1344	Reaction Intensity (1,000 BTU/ft²/min)	0.71	0.71	0.71	0.71	0.71	0.71	1.82	1.82	1.82	1.82	1.82	1.82	2.18	2.18	2.18	2.18	2.18	2.18
	Flame Length (ft)	0.00	0.00	1.02	1.07	1.45	1.49	0.00	0.00	1.51	1.59	2.16	2.21	0.00	0.00	1.89	1.99	2.69	2.76
	Rate of Spread (ft/min)	0.00	0.00	1.30	1.46	2.82	2.98	0.00	0.00	1.80	2.02	3.89	4.11	0.00	0.00	2.42	2.72	5.25	5.55
	FCCS Fire Potentials	332	332	332	332	332	332	332	332	332	332	332	332	332	332	332	332	332	332
	Crosswalk – FBPS FMs	2	2	8	8	8	8	2	2	8	8	9	9	2	2	8	8	9	9
	Crosswalk – Standard FMs	121	121	184	184	185	185	121	121	188	186	183	186	121	121	186	186	188	188
FB_1345	Reaction Intensity (1,000 BTU/ft²/min)	1.11	1.11	1.11	1.11	1.11	1.11	1.64	1.64	1.64	1.64	1.64	1.64	1.97	1.97	1.97	1.97	1.97	1.97
	Flame Length (ft)	0.00	0.00	1.75	1.85	2.52	2.59	0.00	0.00	2.27	2.41	3.27	3.37	0.00	0.00	2.84	3.01	4.09	4.21
	Rate of Spread (ft/min)	0.00	0.00	2.81	3.20	6.22	6.62	0.00	0.00	3.87	4.42	8.59	9.13	0.00	0.00	5.22	5.96	11.59	12.32
	FCCS Fire Potentials	442	442	442	442	442	442	442	442	442	442	442	442	442	442	442	442	442	442
	Crosswalk – FBPS FMs	2	2	8	8	9	9	2	2	9	9	9	9	2	2	9	9	10	10
	Crosswalk – Standard FMs	121	121	186	186	188	188	121	121	186	186	164	164	121	121	189	189	162	164

		FCCS Fire Behavior Predictions Loblolly pine fuelbeds																	
		D4L4C1 Moisture Scenario						D2L2C3 Moisture Scenario						D1L1C4 Moisture Scenario					
	Windspeed mph	0	0	3	3	7	7	0	0	3	3	7	7	0	0	3	3	7	7
	Slope %	00	15	00	15	00	15	00	15	00	15	00	15	00	15	00	15	00	15
FB_1346	Reaction Intensity (1,000 BTU/ft²/min)	1.06	1.06	1.06	1.06	1.06	1.06	1.58	1.58	1.58	1.58	1.58	1.58	1.90	1.90	1.90	1.90	1.90	1.90
	Flame Length (ft)	0.00	0.00	1.69	1.80	2.44	2.51	0.00	0.00	2.21	2.34	3.18	3.27	0.00	0.00	2.76	2.93	3.98	4.09
	Rate of Spread (ft/min)	0.00	0.00	2.80	3.20	6.22	6.61	0.00	0.00	3.87	4.41	8.58	9.12	0.00	0.00	5.22	5.96	11.58	12.31
	FCCS Fire Potentials	443	443	443	443	443	443	443	443	443	443	443	443	443	443	443	443	443	443
	Crosswalk – FBPS FMs	2	2	8	8	9	9	2	2	9	9	9	9	2	2	9	9	9	6
	Crosswalk – Standard FMs	121	121	186	186	186	188	121	121	186	186	164	164	121	121	188	189	148	142
FB_1347	Reaction Intensity (1,000 BTU/ft²/min)	1.06	1.06	1.06	1.06	1.06	1.06	1.58	1.58	1.58	1.58	1.58	1.58	1.90	1.90	1.90	1.90	1.90	1.90
	Flame Length (ft)	0.00	0.00	1.68	1.79	2.41	2.48	0.00	0.00	2.19	2.33	3.15	3.24	0.00	0.00	2.74	2.91	3.94	4.05
	Rate of Spread (ft/min)	0.00	0.00	2.76	3.16	6.07	6.46	0.00	0.00	3.81	4.36	8.37	8.92	0.00	0.00	5.14	5.88	11.30	12.04
	FCCS Fire Potentials	444	444	444	444	444	444	444	444	444	444	444	444	444	444	444	444	444	444
	Crosswalk – FBPS FMs	2	2	8	8	9	9	2	2	9	9	9	9	2	2	9	9	9	10
	Crosswalk – Standard FMs	121	121	186	186	186	186	121	121	186	186	164	164	121	121	188	189	148	162

		FCCS Fire Behavior Predictions Loblolly pine fuelbeds																	
		D4L4C1 Moisture Scenario						D2L2C3 Moisture Scenario						D1L1C4 Moisture Scenario					
	Windspeed mph	0	0	3	3	7	7	0	0	3	3	7	7	0	0	3	3	7	7
	Slope %	00	15	00	15	00	15	00	15	00	15	00	15	00	15	00	15	00	15
FB_1348	Reaction Intensity (1,000 BTU/ft²/min)	0.76	0.76	0.76	0.76	0.76	0.76	2.68	2.68	2.68	2.68	2.68	2.68	3.21	3.21	3.21	3.21	3.21	3.21
	Flame Length (ft)	0.00	0.00	1.15	1.21	1.66	1.70	0.00	0.00	1.87	1.97	3.02	3.04	0.00	0.00	2.33	2.46	3.86	3.88
	Rate of Spread (ft/min)	0.00	0.00	1.55	1.73	3.44	3.62	0.00	0.00	2.14	2.39	6.07	6.15	0.00	0.00	2.89	3.23	8.62	8.74
	FCCS Fire Potentials	342	342	342	342	342	342	342	342	342	342	342	342	342	342	342	342	342	342
	Crosswalk – FBPS FMs	2	2	8	8	8	8	2	2	8	8	9	9	2	2	9	9	9	9
	Crosswalk – Standard FMs	121	121	187	187	186	186	121	121	186	186	189	189	121	121	185	185	146	146
FB_1352	Reaction Intensity (1,000 BTU/ft²/min)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Flame Length (ft)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Rate of Spread (ft/min)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	FCCS Fire Potentials	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Crosswalk – FBPS FMs	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	Crosswalk – Standard FMs	121	121	121	121	121	121	121	121	121	121	121	121	121	121	121	121	121	121

		FCCS Fire Behavior Predictions Loblolly pine fuelbeds																	
		D4L4C1 Moisture Scenario						D2L2C3 Moisture Scenario						D1L1C4 Moisture Scenario					
	Windspeed mph	0	0	3	3	7	7	0	0	3	3	7	7	0	0	3	3	7	7
	Slope %	00	15	00	15	00	15	00	15	00	15	00	15	00	15	00	15	00	15
FB_1353	Reaction Intensity (1,000 BTU/ft²/min)	0.00	0.00	0.00	0.00	0.00	0.00	2.47	2.47	2.47	2.47	2.47	2.47	2.93	2.93	2.93	2.93	2.93	2.93
	Flame Length (ft)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.00	3.09	5.22	5.27	0.00	0.00	4.19	4.31	7.28	7.35
	Rate of Spread (ft/min)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.80	10.45	32.65	33.30	0.00	0.00	16.99	18.13	56.61	57.74
	FCCS Fire Potentials	810	810	810	810	810	810	810	810	810	810	810	810	810	810	810	810	810	810
	Crosswalk – FBPS FMs	2	2	8	8	8	8	2	2	11	11	2	2	2	2	6	6	1	1
	Crosswalk – Standard FMs	121	121	181	181	181	181	121	121	201	201	103	103	121	121	142	142	109	109

Table 8. FCCS fire behavior predictions for additional Southern United States fuelbeds. Windspeed = input midflame windspeed (mph), Slope = input slope gradient. Surface fire behavior outputs include reaction intensity (BTU $ft^{-2}min^{-1}$), flame length (ft), and rate of spread (ft min^{-1}). The 3-digit FCCS fire potential code includes a combined index (0-9) of surface fire behavior, crown fire behavior, and available fuel potentials. Suggested crosswalks to the original 13 fire behavior fuel models (Rothermel 1972, Albini 1976) and standard 40 fire behavior fuel models (Scott and Burgan 2005) are also included. To convert rate of spread to ch/hr multiply ft/min by 0.9091.

		FCCS Fire Behavior Predictions Mixed hardwood and agriculture fuelbeds																	
		D4L4C1 Moisture Scenario						D2L2C3 Moisture Scenario						D1L1C4 Moisture Scenario					
	Windspeed mph	0	0	3	3	7	7	0	0	3	3	7	7	0	0	3	3	7	7
	Slope %	00	15	00	15	00	15	00	15	00	15	00	15	00	15	00	15	00	15
FB_0129	Reaction Intensity (1,000 BTU/ft²/min)	0.00	0.00	1.20	1.40	2.65	2.84	0.00	0.00	1.66	1.94	3.65	3.92	0.00	0.00	2.24	2.61	4.93	5.30
	Flame Length (ft)	0.00	0.00	0.69	0.74	0.98	1.02	0.00	0.00	0.97	1.04	1.39	1.44	0.00	0.00	1.20	1.29	1.73	1.79
	Rate of Spread (ft/min)	0.49	0.49	0.49	0.49	0.49	0.49	0.89	0.89	0.89	0.89	0.89	0.89	1.05	1.05	1.05	1.05	1.05	1.05
	FCCS Fire Potentials	301	301	301	301	301	301	301	301	301	301	301	301	121	301	301	301	301	301
	Crosswalk – FBPS FMs	2	2	8	8	8	8	2	2	8	8	8	8	301	2	8	8	8	8
	Crosswalk – Standard FMs	121	121	183	183	183	184	121	121	183	184	185	185	2	121	161	185	186	186
FB_0157	Reaction Intensity (1,000 BTU/ft²/min)	0.00	0.00	3.54	3.87	7.90	8.23	0.00	0.00	4.88	5.34	10.90	11.36	0.00	0.00	6.58	7.21	14.71	15.33
	Flame Length (ft)	0.00	0.00	2.82	2.94	4.08	4.15	0.00	0.00	3.58	3.73	5.18	5.28	0.00	0.00	4.44	4.63	6.43	6.55
	Rate of Spread (ft/min)	2.59	2.59	2.59	2.59	2.59	2.59	3.38	3.38	3.38	3.38	3.38	3.38	3.98	3.98	3.98	3.98	3.98	3.98
	FCCS Fire Potentials	534	534	534	534	534	534	534	534	534	534	534	534	121	534	534	534	534	534
	Crosswalk – FBPS FMs	2	2	9	9	10	10	2	2	9	9	10	10	534	2	10	10	12	12
	Crosswalk – Standard FMs	121	121	189	189	162	164	121	121	189	189	163	163	2	121	162	162	203	203

		FCCS Fire Behavior Predictions Mixed hardwood and agriculture fuelbeds																	
		D4L4C1 Moisture Scenario						D2L2C3 Moisture Scenario						D1L1C4 Moisture Scenario					
	Windspeed mph	0	0	3	3	7	7	0	0	3	3	7	7	0	0	3	3	7	7
	Slope %	00	15	00	15	00	15	00	15	00	15	00	15	00	15	00	15	00	15
FB_0158	Reaction Intensity (1,000 BTU/ft²/min)	0.00	0.00	3.77	4.13	9.30	9.35	0.00	0.00	6.25	6.34	20.92	21.01	0.00	0.00	8.92	9.05	29.87	30.00
	Flame Length (ft)	0.00	0.00	1.92	2.00	2.90	2.91	0.00	0.00	2.75	2.76	4.79	4.80	0.00	0.00	3.49	3.52	6.09	6.10
	Rate of Spread (ft/min)	1.27	1.27	1.27	1.27	1.27	1.27	1.83	1.83	1.83	1.83	1.83	1.83	2.15	2.15	2.15	2.15	2.15	2.15
	FCCS Fire Potentials	649	649	649	649	649	649	649	649	649	649	649	649	121	649	649	649	649	649
	Crosswalk – FBPS FMs	2	2	8	8	11	11	2	2	9	9	6	6	649	2	9	9	5	5
	Crosswalk – Standard FMs	121	121	186	186	201	201	121	121	188	188	144	144	2	121	164	164	165	165
FB_0186	Reaction Intensity (1,000 BTU/ft²/min)	0.00	0.00	4.11	4.49	9.04	9.43	0.00	0.00	5.67	6.20	12.48	13.01	0.00	0.00	7.65	8.37	16.84	17.56
	Flame Length (ft)	0.00	0.00	1.75	1.82	2.51	2.56	0.00	0.00	2.35	2.45	3.38	3.45	0.00	0.00	2.90	3.02	4.17	4.25
	Rate of Spread (ft/min)	1.08	1.08	1.08	1.08	1.08	1.08	1.63	1.63	1.63	1.63	1.63	1.63	1.89	1.89	1.89	1.89	1.89	1.89
	FCCS Fire Potentials	501	501	501	501	501	501	501	501	501	501	501	501	121	501	501	501	501	501
	Crosswalk – FBPS FMs	2	2	8	8	11	11	2	2	9	9	6	6	501	2	9	9	6	6
	Crosswalk – Standard FMs	121	121	186	186	201	201	121	121	186	186	142	142	2	121	189	164	142	142

		FCCS Fire Behavior Predictions Mixed hardwood and agriculture fuelbeds																	
		D4L4C1 Moisture Scenario						D2L2C3 Moisture Scenario						D1L1C4 Moisture Scenario					
	Windspeed mph	0	0	3	3	7	7	0	0	3	3	7	7	0	0	3	3	7	7
	Slope %	00	15	00	15	00	15	00	15	00	15	00	15	00	15	00	15	00	15
FB_0276	Reaction Intensity (1,000 BTU/ft²/min)	0.00	0.00	2.61	2.88	5.70	5.97	0.00	0.00	3.60	3.98	7.86	8.24	0.00	0.00	4.86	5.36	10.61	11.11
	Flame Length (ft)	0.00	0.00	1.85	1.94	2.65	2.71	0.00	0.00	2.45	2.57	3.51	3.59	0.00	0.00	3.03	3.17	4.34	4.43
	Rate of Spread (ft/min)	1.48	1.48	1.48	1.48	1.48	1.48	2.19	2.19	2.19	2.19	2.19	2.19	2.56	2.56	2.56	2.56	2.56	2.56
	FCCS Fire Potentials	455	455	455	455	455	455	455	455	455	455	455	455	121	455	455	455	455	455
	Crosswalk – FBPS FMs	2	2	8	8	9	9	2	2	9	9	9	9	455	2	9	9	10	10
	Crosswalk – Standard FMs	121	121	186	186	188	188	121	121	186	188	164	164	2	121	189	189	164	164
FB_0281	Reaction Intensity (1,000 BTU/ft²/min)	0.00	0.00	2.28	2.55	4.89	5.15	0.00	0.00	3.15	3.51	6.74	7.11	0.00	0.00	4.25	4.74	9.10	9.59
	Flame Length (ft)	0.00	0.00	0.95	1.00	1.35	1.38	0.00	0.00	1.25	1.31	1.77	1.81	0.00	0.00	1.53	1.61	2.18	2.23
	Rate of Spread (ft/min)	0.61	0.61	0.61	0.61	0.61	0.61	0.79	0.79	0.79	0.79	0.79	0.79	0.93	0.93	0.93	0.93	0.93	0.93
	FCCS Fire Potentials	434	434	434	434	434	434	434	434	434	434	434	434	121	434	434	434	434	434
	Crosswalk – FBPS FMs	2	2	8	8	8	8	2	2	8	8	8	8	434	2	8	8	11	11
	Crosswalk – Standard FMs	121	121	183	183	185	185	121	121	185	185	186	186	2	121	186	186	201	201

		FCCS Fire Behavior Predictions Mixed hardwood and agriculture fuelbeds																	
		D4L4C1 Moisture Scenario						D2L2C3 Moisture Scenario						D1L1C4 Moisture Scenario					
	Windspeed mph	0	0	3	3	7	7	0	0	3	3	7	7	0	0	3	3	7	7
	Slope %	00	15	00	15	00	15	00	15	00	15	00	15	00	15	00	15	00	15
FB_0283	Reaction Intensity (1,000 BTU/ft²/min)	0.00	0.00	0.40	0.50	1.00	1.00	0.00	0.00	0.56	0.68	1.83	1.85	0.00	0.00	0.75	0.92	2.42	2.43
	Flame Length (ft)	0.00	0.00	0.40	0.44	0.61	0.61	0.00	0.00	0.53	0.58	0.92	0.92	0.00	0.00	0.65	0.72	1.12	1.12
	Rate of Spread (ft/min)	0.36	0.36	0.36	0.36	0.36	0.36	0.50	0.50	0.50	0.50	0.50	0.50	0.58	0.58	0.58	0.58	0.58	0.58
	FCCS Fire Potentials	201	201	201	201	201	201	201	201	201	201	201	201	121	201	201	201	201	201
	Crosswalk – FBPS FMs	2	2	8	8	8	8	2	2	8	8	8	8	201	2	8	8	8	8
	Crosswalk – Standard FMs	121	121	181	181	183	183	121	121	183	183	183	183	2	121	183	183	184	184
FB_0402	Reaction Intensity (1,000 BTU/ft²/min)	0.00	0.00	4.25	4.38	13.80	13.93	0.00	0.00	7.79	8.03	25.34	25.58	0.00	0.00	11.23	11.58	36.54	36.89
	Flame Length (ft)	0.00	0.00	3.13	3.18	5.39	5.41	0.00	0.00	4.54	4.60	7.81	7.84	0.00	0.00	5.82	5.91	10.02	10.07
	Rate of Spread (ft/min)	2.40	2.40	2.40	2.40	2.40	2.40	3.13	3.13	3.13	3.13	3.13	3.13	3.71	3.71	3.71	3.71	3.71	3.71
	FCCS Fire Potentials	755	755	755	755	755	755	755	755	755	755	755	755	121	755	755	755	755	755
	Crosswalk – FBPS FMs	2	2	9	9	10	10	2	2	10	10	5	5	755	2	10	10	5	5
	Crosswalk – Standard FMs	121	121	189	189	163	163	121	121	164	164	147	147	2	121	163	163	145	145

		FCCS Fire Behavior Predictions Mixed hardwood and agriculture fuelbeds																	
		D4L4C1 Moisture Scenario						D2L2C3 Moisture Scenario						D1L1C4 Moisture Scenario					
	Windspeed mph	0	0	3	3	7	7	0	0	3	3	7	7	0	0	3	3	7	7
	Slope %	00	15	00	15	00	15	00	15	00	15	00	15	00	15	00	15	00	15
FB_0406	Reaction Intensity (1,000 BTU/ft²/min)	0.00	0.00	2.60	2.90	5.64	5.95	0.00	0.00	3.58	4.01	7.78	8.21	0.00	0.00	4.83	5.41	10.50	11.07
	Flame Length (ft)	0.00	0.00	1.65	1.74	2.36	2.42	0.00	0.00	2.18	2.30	3.12	3.20	0.00	0.00	2.70	2.84	3.85	3.95
	Rate of Spread (ft/min)	1.20	1.20	1.20	1.20	1.20	1.20	1.74	1.74	1.74	1.74	1.74	1.74	2.03	2.03	2.03	2.03	2.03	2.03
	FCCS Fire Potentials	432	432	432	432	432	432	432	432	432	432	432	432	121	432	432	432	432	432
	Crosswalk – FBPS FMs	2	2	8	8	9	9	2	2	9	9	9	9	432	2	9	9	9	9
	Crosswalk – Standard FMs	121	121	186	186	186	186	121	121	183	186	164	164	2	121	188	189	148	148
FB_0407	Reaction Intensity (1,000 BTU/ft²/min)	0.00	0.00	2.91	3.28	6.28	6.65	0.00	0.00	4.02	4.52	8.67	9.17	0.00	0.00	5.43	6.10	11.70	12.37
	Flame Length (ft)	0.00	0.00	1.82	1.92	2.60	2.66	0.00	0.00	2.32	2.45	3.31	3.40	0.00	0.00	2.90	3.06	4.13	4.23
	Rate of Spread (ft/min)	1.19	1.19	1.19	1.19	1.19	1.19	1.60	1.60	1.60	1.60	1.60	1.60	1.90	1.90	1.90	1.90	1.90	1.90
	FCCS Fire Potentials	432	432	432	432	432	432	432	432	432	432	432	432	121	432	432	432	432	432
	Crosswalk – FBPS FMs	2	2	8	8	9	9	2	2	9	9	9	9	432	2	9	9	10	10
	Crosswalk – Standard FMs	121	121	186	186	188	188	121	121	186	186	164	164	2	121	189	189	164	164

		FCCS Fire Behavior Predictions Mixed hardwood and agriculture fuelbeds																	
		D4L4C1 Moisture Scenario						D2L2C3 Moisture Scenario						D1L1C4 Moisture Scenario					
	Windspeed mph	0	0	3	3	7	7	0	0	3	3	7	7	0	0	3	3	7	7
	Slope %	00	15	00	15	00	15	00	15	00	15	00	15	00	15	00	15	00	15
FB_1201	Reaction Intensity (1,000 BTU/ft²/min)	0.00	0.00	14.60	15.37	49.27	50.04	0.00	0.00	21.75	22.89	73.41	74.55	0.00	0.00	27.04	28.46	91.23	92.65
	Flame Length (ft)	0.00	0.00	2.86	2.93	5.01	5.05	0.00	0.00	3.78	3.87	6.61	6.66	0.00	0.00	4.39	4.50	7.69	7.74
	Rate of Spread (ft/min)	1.25	1.25	1.25	1.25	1.25	1.25	1.53	1.53	1.53	1.53	1.53	1.53	1.71	1.71	1.71	1.71	1.71	1.71
	FCCS Fire Potentials	900	900	900	900	900	900	900	900	900	900	900	900	121	900	900	900	900	900
	Crosswalk – FBPS FMs	2	2	6	6	1	1	2	2	6	6	1	1	900	2	2	2	3	3
	Crosswalk – Standard FMs	121	121	142	142	107	107	121	121	142	142	109	109	2	121	102	102	104	104
FB_1202	Reaction Intensity (1,000 BTU/ft²/min)	0.00	0.00	24.75	26.08	83.17	84.50	0.00	0.00	36.88	38.86	123.94	125.93	0.00	0.00	45.83	48.29	153.99	156.46
	Flame Length (ft)	0.00	0.00	4.62	4.73	8.07	8.12	0.00	0.00	6.10	6.25	10.65	10.73	0.00	0.00	7.08	7.26	12.37	12.46
	Rate of Spread (ft/min)	2.53	2.53	2.53	2.53	2.53	2.53	3.10	3.10	3.10	3.10	3.10	3.10	3.46	3.46	3.46	3.46	3.46	3.46
	FCCS Fire Potentials	900	900	900	900	900	900	900	900	900	900	900	900	121	900	900	900	900	900
	Crosswalk – FBPS FMs	2	2	6	6	1	3	2	2	1	1	3	3	900	2	1	1	3	3
	Crosswalk – Standard FMs	121	121	142	144	109	104	121	121	109	109	106	106	2	121	109	109	108	108

		FCCS Fire Behavior Predictions Mixed hardwood and agriculture fuelbeds																	
		D4L4C1 Moisture Scenario						D2L2C3 Moisture Scenario						D1L1C4 Moisture Scenario					
	Windspeed mph	0	0	3	3	7	7	0	0	3	3	7	7	0	0	3	3	7	7
	Slope %	00	15	00	15	00	15	00	15	00	15	00	15	00	15	00	15	00	15
FB_1203	Reaction Intensity (1,000 BTU/ft²/min)	0.00	0.00	72.58	76.63	233.11	237.16	0.00	0.00	108.19	114.23	347.50	353.54	0.00	0.00	134.38	141.89	431.60	439.11
	Flame Length (ft)	0.00	0.00	20.60	21.12	35.23	35.51	0.00	0.00	27.24	27.93	46.59	46.96	0.00	0.00	31.60	32.40	54.04	54.47
	Rate of Spread (ft/min)	26.33	26.33	26.33	26.33	26.33	26.33	32.42	32.42	32.42	32.42	32.42	32.42	36.05	36.05	36.05	36.05	36.05	36.05
	FCCS Fire Potentials	900	900	900	900	900	900	900	900	900	900	900	900	121	900	900	900	900	900
	Crosswalk – FBPS FMs	2	2	4	4	3	3	2	2	4	4	3	3	900	2	4	4	3	3
	Crosswalk – Standard FMs	121	121	108	108	109	109	121	121	109	109	109	109	2	121	109	109	109	109
FB_1205	Reaction Intensity (1,000 BTU/ft²/min)	0.00	0.00	8.53	8.94	29.09	29.49	0.00	0.00	12.70	13.30	43.31	43.91	0.00	0.00	15.80	16.55	53.86	54.61
	Flame Length (ft)	0.00	0.00	1.36	1.38	2.38	2.40	0.00	0.00	1.78	1.82	3.13	3.15	0.00	0.00	2.08	2.13	3.66	3.68
	Rate of Spread (ft/min)	0.54	0.54	0.54	0.54	0.54	0.54	0.65	0.65	0.65	0.65	0.65	0.65	0.74	0.74	0.74	0.74	0.74	0.74
	FCCS Fire Potentials	900	900	900	900	900	900	900	900	900	900	900	900	121	900	900	900	900	900
	Crosswalk – FBPS FMs	2	2	2	2	2	2	2	2	2	2	1	1	900	2	2	2	1	1
	Crosswalk – Standard FMs	121	121	121	121	121	121	121	121	121	121	101	101	2	121	121	121	102	102

		FCCS Fire Behavior Predictions Mixed hardwood and agriculture fuelbeds																	
		D4L4C1 Moisture Scenario						D2L2C3 Moisture Scenario						D1L1C4 Moisture Scenario					
	Windspeed mph	0	0	3	3	7	7	0	0	3	3	7	7	0	0	3	3	7	7
	Slope %	00	15	00	15	00	15	00	15	00	15	00	15	00	15	00	15	00	15
FB_1223	Reaction Intensity (1,000 BTU/ft²/min)	0.00	0.00	6.10	6.38	20.69	20.97	0.00	0.00	9.06	9.48	30.79	31.21	0.00	0.00	11.29	11.81	38.32	38.84
	Flame Length (ft)	0.00	0.00	1.10	1.13	1.94	1.95	0.00	0.00	1.45	1.48	2.54	2.56	0.00	0.00	1.69	1.73	2.97	2.99
	Rate of Spread (ft/min)	0.41	0.41	0.41	0.41	0.41	0.41	0.50	0.50	0.50	0.50	0.50	0.50	0.57	0.57	0.57	0.57	0.57	0.57
	FCCS Fire Potentials	700	700	700	700	700	700	700	700	700	700	700	700	121	700	700	700	700	700
	Crosswalk – FBPS FMs	2	2	8	8	2	2	2	2	2	2	2	2	700	2	2	2	1	1
	Crosswalk – Standard FMs	121	121	184	185	121	121	121	121	121	121	122	122	2	121	121	121	101	101
FB_1273	Reaction Intensity (1,000 BTU/ft²/min)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Flame Length (ft)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Rate of Spread (ft/min)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	FCCS Fire Potentials	0	0	0	0	0	0	0	0	0	0	0	0	121	0	0	0	0	0
	Crosswalk – FBPS FMs	2	2	2	2	2	2	2	2	2	2	2	2	0	2	2	2	2	2
	Crosswalk – Standard FMs	121	121	121	121	121	121	121	121	121	121	121	121	2	121	121	121	121	121

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Appendix A. FTE plantation fuelbed representative photographs

The photographs on the following pages only represent the general concept of each fuelbed within the FTE plantation pathways. The photographs were not used to build the fuelbeds. For many of the FTE fuelbeds, no representative photographs were available.

FB_1301: 15 months, 10X4 spacing (ArborGen 2013)	**FB_1302: Uruguay poor growth, stunted at 2 yrs (Fox 2013)**
FB_1303: Central FL Mine Reclamation, 10 weeks (Common Purpose Institute 2003)	**FB_1304: 0-1 yr stand (Stape 2012)**

FB_1305: 15 months, 10X4 spacing (ArborGen 2013)	**FB_1306: 2700 trees per acre, 2 years (Cuoto 2012)**

FB_1307: 2 years, 10x4 spacing (ArborGen 2013)	FB_1309: Eucalyptus amplifolia biofuels (Minogue 2008)
FB_1310: 2 years, 10x7 spacing (ArborGen 2013)	FB_1312: 2 years, 10x7 spacing (ArborGen 2013)

FB_1313: 2yr, 8x4 spacing (ArborGen 2013) 	**FB_1314: No photo**
FB_1315: Post-freeze Eucalyptus plantation (Stape 2012) 	**FB_1316: Post-freeze Eucalyptus plantation (Loxley, AL) (Raines 2010)**

FB_1317: Eucalyptus urograndis, 5 yr. (Sao Paulo; Couto 2011) 	**FB_1318: No photo**
FB_1319: Eucalyptus forest, 5.5 years (Vidal 2012) 	**FB_1320: Eucalyptus forest, 5 years (Wright & Vihnanek 2013)**

FB_1349: No photo	**FB_1350: No photo**
FB_1321: No photo	**FB_1322: FTE, 7 years, 10x8 spacing (ArborGen 2013)**

FB_1323: FTE, 7yrs, 10x8 spacing (ArborGen 2013) 	**FB_1324: No photo**
FB_1325: Eucalyptus forest, Florida (Barnard 2001) 	**FB_1326: No photo**

FB_1327: No photo	**FB_1328: Eucalyptus forest, Florida (Barnard 2001)**
FB_1329: No photo	**FB_1330: Eucalyptus forest. (Wright & Vihnanek 2013)**

FB_1350: No photo	**FB_1331: No photo**

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APPENDIX E. LIST OF COUNTIES WHERE FREEZE TOLERANT EUCALYPTUS MAY BE EXPECTED TO BE GROWN

State	County
Alabama	Baldwin County
Alabama	Geneva County
Alabama	Henry County
Alabama	Houston County
Alabama	Mobile County
Florida	Alachua County
Florida	Baker County
Florida	Bay County
Florida	Bradford County
Florida	Brevard County
Florida	Calhoun County
Florida	Citrus County
Florida	Clay County
Florida	Columbia County
Florida	Dixie County
Florida	Duval County
Florida	Escambia County
Florida	Flagler County
Florida	Franklin County
Florida	Gadsden County
Florida	Gilchrist County
Florida	Glades County
Florida	Gulf County
Florida	Hamilton County
Florida	Hernando County
Florida	Highlands County
Florida	Hillsborough County
Florida	Holmes County
Florida	Jackson County
Florida	Jefferson County
Florida	Lafayette County
Florida	Lake County
Florida	Leon County
Florida	Levy County
Florida	Liberty County
Florida	Madison County

Florida	Manatee County
Florida	Marion County
Florida	Martin County
Florida	Nassau County
Florida	Okaloosa County
Florida	Okeechobee County
Florida	Orange County
Florida	Osceola County
Florida	Pasco County
Florida	Polk County
Florida	Putnam County
Florida	Santa Rosa County
Florida	St. Johns County
Florida	Sumter County
Florida	Suwannee County
Florida	Taylor County
Florida	Union County
Florida	Volusia County
Florida	Wakulla County
Florida	Walton County
Florida	Washington County
Georgia	Appling County
Georgia	Atkinson County
Georgia	Bacon County
Georgia	Baker County
Georgia	Ben Hill County
Georgia	Berrien County
Georgia	Brantley County
Georgia	Brooks County
Georgia	Bryan County
Georgia	Bulloch County
Georgia	Calhoun County
Georgia	Camden County
Georgia	Candler County
Georgia	Charlton County
Georgia	Chatham County
Georgia	Clay County
Georgia	Clinch County
Georgia	Coffee County
Georgia	Colquitt County
Georgia	Cook County

Georgia	Crisp County
Georgia	Decatur County
Georgia	Dodge County
Georgia	Dooly County
Georgia	Dougherty County
Georgia	Early County
Georgia	Echols County
Georgia	Effingham County
Georgia	Emanuel County
Georgia	Evans County
Georgia	Glynn County
Georgia	Grady County
Georgia	Irwin County
Georgia	Jeff Davis County
Georgia	Lanier County
Georgia	Lee County
Georgia	Liberty County
Georgia	Long County
Georgia	Lowndes County
Georgia	McIntosh County
Georgia	Miller County
Georgia	Mitchell County
Georgia	Montgomery County
Georgia	Pierce County
Georgia	Pulaski County
Georgia	Randolph County
Georgia	Screven County
Georgia	Seminole County
Georgia	Tattnall County
Georgia	Telfair County
Georgia	Terrell County
Georgia	Thomas County
Georgia	Tift County
Georgia	Toombs County
Georgia	Treutlen County
Georgia	Turner County
Georgia	Ware County
Georgia	Wayne County
Georgia	Wheeler County
Georgia	Wilcox County
Georgia	Worth County

Louisiana	Acadia Parish
Louisiana	Allen Parish
Louisiana	Avoyelles Parish
Louisiana	Beauregard Parish
Louisiana	Caddo Parish
Louisiana	Calcasieu Parish
Louisiana	Caldwell Parish
Louisiana	Catahoula Parish
Louisiana	De Soto Parish
Louisiana	East Baton Rouge
Louisiana	East Feliciana Parish
Louisiana	Evangeline Parish
Louisiana	Grant Parish
Louisiana	Jefferson Davis Parish
Louisiana	La Salle Parish
Louisiana	Livingston Parish
Louisiana	Morehouse Parish
Louisiana	Natchitoches Parish
Louisiana	Ouachita Parish
Louisiana	Rapides Parish
Louisiana	Richland Parish
Louisiana	Sabine Parish
Louisiana	St. Helena Parish
Louisiana	St. Landry Parish
Louisiana	St. Tammany Parish
Louisiana	Tangipahoa Parish
Louisiana	Vernon Parish
Louisiana	Washington Parish
Louisiana	West Carroll Parish
Louisiana	West Feliciana Parish
Louisiana	Winn Parish
Mississippi	Adams County
Mississippi	Amite County
Mississippi	Claiborne County
Mississippi	Forrest County
Mississippi	Franklin County
Mississippi	George County
Mississippi	Hancock County
Mississippi	Harrison County
Mississippi	Jackson County

Mississippi	Jefferson County
Mississippi	Jefferson Davis County
Mississippi	Lamar County
Mississippi	Lawrence County
Mississippi	Lincoln County
Mississippi	Marion County
Mississippi	Pearl River County
Mississippi	Pike County
Mississippi	Stone County
Mississippi	Walthall County
Mississippi	Wilkinson County
South Carolina	Bamberg County
South Carolina	Beaufort County
South Carolina	Berkeley County
South Carolina	Charleston County
South Carolina	Colleton County
South Carolina	Dorchester County
South Carolina	Georgetown County
South Carolina	Hampton County
South Carolina	Jasper County
Texas	Anderson County
Texas	Angelina County
Texas	Cherokee County
Texas	Grimes County
Texas	Hardin County
Texas	Harrison County
Texas	Houston County
Texas	Jasper County
Texas	Jefferson County
Texas	Liberty County
Texas	Montgomery County
Texas	Nacogdoches County
Texas	Newton County
Texas	Orange County
Texas	Panola County
Texas	Polk County
Texas	Rusk County

Texas	Sabine County
Texas	San Augustine County
Texas	San Jacinto County
Texas	Shelby County
Texas	Smith County
Texas	Trinity County
Texas	Tyler County
Texas	Walker County

APPENDIX F. THREATENED AND ENDANGERED SPECIES RECORDED IN COUNTIES WITHIN THE FTE ACTION AREA

Group	Scientific Name	Common Name	Status	CH	States Within Action Area
Amphibians	*Ambystoma cingulatum*	Frosted Flatwoods salamander	Threatened	Yes	FL, GA, SC
Amphibians	*Rana capito sevosa*	Dusky gopher frog	Endangered	Yes	MS
Amphibians	*Ambystoma bishopi*	Reticulated flatwoods salamander	Endangered	Yes	FL, GA
Birds	*Polyborus plancus audubonii*	Audubon's crested caracara	Threatened	No	FL
Birds	*Vermivora bachmanii*	Bachman's warbler (=wood)	Endangered	No	FL, SC
Birds	*Rostrhamus sociabilis plumbeus*	Everglade snail kite	Endangered	Yes	FL
Birds	*Ammodramus savannarum floridanus*	Florida grasshopper sparrow	Endangered	No	FL
Birds	*Aphelocoma coerulescens*	Florida scrub-jay	Threatened	No	FL

Group	Scientific Name	Common Name	Status	CH	States Within Action Area
Birds	*Dendroica kirtlandii*	Kirtland's Warbler	Endangered	No	FL, SC
Birds	*Sterna antillarum*	Least tern (interior pop.)	Endangered	No	LA, MS, TX
Birds	*Grus canadensis pulla*	Mississippi sandhill crane	Endangered	Yes	MS
Birds	*Charadrius melodus*	Piping Plover, except GL watershed	Threatened	Yes	AL, FL, LA, SC, TX
Birds	*Charadrius melodus*	Piping Plover, Great Lakes watershed	Endangered	Yes	MS
Birds	*Picoides borealis*	Red-cockaded woodpecker	Endangered	No	AL, FL, GA, LA, MS, SC, TX
Birds	*Calidris canutus fufa*	Red Knot	Threatened	No	AL, GA, FL, MS, SC, TX
Birds	*Grus americana*	Whooping crane	Endangered, NE EXPN pop.	Yes	FL, TX
Birds	*Mycteria americana*	Wood stork	Endangered	No	AL, FL, GA, LA, MS, SC

Group	Scientific Name	Common Name	Status	CH	States Within Action Area
Clams	*Potamilus inflatus*	Alabama heelsplitter	Threatened	No	AL, LA, MS
Clams	*Elliptio spinosa*	Altamaha spinymussel	Endangered	Yes	GA
Clams	*Elliptio chipolaensis*	Chipola slabshell	Threatened	Yes	AL, FL
Clams	*Villosa choctawensis*	Choctaw bean	Endangered	Yes	AL, FL
Clams	*Potamilus capax*	Fat pocketbook	Endangered	No	LA, MS
Clams	*Amblema neislerii*	Fat three-ridge (mussel)	Endangered	Yes	FL, GA
Clams	*Pleurobema strodeanum*	Fuzzy pigtoe	Threatened	Yes	AL, FL
Clams	*Medionidus penicillatus*	Gulf moccasinshell	Endangered	Yes	AL, FL, GA
Clams	*Margaritifera hembeli*	Louisiana pearlshell	Threatened	No	LA

Group	Scientific Name	Common Name	Status	CH	States Within Action Area
Clams	*Fusconaia escambia*	Narrow pigtoe	Threatened	Yes	AL, FL
Clams	*Medionidus simpsonianus*	Ochlockonee moccasinshell	Endangered	Yes	FL, GA
Clams	*Pleurobema pyriforme*	Oval pigtoe	Endangered	Yes	AL, FL, GA
Clams	*Lampsilis abrupta*	Pink mucket (pearlymussel)	Endangered	No	LA
Clams	*Elliptoideus sloatianus*	Purple bankclimber (mussel)	Threatened	Yes	AL, FL, GA
Clams	*Quadrula cylindrica cylindrica*	Rabbitsfoot	Threatened	PCH	MS
Clams	*Lampsilis subangulata*	Shinyrayed pocketbook	Endangered	Yes	AL, FL, GA
Clams	*Pleurobema decisum*	Southern clubshell	Endangered	Yes	AL
Clams	*Ptychobranchus jonesi*	Southern kidneyshell	Endangered	Yes	AL, FL

Group	Scientific Name	Common Name	Status	CH	States Within Action Area
Clams	*Hamiota (=Lampsilis) australis*	Southern sandshell	Threatened	Yes	AL, FL
Clams	*Fusconaia burkei*	Tapered pigtoe	Threatened	Yes	AL, FL
Conifers and Cycads	*Torreya taxifolia*	Florida torreya	Endangered	No	FL, GA
Crustaceans	*Palaemonetes cummingi*	Squirrel Chimney Cave shrimp	Threatened	No	FL
Ferns and Allies	*Isoetes louisianensis*	Louisiana quillwort	Endangered	No	AL, LA, MS
Ferns and Allies	*Trichomanes punctatum ssp. floridanum*	Florida bristle fern	Proposed Endangered	No	FL
Fishes	*Scaphirhynchus suttkusi*	Alabama sturgeon	Endangered	Yes	AL
Fishes	*Etheostoma rubrum*	Bayou darter	Threatened	No	MS

Group	Scientific Name	Common Name	Status	CH	States Within Action Area
Fishes	*Acipenser oxyrinchus desotoi*	Gulf sturgeon	Threatened	Yes	AL, FL, LA, MS
Fishes	*Etheostoma okaloosae*	Okaloosa darter	Threatened	No	FL
Fishes	*Scaphirhynchus albus*	Pallid sturgeon	Endangered	No	AR, LA, MS
Flowering Plants	*Schwalbea americana*	American chaffseed	Endangered	No	AL, FL, GA, LA, SC
Flowering Plants	*Conradina glabra*	Apalachicola rosemary	Endangered	No	FL
Flowering Plants	*Crotalaria avonensis*	Avon Park harebells	Endangered	No	FL
Flowering Plants	*Deeringothamnus pulchellus*	Beautiful pawpaw	Endangered	No	Fl
Flowering Plants	*Nolina brittoniana*	Britton's beargrass	Endangered	No	FL
Flowering Plants	*Campanula robinsiae*	Brooksville bellflower	Endangered	No	FL
Flowering Plants	*Oxypolis canbyi*	Canby's dropwort	Endangered	No	GA, SC

Group	Scientific Name	Common Name	Status	CH	States Within Action Area
Flowering Plants	*Warea carteri*	Carter's mustard	Endangered	No	FL
Flowering Plants	*Rhododendron chapmanii*	Chapman rhododendron	Endangered	No	FL
Flowering Plants	*Thalictrum cooleyi*	Cooley's meadowrue	Endangered	No	FL, GA
Flowering Plants	*Justicia cooleyi*	Cooley's water-willow	Endangered	No	FL
Flowering Plants	*Conradina etonia*	Etonia rosemary	Endangered	No	FL
Flowering Plants	*Bonamia grandiflora*	Florida bonamia	Threatened	No	FL
Flowering Plants	*Chrysopsis floridada*	Florida golden aster	Endangered	No	FL
Flowering Plants	*Cladonia perforata*	Florida perforate cladonia	Endangered	No	FL
Flowering Plants	*Scutellaria floridana*	Florida skullcap	Threatened	No	FL
Flowering Plants	*Ziziphus celata*	Florida ziziphus	Endangered	No	FL

Group	Scientific Name	Common Name	Status	CH	States Within Action Area
Flowering Plants	*Asimina tetramera*	Four petal paw paw	Endangered	No	FL
Flowering Plants	*Silene polypetala*	Fringed campion	Endangered	No	FL, GA
Flowering Plants	*Dicerandra christmanii*	Garrett's mint	Endangered	No	FL
Flowering Plants	*Spigelia gentianoides*	Gentian pinkroot	Endangered	No	AL, FL
Flowering Plants	*Pinguicula ionantha*	Godfrey's butterwort	Threatened	No	FL
Flowering Plants	*Arabis georgiana*	Gerogia rockcress	Threatened	Yes	GA
Flowering Plants	*Baptisia arachnifera*	Hairy rattleweed	Endangered	No	GA
Flowering Plants	*Ptilimnium nodosum*	Harperella	Endangered	No	GA
Flowering Plants	*Harperocallis flava*	Harper's beauty	Endangered	No	FL
Flowering Plants	*Hypericum cumulicola*	Highlands scrub hypericum	Endangered	No	FL

Group	Scientific Name	Common Name	Status	CH	States Within Action Area
Flowering Plants	*Dicerandra immaculata*	Lakela's mint	Endangered	No	FL
Flowering Plants	*Polygala lewtonii*	Lewton's polygala	Endangered	No	FL
Flowering Plants	*Dicerandra cornutissima*	Longspurred mint	Endangered	No	FL
Flowering Plants	*Ribes echinellum*	Miccosukee gooseberry	Theatened	No	FL
Flowering Plants	*Spiranthes parksii*	Navasota ladies'-tresses	Endangered	No	TX
Flowering Plants	*Hibiscus dasycalyx*	Neches River rose-mallow	Threatened	Yes	TX
Flowering Plants	*Geocarpon minimum*	No Common name	Threatened	No	LA, TX
Flowering Plants	*Cucurbita okeechobeensis ssp. okeechobeensis*	Okeechobee gourd	Endangered	No	FL
Flowering Plants	*Paronychia chartacea*	Papery whitlow-wort	Threatened	No	FL

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Flowering Plants	*Clitoria fragrans*	Pigeon wings	Threatened	No	FL
Flowering Plants	*Lindera melissifolia*	Pondberry	Endangered	No	AL, GA, MS, SC
Flowering Plants	*Chionanthus pygmaeus*	Pygmy fringe-tree	Endangered	No	FL
Flowering Plants	*Trillium reliquum*	Relict trillium	Endangered	No	AL, GA
Flowering Plants	*Deeringothamnus rugelii*	Rugel's pawpaw	Endangered	No	FL
Flowering Plants	*Polygonella myriophylla*	Sandlace	Endangered	No	FL
Flowering Plants	*Liatris ohlingerae*	Scrub blazingstar	Endangered	No	FL
Flowering Plants	*Eriogonum longifolium var. gnaphalifolium*	Scrub buckwheat	Threatened	No	FL
Flowering Plants	*Lupinus aridorum*	Scrub lupine	Endangered	No	FL
Flowering Plants	*Dicerandra frutescens*	Scrub mint	Endangered	No	FL

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Flowering Plants	*Prunus geniculata*	Scrub plum	Endangered	No	FL
Flowering Plants	*Amaranthus pumilus*	Seabeach amaranth	Threatened	No	SC
Flowering Plants	*Conradina brevifolia*	Short-leaved rosemary	Endangered	No	FL
Flowering Plants	*Eryngium cuneifolium*	Snakeroot	Endangered	No	FL
Flowering Plants	*Euphorbia telephioides*	Telephus spurge	Threatened	No	FL
Flowering Plants	*Leavenworthia texana*	Texas golden gladecress	Endangered	Yes	TX
Flowering Plants	*Hymenoxys texana*	Texas prairie dawn-flower	Endangered	No	TX
Flowering Plants	*Phlox nivalis ssp. texensis*	Texas trailing phlox	Endangered	No	TX
Flowering Plants	*Polygala smallii*	Tiny polygala	Endangered	No	FL

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Flowering Plants	*Macbridea alba*	White birds-in-a-nest	Threatened	No	FL
Flowering Plants	*Lesquerella pallida*	White bladderpod	Endangered	No	TX
Flowering Plants	*Warea amplexifolia*	Wide-leaf warea	Endangered	No	FL
Flowering Plants	*Polygonella basiramia*	Wireweed	Endangered	No	FL
Lichens	*Cladonia perforata*	Florida perforate cladonia	Endangered	No	FL
Mammals	*Peromyscus polionotus ammobates*	Alabama beach mouse	Endangered	Yes	AL
Mammals	*Peromyscus polionotus phasma*	Anastasia Island beach mouse	Endangered	No	FL
Mammals	*Peromyscus polionotus allophrys*	Choctawhatchee beach mouse	Endangered	Yes	FL

Group	Scientific Name	Common Name	Status	CH	States Within Action Area
Mammals	*Eumops floridanus*	Florida bonneted bat	Proposed endangered	No	FL
Mammals	*Puma (=Felis) concolor coryi*	Florida panther	Endangered	No	FL
Mammals	*Microtus pennsylvanicus dukecampbelli*	Florida salt marsh vole	Endangered	No	FL
Mammals	*Myotis grisescens*	Gray bat	Endangered	No	AL, FL
Mammals	*Herpailurus (=Felis) yagouaroundi cacomitli)*	Gulf Coast jaguarundi	Endangered	No	TX
Mammals	*Myotis sodalis*	Indiana bat	Endangered	Yes	FL
Mammals	*Ursus americanus luteolus*	Louisiana black bear	Threatened	Yes	LA, MS, TX
Mammals	*Myotis septentrionalis*	Northern Big-Eared Bat	Proposed Endangered	No	AL, GA, LA, MS, SC
Mammals	*Peromyscus polionotus trissyllepsis*	Perdido Key beach mouse	Endangered	Yes	AL, FL

Group	Scientific Name	Common Name	Status	CH	States Within Action Area
Mammals	*Puma (=Felis) concolor (all subsp. except coryi)*	Puma (=mountain lion)	Similarity of Appearance to a Threatened Taxon	No	FL
Mammals	*Peromyscus polionotus niveiventris*	Southeastern beach mouse	Threatened	No	FL
Mammals	*Peromyscus polionotus peninsularis*	St. Andrew beach mouse	Endangered	Yes	FL
Mammals	*Trichechus manatus*	West Indian manatee	Endangered	Yes	AL, FL, GA, LA, MS, SC, TX
Reptiles	*Pseudemys alabamensis*	Alabama red-belly turtle	Endangered	No	AL, MS
Reptiles	*Nerodia clarkii taeniata*	Atlantic salt marsh snake	Threatened	No	FL
Reptiles	*Pituophis melanoleucus lodingi*	Black Pine Snake	Proposed Threatened	No	AL, MS
Reptiles	*Eumeces egregius lividus*	Bluetail mole skink	Threatened	No	FL

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Reptiles	*Drymarchon corais couperi*	Eastern indigo snake	Threatened	No	Al, FL, GA
Reptiles	*Gopherus polyphemus*	Gopher tortoise (w of Mobile/Tombigbee Rs.) Candidate species east of this point in AL, FL, GA, and SC.	Threatened	No	AL, LA, MS
Reptiles	*Chelonia mydas*	Green sea turtle	Endangered	Yes	AL, FL, GA, LA, MS, SC, TX
Reptiles	*Eretmochelys imbricata*	Hawksbill sea turtle	Endangered	Yes	AL, FL, GA, LA, MS, SC, TX
Reptiles	*Lepidochelys kempii*	Kemp's ridley sea turtle	Endangered	No	AL, FL, GA, LA, MS, SC, TX
Reptiles	*Dermochelys coriacea*	Leatherback sea turtle	Endangered	Yes	AL, FL, GA, LA, MS, SC, TX
Reptiles	*Caretta caretta*	Loggerhead sea turtle	Threatened	No	AL, FL, GA, LA, MS, SC, TX
Reptiles	*Graptemys oculifera*	Ringed map turtle	Threatened	No	LA, MS
Reptiles	*Neoseps reynoldsi*	Sand skink	Threatened	No	FL

Group	Scientific Name	Common Name	Status	CH	States Within Action Area
Reptiles	*Graptemys flavimaculata*	Yellow-blotched map turtle	Threatened	No	MS