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Changes in vegetative communities and water table dynamics following timber harvesting in small headwater streams

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ABSTRACT

In order to better understand the relationship between vegetation communities and water table in the uppermost portions (ephemeral–intermittent streams) of headwater systems, seasonal plot-based field characterizations of vegetation were used in conjunction with monthly water table measurements. Vegetation, soils, and water table data were examined to determine potential indicator species of near-surface water that could be used in rapid delineation of Streamside Management Zones (SMZs) by forest managers. Twelve watersheds were instrumented with three hundred screened wells, installed in grids of 25 per sub-watershed. Well locations were used to monitor water table and vegetation communities. Species were classified according to their wetland indicator status for Region 2; communities were evaluated using a prevalence index (PI). As part of a larger study, the uppermost reaches of the headwater systems were treated one of four treatments: (1) removal of all merchantable stems leaving understory intact with minimum surface soil disturbance (BMP1), (2) the same as treatment BMP1with the addition of logging debris in the drainage channel (BMP2), (3) total harvest with no BMPs applied (clearcut) and (4) no harvest (reference). Post-harvest increases in water table ranged from 1.6 cm in BMP1 to 28.2 cm in clearcut treatments during 2008, from 10.5 cm in BMP1 to 54.2 cm in BMP2 during 2009. PI differed significantly between channel and hillslope positions and represent distinctive vegetation communities. Forest clearcutting affected vegetation communities through combined direct and indirect disturbances. PI in the clearcut did not respond directly to changes in water table. In the two treatments where BMPs were employed, changes in vegetative communities corresponded to both changes in water table and changes in the microclimate as a result of harvesting intensity and changing stand heterogeneity. A vegetative indicator analysis, based on the presence of saturated soil conditions and water table elevation, was used to determine potential indicators of the true hydrologic boundaries of the headwater streams. Three potential indicator species (*Viola blanda*, *Ludwigia glandulosa*, and *Arundinaria gigantean Ssp. Tecta*) were more prevalent within "wet" channel positions but exhibited less total frequency of occurrence across the study areas than the fern species *Polystichum acrostichoides*, which is locally used for rapid estimation of intermittent stream extent). The combined use of the strong indicator species identified in this study and the "fern line" used by local industry foresters provides a means for rapid assessment of hydrologically functional SMZs in these headwater streams.

1. Introduction

Headwaters are a critical component of the stream network and represent from 50% to 80% of the total stream length in the US (Leopold et al., 1964; Hansen, 2001; Benda et al., 2005). Headwater streams occupy topographically high positions and a substantial portion of drainage basins at points of stream initiation. They initiate fluvial transport of materials, energy, and nutrients to larger streams. The ecological connection between headwater streams and downstream water quality is of increasing interest to researchers and regulators; however traditional stream assessment tools do not work in temporary streams (Fritz et al., 2008). The ecological role of headwater streams also tends to be underestimated because of their small source areas (Gomi et al., 2002); subsequently they are rarely considered in forest management (Wipfli et al., 2007).

Riparian zones are three-dimensional zones of direct interaction between terrestrial and aquatic ecosystems (Gregory et al., 1991). Most of the scientific information on the functional definition and delineation of riparian areas has been gleaned from

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studies conducted in higher-order streams (Verry et al., 2004). In higher-order stream systems, repeated fluvial and alluvial events result in the development of distinct geomorphic surfaces that can be linked to subsurface hydrology and geomorphology. These characteristics of higher-order streams are often useful for definition and delineation of the riparian zone. First-order streams are the dominant stream type in most forested headwater systems (Wipfli et al., 2007). Although fluvial and geomorphic processes are at work in first-order headwater streams (Clinton et al., 2010), little research has documented vegetation communities in the uppermost portions of headwater systems (Sheridan and Thomas, 2005). It is not obvious whether the distribution of vegetation communities follow hillslope gradients and whether there are distinct vegetation communities between these drainage channels and surrounding hillslopes (Gemborys and Hodgkins, 1971; Spackman and Hughes, 1995; Hughes and Cass, 1997; Zimmerman et al., 1999).

Streamside Management Zones (SMZs) are vegetated buffers designated along riparian areas that are a useful Best Management Practice (BMP) for protecting water quality and riparian ecosystem health (Vowell, 2001). SMZs have the ability to reduce excess sediment and nutrients from overland flow, provide shade, moderate water temperatures for aquatic wildlife, decrease erosion, stabilize stream banks, and provide wildlife and aquatic habitat. Most forestry BMP programs in the Southern US contain guidelines for intermittent and perennial streams; however there are few recommendations for small headwater areas characterized by ephemeral streams.

There is growing concern that SMZs should be extended to their upstream limits (e.g. ephemeral streams) in order to maintain hydrologic functions, and to preserve productivity, downstream water quality, and biota within the watershed. However, there is considerable debate surrounding buffer width and extent in forest management. Can ephemeral streams have riparian zones and if so, how far should buffers be extended to maintain hydrologic and ecologic function? Criteria for defining the upstream limits of SMZs are indefinite which makes it difficult for landowners and forest managers to identify and determine functional upstream limits of SMZs. In Webster County, Mississippi, the upper limit is often locally defined by the "fern line" based on the experience of local foresters without corroborating data indicating that the fern line represents the hydrologic and ecologic functional limits of the watershed. In addition, the blue-line streams from US Geological Survey (USGS) topographic contour maps are not reliable tools for determining stream extent and are not designed to represent ephemeral streams (Hansen, 2001). Policy makers and forest managers are faced with the difficulty of making decisions about appropriate riparian zone protection for ephemeral streams based on insufficient information regarding the contributions of ephemeral streams to downstream segments.

In this study, plot-based field characterizations of vegetation were used in conjunction with water table measurements to document changes in vegetation communities and water table in the uppermost portion of small headwater streams and to determine to what extent water table is linked to vegetation communities. The study includes pre- and post-harvest observations documenting two potential best management strategies for headwater areas. Objectives were to (1) detect the transition zone between upland and riparian areas that can be identified based on vegetation communities, (2) determine the effects of timber harvesting on water table and vegetation communities in these transition areas, and (3) determine whether there are plant indicators which can be used in conjunction with geomorphology to infer hydrology.

2. Methods

2.1. Site description

The study area comprises three first-order headwater catchments located in Webster County, Mississippi, within the Sand-Clay Hills subsection of the Hilly Coastal Plain Province. Study sites were chosen based on the presence of intermittent streams, forest land available for research, and similarity of vegetation, topography, and soils. The study area has a humid subtropical climate characterized by long, hot summers and short, mild winters. Precipitation is well distributed throughout the year with a 30 year mean of 1451 mm. Short, high-intensity storms are common and storm precipitation can exceed 100 mm on occasions. Average winter temperature is 7 °C; average summer temperature is 26 °C (US National Weather Service station 222896 Webster, MS). Watershed size ranged from 3.8 to 9.2 ha among the 12 watersheds. Geomorphic setting is similar across watersheds. Stream gradients and hillslope gradients ranged from 2% to 19% and 2% to 26%, respectively, but both were consistent within catchments (Table 1). Two soil types were present: well drained, Fine, mixed, semiactive, thermic Typic Hapludults (Sweatman Series) and moderately well drained Fine-silty, mixed, active, thermic Oxyaquic Fragiudalfs (Providence Series) (McMullen and Ford, 1978). Soils within the rolling to ruggedly hilly area are high in clay content with A-horizons of either loam or silt loam. Streamflow occurs in response to a combination of precipitation and groundwater discharge during wet-season months. Streamflow during the summer months or drought years occurs in response to precipitation; hillslope water table drops to >2 m below the surface in the summer.

Table 1
Physical characteristics of study headwater streams in Webster County, Mississippi.

Watershed	Treatment	Watershed area (ha)	Stream length (m)[a]	Stream gradient (%) mean (min, max)[b]	Hillslope gradient (%) mean (min, max)	Basal area removed (%)[c]
Union	BMP1	2.4	92	5 (4, 6)	26 (13, 39)	8.9
Union	BMP2	3.6	83	4 (3, 5)	22 (3, 42)	32.4
Union	Clearcut	3.8	81	4 (3, 5)	26 (14, 40)	70.1
Union	Reference	1.8	78	5 (4, 5)	21 (3, 39)	–
Congress	BMP1	2.9	117	5 (4, 5)	15 (2, 29)	28.1
Congress	BMP2	2.4	96	13 (6, 19)	14 (3, 31)	53.1
Congress	Clearcut	2.5	95	19 (12, 22)	18 (12, 30)	88.3
Congress	Reference	2.1	102	12 (11, 13)	18 (10, 40)	–
Ingram	BMP1	6.7	73	3 (2, 4)	19 (16, 24)	55.4
Ingram	BMP2	3.3	55	2 (2, 3)	2 (2, 3)	75.1
Ingram	Clearcut	7.1	85	5 (4, 6)	16 (10, 22)	95.2
Ingram	Reference	6.3	116	5 (4, 6)	20 (5, 29)	–

[a] Stream length was a distance from the center well of the first measurement transect to the center well of 5th measurement transect.
[b] Stream gradient was measured within measurement transects.
[c] Values are approximate based on subsample within water table well transects.

Study sites are in the Southeastern Mixed Forest Province (Bailey, 1983). Overstory vegetation is loblolly pine (*Pinus taeda* L.) of similar age with a lesser component of mixed hardwoods. Common hardwood species are yellow poplar (*Liriodendron tulipifera* L.), sweetgum (*Liquidambar styraciflua* L.), eastern hophornbeam (*Ostrya virginiana* (Mill.) K. Koch), American beech (*Fagus grandifolia* Ehrh.), black cherry (*Prunus serotina* Ehrh.), oak species (*Quercus* spp.), and hickory species (*Carya* spp.). Dominant shrubs include American beautyberry (*Callicarpa americana* L.), switchcane (*Arundinaria gigantea* (Walter) Muhl.), red buckeye (*Aesculus pavia* L.), and American witchhazel (*Hamamelis virginiana* L.). Common herbaceous species are Christmas fern (*Polystichum acrostichoides* (Michx.) Schott), sweet white violet (*Viola blanda* Willd.), yellow wood sorrel (*Oxalis stricta* L.), variable panicgrass (*Dichanthelium commutatum* (Schult.) Gould), and Vasey's grass (*Paspalum urvillei* Steud.).

2.2. Study design and treatment

Twelve similar first-order headwater streams were selected for study; four streams within each of three first-order catchments (Table 1). The uppermost reaches (ephemeral streams) not governed by Mississippi's Forestry BMP guidelines (Mississippi Forestry Commission, 2000) received one of the following treatments: (1) Clearcut – total harvest with no BMPs applied within the drainage channels. (2) BMP1 – removal of all merchantable stems greater than 15.2 cm DBH leaving understory intact with minimum surface soil and forest floor disturbance. Logging debris was prohibited in the drainage channel. (3) BMP2 – same as BMP 1 with the addition of logging debris to the drainage channel in an attempt to decrease energy in the system and minimize head-cutting and continued channel development in the ephemeral area. The objective of adding logging debris in BMP2 was not part of this study; the only effective difference between BMP1 and BMP2 was greater basal area removal in BMP2. (4) No harvest – left uncut as a reference or control. Treatment boundaries were delineated using watershed contours in September 2007. Timber harvesting was conducted using rubber tired feller–bunchers and grapple skidders during October–December 2007 while surface soil conditions were dry. Commercial timber harvesting was carried out in accordance with Mississippi's Forestry BMP guidelines; the only exception was BMP2 in which tops were left in drainage channels.

Ephemeral–intermittent transition zones for each of the twelve streams were identified based on field observation of the location where each stream transitioned from the upslope limit of normal channel development (channel head) to a clearly defined channel with evidence of overbank deposits and seasonal streamflow. Measurement grids were established to encompass the transition zone between ephemeral and intermittent stream segments. Upslope transect limits were defined by the upstream limits of channel development; downslope transect limits were defined by the point just above the downstream perennial stream. Longitudinal extent of this transition zone was variable among streams. Lateral extent of observation was determined based on the presence of high water indicators at the location of the downstream transect; in general this width was consistent among streams. While geomorphic indicators of streamflow were used to establish grid locations, in many cases the majority of each stream segment from the channel head to the junction with the perennial stream was encompassed, due to the small size of the individual watersheds. Central transects may not have coincided with the inferred ephemeral–intermittent zone: however the likelihood that this boundary lays within the monitoring grids during any given season is high.

The study approach involved collecting concomitant data on vegetation and water table across longitudinal (parallel to channel) and lateral (perpendicular to channel) gradients. In order to detect relationships between vegetation communities and water table, plot positions were categorized in lateral zones as either hillslope or channel and in longitudinal zones as ephemeral, transitional, or intermittent. Six classes consisting of nine plot locations (three channels and six hillslopes) for each treatment were considered for data analysis: channel within intermittent zone (CI), hillslope within intermittent zone (HI), channel within transitional zone (CT), hillslope within transitional zone (HT), channel within ephemeral zone (CE), hillslope within ephemeral zone (HE) (Fig. 1). The hypothesis was that there is a link between vegetative assemblages and soil moisture regime; such that the presence of hydrophytic vegetation could be indicative of streamflow, near-surface groundwater, or saturated soils.

2.3. Data collection

2.3.1. Water table measurement

At the head of each intermittent stream, five transects were established perpendicular to the developed channel from the top of the ephemeral streams through the entire length of the intermittent stream (Fig. 1). Spacing between transects was dependent on the length and slope of the drain as well as the areal extent of the watershed and ranged from 12 to 30 m. Monitoring stations were located at 5 m intervals along each transect (Fig. 1). Three hundred screened wells, 3 m in depth and 5 cm internal diameter, were constructed of 0.25 cm thick polyvinyl chloride pipe and installed in grids of 25 per sub-watershed to monitor water table. Boreholes were drilled with a 5 cm hand auger to a depth of approximately 2.5 m or until water, gravel, and rocks prevented further drilling; final depths ranged from 1.5 to 2.5 m below the soil surface. Following well installation, boreholes were backfilled with excavated soil and packed with bentonite clay at the surface to prevent infiltration along the pipe–soil interface. Groundwater wells were monitored on a monthly schedule from January 2007 to December 2009 using an electronic measuring tape. All measurements were referenced to the soil surface datum.

2.3.2. Vegetation

A vegetation inventory was conducted prior to treatment installation in September, 2007. Vegetation surveys were conducted twice yearly at the beginning and end of the growing season (May and September). Overstory, midstory, and understory strata

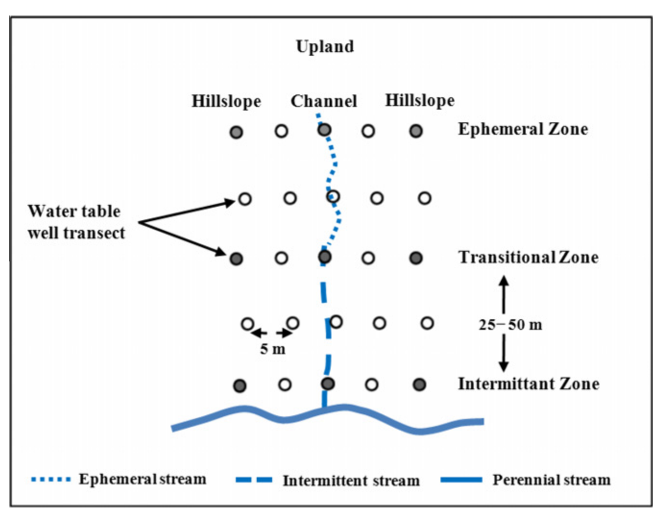

Fig. 1. Schematic of field sampling design in the study watersheds of Webster County, Mississippi. Water table wells served as the center for vegetation sampling strata. Vegetation plots used to calculate prevalence index (PI) are indicated by grey circles located at the 1st, 3rd, or 5th wells of the 1st, 3rd, or 5th transects.

were measured using methods similar to the modified approach for areas greater than 2 ha in size as described in the Corps of Engineers Wetland Delineation Manual (Environmental Laboratory, 1987). Diameter at breast height was measured for all overstory trees having a DBH $\geqslant$ 7.62 cm within a 9.14 m fixed-radius plot where plot center was located at the center well of the 1st, 3rd, and 5th transect (3 per treatment); DBH was converted to basal area by species. The midstory stratum was comprised of saplings and shrubs having a DBH < 7.62 cm and a height $\geqslant$ 1 m within a 3.05 m fixed-radius plot where plot center was located at the 1st, 3rd, and 5th well of each transect (15 per treatment). Measurements were converted to total height-per-species using midpoints of the following height classes and ranges: (1) 0.3–0.9 m, (2) 0.91–1.5 m, (3) 1.51–2.1 m, (4) 2.11–2.7 m, (5) 2.71–3.3 m, and (6) >3.3 m. Woody vine measurements comprised a count of woody vines having a height of $\geqslant$1 m located within the same measurement points as the shrub stratum. The understory stratum was comprised of all plants <1 m in height. Vegetative cover class was visually estimated using a 1 m^2 quadrat with the center of each well serving as the observation point (Fig. 1). Measurements were converted to total cover-per-species using midpoints of the following cover classes and ranges: (1) 0–5%, (2) 6–25%, (3) 26–50%, (4) 51–75%, (5) 76–95%, and (6) 96–100%.

2.4. Data analysis

2.4.1. Prevalence index

Indicator species are useful for evaluating the fundamental nature of vegetation responses to management. A modified Corps approach (Environmental Laboratory, 1987) was used to evaluate "affinity for wetness" of the dominant vegetation through a weighted average or prevalence index (PI). Species were classified according to their wetland indicator status based on designations in the National List of Vascular Plant Species that Occur in Wetlands for Region 2 (US Fish and Wildlife Service, 1996); obligate (OBL), facultative wetland (FACW), facultative (FAC), facultative upland (FACU), upland (UPL), non-indicator (NI) (Table 2). Species that were not on the National List for Region 2 and plants that were not identified at the species level were assigned as non-indicators and were not counted in the assessment.

A PI was calculated for nine vegetation plots located at the 1st, 3rd, and 5th well of the 1st, 3rd, and 5th transect from the head of intermittent streams adjacent to perennial streams (Fig. 1). PI was determined by calculating the weighted average for each stratum (Eq. (1)) and then calculating the mean for all strata within a plot. "Plus" and "minus" designations were not considered in the assigned indicator status (e.g. both FAC− and FAC+ were counted as FAC). Individual weighted averages for each stratum were calculated as follows (Environmental Laboratory, 1987; Federal Interagency Committee for Wetland Delineation, 1989):

$$\mathrm{PI} = \frac{(1 \times F_{\mathrm{OBL}}) + (2 \times F_{\mathrm{FACW}}) + (3 \times F_{\mathrm{FAC}}) + (4 \times F_{\mathrm{FACU}}) + (5 \times F_{\mathrm{UPL}})}{F_{\mathrm{OBL}} + F_{\mathrm{FACW}} + F_{\mathrm{FAC}} + F_{\mathrm{FACU}} + F_{\mathrm{UPL}}} \quad (1)$$

where PI is prevalence index for stratum; F_{OBL} is abundance measure of obligate species; F_{FACW} is abundance measure of facultative wetland species; F_{FAC} is abundance measure of facultative species; F_{FACU} is abundance measure of facultative upland species; F_{UPL} is abundance measure of upland species.

Mean PI was calculated as:

$$\left(\sum \mathrm{PI}_s\right)/S \quad (2)$$

where $\sum \mathrm{PI}_s$ is sum of PI for all strata; S is number of strata.

The resultant PI is a value between 1.0 and 5.0 that reflects the wetland potential of a vegetation community, where 3.0 is the threshold that separates wetlands from uplands (Wentworth et al., 1988; Federal Interagency Committee for Wetland Delineation, 1989). Segelquist et al. (1990) suggested that a vegetation community is considered to be hydrophytic if PI < 3.0; however Wentworth et al. (1988) suggested that where PI < 2.0 or PI > 4.0, the area has a high probability of being a wetland or upland, respectively, based on vegetation data alone. For scores within 0.5 units of 3.0, additional data regarding soils and/or hydrology should be incorporated (Wentworth et al., 1988; Tiner, 1991). PI for each independent stratum and mean PI across all strata were examined by year of observation to elucidate changes in vegetative structure (by stratum and overall, respectively) over time at each vegetation plot.

Eq. (2) averages PI across all strata, however in nine of the 12 watersheds, overstory and midstory strata were removed through timber harvest. For comparative purposes and to reduce the likelihood that the resultant "wetness evaluation" might be skewed by timber harvest, an individual PI analysis was conducted for the understory (herbaceous) stratum. The herbaceous stratum was not harvested and should theoretically have been less influenced by vegetation removal and more sensitive to changes in water table than other strata.

The normalized difference between pre- and post-harvest PI for understory strata was used to detect changes in vegetation communities. The normalized difference between pre- and post-harvest PI for each understory plot was quantified as follows:

$$NDPI_{ijk} = (Post\_\mathrm{PI}_{ijk} - Pre\_\mathrm{PI}_{ij})/Pre\_\mathrm{PI}_{ij} \quad (3)$$

where $NDPI_{ijk}$ is normalized difference in PI for each understory plot in treatment j in block i at observation period k; $Post\_\mathrm{PI}_{ijk}$ is post-harvest PI for each understory plot in treatment j in block i at observation period k; Pre_PI_{ij} is pre-harvest PI for each understory plot in treatment j in block i; i, j, and k represent each block, treatment, and observation period, respectively.

2.4.2. Effects of timber harvesting on vegetation communities

Water table data and PI were used to evaluate the effects of timber harvesting on vegetation communities and to examine influences of water table on vegetation communities. To detect timber harvesting effects on water table through time, differences between pre- and post-harvest mean water table were used. Pre-harvest mean water table was determined for the months January 2007 (project inception) through November 2007 (harvest). The

Table 2
Distribution of plant species by indicator category (US Fish and Wildlife Service, 1996) in small headwater streams in Webster County, Mississippi.

Wetland indicator status	Numeric index	Probability of occurrence in wetlands (%)	Number of species			
			Tree	Shrub/woody vine	Herbaceous/forbs	Total
Obligate wetland (OBL)	1	>99	1	1/0	5	7
Facultative wetland (FACW)	2	67–99	6	2/4	9	21
Facultative (FAC)	3	34–66	10	9/12	14	45
Facultative upland (FACU)	4	1–33	13	11/0	21	45
Upland (UPL)	5	<1	0	0/0	3	3

difference between pre- and post-harvest water table (DWT) for each well was quantified as follows:

$$DWT_{ij} = Post\_WT_{ij} - Pre\_MWT_{ij} \quad (4)$$

where DWT_{ij} is difference in monthly water table for each well in treatment *j* in block *i*; $Post\_WT_{ij}$ is post-harvest monthly water table for each well in treatment *j* in block *i*; Pre_MWT_{ij} is pre-harvest mean water table (January 2007–November 2007) for each well in treatment *j* in block *i*; *i* and *j* represent each block and treatment, respectively.

The difference in monthly water table for each well was averaged for each period.

A randomized complete block (RCB) design was used to evaluate the effects of timber harvesting on water table and vegetation communities. The MIXED procedure of SAS (SAS Institute Inc., 2008) was used to fit a mixed linear model to water table data composed of the means of water table measurements taken monthly and to vegetation data composed of PI for each plot taken seasonally (wet, dry) in the six classes (nine plot locations) of each treatment.

$$Y_{ijkl} = \mu + blk_i + trt_{ij} + t_{ijk} + trt_{ij} \times t_k + psn_l + trt_{ij} \times t_k \times psn_l + \varepsilon_{ijkl}$$
$$(i = 1, \ldots, 4; j = 1, \ldots, 4; k = 1, \ldots, 4; l = 1, \ldots, 6) \quad (5)$$

where Y_{ijkl} is the mean DWT, *DPI*, or *NDPI* for position *l* in treatment *j* in block *i* at time *k*; μ is the grand mean; blk_i is the random effect for block *i*; trt_{ij} is the fixed effect for treatment *j* in block *i*; t_k is a fixed factor for time *k*; where 1 and 2 represent wet and dry season measurements of 2008 and 3 and 4 represent wet and dry season measurements of 2009, respectively; psn_l is a fixed factor for position *l*, where 1, 2, 3, 4, 5, and 6 represent CI, HI, CT, HT, CE, and HE, respectively, in treatment *j* in block *i* at time *k*; ε_{ijkl} is the random error for position *l* in treatment *j* in block *i* at time *k*; *DPI* is difference in PI for each understory plot.

The overall objective of this study was to evaluate the effects of timber harvesting on vegetation communities and the changes in vegetation communities along an inferred water table gradient. Therefore, when interactions among main effects were significant, planned comparisons were tested using pairwise contrasts of the least square means for water table and PI at the same plot/well classes which represent gradients in lateral and longitudinal zones within each treatment. Significance of $\alpha = 0.05$ was used for all statistical tests.

2.4.3. Determination of indicator species

Two procedures were used in the synthesis of vegetation, soils, and water table data to determine which plots may contain potential indicator species. The first procedure was a simple analysis of PI based on the recommendations of Wentworth et al. (1988). Plots that exhibited $PI_s < 3.0$ over three years of study were included in the initial classification. In a second procedure, indicators of saturated soil conditions and evidence of water table within 30 cm of the surface were used to corroborate data for understory plots that met the criteria for hydrophytic vegetation. Plots which had little evidence of hydric soils (e.g. gleyed soil colors and redoximorphic features) were dropped from the initial "potential wetland" plot list. Plots which did not meet a 30 cm minimum for at least half of the growing season (5 months) were removed from the "potential wetland" plot list. All OBL and FACW species that occurred in the remaining plots were examined across all 5 vegetation surveys using an indicator evaluation statistic the following equation:Frequency of indicator occurring within the plot location

$$\text{Validity} = \frac{\text{Frequency of indicator occurring within the plot location}}{\text{Total Frequency of indicator}} \times 100 \quad (6)$$

where Validity is a measure of whether an indicator occurred only within a channel or hillslope position, and is expressed as a percentage.

Validity was chosen as a measure of indicator utility because it emphasizes species presence rather than species absence; species absence can be due to other factors besides the presence of a specific moisture gradient (Goslee et al., 1997). *P. acrostichoides* (Michx.) Schott is a species used for rapid estimation of intermittent stream extent by local industry foresters. The utility of *P. acrostichoides* as an indicator was compared with that of other species identified in the study area. Two criteria were used for identification of potential indicators in this study: (1) the species must have greater validity associated with channel positions than the fern species *P. acrostichoides* or (2) the species must have greater than 70% association with channel positions.

3. Results

3.1. Precipitation

This study encompassed three years (one pre- and two post-harvest) with three distinct precipitation patterns. Total precipitation for 2007 (pre-harvest) was below-average at 1001 mm (30 year mean = 1451 mm). Total precipitation for 2008 (1st year post-harvest) was similar to the 30 year mean at 1498 mm; however, 28% of the total precipitation for 2008 fell during the months of August and December (Fig. 2). The net result was that the study watersheds experienced a severe regional drought from February 2007–December 2008 (National Drought Mitigation Center, http://drought.unl.edu/dm/archive.html). Total precipitation for 2009 (2nd year post-harvest) was 2194 mm, the highest in the 25 year record for Webster County, Mississippi (Fig. 2).

3.2. Vegetation

Over three years of study, a total of 150 species were observed, of which 121 species were used for analysis: 30 trees, 23 shrubs, 16 vines, and 52 herbaceous plants. Distribution among indicator status categories (US Fish and Wildlife Service, 1996) was as follows: 7 OBL, 21 FACW, 45 FAC, 45 FACU, and 3 UPL (2). Three species were listed as non-indicator (NI) and 23 species were not on the National List for Region 2. Three grasses were not identified at the species level.

Vegetation comprised predominantly FAC species followed by FACU and FACW species with comparatively few OBL or UPL species (Table 3; Fig. 3). There was little temporal variation in abundance by wetland designation across treatments; the greatest variation occurred within the FAC classification. Over the three years of study, the number of species increased for most classification groups across all treatments, however it is important to note that the apparent increases correspond to an increase in yearly total rainfall amounts. Relative percentages of wetland/transitional/upland plots across understory stratum did not change over time; ratios were: 1/81/18 in 2007, 2/78/20 in 2008, and 2/77/21 in 2009.

Some species exhibited a clear spatial difference with lateral gradient, but not with longitudinal gradient. *Arisaema dracontium* (L.) Schott (FACW), *Ludwigia glandulosa* Walter (OBL), *Ludwigia alternifolia L.* (OBL), *Hydrangea quercifolia* Bartram (NI), and *Osmunda regalis* L. (OBL) occurred mostly within channel. *Berchemia scandens* (Hill) K. Koch (FACW), *D. commutatum* (Schult.) Gould (FAC), *Lonicera japonica* Thunb. (FAC), *Smilax rotundifolia* L. (FAC), *Vitis rotundifolia* Michx. (FAC), and *P. urvillei* Steud. (FAC) were observed over a wide range of riparian areas. Exotic or pioneer plants such as *Conyza canadensis* (L.) Cronquist (FACU), *Solidago canadensis* L.

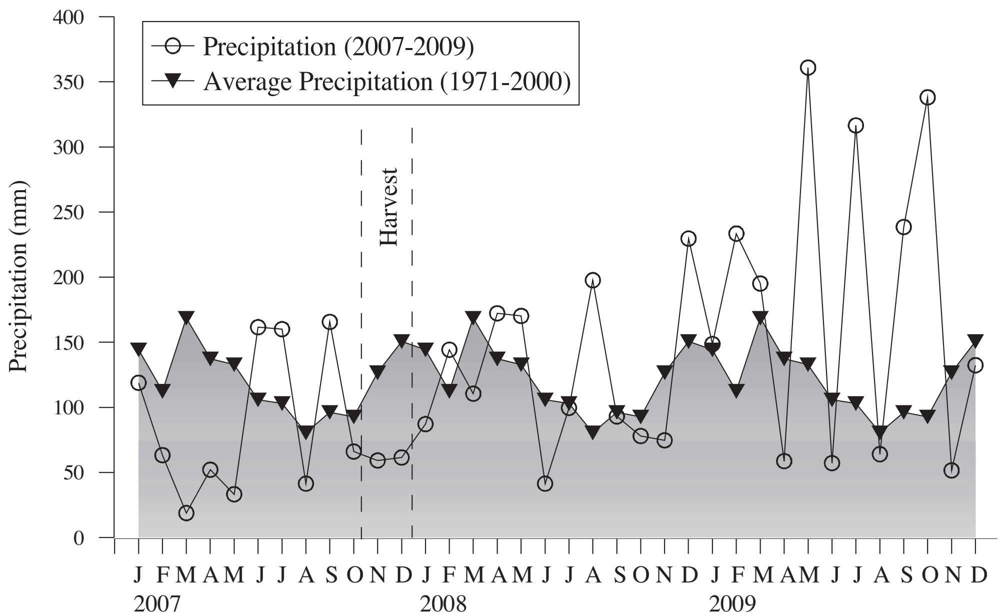

Fig. 2. Precipitation from January 2007 through December 2009 and 30 year mean precipitation (1971–2000) for Webster County, Mississippi.

Table 3
Number of sample plots designated wetland, transitional, and upland for each vegetation stratum by year of observation in small headwater stream riparian areas of Webster County, Mississippi.

Year	Type of stratum	Wetland (PI < 2.5)[a]		Transition zone (2.5 < PI < 3.5)		Upland (PI > 3.5)	
		Number designated	Range	Number designated	Range	Number designated	Range
Pre-harvest	Overstory	0	0	99 (91.7)	2.63–3.41	9 (8.3)	3.53–3.72
	Midstory	0	0	70 (64.8)	2.50–3.48	38 (35.2)	3.50–4.00
	Understory	1 (0.9)[c]	2.38	88 (81.5)	2.50–3.46	19 (17.6)	3.50–3.89
	Combined[d]	0	0	102 (94.4)	2.71–3.47	6 (5.6)	3.57–3.66
1st year post-harvest[b]	Overstory	0	0	156 (72.2)	2.51–3.41	60 (27.8)	3.50–4.00
	Midstory	5 (2.3)	2.00–2.33	108 (50)	2.50–3.48	103 (47.7)	3.50–4.00
	Understory	4 (1.8)	2.20–2.41	169 (78.2)	2.50–3.47	43 (20)	3.50–4.00
	Combined	0	0	170 (78.7)	2.56–3.49	46 (21.3)	3.50–3.84
2nd year post-harvest[b]	Overstory	0	0	150 (69.4)	2.51–3.41	66 (30.6)	3.50–4.00
	Midstory	3 (1.4)	2.25–2.40	115 (53.2)	2.57–3.48	98 (45.4)	3.50–4.00
	Understory	4 (1.8)	1.80–2.33	166 (76.9)	2.50–3.47	46 (21.3)	3.50–4.00
	Combined	0	0	170 (78.7)	2.61–3.49	46 (21.3)	3.50–3.78

[a] Zone criteria recommended by Wentworth et al. (1988).
[b] Post-harvest years represent wet and dry seasons data combined (n = 216).
[c] Numbers in parenthesis indicate percent designated.
[d] Mean across all strata.

(FACU), *Solanum nigrum* L. (FACU), *Eupatorium sertinum* Michx. (FAC), and *Rubus argutus* Link (FACU) were most abundant in disturbed areas and under open canopies. Prior to harvesting, mean PI was similar across all treatments and ranged from 3.19 to 3.25; no significant difference was evident among treatments. Mean PIs were 3.20, 3.24, 3.06, 3.27, 3.13, and 3.27 on CI, HI, CT, HT, CE, and HE locations, respectively. Significant differences in mean PI were detected in lateral gradients ($p < 0.0057$), but not in longitudinal gradients ($p = 0.315$); mean PI was always lower on channel than on hillslope positions with no significant difference between the two classes within intermittent zone locations.

3.3. Treatment effects

Increases in water table following timber harvesting ranged from 1.6 cm in BMP1 to 28.2 cm in the clearcut treatment during 2008, and from 10.5 cm in BMP1 to 54.2 cm in BMP2 during 2009. Post-harvest differences in mean water table were significantly higher in 2009 than in 2008 ($p < 0.001$) as a result of higher precipitation in 2009. Significant differences in mean water table were apparent between channel and hillslope positions reflecting topographic locations in lateral zones ($p < 0.001$).

PI differed significantly among treatments ($p < 0.001$). Post-harvest increase in PI was greatest in the clearcut (7.1%); other treatments responded similarly (values ranged from 0.5% in BMP1 to 1.3% in the reference). Comparisons among plot positions in longitudinal zones were variable across treatments, seasons, and years of observation with no general trends. Within transects, there were significant differences among PI between channel and hillslope positions during 2 years of post-harvest measurement ($p < 0.001$). Interaction effects occurred between treatments and plot/well locations for both mean water table ($p < 0.001$) and PI ($p < 0.001$).

For normalized change in PI, a positive number indicates a shift toward drier assemblages following harvesting; a negative number indicates a shift toward wetter assemblages. Theoretically, the understory layer would be less affected by timber removal than the shrub and overstory layer; however results of the understory vegetation analysis were similar to results using all strata. In most

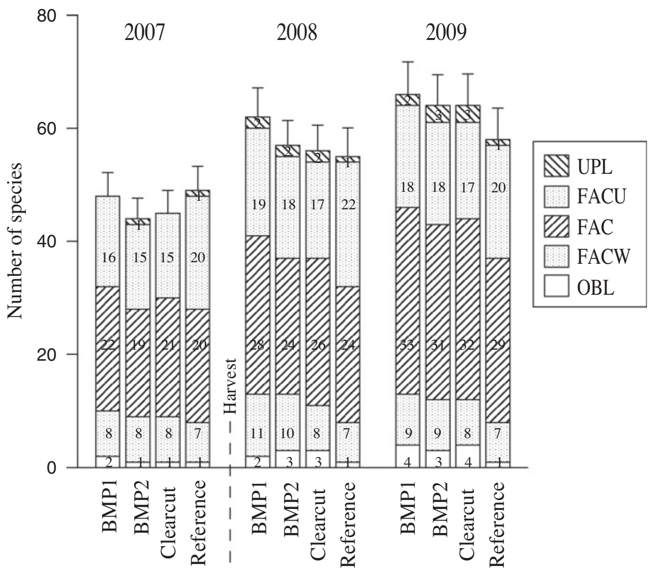

Fig. 3. Proportion of species by wetland indicator classes within treatments by year in small headwater streams of Webster County, Mississippi.

cases, the direction of shift in PI following harvesting was the same for all strata and for understory alone, however variations occurred in the magnitude of that shift. Regardless of which method was used, the magnitude of change in PI was less than 0.15. The understory layer contained the majority of potential indicator species; therefore much of the ensuing discussion of PI refers to the analysis of understory vegetation.

Following harvesting, the two BMP treatments exhibited a shift in PI towards wetter assemblages associated with increased water table (Fig. 4). This trend was observed on most plot/well locations suggesting that there is a relationship between water table response and PI. Responses in PI were similar between BMP1 and BMP2 treatments and notable changes were observed on hillslope positions in BMP2 compared to BMP1 (Fig. 4). Conversely, in the clearcut treatment PI shifted toward drier species assemblages relative to all other treatments. PI in all plot locations within clearcuts increased consistently post-harvest while those of other treatments varied with time of observation (Fig. 4). The shift toward drier assemblages in the clearcut is most likely the result of increased insolation following canopy removal indicating vegetation communities in the study areas may have been more affected by direct disturbances post-harvest than changes in water table (Fig. 4).

3.4. Determination of indicator species

Over three years of study there were 21 understory plots (most of which were in channel locations) that met the new classification criteria and could be construed as having a predominance of hydrophytic vegetation (Table 4). Seven channel and two hillslope positions that did not meet soil and water table criteria were not included in the revised procedure. Eleven potential indicator species were identified after the second procedure; 8 herbs/forbs, two trees, and one shrub (Table 4). Species such as *G. obtusum* and *F. pennsylvanica* that were weakly associated with channel positions were not included. The analysis resulted in 3 indicator species meeting validity criteria that were strongly associated with channel positions (Table 5). *P. acrostichoides*, a species used for rapid estimation of intermittent stream extent by local industry foresters, was also strongly associated with channels at 68%. Each indicator species identified had higher validity than *P. acrostichoides*, but less total frequency of occurrence across the study areas.

4. Discussion

In Webster County, MS, overall plant species abundance increased after harvesting. Increases reflected colonization by generalist FAC species that are well adapted to changing environmental conditions (Fig. 4). However, increases in abundance might be due in part to timber harvesting and in part to drought recovery and increased precipitation post-harvest because the same increasing trend in abundance was found in the reference. Pairwise comparisons of changes in mean water table depth and PI (Fig. 4) elucidate the effects of timber harvesting, especially with respect to the reference condition. The two BMP treatments, when compared to the reference, demonstrate moderate increases in water table across most slope positions. Given an increase in water table, a corresponding shift toward wetter PI of associated vegetation would be expected. In general, this was true within channel; however effects were variable on hillslope positions. In the hillslope positions, micrometeorological changes (e.g. soil temperature, air temperature, and humidity) following harvest may have had a greater impact on vegetation communities than changes in water table.

The shift in PI in the two BMP treatments toward wetter assemblages may indicate that BMP prescriptions provide enough residual habitat for the survival and the growth of OBL and FACW species in spite of harvesting disturbances; BMPs for these treatments required leaving understory intact, minimum surface soil and forest floor disturbance, and prohibition of logging equipment within channel. Selective harvesting in these two BMP treatments resulted in more available light at the forest floor, drier soil, and microclimatic zones that create greater opportunities for opportunistic pioneer species consisting of FAC and FACU species. A minor tendency toward drier microclimates was apparent in hillslope positions; however these patterns are likely to be short-term effects and most of the pioneer species will become less abundant as the residual canopy becomes more dense (Davies et al., 2005). Unexpected results such as a small shift toward wetter PI in hillslope positions of BMP1 and BMP2 may be attributed to the presence of shallow seeps perched above less permeable soil layers. Seeps were observed on hillslopes following precipitation events especially as water tables increased, suggesting that the water table follows the geomorphic surface.

Stand heterogeneity may also be a factor, in that selective cuts preferentially remove more timber where there is a concentration of high-value timber, resulting in greater canopy opening and light penetration as well as increased soil disturbance. Sites with similar soil and forest floor conditions, but different insolation would show different patterns of community response (Fenton and Frego, 2005). Removal of overstory vegetation may alter the microclimate (through increased insolation, higher air and soil temperature, and lower relative humidity) sufficient to permit opportunistic pioneer FAC or FACU species to colonize and proliferate across disturbed riparian areas (Appleby, 1998). More basal area was removed in BMP2 than in BMP1 (Table 1) because of reduced operational constraints. The additional basal area removal resulted in a somewhat more elevated water table in BMP2 than in BMP1; however this response was not mirrored by vegetation communities. Moreover, clearcut treatments (relative to BMP treatments) exhibited the greatest rise in water table following harvesting, simultaneous with a shift toward drier species assemblages. As was the case with BMP treatments, PI in the clearcut did not respond directly to elevated water tables. Changes in microclimate could be driving vegetation assemblages toward a more upland type plant community in these headwater streams. Similar results were described by

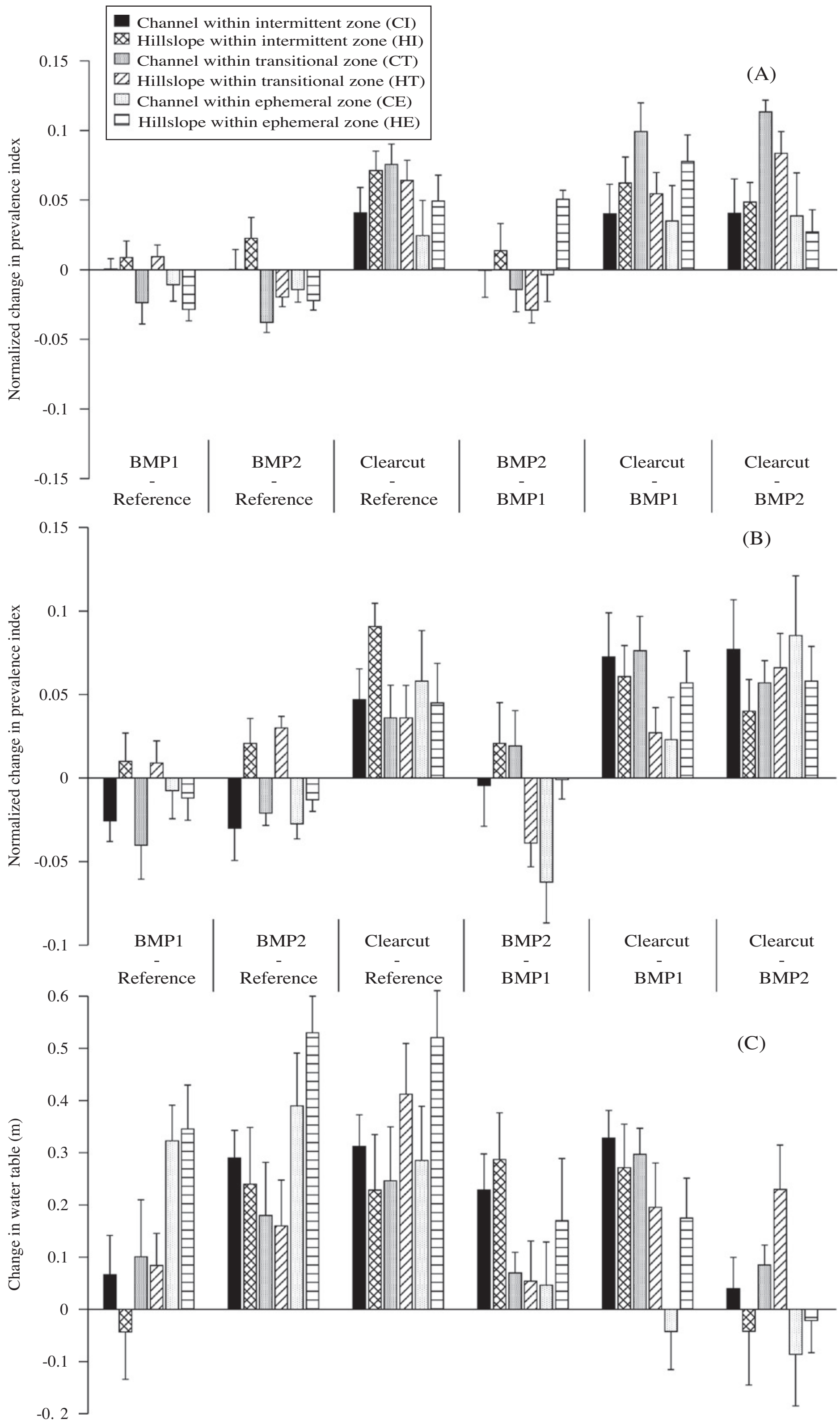

Fig. 4. Pairwise comparisons by treatment for change in mean water table and mean PI in small headwater streams of Webster County, Mississippi. Graph (A) comparisons between prevalence index (PI) of plots across all strata at the same topographic positions. Graph (B): comparisons between prevalence index (PI) of plots for understory stratum at the same topographic positions. Graph C: comparisons of change in water table (DWT) among plots at the same topographic positions. Pairwise comparison was conducted between the two listed treatments (i.e. top minus bottom). For pairwise comparisons of normalized change in PI, positive PI values indicate a shift toward drier species assemblages and negative values indicate a shift toward wetter species assemblages. For pairwise comparisons of change in water table, positive values indicate a shift toward higher water table and negative values indicate a shift toward lower water table.

Table 4
List of potential indicator species and understory plots with PI < 3.0 by treatment in small headwater stream riparian areas of Webster County, Mississippi.

Watershed	Species	Understory plots with PI < 3.0 within treatment			
		BMP1	BMP2	Clear-cut	Reference
Union	*Arisaema dracontium* (L.) Schott[c]	CT[b] (3)		CI[b] (4)	
	Arundinaria gigantea (Walter) Muhl.[c]				
	Leersia oryzoides (L.) Sw[c]		CI (6)[a]		CE[b] (0)
	Ludwigia glandulosa Walter[c]		CT (5)		CI[b] (2)
	Osmunda regalis L.[c]		CE (6)		
	Viola blanda Willd.[c]				
Congress	*Arundinaria gigantea* (Walter) Muhl.[c]				
	Galium obtusum Bigelow[d]				
	Fraxinus pennsylvanical Marsh.[d]	CI (5)	CT (3)		
	Ludwigia glandulosa Walter[c]	HI[b] (0)	CI (4)	CE (6)	–
	Mikania scandens (L.) Willd[c]	CT (7)	CE[b] (3)		
	Salix nigra Marsh.[c]				
	Viola blanda Willd.[c]				
Ingram	*Arundinaria gigantea* (Walter) Muhl.[c]				
	Galium obtusum Bigelow[d]				
	Leersia oryzoides (L.) Sw.[c]		CI (6)		
	Ludwigia alternifolia L.[c]	CT (5)	CT (5)	CI (6)	–
	Ludwigia glandulosa Walter[c]	CE (5)	CE (6)	HI[b] (0)	
	Osmund a regalis L.[c]				
	Viola blanda Willd.[c]				

[a] Numbers in parenthesis are the mean number of months water-table was within 30 cm from the surface.
[b] Plots that had little evidence of hydric soils.
[c] Species strongly associated with channels.
[d] Species strongly associated with hillslopes.

Table 5
List of potential indicator species for determining hydrologically influenced portions in small headwater riparian areas of Webster County, Mississippi.

Species	Common name	US&FWS Indicator Status	Total frequency (%)	Validity (%)	
				Channel	Hillslope
Viola blanda Willd.	Sweet white violet	FACW-	22.8	70.5	29.5
Ludwigia glandulosa Walter	Cylindricfruit primrose-willow	OBL	7.2	100	–
Arundinaria gigantea (Walter) Muhl. *Ssp. Tecta* (Walter) McClure	Switchcane	FACW	25.8	75.3	24.7
Combined			55.8	76.1	23.9
Polystichum acrostichoides (Michx.) Schott	Christmas fern	FAC	28.1	68.3	31.7

Dewey et al. (2006) in a study on wetland delineation of a bottomland hardwood forest in East Texas. It is also possible that alterations in ground surface microtopography, mobilization of mineral soil and damage to residual plants through harvesting activities may affect the composition of riparian vegetation (Jolley et al., 2010) by creating microhabitats which permit opportunistic FAC or FACU species to colonize.

Vegetation communities are related to topographic positions which may represent gradients of water availability. This idea is often useful for identifying riparian zones as described in larger order riparian systems (Pabst and Spies, 1998; Lite et al., 2005); however it is not obvious whether vegetation communities in low order basins follow topographic patterns. Clinton et al. (2010), in a study on identification of riparian zone width using structural and functional characteristics in Southern Appalachian first order headwater streams, found that vegetation composition was not a good parameter for defining riparian zone width. In the present study, prior to harvesting, mean PI differed significantly in lateral gradient between channel and hillslope positions. These differences may represent distinct vegetation communities between channel and hillslope positions in the study ephemeral–intermittent streams, even though there may not be a pronounced transition zone. A similar result was reported by Sheridan and Thomas (2005) in a study on vegetation-environment relationships in zero-order basins in coastal Oregon, in which they found that the understory stratum follows gradients in geomorphic conditions. In the present study, understory vegetation reflects, to some degree, gradients in geomorphic environment. Post-harvest changes in vegetation communities may reflect geomorphic environmental parameters such as water availability, increased insolation and forest floor disturbance (Roberts and Zhu, 2002).

Evaluation of soils and hydrologic characteristics in conjunction with hydrophytic vegetation is essential to describing riparian function. In general, there was a good correlation between PI calculated by plot-based weighted averages and water table. Twenty-one understory plots that had PI < 3.0 were identified for evaluating potential indicator species and most of those plots were in channel locations suggesting that water table could be the primary factor influencing vegetative communities in ephemeral–intermittent streams of this study (Table 4). Nine of the 11 potential indicator species were associated with channel positions while two species were identified as probable indicators of hillslope positions (Table 4). Most wetland indicator species identified in the study were herbaceous, thus herbaceous plants may be more sensitive to moisture gradients and disturbance. This is consistent with other work documenting the use of herbaceous plants as indicators to identify wetland water sources (Goslee et al., 1997) and riparian zones (Hagan et al., 2006). While there is no universal method for bioindicator selection criteria, it is recognized that the indicator(s) selected should at the very least (1) be expected to mimic the structure and function of ecological processes, (2) have sufficient biotic integrity that the measure will change when the environment that supports the community changes, (3) be realistically manageable and (4) be appropriate to ecosystem scale of interest and, where possible, link across scales (Brooks et al., 1998; Hilty and Merenlender, 2000). The present analysis involved the a priori expectation that wetland indicator species would have been associated with channel positions and/or periodically saturated soil conditions. The nine species presented in Table 4 could be used as indicators for channel positions within ephemeral–intermittent streams in the study area. However, among the nine indicator species, *V. blanda*, *L. glandulosa*, and *A. gigantea* had higher frequency of occurrence than that of the remaining species which represented <5% across all understory plots. This suggests that these three species are therefore the more appropriate indicators of changes in soil moisture regime and possibly water table for this study area and that the others are too rare to be useful as indicators. This also suggests that using only strong indicator species may give better results than using all potential indicators. *P. acrostichoides* was strongly associated with channel positions and had highest total frequency of occurrence across the study areas, which suggests that this species alone is viable as an indicator of patterns in soil moisture in these systems. However, the combined use of three most indicative species yielded nearly double the occurrence than that of *P. acrostichoides* and increased validity by 8% (Table 5). The combined use of strong indicator species identified in this study and the "fern line" used by local industry foresters would provide a means for rapid assessment of hydrologically functional SMZs in these headwater streams.

5. Conclusions

In the present study, two distinct vegetation communities (channel and hillslope) corresponded to water table gradients. Timber harvesting affected these vegetation patterns directly as a result of changes in forest structure through basal area removal and indirectly through soil disturbances within these riparian areas. Combined direct and indirect disturbances affected vegetation communities in clearcuts, whereas direct disturbances were the primary driving factors with respect to changes in vegetation community in the two treatments where BMPs were employed. Four indicator species (*V. blanda*, *L. glandulosa*, *A. gigantean*, and *P. acrostichoides*) were identified as having a close association between these species and the presence of near surface water (either saturated soils or a water table within 30 cm). Indicator species identified in this study may be absent or of limited value as indicators in headwater streams outside the study area, therefore, care should be taken when applying indicator species found in this study to other areas. However, the procedure used to determine these indicator species will be useful to those outside the region. An indicator analysis based on soils and water table has the potential for rapid estimation of true hydrologic boundaries of headwater streams and mapping of SMZs by field foresters.

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