Application of Diversity Indices and an Index of Biotic Integrity to a Basin Area Stream Survey (BASS) Fish Dataset Collected on the Ouachita National Forest, 1990 – 2011

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Introduction

The Ouachita National Forest (ONF) began physical, chemical, and biological watershed monitoring using basin area stream surveys (BASS) (Clingenpeel and Cochran, 1992; Williams et al., 2002) in 1990. Watersheds with active forest management (i.e. managed) were paired with adjacent watersheds without active forest management (i.e. reference). Samples collected in 1990, 1991, and 1992 (USDA Forest Service, Ouachita National Forest 1994) provided a baseline for future Forest monitoring; additional BASS surveys were completed every 4 - 5 years thereafter.

In 1998, the ONF began surveys in two additional watersheds to address concerns over possible effects of off highway vehicle (OHV) use on stream habitat, water quality, and biota (Clingenpeel, 2012). These two watersheds are located in the Lower Ouachita Mountains ecoregion in close proximity to but in a different drainage basin from a pair of BASS monitoring watersheds (Table 1). The four watersheds offered the possibility to compare conditions in reference, managed, and OHV impacted watersheds (Figure 1). All four watersheds were sampled in 2001, 2006, and 2011 (Table 1). Detailed descriptions of watershed characteristics and management history can be found in Clingenpeel (2012).

The ONF analyzed physical, chemical, and biological data for the four watersheds following the 2011 inventories (Clingenpeel, 2012). Fish data analysis focused on relative abundance and density of sensitive fish species, benthic insectivores, central stonerollers (*Campostoma anomalum*[1]), and orangebelly darters (*Etheostoma radiosum*). Comparisons among OHV, managed, and reference watersheds formed the basis for a multimetric approach to determining relative stream condition. Results of the analysis suggested impairment in the OHV watersheds in some years.

The ONF requested assistance from the U.S. Forest Service, Southern Research Station, Center for Aquatic Technology Transfer in applying additional analytical approaches to the biological data. Our objectives were to apply common diversity indices including species richness, Simpson's Index of Diversity, Shannon's Diversity Index and an index of biotic integrity (IBI) developed specifically for use in the Ouachita Mountains (Dauwalter and Jackson, 2004).

[1]Central stonerollers (*C. anomalum*) in this region were re-described in 2010 as the Highlands stoneroller (*C. spadiceum*) (Cashner et al., 2010)

Methods

Data Sources

We obtained the BASS dataset from the ONF as a set of Excel spreadsheets, which we reformatted and uploaded to an Access database. We used a series of table relationships and queries to link BASS habitat data and fish sample data, group species records, and output species capture tables. The resulting outputs were used to determine the appropriate scale for analysis and provide fish data needed for diversity indices and IBI calculations.

Analysis Scale

The location of fish samples is based on the results of a BASS stream habitat inventory. During the habitat inventory the entire length of the wetted stream channel is divided into individual habitat units (e.g. pools, riffles, runs, etc.). Fish are sampled in 10 percent of each habitat unit type; for example, if 30 pools are identified, then 3 would be sampled for fish. For simplicity, individual sample units are often grouped together into sample reaches consisting of multiple consecutive habitat units. Sample reaches are spread throughout the length of the stream (Figure 2). Blocknets are placed at the downstream and upstream end of each sample reach. A minimum of two passes are made through each sample reach with a backpack electrofishing unit.

Because the areas of the four watersheds (Table 1) vary considerably, Clingenpeel (2012) divided each watershed into zones (Figure 2) prior to analysis to compensate for differences in watershed area. When comparing large and small watersheds Clingenpeel (2112) removed the most downstream zones from his analyses until watersheds were approximately equal in area. We considered several options for analysis: 1) calculate scores for every sample reach, 2) group sample reaches by zone, or 3) group all sample reaches in a given year by stream.

Species Richness

Easily measured and interpreted, species richness is one of the simplest but most widely used metrics for assessing diversity (Mendes, 2008). We calculated species richness as the number of fish species sampled in each stream for each given year. However, care must be taken when interpreting species richness, as species assemblages and thus maximum possible richness varies by drainage (Table 2). To adjust for differences in species richness between the two major drainages, we divided species richness by the total number of species in the drainage as provided by Matthews and Robison (1998).

Simpson's Index of Diversity

Simpson's Index of Diversity is a dominance index that differentially assigns weight to common species (Cianfrani 2009). We calculated Simpson's Index of Diversity as 1 – D, where D is calculated as:

$$D = \frac{\Sigma\, n(n-1)}{N(N-1)},$$

n = total number of individuals of a given species, and N = the total number of species collected. In this form the index essentially measures the probability that two individuals selected from a sample will belong to different species; values range from 0 - 1 with 1 representing the highest possible diversity.

Shannon's Diversity Index

Shannon's Diversity Index incorporates both number of species and their evenness in a sample (Cianfrani 2009). Shannon's is a good middle of the road index that takes into account both aspects of diversity: richness and evenness (Mendes 2008). We calculated Shannon's Index (H) as:

$$H = -\sum_{i=1}^{s} p_i \ln p_i,$$

where S is total species in the sample and p_i is proportion of S comprized of the *i*th species; higher scores indicate higher diversity.

Index of Biotic Integrity

IBIs are multimetric indices used for biomonitoring. Initially developed by Karr (1981), IBIs have been widely adapted and applied to streams throughout the U.S., including the Ouachita Mountains Ecoregion (Hlass et al., 1998; Dauwalter and Jackson, 2004). We selected the IBI developed by Dauwalter and Jackson (2004) because 1) the IBI was developed using 38 stream samples from the Lower Ouachita Ecoregion, 2) the 12 metrics in the IBI were rigorously and quantitatively selected from a pool of 62 candidate metrics, and 3) the 12 metrics are the same as or are adaptations of commonly used IBI metrics (Table 3).

The IBI score is calculated as:

$$IBI = \frac{\left(\sum_{i=1}^{n} MS_i\right) \cdot 10}{N},$$

where MS_i is the score of the *i*th metric, and N = the number of metrics; scores range from 0 to 100 with 100 indicating the highest biotic integrity (Table 4). The scoring of individual metrics is described in detail in Dauwalter and Jackson (2004). We imported BASS data into an Access database provided by Dan Dauwalter for calculating metric scores and IBI ratings.

Results

Analysis Scale

The number of sample reaches, the location of sample reaches relative to other reaches, and the distribution of sample reaches within each stream varied among sample years (Figure 2). The number of habitat units in sample reaches also ranged widely, from 1 – 9 units per reach (Figure 3). In addition, sample reaches occasionally overlapped zone boundaries. Preliminary testing showed that IBI scores were influenced by sampling effort. At the reach level, IBI scores decreased as the number of habitat units in a reach fell below five (Figure 3). At the stream level, IBI scores decreased as the percent of total stream area dropped below 5.5% (Figure 4). Given the variability in reach size and location we chose to group data for all additional analyses by stream for each sample year.

Species Richness

Unadjusted species richness ranged from 10 to 19 species across all streams in all years (Figure 5). With the exception of the year 2000, the two OHV streams in the Ouachita Basin, Board Camp and Gap Creeks, had higher species richness than either the managed (Brushy Creek) or reference (Caney Creek) streams, which are located in the Little River Basin. The Ouachita River basin contains 87 species, whereas 61 species occur in the Little River basin (Matthews and Robison, 1998). After adjusting for the number of species potentially present all streams contained between 16% and 23% of their respective regional species pools, with the exception of Brushy Creek in 2001 (Figure 6).

Simpson's Index of Diversity

Simpson's Index of Diversity generally ranged from 0.66 to 0.85. The exception was Gap Creek, where scores in 2001 and 2006 dipped sharply (Figure 7). Scores in Brushy Creek trended downward over time from a high of 0.83 in 1990 to a low of 0.66 in 2011.

Shannon's Diversity Index

Shannon's Index was generally between 1.5 and 2.0 (Figure 8). The two exceptions were Gap Creek in 1998 with a score of 2.2, and Board Camp Creek which saw scores dip below 1.5 in 2001 and 2006. Scores in Brushy Creek trended downward over time from a high of 2.0 in 1990 to a low of 1.6 in 2011.

Index of Biotic Integrity

The total percentage of stream length sampled was greater than 5% for all streams in all years (Figure 4). IBI scores fell within the 'Good' to 'Reference' categories for all streams across all years (Figure 9). There was a decreasing trend in IBI scores in Caney Creek, from a high of 88 in 1990 to a low of 70 in 2011.

Discussion

Taken in total, our results indicate overall diversity and biotic integrity are relatively high in all four watersheds. However, there are some notable caveats and exceptions. The IBI was developed using data from across the Lower Ouachita Mountains ecoregion (Dan Dauwalter, pers. comm.), not just from streams on National Forest managed lands. As a result, the overall score reflects conditions relative to the condition of all streams in the Ouachita Mountains, not just those under Forest Service management. The management objective for each of these watersheds should be to maintain or restore them to the IBI reference condition.

The four watersheds are spread across two river basins, which clearly influence species richness. When adjusted for the total number of species present in each basin, overall species richness was similar among streams. However, species richness has the potential to affect IBI scores; for example 3 of the 12 metrics reflect some form of species richness (TCENTR, TOMIND, TOKEY). A review of metric scores revealed that only TOMKEY scores were higher (10 vs. 7.5) in streams in the more specious Ouachita River drainage. Further review found that the difference was accounted for by the presence of a single additional species, the northern hogsucker (*Hypentelium nigricans*). This species was present in only a single sample from the Little River drainage in 2011, and this may be an errant record as the species has not been found in the drainage previously (Robinson and Buchanan, 1988). However, the

overall effect on the IBI score is less than 3 points. Differences in species richness therefore did not have a significant effect on overall IBI scores.

Both Simpson's and Shannon's diversity dropped notably in Board Camp Creek in 2001 and 2006. A review of the raw fish data showed that while the numbers of individuals of most species did not change significantly among years, relative abundance of central stoneroller increased dramatically in 2001 and 2006, resulting in decreased diversity scores (Figure 10). The drop in Simpson's index was more dramatic as Simpson's is a dominance index and thus is more sensitive to changes in relative abundance of dominant species in the fish community. Clingenpeel (2012) showed a similar result, and attributed increases in stoneroller populations in Board Camp Creek to changes in streamside habitat related to OHV use, including loss of riparian vegetation. Stonerollers prefer small, clear streams with rocky substrates (Robinson and Buchanan, 1988), but may become more abundant in areas where increased solar radiation or increased nutrient input provide more abundant periphyton (Petersen, 1998), their primary food source. Simpson's and Shannon's Diversity increased in 2011, but the situation warrants additional monitoring and an assessment of changes in streamside vegetation in the watershed.

We also observed downward trends in diversity scores in Brushy Creek and downward trends in IBI scores in Caney Creek over the monitoring period. Brushy Creek is within a 'managed' watershed and Caney Creek within a wilderness area, and neither were noted for excessive OHV use in Clingenpeel (2012). Brushy Creek showed downward trends in both Simpson's and Shannon's diversity over time. The total number of species present in Brushy Creek was reasonably consistent over time with the exception of an unexplained and dramatic increase in total species in 2001. The decrease in diversity scores thus is likely due to changes in dominance or evenness in the fish community (i.e. some species are becoming numerically more dominant over time). A review of the raw fish data once again revealed that a sharp increase in central stoneroller relative abundance was responsible for the decreasing trend in the diversity indices (Figure 11). As in Board Camp Creek, this trend warrants additional monitoring and an investigation into possible changes in watershed management, recreational use, or other environmental conditions that may account for the increase in stoneroller abundance.

In Caney Creek IBI scores trended downward over time. Review of individual IBI metric scores revealed drops in 2 metrics over time, the percent black bass (PBBASS) and the percent mineral, site-prep, and parental-care spawners (PMSPPC) (Figure 12). Review of the raw data revealed that smallmouth bass (*Micropterus salmoides*) is the most significant contributor to both PBASS and PMSPPC scores in Caney Creek. Black bass are not abundant in any of the monitored streams, and when present

can be difficult to capture using backpack electrofishing (Mitzi Cole, pers. comm.) Given their relative rarity the ONF may wish to consider removing the black bass metric from future IBI analyses. Removal of underperforming metrics is described in Dauwalter and Jackson (2004).

Our results highlight the importance of consistent and sustained effort and the use of a variety of analytical approaches when conducting a long term monitoring plan. The ONF should be applauded for developing and sustaining the BASS monitoring program over a period of more than 20 years; subtle trends observed in both Caney and Brushy Creeks would not be evident without long term data. Similar trends may be developing in Board Camp Creek and Gap Creeks. We suggest that the ONF continue monitoring all four watersheds both to strengthen the baseline dataset and to increase confidence in estimates of the magnitude and direction of long-term trends.

Our results demonstrate that total IBI scores can fall dramatically when sampling effort falls below a threshold, and that some metrics may be sensitive to sample size and distribution. When faced with the decision of how to allocate scarce resources for future monitoring, we recommend sampling fewer sites (streams) with adequate effort rather than including more streams but expending minimal sampling effort in each.

No single analytical approach can completely capture or describe all facets of diversity or stream health. We applied different analyses to the BASS dataset than did Clingenpeel (2012). Some of our results were similar; others provided new or additional insights. We encourage the ONF to use a variety of techniques when analyzing datasets in the future.

In summary, while overall diversity and biotic integrity in the four watersheds were relatively good over the study period some results suggest that changes in the fish community may warrant additional monitoring and investigation into its possible causes. In addition, we recommend the ONF continue its monitoring program and ensure that changes in sampling effort and frequency do not impact the quality and utility of future monitoring analyses.

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Tables

Table 1. Streams surveyed using BASS methods on the Ouachita National Forest, 1990 – 2011. LOM = Lower Ouachita Mountains; LR = Little River; OR = Ouachita River; OHV = off-highway vehicle.

Stream	Area (mi^2)	Ecoregion	Drainage	Status	1990	1991	1992	1996	1998	2001	2006	2011
Brushy Creek	9	LOM	LR	Managed	x	x	x	x		x	x	x
Caney Creek	13	LOM	LR	Reference	x	x	x	x		x	x	x
Board Camp Creek	8	LOM	OR	OHV					x	x	x	x
Gap Creek	3	LOM	OR	OHV					x	x	x	x

Table 2. Species collected from Ouachita National Forest streams during BASS sampling, 1990 – 2011.

			Little River		Ouachita River	
Common Name	Family	Species	Caney	Brushy	Board Camp	Gap
Northern Hogsucker	Catostomidae	*Hypentelium nigricans*		x*	x	x
Shadow Bass	Centrarchidae	*Ambloplites ariommus*			x	
Green Sunfish	Centrarchidae	*Lepomis cyanellus*	x	x	x	x
Bluegill	Centrarchidae	*Lepomis macrochirus*	x	x		x
Longear Sunfish	Centrarchidae	*Lepomis megalotis*	x	x	x	x
Spotted Sunfish	Centrarchidae	*Lepomis punctatus*			x	
Smallmouth Bass	Centrarchidae	*Micropterus dolomieu*	x	x	x	x
Spotted Bass	Centrarchidae	*Micropterus punctulatus*		x		
Largemouth Bass	Centrarchidae	*Micropterus salmoides*		x		
Central Stoneroller	Cyprinidae	*Campostoma anomalum*	x	x	x	x
Creek chubsucker	Cyprinidae	*Erimyzon oblongus*	x	x	x	x
Striped Shiner	Cyprinidae	*Luxilus chrysocephalus*	x	x	x	x
Ouachita Mountain Shiner	Cyprinidae	*Lythrurus snelsoni*	x	x		
Redfin Shiner	Cyprinidae	*Lythrurus umbratilis*	x	x	x	x
Bigeye Shiner	Cyprinidae	*Notropis boops*	x	x	x	x
Kiamichi Shiner	Cyprinidae	*Notropis ortenburgeri*			x	x
Bluntnose minnow	Cyprinidae	*Pimephales notatus*		x	x	x
Creek Chub	Cyprinidae	*Semotilus atromaculatus*	x	x	x	x
Grass Pickerel	Esocidae	*Esox americanus*		x		
Northern Studfish	Fundulidae	*Fundulus catenatus*	x	x	x	x
Blackspotted Topminnow	Fundulidae	*Fundulus olivaceus*	x	x		x
Yellow Bullhead	Ictaluridae	*Ameiurus natalis*	x	x	x	x
Slender Madtom	Ictaluridae	*Noturus exilis*		x	x	x
Ouachita Madtom	Ictaluridae	*Noturus lachneri*			x	
Freckled Madtom	Ictaluridae	*Noturus nocturnus*			x	x
Greenside Darter	Percidae	*Etheostoma blennioides*			x	x
Creole Darter	Percidae	*Etheostoma collettei*		x		
Orangebelly Darter	Percidae	*Etheostoma radiosum*	x	x	x	x
Orangethroat Darter	Percidae	*Etheostoma spectabile*	x	x		
Redfin Darter	Percidae	*Etheostoma whipplei*	x	x		x
Logperch	Percidae	*Percina caprodes*			x	x
Southern Brook Lamprey	Petromyzontidae	*Ichthyomyzon gagei*			x	

**Not previously recorded in Little River drainage.*

	Total Species	Unique Species
Little River	24	5
Ouachita River	26	8

Table 3. Metrics used to calculate IBI scores, from Dauwalter and Jackson (2004). Sign indicates direction of relationship between metric and overall IBI score.

Metric		Description
PBBASS	+	Percent as black bass
PBENTH	+	Percent as benthic feeders
PCENTR	-	Percent as centrarchids
PCYPRI	+	Percent as cyprinids
PICTAL	-	Percent as ictalurids
PMINSP	+	Percent as mineral, site-prep spawners
PMSPPC	+	Percent as mineral, site-prep, parental-care spawners
PSIMLI	+	Percent as simple, mineral substrate spawners
PXSPPC	-	Percent as miscellaneous, parental-care spawners
TCENTR	+	Total number of centrarchid species
TOMIND	+	Total number of ADEQ Ouachita Mtns indicator species
TOMKEY	+	Total number of ADEQ Ouachita Mtns keyspecies

Table 4. Ratings for IBI scores, from Dauwalter and Jackson (2004).

Rating	IBI Score
Very Poor	0 - 19
Poor	20 - 39
Fair	40 - 59
Good	60 - 79
Reference	80 - 100

Figures

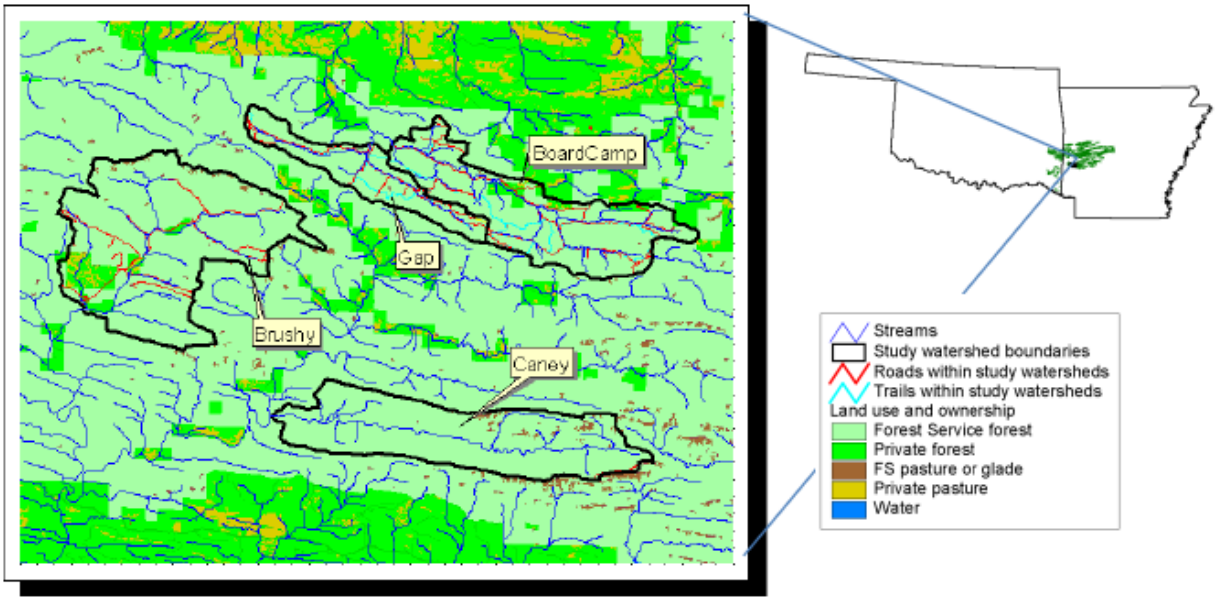

Figure 1. Caney Creek (reference), Brushy Creek (managed), Board Camp Creek (OHV), and Gap Creek (OHV) within the Ouachita National Forest. Figure is from Clingenpeel (2012).

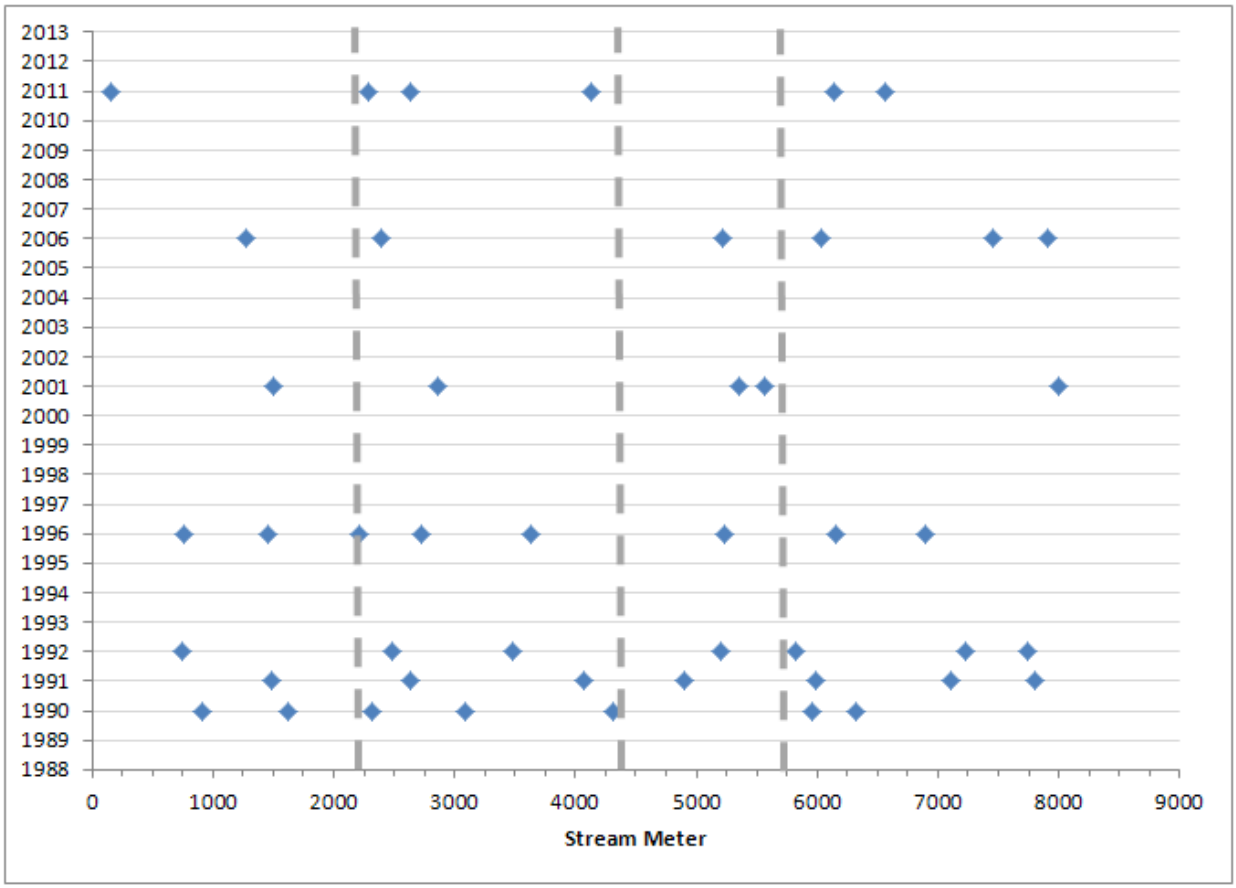

Figure 2. Location of fish sample reaches on Brushy Creek, Ouachita National Forest, 1990 – 2011. Points represent the start of sample reaches. Number and location of sample reaches varied among years, but total stream length sampled was relatively consistent, ranging from 7-10% of wetted stream length. Vertical dashed lines indicate average location of breaks between stream zones used to match watersheds by size in Clingenpeel (2012). Other streams were similarly sampled and divided into reaches. We did not incorporate the zones into our analysis.

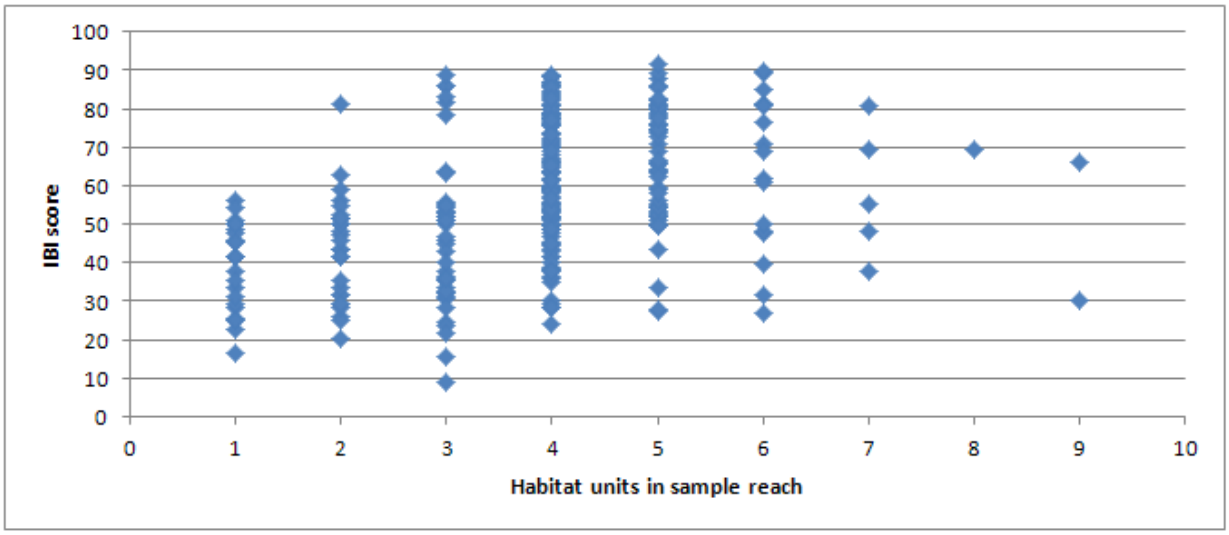

Figure 3. Ouachita Mountain IBI scores for reaches sampled using BASS on the Ouachita National Forest, 1990 – 2011. Sample reaches contained from 1 – 9 continuous habitat units (e.g. riffle, run, pool).

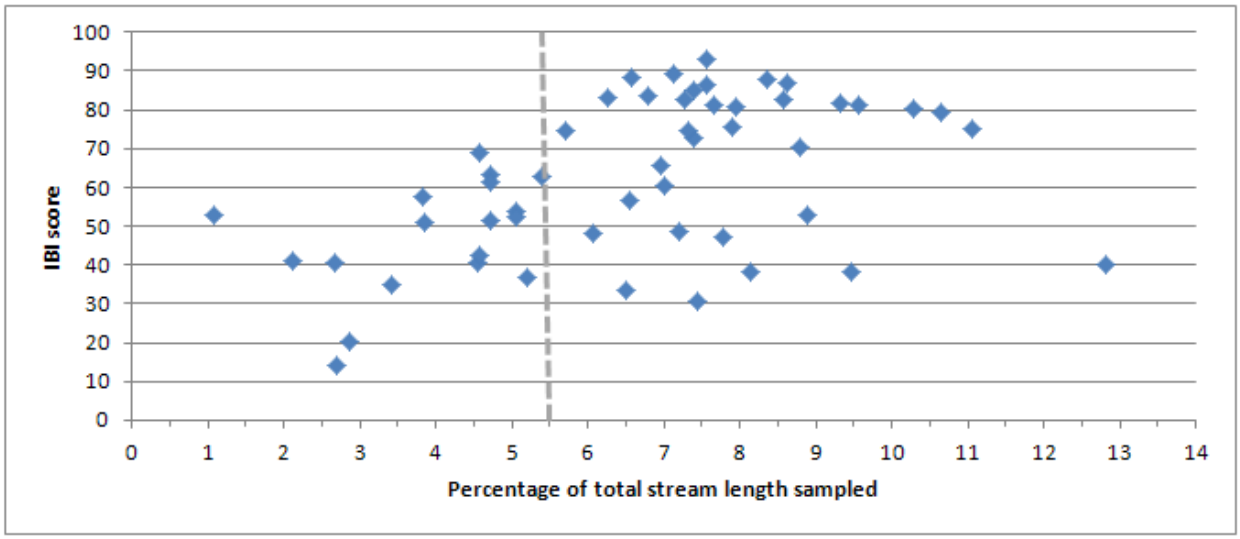

Figure 4. Ouachita Mountain IBI scores for 9 streams sampled using BASS on the Ouachita National Forest, 1990 – 2011. Percentage of total stream length is calculated as the sum of all sample reach lengths divided by total stream length. All samples from Brushy, Caney, Gap, and Board Camp Creeks fell to the right of the vertical dashed line.

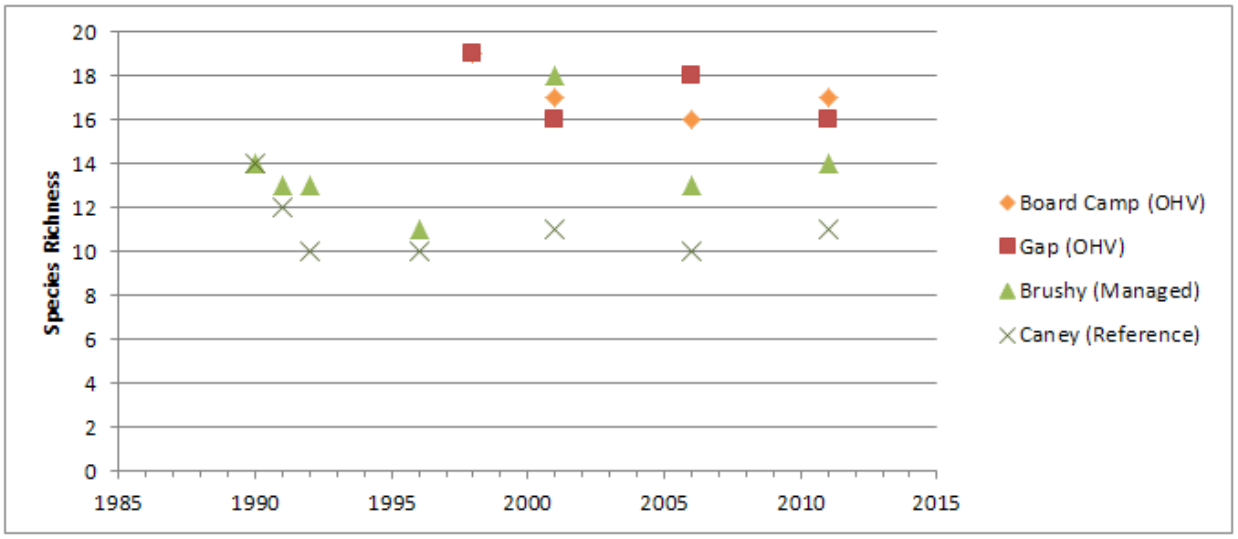

Figure 5. Total number of species collected in Ouachita National Forest streams during BASS surveys, 1990 - 2011.

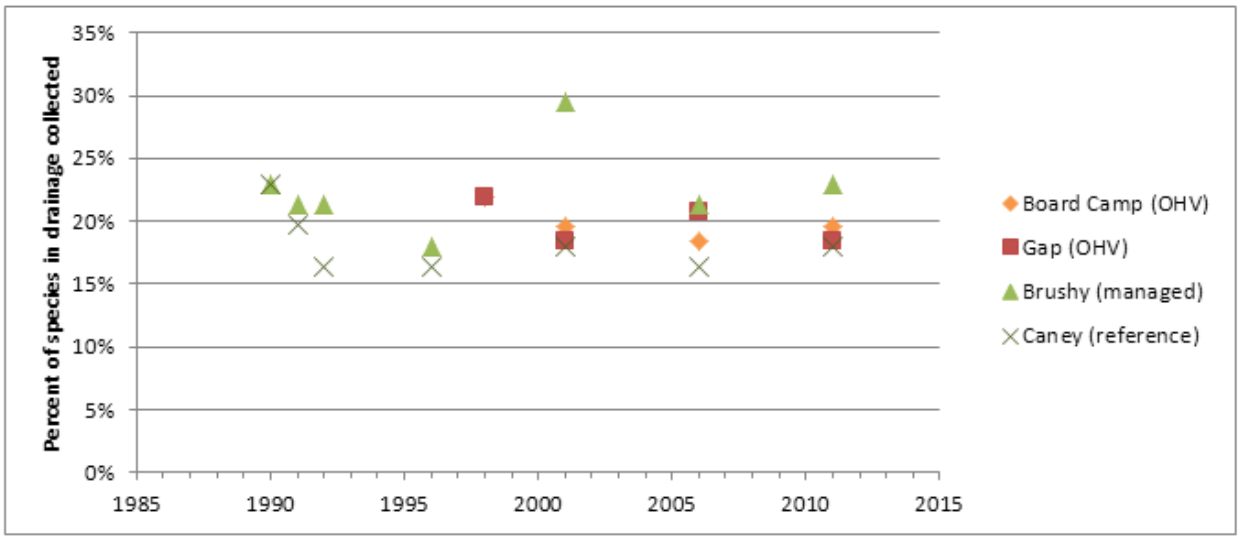

Figure 6. The total percent of species in each major drainage that was collected during BASS sampling on the Ouachita National Forest, 1990 – 2011.. Regional fish species richness for Little River and Ouachita drainage streams is 61 and 87 species, respectively (Matthews and Robison, 1998). Board Camp Creek and Gap Creek are in the Ouachita River drainage, whereas Brushy Creek and Caney Creek are in the Little River drainage.

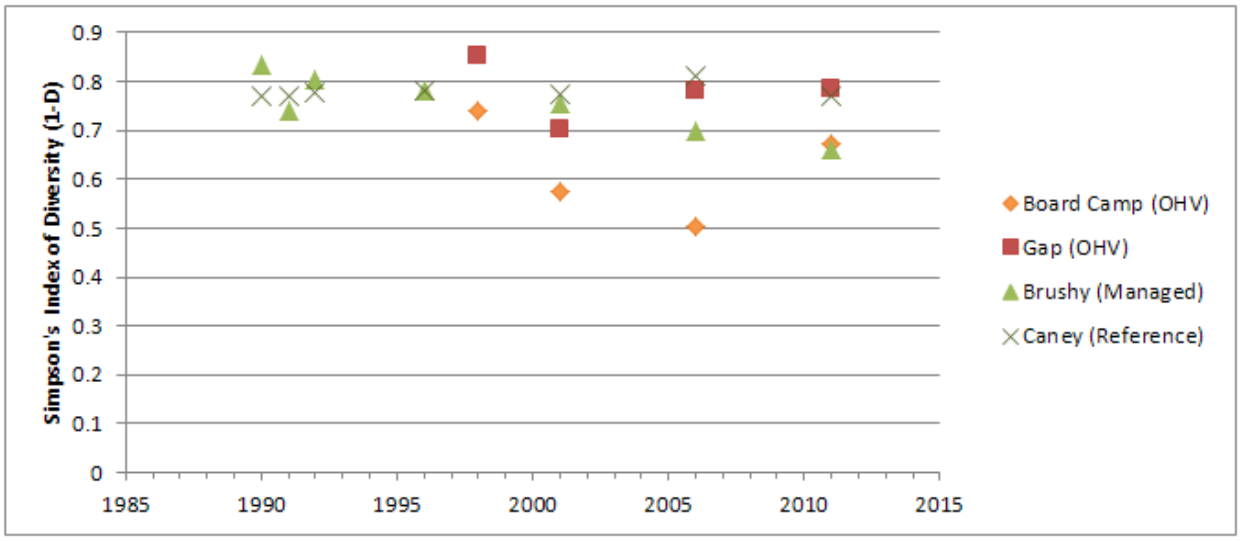

Figure 7. Simpson's Index of Diversity (1 – D) scores for Ouachita National Forest stream BASS surveys, 1990 – 2011.

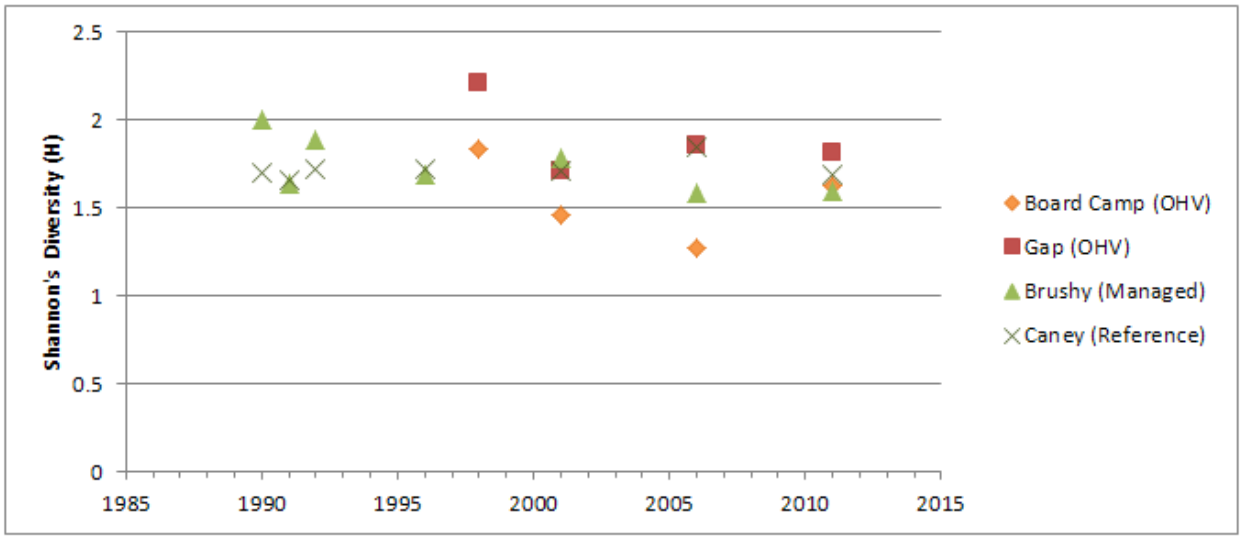

Figure 8. Shannon's Diversity Index (H) scores for Ouachita National Forest stream BASS surveys, 1990 – 2011.

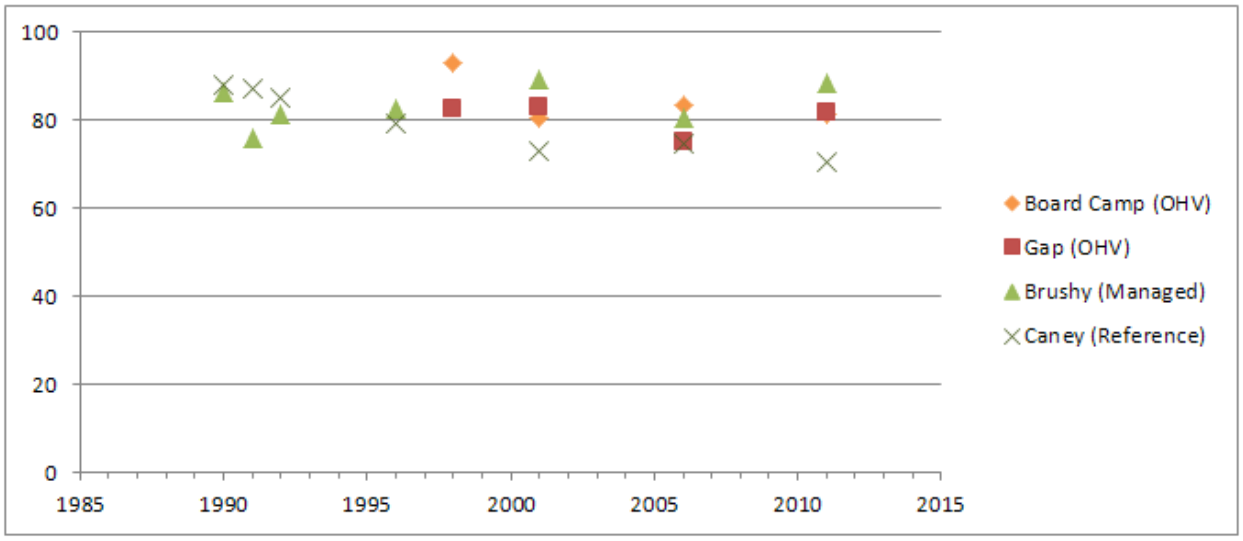

Figure 9. IBI scores for Ouachita National Forest streams sampled with the BASS, 1990 – 2011. Scores between 60 and 79 are considered 'Good' and scores between 80 and 100 are considered 'Reference' (Dauwalter and Jackson, 2004).

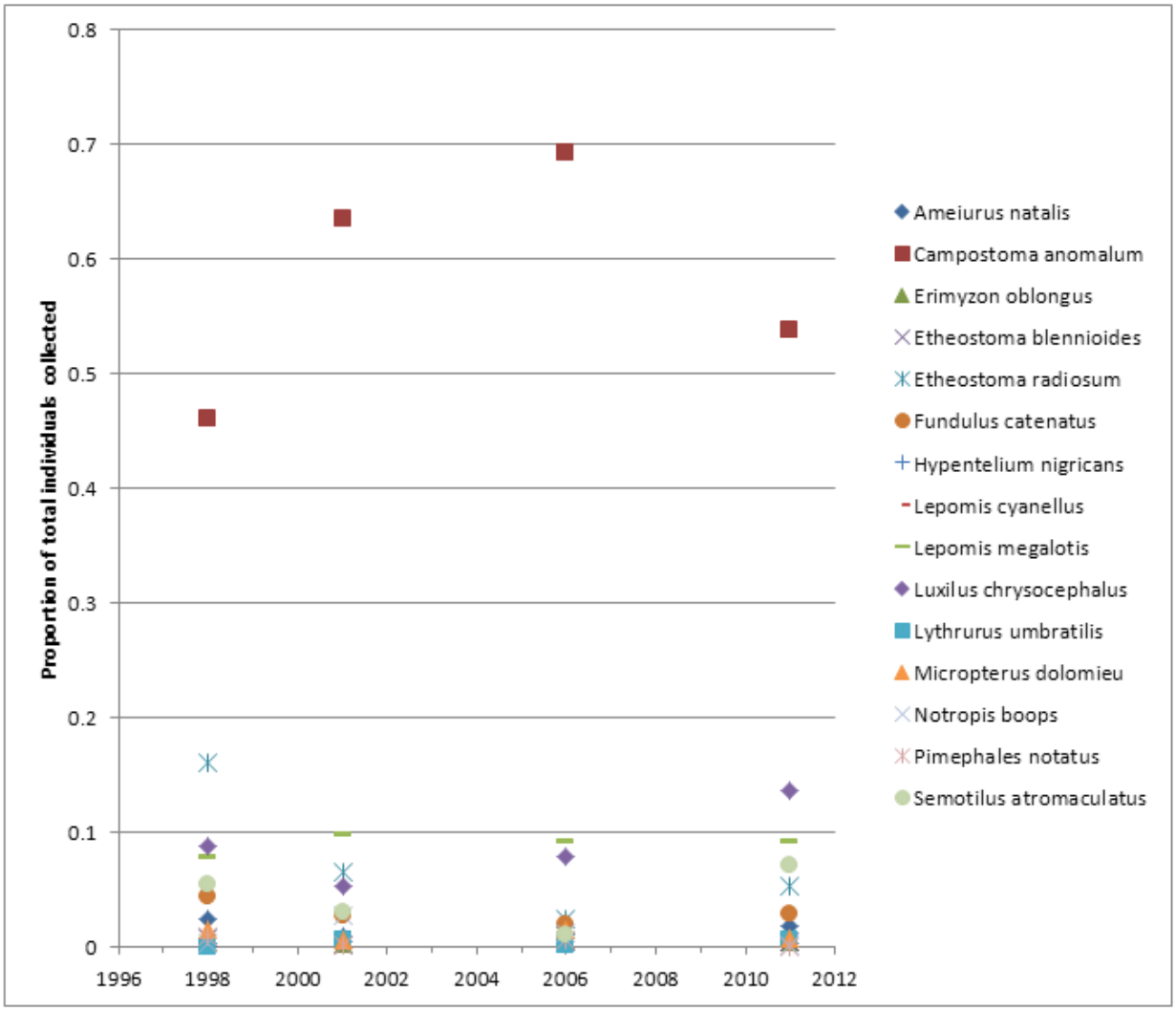

Figure 10. Proportion of total individuals collected during BASS sampling in Board Camp Creek, Ouachita National Forest, 1998 – 2011. Graph includes the 15 species that were present in a minimum of 3 of the 4 sample years.

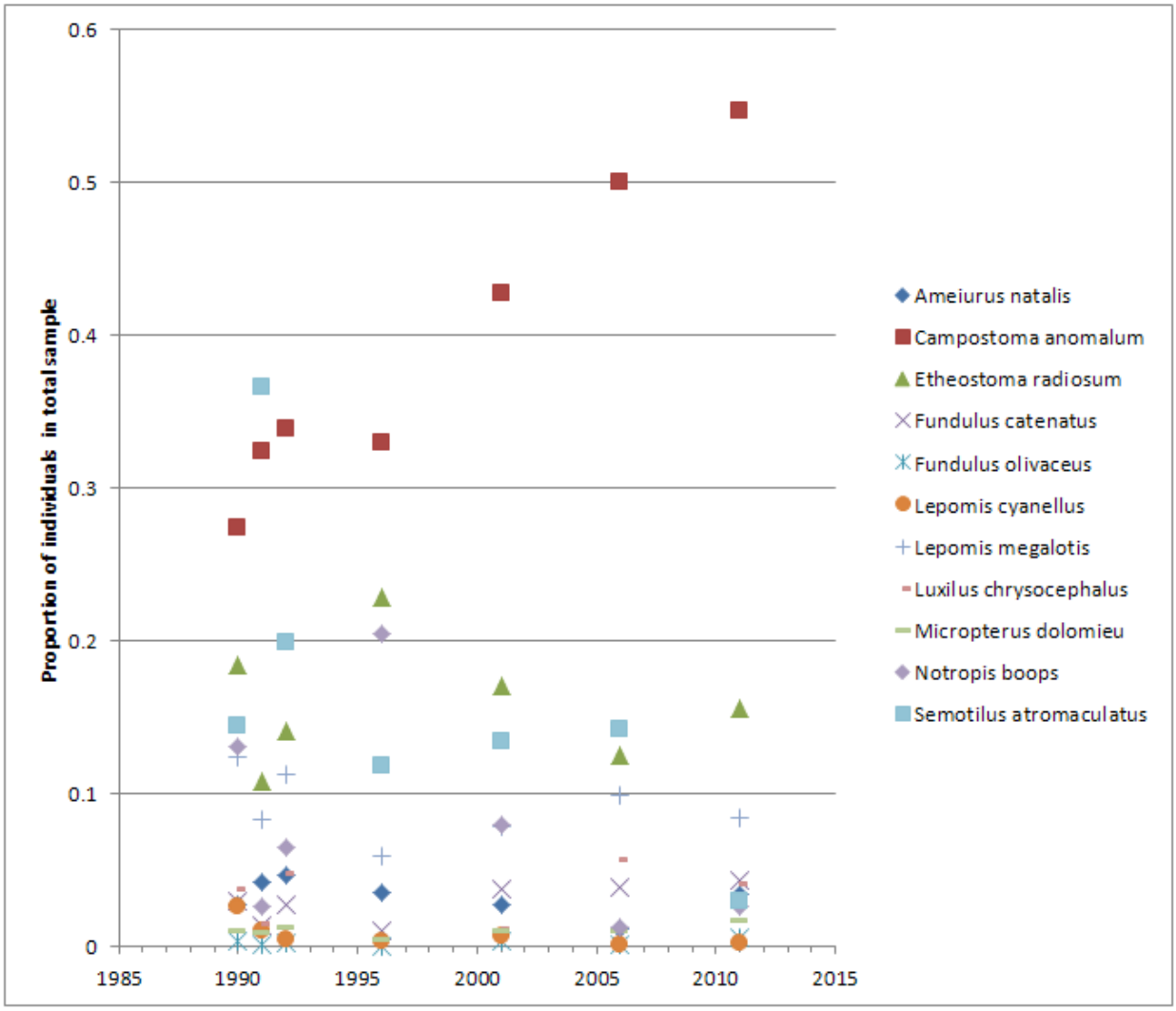

Figure 11. Proportion of total individuals collected during BASS sampling in Brushy Creek, Ouachita National Forest, 1990 – 2011. Graph includes 11 species that were present in a minimum of 6 of the 7 years.

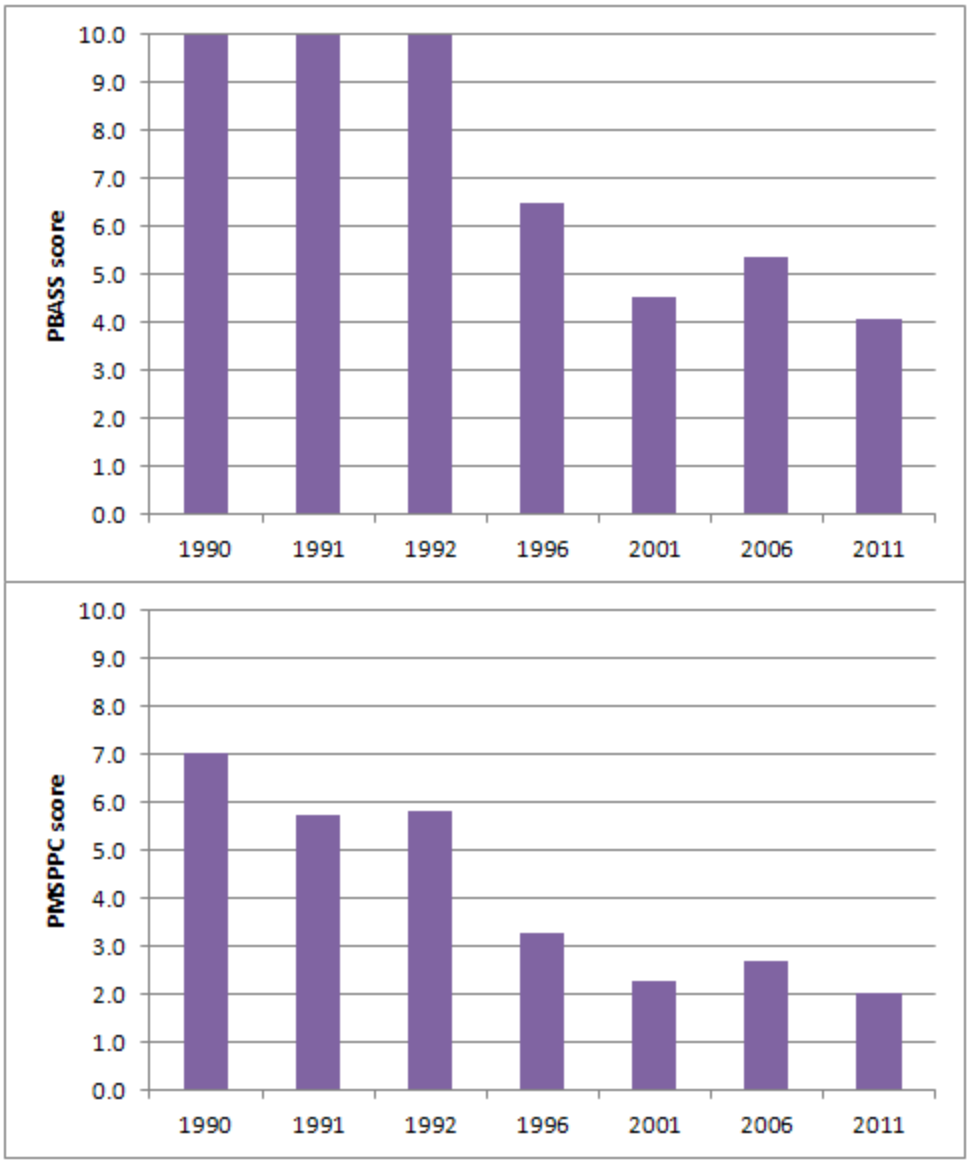

Figure 12. IBI metrics for Caney Creek BASS samples, Ouachita National Forest, 1990 – 2011. PBASS = the percent of individuals as black bass. PMSPPC = the percent of individuals as mineral, site-prep, parental-care spawners. Smallmouth bass was the most significant contributor in Caney Creek to either metric.