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Pondberry (*Lindera melissifolia*, Lauraceae) seed and seedling dispersers and predators

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HIGHLIGHTS

- We used video cameras to monitor visitors to plots with *Lindera melissifolia* seeds or seedlings.
- Swamp rabbits (*Sylvilagus aquaticus*) and wood rats (*Neotoma floridana*) cut or ate seedlings.
- Several actual and possible seed dispersers and seed predators were identified.
- Survival of seeds in plots with higher understory cover was lower than that of plots with lower cover.
- Video monitoring was shown to be an important method of collecting data on plant and animal species.

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ABSTRACT

Pondberry (*Lindera melissifolia*(Walter) Blume) is an endangered dioecious, clonal shrub that grows in periodically flooded forests of the southeastern United States. The probability of survival of dispersed pondberry seeds and new germinants is unknown, but few

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seedlings are noted in the forest. This study was undertaken to: (1) identify herbivores and predators of pondberry seeds and seedlings, (2) record the fate of pondberry seeds and seedlings after simulated dispersal in areas with lower and higher understory cover, and (3) calculate the probability of seed survival in the two cover types. The study was conducted in or near the Delta National Forest and the Delta Experimental Forest, MS. Pondberry seed and seedling plots were established at sites with high or low cover. Video cameras with infrared illumination were set up to monitor animal visitors to the plots. Image analysis indicated that swamp rabbits (*Sylvilagus aquaticus* (Bachman)) and wood rats (*Neotoma floridana* Ord) cut or ate seedlings, while other animals visited the plots without damaging seedlings. Numerous bird species and mammals visited the seed plots and some were filmed eating seeds. Pondberry seeds exposed in open habitats had a significantly higher survival rate than those exposed in habitats with more herbaceous and woody understory cover. The novelty and quality of the temporal data collected via video monitoring indicate the importance of this method in collecting data that are not otherwise available on endangered and rare species.

1. Introduction

Pondberry (*Lindera melissifolia* (Walter) Blume), a member of the Lauraceae, is a rhizomatous, clonal shrub that grows up to 2 m tall in seasonally flooded wetlands and on the wet edges of sinks, ponds, and depressions in the southeastern United States (Devall et al., 2001; Devall, 2013; Radford et al., 1968). In some areas pondberry populations occur in only one or two forest stands, but colonies may be numerous within individual patches (Morgan, 1983; Smith et al., 2004). In Mississippi, the largest populations occur on the Delta National Forest (DNF), a bottomland hardwoods forest in Sharkey County (Devall and Schiff, 2002), where 273 colonies are currently known.

In general pondberry occupies forested habitats that are normally flooded or have saturated soils during the dormant season, but infrequently experience periods of extended flooding during the growing season (Tucker, 1984). Klomps (1980) and Tucker (1984) suggested that pondberry populations usually occur as understory plants associated with mature forests and may be shade-dependent, although its habitat can be variable. The distribution and abundance of pondberry are believed to be affected by habitat destruction and alteration, especially timber cutting, clearing of land, and local drainage or flooding of wetlands. The species was listed as endangered under the Endangered Species Act by the US Fish and Wildlife Service in 1986 US Fish and Wildlife Service (1986).

Pondberry usually occurs in colonies made up of one or more clones of numerous stems up to 2 m tall with erect or ascending shoots and few branches. The species is dioecious, flowering in spring before the leaves emerge (Devall et al., 2001; Devall, 2013). From August to early October, pondberry produces many red, ellipsoid to oval-shaped drupes that measure about 1 cm long (Connor et al., 2007), with seeds that are approximately 7.51 mm long by 6.99 mm wide (unpublished data). Seeds reach their mature weight in August and peak at 0.18 g (Connor et al., 2005).

Very little is known of the biology, survival or herbivores/predators of pondberry seeds or seedlings in the wild. Seeds have nondeep physiological dormancy, requiring only 12 weeks of cold stratification (Hawkins et al., 2011) and they remain viable for at least a year (Connor et al., 2012). Hermit thrushes (*Catharus guttatus* Pallas) eat the fruits and regurgitate the seeds, and are short-distance seed dispersers while northern cardinals (*Cardinalis cardinalis L.*) (hereafter cardinal) consume the seeds and are seed predators (Smith et al., 2004; Abilio et al., 2008). Detailed information on the probability of seed survival to germination and beyond is lacking and earlier researchers have noted that few seedlings were observed in the wild (Devall et al., 2001; Devall, 2013; Smith, 2003; Wright, 1990). No previous studies have considered the effect of understory cover on pondberry seed or seedling survival from predators and herbivores. Wright (1990) found a few seedlings within a heavily shaded pondberry colony and suggested that competition for light and water may prevent most seedlings from reaching the shrub canopy. Unks (2011) studied seedling growth in the greenhouse under various light and moisture conditions and noted seedling distribution in a natural stand and concluded that hydrology was more important than light for seedlings. Lockhart et al. (2013) found that flooding had little effect on steckling survival; steckling survival and stem length were best at 37% light but stem diameter growth was best at 70% light and the number of ramets produced increased as light increased. To help understand these critical stages in the life cycle of the plant, the objectives of this study were to: (1) identify herbivores and predators of pondberry seeds and seedlings, (2) record the fate of pondberry seeds and seedlings regarding herbivory and predation after simulated dispersal in areas with lower and higher understory cover, and (3) calculate the probability of seed survival from herbivores and predators after being shed from the plant in the two cover types. We hypothesized that daily survival rate did not differ for seeds exposed in paired plots with greater vs. lesser herbaceous cover. This prediction was based on the behavior of animal predators and herbivores as well as the habitat of the plant. Swamp rabbits and cardinals prefer areas with more herbaceous cover (Allen, 1985; Anderson and Connor, 1985) but competition for light and water may be important for survival (Wright, 1990).

Abundant species that are attacked by herbivores may often spend more of their resources on chemical defenses. Consequently, rare plants may be particularly appealing to generalist herbivores or seed predators (Landa and Rabinowitz, 1983; Menges et al., 1986). Losses of seeds to granivores could be important causes in limiting population growth and population sizes (Menges et al., 1986). Pondberry seeds germinate readily in the lab, but seedlings are rarely observed in the wild, suggesting that pondberry seed or seedling predators may be numerous or that available safe sites for seedlings may be limited.

Video monitoring can be useful for observation of predator–prey interactions in the field because a number of prey individuals can be observed at the same time (Schenk and Bacher, 2002) and timid predators are not frightened by the presence of humans. We used video surveillance to identify the predators of pondberry seeds and seedlings and possible dispersers of seeds in this exploratory study. The use of infrared illuminators provided the opportunity to monitor night visitors.

2. Methods

2.1. Study areas

The Delta National Forest (DNF), managed by the US Forest Service, is one of the largest remaining bottomland hardwood tracts in the United States, with over 24,000 hectares. The forest consists mainly of oaks (*Quercus* spp.), sweetgum (*Liquidambar styraciflua* L.), tupelo (*Nyssa aquatica* L.), green ash (*Fraxinus pennsylvanica* Marshall) and bald cypress (*Taxodium distichum* [L.] Richard). The DNF lies entirely within areas protected by the mainline levee system from flooding from the Mississippi River. The Sharkey Restoration Research and Demonstration Site (Sharkey site) is a 688 ha tract managed by the US Fish and Wildlife Service, located immediately to the north of the DNF. The Sharkey site consists of farmland abandoned in 1993 which has been afforested between 1994 and 1997 primarily to Nuttall oak (*Quercus nuttallii* Palmer), usually planted alone, or underplanted beneath cottonwood (*Populus deltoides* Bartr.) on 8-ha plots, between 1994 and 1997 (Fisher et al., 2002; Gardiner et al., 2008). The Delta Experimental Forest (DEF) is a 1052 ha site that is owned by Mississippi State University and managed by the CBHR, Stoneville, MS. Regeneration techniques for hardwood plantations are being studied there. The site has heavy clay soils and is forested with bottomland hardwoods.

2.2. Monitoring protocol

The basic design for both seedling and seed observation studies consisted of establishing 1-m^2 plots in the forest on DNF, Sharkey site or DEF. One plot was chosen in an area with heavier cover and the second plot was placed nearby in lighter cover, but with similar soil and hydrology. Each 1-m^2 plot was cleared to bare soil so that seeds (and predators taking the seeds) would be visible on the tapes and the seedlings or seeds placed on it in a square array, 20 cm from the edge of the plot. Seedlings were planted into the soil of the plot and seeds laid on the soil surface. Each plot was monitored for animal activity with a continuously-operating video camera fitted with infrared illuminators for night viewing, continuously recording four frames per second to a video recorder (Fuhrman Diversified, Inc.). The entire apparatus was powered by four 12-V vehicle batteries. The camera and the box containing the batteries and the video tape were installed two and five meters away from the plot, respectively. Plots were visited twice each week to count remaining propagules, replace the batteries and video tape, and adjust the camera focus. At the end of each study, all equipment was removed and plots were not reused. Seeds and seedlings were not left in the plots, because we did not have permission from the US Fish and Wildlife Service to establish new colonies.

The tapes were viewed in the lab and the types of animals, dates, and times of visits to the plots were recorded. Animals were identified as accurately as the videotape permitted. Following Herrera et al. (1994), we defined seed dispersers as species that feed on whole fleshy fruits and do not destroy the seeds, but disperse them, and we defined seed predators as species that feed on the pulp or the seeds or both but usually destroy the seeds instead of dispersing them. Animals that were seen chewing the seeds were identified as seed predators, and seed-destroying animals that entered the plots but were not seen eating pondberry seeds were identified as possible predators. Seed predators may occasionally drop seeds or may cache them in places where they could germinate.

2.3. Seedling study

The first pondberry seedling study was installed on the Red Gum Research Natural Area (RNA) in the DNF on July 28, 2005 and lasted 10 weeks. Thirty-seven pondberry seedlings (grown in the greenhouse) 10–15 cm tall were planted in one plot, tagged and photographed (Fig. 1). During each visit the seedlings were counted and irrigated with approximately 5–7 liters of water because they were outplanted in the summer and were not able to become acclimated to the forest during mild weather. Video monitoring was conducted on the plot as described above (Fig. 2), and leaves were evaluated for percent insect damage during the 8th week. The study was terminated because all the seedlings were eaten Additional seedling studies with three sets of paired plots with 25 seedlings each were carried out in 2010 on the DNF and DEF using the same methods. The seedling data are presented but not analyzed because of the small number of plots and problems with the cameras and with flooding.

Fig. 1. Plot with pondberry (*Lindera melissifolia*) seedlings in the Delta National Forest.

Fig. 2. The video camera with infrared illumination used to monitor visitors to the seed and seedling plots in the Delta National Forest.

Table 1
Paired seed plots and dates of monitoring.

Pairs	High cover	Low cover	Date
DNFp1	Red Gum	GSRC42	9/30 2005–1/27/2006
DNFp2	Red Gum	Compartment 8	12/12/2006–2/16/2007
SHp1	PLN	NUR	12/12/2006–2/16/2007
DNFp4	GSRC43	JB Trail1	12/30/2007–3/06/2008
DNFp5	Red Gum 07	Compartment 8 07	12/30/2007– 3/06/2008
DNFp6	JB Trail N	JB Trail S	1/03/2009–2/26/2009
DNFp7	Red Gum hi	Red Gum lo	1/09/2009–2/26/2009
SHp2	SOW hi	NUR lo	1/03/2009–2/26/2009
DEFp1	DEF2	DEF1	2/11/2010–5/20/2010
DEFp2	DEF4	DEF3	2/09/2010–5/20/2010

2.4. Seed study

The pondberry seed survival study was conducted during fall and/or winter in 2005–2010 with seeds collected in the DNF (details in Table 1). Plots were established on DNF (14), the Sharkey site (4) and the DEF (4). Seed plots were paired and the percent understory cover (including herbaceous vegetation, low-growing vines and small trees and shrubs up to 1 m high) was estimated by eye for eight plots so that one of each pair was in an area with higher (50%–100%) understory cover and the other was in an area with lower (0–49) cover. For the remaining plots, cover was assigned based on the previous estimates (67.5 for high cover and 25% for low cover). In each plot, 25 pondberry seeds were placed on the soil surface in a grid pattern. Video monitoring was conducted on each of these plots as described above, and counts of present or missing seeds were made twice weekly.

2.5. Survival analysis

Because pondberry is an endangered species, propagules for research are limited. We sought appropriate methodology to evaluate fruit fates between habitats with higher (51%–100%) or lower (0–50) cover that would permit evaluation of survival for propagules in plots in which they all disappeared during the course of the study. An estimated survival probability of "zero" resulting from such a situation is uninformative, and because of the small number of plots available for study, may obscure biologically useful information in the data. Calculating a simple survival rate for the entire plot as the number of propagules remaining at the end of the study period ignores the relative survival time and necessary differences in length of study of individual plots.

The rate at which seeds disappeared for sites in higher and lower cover areas was estimated in a joint analysis using survival estimates (Lifereg Procedure in SAS, SAS Institute, 2008) For each seed survival test there was a unique variable for each site and a variable (sitepair) showing the pairing used for Proc Lifereg. This provided tests for any interaction of site and cover type and the main effects for site and cover type. We used the log–logistic distribution function, the logistic distribution of survival days as a linear function of the predictors. Alpha was set at 0.05.

Survival analysis examines the occurrence of an event as well as the timing (Greenberg and Walter, 2010; McCarty et al., 2002; Williams, 2008). Individuals that did not experience the event being monitored are 'censored', so seeds that remained at the end of the study were censored because they did not have the event of interest (Williams, 2008).

3. Results

3.1. Seedlings

In the 2005 study, many seedlings developed chlorotic leaves after outplanting, and a fungus was observed on leaves of 93% of the seedlings in early September (Fig. 3). Round holes were cut in some leaves, characteristic of leafcutter bee damage and a leafcutter bee (*Megachile texana* Cresson (Megachilidae)) was found on an adult pondberry plant nearby. Two leaves were damaged, possibly by geometrid moth larvae (Geometridae). A cocoon was collected inside a leaf and brought to the lab, where a moth (*Choristoneura rosaceana* Harris, Tortricidae) emerged, and spicebush swallowtail (*Papilio troilus* L., Papilionidae) larvae were collected inside leaves of three seedlings. Other, unidentified insects caused a small proportion of damage (Fig. 3).

By Week 2, two seedlings had some cut leaves, and a swamp rabbit (*Sylvilagus aquaticus* (Bachman)) was recorded near the cut seedlings. Later, seedlings were found cut at the root collar, and the video showed a swamp rabbit cutting them. A swamp rabbit came to the plot 20 times, cut seedlings twice, and ate all the seedlings by the 10th week, killing them. Other animals recorded on the plot, without damaging seedlings, were birds, a gray squirrel *Sciurus carolinensis*, a raccoon (*Procyon lotor* L.), an opossum (*Didelphis virginiana* Kerr), a snake, a rat, a mouse, a lizard, a butterfly, a frog, a white-tailed deer (*Odocoileus virginianus* Boddaert), a nine-banded armadillo (*Dasypus novemcinctus* L.), a spider and small insects on the soil and in flight.

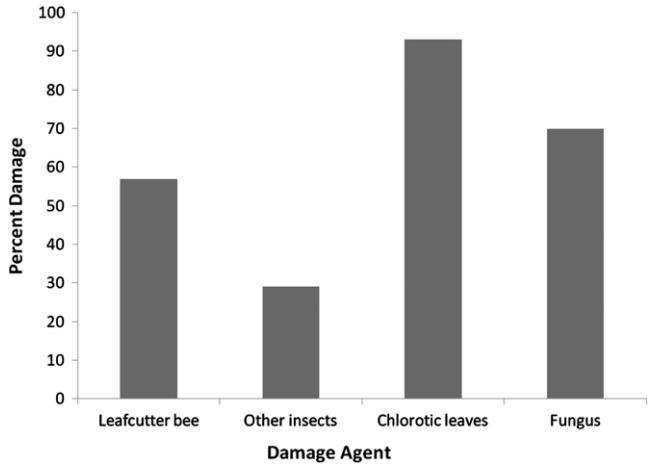

Fig. 3. Percent of pondberry (*Lindera melissifolia*) seedlings damaged by different agents. A seedling may have more than one type of damage.

Table 2
Animals that visited pondberry (*Lindera melissifolia*) research seedling plots in the Delta Experimental Forest (DEF) and the Delta National Forest (DNF) in 2010.

Visitors	Scientific names	DEF 1 Low cover	DEF 2 High cover	DEF 3 Low cover	DEF 4 High cover	DNF Low cover	DNF High cover
Birds							
Unidentifiable species		6	0	0	0	7	2
Northern cardinal	*Cardinalis cardinalis*	4	0	0	0	1	4
Swainson's Warbler	*Limnothlypis swainsonii*	0	0	0	0	1	2
Prothonotary Warbler	*Protonotaria citrea*	0	0	0	0	0	13
Blue-gray Gnatcatcher	*Polioptila caerulea*	1	0	0	0	1	1
Carolina Wren	*Thryothorus ludovicianus*	1	0	0	0	0	1
Mourning Dove	*Zenaida macroura*	0	16	0	0	0	0
Eastern Screech Owl	*Otus asio*	1	0	0	0	0	0
Yellow-breasted Chat	*Icteria virens*	1	0	0	0	0	0
Thrush sp.	*Catharus* sp.	1	0	0	0	0	1
Gray Catbird	*Dumetella carolinensis*	1	0	0	0	0	0
Tufted titmouse	*Baeolophus bicolor*	1	0	0	0	0	2
Wood thrush	*Hylocichla mustelina*	1	0	0	0	0	2
White-throated sparrow	*Zonotrichia albicollis*	0	2	0	0	0	0
Northern mockingbird	*Mimus polyglottos*	0	1	0	0	0	0
Hermit thrush	*Catharus guttatus*	4	0	21	0	2	0
Golden-crowned Kinglet	*Regulus satrapa*	0	0	1	0	0	0
Worm-eating Warbler	*Helmitheros vermivorum*	0	0	0	0	0	1
Ovenbird	*Seiurus aurocapilla*	0	0	0	0	1	0
Kentucky Warbler	*Geothlypis formosa*	0	0	0	0	2	0
Mammals							
Armadillo	*Dasypus novemcinctus*	7	0	5	1	26	2
Virginia opossum	*Didelphis virginiana*	6	0	2	1	0	1
Eastern Wood Rat[a]	*Neotoma floridana*	2	53	0	0	3	0
White-footed/Cotton mouse	*Peromyscus leucopus/gossypinus*	9	1	4	0	25	0
Raccoon	*Procyon lotor*	0	0	0	0	3	0
Eastern gray squirrel	*Sciurus carolinensis*	2	0	1	1	18	1
Eastern fox squirrel	*Sciurus niger*	0	0	0	0	0	1
Swamp rabbit[a]	*Sylvilagus aquaticus*	0	3	0	3	1	0
Eastern Chipmunk	*Tamias striatus*	1	0	0	0	0	0
Louisiana black bear	*Ursus americanus luteolus*	0	0	0	0	0	1

[a] Seedling predator.

In 2010, a wood rat (*Neotoma floridana* Ord) was seen in the video clipping the base of the pondberry seedlings in DEF1 (high cover) and a rabbit was observed in both plots. The wood rat cut the seedlings off at ground level, killing the seedlings, but ate only the root collar. The animals identified in the plots and the numbers of their visits are shown in Table 2. Thirteen bird species and 11 mammals were filmed in the plots, including a black bear (*Ursus americanus* Pallas).

Table 3
Seed dispersers and predators and other animals visiting pondberry (*Lindera melissifolia*) research seed plots in the Delta National Forest (DNF), the Delta Experimental Forest (DEF) and/or the Sharkey site (SH) during 2005–2010. 1a = GSRC42, 1b = Red Gum (2005–2006); 2a = Compartment 8, 2b = Red Gum (2006–2007); SHa = NURII, SHb = PLN2 (2006–2007); 3a = GSRC42, 3b = GSRC43 (2006–2007); 4a = JB Trail 1, 4b = GSRC4307 (2008–2009); 5a = Compartment 8 07, 5b = Red Gum 07 (2007–2008); 6a = JB Trail S, 6b = JB Trail N (2008–2009); 7a = NUR, 7b = SOW (2008–2009); 8a = DEF1 low cover, 8b = DEF2 high cover, (2010); 9a = DEF3 low cover, 9b = DEF4 high cover (2010). At the Red Gum high cover and Red Gum low cover plots in 2010 the cameras malfunctioned and no animal data were recorded.

Visitors	Scientific names	1a	1b	2a	2b	SHa	SHb	3a	3b	4a	4b	5a	5b	6a	6b	7a	7b	8a	8b	9a	9b
Birds																					
Tufted titmouse[c]	*Baeolophus bicolor*	22	1	1	1	0	0	1	10	0	0	0	2	0	0	0	0	0	0	0	0
Hermit thrush[b]	*Catharus guttatus*	38	1	54	38	2	0	3	53	0	26	13	53	1	0	1	0	0	4	21	0
Northern cardinal[a]	*Cardinalis cardinalis*	4	17	7	4	1	0	1	1	0	0	0	1	0	0	2	3	0	6	3	0
Dark-eyed Junco	*Junco hyemalis*	0	0	1	0	0	0	0	0	0	0	9	0	0	0	0	0	0	0	0	0
Swamp sparrow	*Melospiza georgiana*	0	0	0	0	0	2–3	0	0	0	0	0	0	0	0	1	6	0	0	0	0
Song sparrow	*Melospiza melodia*	0	0	0–1	0	0–1	0	0	0–1	0	0	0	0	0	0	0	0	0	0	0	0
Northern mockingbird	*Mimus polyglottos*	0	0	0–1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0
Carolina Chickadee	*Poecile carolinensis*	0	0	0	0	0	0	0	1	0	0	0	0	2	0	1	0	0	0	0	0
Ruby-crowned Kinglet	*Regulus calendula*	0	0	1	2	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
Golden-crowned Kinglet	*Regulus satrapa*	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Eastern phoebe	*Sayornis phoebe*	4	0	1	0	0	0	0	0	0	9	1	3	0	0	0	0	0	0	0	0
American Woodcock	*Scolopax minor*	0	0	0	0	2	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow-rumped Warbler	*Setophaga coronata*	0	0	0	1	1	0	6	3	0	0	0	0	0	0	3	0	0	0	0	0
Palm Warbler	*Setophaga palmarum*	0	0	0	1–2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pine Warbler	*Setophaga pinus*	0	0	0	1–2	0	0	0	1	0	2	0	0	0	0	0	0	0	0	0	0
Eastern Bluebird	*Sialia sialis*	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Field sparrow	*Spizella pusilla*	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carolina Wren	*Thryothorus ludovicianus*	1	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	3	0
Brown thrasher[d]	*Toxostoma rufum*	0	0	0–1	7	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Winter Wren	*Troglodytes troglodytes*	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
American Robin	*Turdus migratorius*	3	0	0–1	0	3	7	0	0	0	0	5	0	0	0	0	0	0	0	0	0
White-throated sparrow[c]	*Zonotrichia albicollis*	2	0	2	11	0–1	0	23	93–94	0	0	0	57	0	0	0		0	2	2	0
Unidentified Bird		0	0	0	0	0	1–2	1	0	0	0	0	0	0	0	1	0	0	0	0	0
Mammals																					
Gray squirrel[a]	*Sciurus carolinensis*	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Southern flying squirrel	*Glaucomys volans*	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
White-footed/cotton mouse[a]	*Peromyscus leucopus/gossypinus*	1	1	0	1	0	0	0	0	0	0	0	9	40	7	0	0	0	0	0	0
Small Rodent		0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Marsh Rice Rat	*Oryzomys palustris*	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0
Hispid Cotton Rat	*Sigmodon hispidus*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Armadillo[c]	*Dasypus novemcinctus*	2	1	1	1	0	0	0	0	0	0	0	2	5	0	1	0	0	0	0	0
Swamp rabbit[c]	*Sylvilagus aquaticus*	8	1	2	1	2	1	0	0	0	0	0	0	1	0	0	0	3	0	3	0
Virginia opossum	*Didelphis virginiana*	17	1	0	1	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0
Raccoon	*Procyon lotor*	6	0	0	0	0		0	0	0	0	0	1	1	0	0	0	0	0	0	0
White-tailed deer[a]	*Odocoileus virginianus*	1	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0
Coyote	*Canis latrans*	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bobcat	*Lynx rufus*	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Feral hog[c]	*Sus scrofa*	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dog	*Canis domesticus*	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

[a] Seed predator.
[b] Seed disperser.
[c] Possible seed predator.
[d] Seed disperser, possible seed predator.

3.2. Seeds

By the end of Week 1 in 2005 on the DNF all seeds in the high cover site (Red Gum RNA) were gone. A cardinal visited the plot 17 times and was filmed eating seeds 10 times. A mouse, (*Peromyscus gossypinus* (Le Conte) or *P. leucopus* Gloger) was observed to chew on at least one of the seeds. Other animals came to the plot but did not eat seeds (Table 3). The nearby low cover plot (Compartment 8) was observed from October 2005 through the end of January 2006 before the seeds had all been consumed.

In 2006–2007, video recordings were made for 1536 h each in the Red Gum RNA plot and Compartment 8 plot on DNF, on the NUR II and PLN II plots on Sharkey Site, for 840 h in GSRC 43 on DNF and for 240 h in GSRC 42 on DNF. The GSRC 43 plot had the highest activity of animal visitors recorded by the camera (Table 3), with 165 animals. At the Red Gum RNA, 69 animals visited the plot, of 11 species, including ten birds and a gray squirrel. The Compartment 8 seed plot was visited

Table 4
Analysis of effects of cover type on survival of pondberry (*Lindera melissifolia*) seeds.

Effect	DF	Wald Chi-square	Pr > Chisq
Sitepair	9	236.67	<0.0001
Cover	1	209.05	<0.0001
Sitepair*cover	9	167.81	<0.0001

Table 5
Analysis of maximum likelihood parameter effects.

Parameter	DF	Estimate	Standard error	95% Confidence limits		Chi-square	Pr>Chisq
Intercept	1	60.25	6.83	46.85	73.64	77.71	<0.0001
Sitepair DEFp1	1	53.07	9.91	33.65	72.48	28.70	0.1577
Sitepair DEFp2	1	13.47	9.54	−5.22	32.17	2.00	<0.0001
Sitepair DNFp1	1	28.14	8.46	11.57	44.72	11.07	0.0009
Sitepair DNFp2	1	36.47	11.56	13.80	59.13	9.94	0.0016
Sitepair DNFp4	1	55.08	16.95	21.85	88.30	10.56	0.0012
Sitepair DNFp5	1	1.82	8.62	−15.07	18.71	0.04	0.8327
Sitepair DNFp6	1	−47.42	8.22	−63.52	−31.31	33.31	<0.0001
Sitepair DNFp7	1	−13.65	9.24	−31.75	4.45	2.18	0.1394
Sitepair SHp1	1	10.60	9.72	−8.45	29.65	1.19	0.2753
Sitepair SHp2	0	0.00					
Cover high	1	−17.95	9.65	−36.88	0.97	3.46	0.0629
Cover low	0	0.00					
Sitepair*cover DEFp1, high cover	1	−23.92	14.19	−51.75	3.90	2.84	0.0919
Sitepair*cover DEFp1, low cover	0	0.00					
Sitepair*cover DEFp2, high cover	1	−53.46	12.48	−77.91	−29.00	18.36	<0.0001
Sitepair*cover DEFp2, low cover	0	0.00					
Sitepair*cover DNFp1, high cover	1	−66.04	11.67	−88.91	−43.17	32.03	<0.0001
Sitepair*cover DNFp1, low cover	0	0.00					
Sitepair*cover DNFp2, high cover	1	−53.73	14.48	−82.11	−25.35	13.77	0.0002
Sitepair*cover DNFp2, low cover	0	0.00					
Sitepair*cover DNFp4, high cover	1	−85.79	18.89	−122.83	−48.76	20.61	<0.0001
Sitepair*cover DNFp4, low cover	0	0.00					
Sitepair*cover DNFp5, high cover	1	−19.81	11.95	−43.23	3.61	2.75	0.0974
Sitepair*cover DNFp5, low cover	0	0.00					
Sitepair*cover DNFp6, high cover	1	23.83	11.69	0.92	46.73	4.16	0.0414
Sitepair*cover DNFp6, low cover	0	0.00					
Sitepair*cover DNFp7, high cover	1	−17.20	12.27	−41.26	6.86	1.96	0.1611
Sitepair*cover DNFp7, low cover	0	0.00					
Sitepair*cover SHp1, high cover	1	30.95	13.83	3.84	58.05	5.01	0.0252
Sitepair*cover SHp1, low cover	0	0.00					
Sitepair*cover SHp2, high cover	0	0.00					
Sitepair*cover SHp2, low cover	0	0.00					
Scale	1	15.08	0.76	13.67	16.64		

by 71 animals representing nine species. The NUR II site had little activity with only 15 animals recorded. At the PLN II site, none of the seeds had disappeared by the end of the study. Results of trials in subsequent years were similar to these results (Table 3). At the Red Gum high cover and Red Gum low cover plots in 2010 the cameras malfunctioned and no animal data was recorded. The hermit thrush, which had previously been identified as a seed disperser (Smith et al., 2004) visited plots many times. Brown thrashers ate seeds and were considered seed dispersers or possibly predators. Animal visitors identified as pondberry seed predators or possible predators were the northern cardinal, tufted titmouse, white-throated sparrow, swamp rabbit, nine-banded armadillo, cotton mouse, white-footed mouse, white-tailed deer, gray squirrel and fox squirrel.

Ten pairs of high and low cover plots were included in the joint survival analysis. Cover was significant ($X^2 = 209.1$, d.f. $= 1$, $p < 0.0001$) and the interaction between cover and sitepair was significant ($X^2 = 167.8$, d.f. $= 9$, $p < 0.0001$) (Tables 4 and 5). In sitepair DNFp1, all the seeds in the high cover plot disappeared within six days, while the seeds in the low cover plot disappeared gradually over 105 days ($X^2 = 11.1$, d.f. $= 1$, $p < 0.0009$) (Fig. 4(a)). In sitepair DNFp4, eight seeds were left in the high cover plot after 17 days while 24 seeds were left in the low cover plot after 68 days ($X^2 = 10.6$, $p = 0.0012$, Fig. 4(b)). In contrast, in sitepair SHp1, 19 and 17 seeds were left after 67 days and the results were not significantly different. One pair of sites (GSRC42 and GSRC43, 2006) was excluded from the analysis because flooding cut short the observations.

4. Discussion

The chlorotic leaves on some seedlings after outplanting in 2005 were likely caused by a nutritional deficiency. The fungus that occurred may have resulted from atypical weather conditions coincident with hurricane Katrina, which passed over

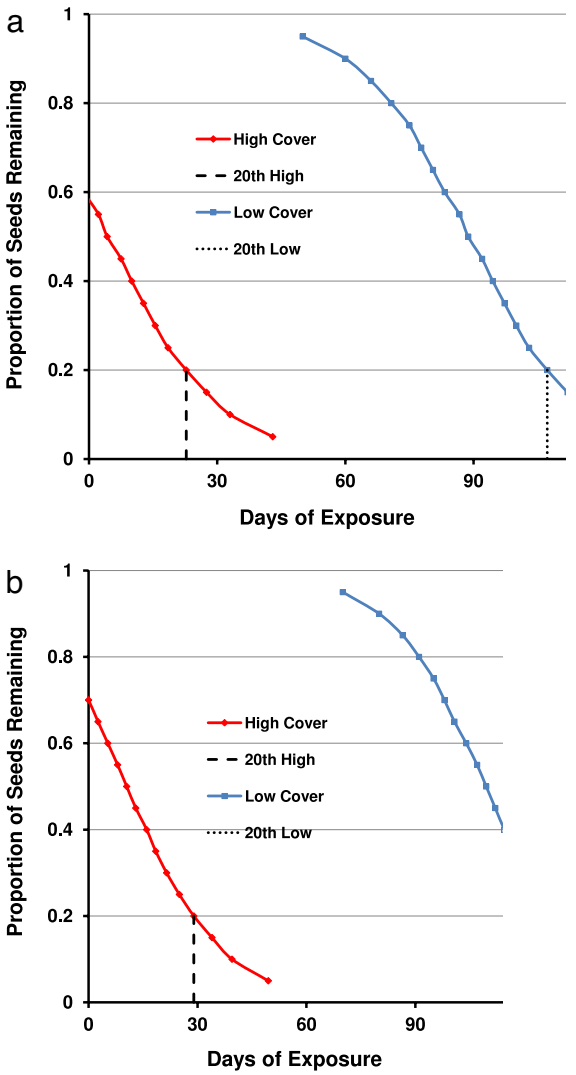

Fig. 4. The modeled values of the proportion of seeds expected to be remaining in a plot after the indicated number of days of exposure. The "20th Low" and "20th High" mark the number of days at which only 20% of the seeds would be expected to be left in the plot. (a) Plot DNFp1. (b) Plot DNFp4.

the area on 28–29 August 2005. The insect that had the most negative impact on pondberry seedlings was the leafcutter bee. Smith (2003) noted that leafcutter bees (Megachilidae) cut sections from leaves of pondberry seedlings in Missouri, sometimes removing most of the leaf tissue. It is not surprising that spicebush swallowtail (*P. troilus)* larvae were found inside pondberry leaves because its usual hosts are shrubs and trees of the Lauraceae Scott (1986), and this species has previously been found on pondberry in the DNF.

Most of the animal species and the highest numbers of identifiable visitors recorded by the cameras at the selected seed study locations were birds, of at least 22 species. Pondberry fruits have characteristics that suggest they are bird-dispersed, including fleshy pulp, high visibility with a red fruit coat, ripeness signaled by change in fruit color, small size and semi-permanent attachment to the stem until removal by a frugivore (Denslow and Moermond, 1985; Ridley, 1930; Snow, 1971; van der Pijl, 1969).

The hermit thrush had previously been shown to be a pondberry seed disperser and the cardinal a seed predator that had earlier been observed to crush and swallow pondberry seeds and to discard the pulp from fruits (Smith et al., 2004). Cardinals are common in open areas and abundant in the LMAV in winter. The brown thrasher ate seeds and was considered a possible pondberry seed disperser because mockingbirds, a closely related species, are seed dispersers (Renne et al., 2002) and curve-billed thrashers are also seed dispersers (Tewksbury et al., 2008). Brown thrashers' diet is known to consist of insects, fruits and nuts. Examination of stomach contents of 266 brown thrashers from around the country found 37% plant material including acorns (*Quercus* spp.), holly (*Ilex* spp.) and sour gum (*Nyssa sylvatica*) (Cavitt and Haas, 2000). Since the pondberry seeds had been depulped, the thrashers may have intended to digest the seeds and were also considered possible predators.

Of the vertebrate visitors, swamp rabbits and wood rats damaged the most seedlings, resulting in total loss in one case. Rabbits can be significant depredators of vegetation (Chapman, 1983), and swamp rabbits are abundant in the Lower Mississippi Alluvial Valley (LMAV) in the habitat where pondberry occurs. It is known that squirrels destroy a large number of seeds in general (Ridley, 1930) although they may remove seeds and cache them in places where they later germinate, and armadillos eat small fruit (Wetzel, 1983). White-tailed deer ate seeds and were classified as seed predators, but some seeds may be swallowed without being crushed and may be dispersed. Feral hogs were not observed eating seeds but were classified as possible seed predators because they are omnivores. As shown in this study, swamp rabbits, wood rats and cardinals may have a significant impact on pondberry reproduction and recruitment. A mouse was filmed chewing on a seed, suggesting that these animals may be seed predators as well.

Denslow and Moermond (1985) state that the rate of fruit removal will depend on the cost to the forager. Animals may use forest floor cover to lengthen their safe foraging range for seeds. Survival probability of seeds in plots with higher understory cover was significantly lower than that of plots with lower cover on many sites, suggesting that pondberry seed survival may be related to understory cover and the period of exposure of seeds in the environment. The mean survival times and their standard errors were underestimated because some studies had to end while seeds remained, due to the limited number of cameras or to flooding. Thus the longest observations were censored and the survival estimates were restricted to the longest times (SAS Institute, 2008). The interaction term was significant, indicating that cover made a difference some places and not others. There may have been other influences on some sites that were not recorded. Once a seed is predated, other seeds in the plot may have an increased chance of being taken because the location has been discovered and a predator may return because of past success. Also, it is not possible to know from this study if there is a linear predation response to percent cover, or if there is rather a threshold response, so that percent cover less than 35, for example would be too open, while sites with percent cover of 50 or 80 would both be safe enough. This variable could be manipulated in future studies.

Few plots were used for the seedling survival studies and this limits the conclusions that can be drawn from them. However, the novelty and quality of the temporal data collected via video monitoring indicate the importance of this method in collecting data that are not otherwise available on endangered and rare species.

Aleric and Kirkman (2005) reported that pondberry is able to adapt to a wide range of light availability. However, Hawkins et al. (2009) found no association between pondberry and tree species sensitive to light and they and Smith (2003) agreed with Wright's (1990) suggestion that pondberry exploits light availability and periodic inundation to limit competition. This study adds one more factor (lack of predation) that may influence the establishment of pondberry. Our results indicate that it may be easier for pondberry seedlings to establish in more open forest floor areas such as GSRC 42, where a closed canopy and/or flooding result in less understory vegetation and fewer seed or seedling predators.

This exploratory investigation is the first study to consider the effect of understory cover on the recruitment success of pondberry propagules and their susceptibility to predation. The present studies showed that seed and seedling stages are very sensitive to natural factors. To increase understanding of pondberry reproduction, the studies should be repeated in other areas and in other seasons because seasonal climate variability may cause important changes in pondberry seedling ecology. Knowledge of pondberry ecological relationships will allow managers to more effectively facilitate the recovery of this endangered species. The factors investigated and discussed in this study should be considered in choosing sites for introduction of pondberry, in managing existing pondberry populations, and in searching for new colonies. The use of video technology in studying predators and dispersers of plants should be more widely employed.

5. Disclaimers

The use of trade or firm names in this publication is for reader information and does not imply endorsement by the United States Department of Agriculture of any product or service.

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