RIVER RESEARCH AND APPLICATIONS
River Res. Applic. (2014)

HEADWATER STREAMS OF FLORIDA: TYPES, DISTRIBUTION AND A FRAMEWORK FOR CONSERVATION

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ABSTRACT

Using geographic information system and topographic maps, 5829 headwater streams in Florida were surveyed for several parameters including elevation, stream length, flow regime and surrounding geology, and vegetation. Each was assigned to one of four headwater types: wetland, seep, lake, and spring. Wetland headwaters were the most common and widespread followed by seeps, many displaying temporary flow, while springs were perennial and least numerous. Four groups of Florida rivers were identified through cluster analysis of drainage densities (number headwaters/km of river length). Group 1 consisted of six rivers with lowest drainage densities (0.30–1.39 streams/km main channel). All were coastal rivers of peninsular Florida and, with one exception, drain to the Gulf of Mexico. Seven of eight rivers (group 2) with intermediate drainage densities (1.77–3.04 streams/km main channel) were located in peninsular Florida. Only three of 12 rivers comprising the two groups (groups 3 and 4) with greatest drainage densities (5.16–9.37 and 15.49–16.96 streams/km main channel) were not located in the Florida panhandle. Stream conservation efforts should focus on both highly complex dendritic river networks of the panhandle and on the 7000 km^2 area in central Florida mostly lacking headwaters that may become a significant dispersal bottleneck for aquatic biota seeking refugia farther north from projected climate change. Copyright © 2014 John Wiley & Sons, Ltd.

KEY WORDS: headwater streams; Florida; temporary; perennial; stream conservation and management

Received 22 August 2014; Accepted 9 September 2014

INTRODUCTION

Headwater streams arise from a variety of sources including lakes, wetlands (marshes and swamps), seeps and springs. Historically, headwaters have been examined primarily as hydrologic sources of streams with emphasis on perennial versus intermittent flow (Allan, 1995). Streams originating from headwaters are designated first-order streams using the Strahler stream order method (Strahler, 1957). The importance of first order, headwater streams cannot be overlooked. They are the most numerous in total number and contribute the most to total stream length in riverine networks (Horton, 1945; Leopold *et al*., 1964). Headwater streams comprise 53% (2 900 000 km) of total stream length in the contiguous USA, excluding Alaska (Nadeau and Rains, 2007). Intermittent and ephemeral flow regimes account for approximately 50% (1 460 000 km) of total headwater stream length (Nadeau and Rains, 2007). When second-order streams are included, headwater streams account for approximately 66% of the total length of an average drainage network (Table I).

Headwater streams are hydrologically connected to downstream habitats, exporting sediment, organic matter and biota, thus linking upland and riparian ecosystems with those downstream (Gomi *et al*., 2002; Moore and Richardson, 2003; Pringle, 2003; Freeman *et al*., 2007; Wipfi *et al*., 2007). Meyer *et al*. (2007) described headwater streams as refugia from physical and biological factors, sites for fish spawning and rearing, sources of food (detritus, organic matter, bacteria and invertebrates) and corridors through which migration can occur. Recently, there has been increased attention paid to the roles that headwater streams and their watersheds play in river ecosystem function (Fisher *et al*., 1998; Lowe and Likens, 2005; Lowe *et al*., 2006).

H.B.N. Hynes (Hynes, 1975) was one of the first to suggest that a stream is integrated with its watershed, especially regarding hydrology, chemistry, sediment type, and organic matter content. Riparian zones are ecotones between upland and riverine systems associated with flooding on a sporadic or recurring basis that act as sources or sinks for physical, chemical and biological factors to affect stream structure and function (Hynes, 1975; Vannote *et al*., 1980; Odum, 1981).

Florida is a rapidly growing state striding the transition between warm temperate and tropical climates. Most growth has occurred during the past century, with population

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Table I. Number of headwaters/km main channel for major rivers of Florida

River	No. of headwaters	River length (km) in study area	Total no. of headwaters per river length (km) in study area
Withlacoochee South	24	79.76	0.30
Nassau	25	40.85	0.61
Myakka	19	30.14	0.63
Econfina-Fenholloway-Steinhatchee	73	72.16	1.01
Manatee	67	56.06	1.20
Little Manatee	97	69.59	1.39
St. Marys	136	76.89	1.77
Ocklawaha	184	102.33	1.80
Aucilla	93	47.71	1.95
Alafia	115	50.90	2.26
Suwannee	414	182.81	2.26
Santa Fe	283	121.30	2.33
Kissimmee	162	59.97	2.70
Waccasassa	51	16.77	3.04
Hillsborough	65	12.59	5.16
St. Johns	886	167.47	5.29
Peace	202	33.33	6.06
St. Marks	139	20.82	6.68
Escambia	256	37.92	6.75
Withlacoochee North	408	58.56	6.97
Blackwater	425	54.57	7.79
Perdido	382	46.43	8.23
Ochlockonee	851	91.64	9.29
Chipola	327	34.90	9.37
Yellow	878	56.70	15.49
Choctawhatchee	2409	142.08	16.96

Headwater counts and river length measurements were extended outside Florida to include whole watersheds. Note that values are for alternate rows of quadrangles across Florida.

increasing from approximately 500 000 in 1900 to almost 16 million by 2000 (Smith, 2005). Projections suggest that Florida's growth will increase by approximately 30% every 20 years, more than doubling the population from 2005 (17 872 295) to 2060 (35 814 574) (Zwick and Carr, 2006). Development is moving progressively from densely populated coasts to interior regions, likely affecting headwaters profoundly. Therefore, it is critical that Florida develops a conservation/management plan for headwaters susceptible to urban expansion. Few, if any, studies have examined both headwater types and their distribution within Florida. This study provides a baseline for the geographic distribution of headwater types and associated first-order streams in Florida relative to elevation, flow regime, geology, and vegetation.

METHODS

US Geological Survey (USGS) 1:24 000 topographic quadrangle maps dating from the 1970s until present were used to locate individual headwaters and associated first-order streams throughout Florida. East–west transects were established using the upper 10 km of each quadrangle map. Starting with the northernmost row of maps located entirely within Florida or extending into Alabama/Georgia for transboundary watersheds, only headwaters with a clear origin and elevation greater than 1.5 m (5 ft) mean sea level in coastal regions (to account for tidal influence) were recorded. Thereafter, the top 10 km of every other east–west rows of quadrangle maps were analyzed, terminating at 27.41 N latitude in southern Florida. The southern extent of the survey reflected where extensive development of canals, and nearly total channelization of natural streams began and extended farther south. Headwater streams that were channelized, dammed (except for seeps with clear origin, mostly located in the panhandle) or otherwise altered were not included in this study.

Characteristics recorded for each headwater stream included coordinates, headwater type (lake, wetland, seep, spring), elevation, first-order channel length, drainage network (watershed) and flow regime. Geographic coordinates of headwaters were located from the websites Terra-Server USA and Google Earth. Aerial photography and satellite imagery were used to determine headwater type and the presence of channelization or impoundments. Elevation,

DOI: 10.1002/rra

stream network, channel length and flow regime were determined from quadrangle maps. Elevation was determined from contours (usually 5 ft). Stream lengths were measured using a flexible tape measure and compared with the map scale (intervals of 125 m). Only streams with clear origins in the top 10 km of the USGS topographical maps were considered. Stream length was defined as the distance from the point of origin of the full or dashed blue line on the quadrangle map downstream to intersection with another first-order stream. Flow regime (perennial vs temporary) was defined by the flow regime at origin given as solid or dashed line.

A base geographic information system (GIS) layer was constructed to determine the spatial distribution of headwaters based on geographic coordinates obtained from Terraserver-usa.com or Google Earth. Data generated were then used to create interpolated maps detailing distribution and density of headwaters through kriging. To accomplish this, a grid with a 12 × 12 km grid cell size was created to capture headwaters within the quadrangle maps surveyed. Grid cells in rows of quadrangle maps that were not surveyed were deleted. The grid layer was then overlaid by the headwater point layer. A count of the number of headwaters per grid cell was calculated and centred as a point within each cell. The data were then interpolated based on the number of headwaters per grid cell, using ordinary kriging. The number of classes (ranges of number headwaters in each cell) was set at the default level then reduced to five (springs only had three) using the Jenks method included in the ArcGIS software. Following reduction of classes, headwater density was determined by dividing the number of headwaters per grid cell by144 km^2.

GIS layers (with headwater geographic locations) were also joined with other layers (vegetation type) to assess relationships among parameters. Vegetation data were obtained from the Florida Geographic Data Library. Vegetation type was based on Florida Vegetative Communities of Davis (1967) in the general map of natural vegetation of Florida. From these GIS layers and data collected from the surveys of the USGS topographic quadrangle maps, general regressions were performed among parameters. Tukey's honestly significant difference (HSD) post hoc tests were used to assess within group differences. Finally, the number of headwater streams per km of main stream channel was calculated for all basins. For this analysis, headwater counts and river length measurements were extended beyond Florida to include whole watersheds of transboundary waters. Headwaters and river lengths were counted and measured according to the alternating transect methodology established earlier, including areas outside of the state. River groups were then delineated via cluster analysis applied to the ratio of number of headwaters/km of river length.

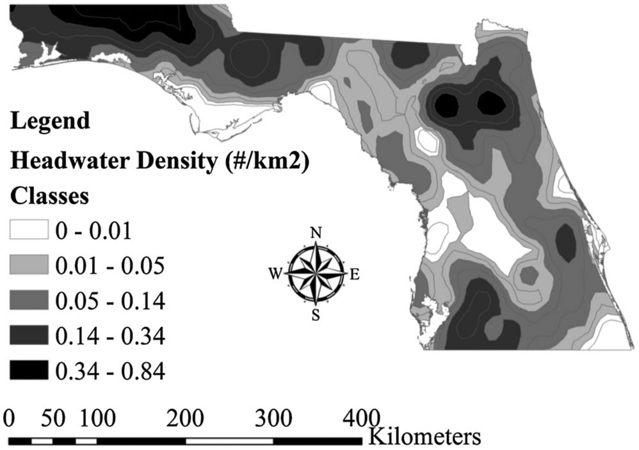

Figure 1. Interpolated distribution and density (#/km) of headwaters in Florida

RESULTS AND DISCUSSION

Distribution of headwaters in Florida

A total of 5829 headwaters were documented in this survey, with greatest densities occurring northwest in the Florida panhandle, northeast in the vicinity of Jacksonville (Baker, Bradford, Clay, Duval, Putnam, Union counties) and central Florida both east of Tampa (Hillsborough, Polk, Manatee, Hardee counties) and the Orlando area (Osceola, Orange, Seminole counties) (Figure 1). There was a large area in interior central Florida (approximately 7000 km^2) essentially lacking headwater streams that extended from 29.22 N to 28.42 N latitude in Levy, Marion, Sumter, Lake, Hernando, Pasco and Orange counties. The majority of this area is associated with the Lake and Sumter Uplands, but a smaller stream impoverished area associated with the Brooksville Ridge is to the west. These uplands were exposed during the Pleistocene and are composed of a limestone core overlain by clayey sediments and undifferentiated sands (Campbell, 1988; Scott, 1997). Ocala Limestone and Cypresshead formations are the major geologic units of the area. The former is at or near the surface towards the northern portion of the range and is extremely permeable, allowing for direct recharge of the Floridan aquifer in some areas (Miller, 1997; Scott, 2001). The latter is characterized by permeable sands that form part of the surficial aquifer and is at or near the surface (Scott, 2001). Because of lack of confinement and undifferentiated sands within the overlying surficial aquifer system, precipitation can rapidly recharge the Upper Floridan aquifer (McBride *et al.*, 2011). Dominant upland vegetation includes forests of longleaf pine and xerophytic oaks and hardwood hammocks (Davis, 1967).

Average Florida headwater stream length in this study was 977 m. The longest was Rocky Creek (10 km) in the

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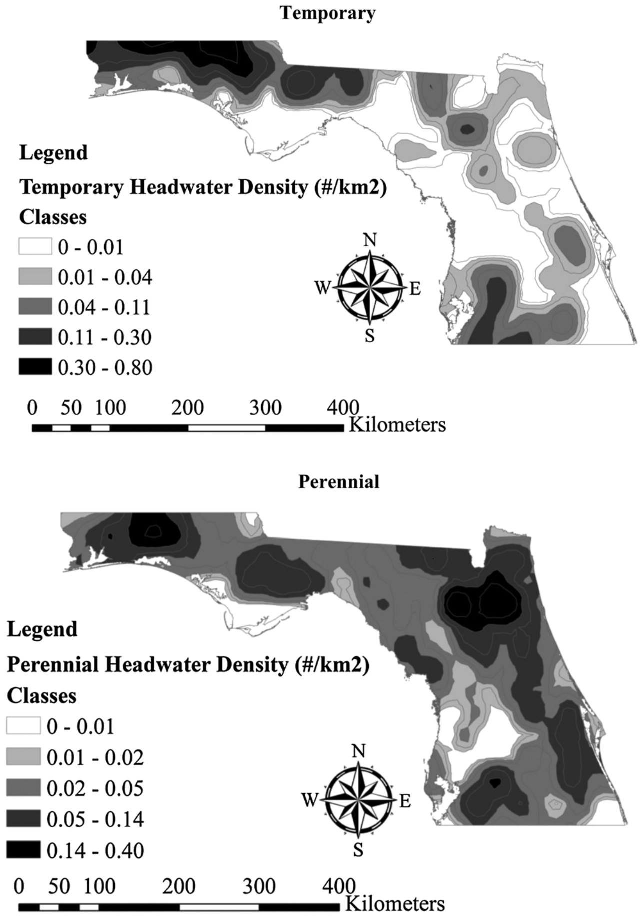

Figure 2. Distribution and density (#/km^2) of headwaters that give rise to temporary and perennial streams in Florida

Econfina-Fenholloway watershed of the Big Bend region (specifically in Dixie and Taylor counties), and the shortest (125 m—lowest resolution when measuring directly from quadrangle maps) characterized several streams throughout the state. Headwater streams originating within the northern and panhandle portions of the state (Tifton Uplands/Tallahassee Hills and Gulf Coast Flatwoods) were significantly longer (Tukey's post hoc HSD test, $p < 0.0001$) than those in eastern and peninsular Florida except for Southern Pine Plains and Hills (Bay, Calhoun, and Liberty counties). Variance in average stream lengths is attributed to the relatively high relief of the panhandle and/or a confining layer (clay in many cases) close to the surface reducing infiltration (Nordlie, 1990).

Perennial and temporary first-order stream lengths were similar (1016 vs 943 m). Perennial streams were distributed throughout the state except for the previously mentioned area within Marion, Citrus, Sumter, Lake, Hernando, and Pasco counties where they were essentially absent. The greatest densities of temporary headwater streams were in the panhandle and west-central Florida (Hillsborough, Polk, Manatee, Hardee counties) (Figure 2). Temporary streams constituted approximately 46% of the total number and 52% of total length of headwater streams of Florida, while in the continental USA, they account for 50% of stream lengths (Nadeau and Rains, 2007). These estimates are in general agreement, even though the current study used USGS Quadrangle 1:24 000 maps, while Nadeau and Rains (2007) used data with a larger scale of 1:100 000. Both methods have intrinsic faults when accurately characterizing lotic features, as demonstrated for the Chattooga River watershed in North Carolina, where only 20% of the streams present were identified from topographic 1:24 000 maps (Hansen, 2001). At a scale of 1:100 000, the actual number and length of ephemeral and intermittent headwater streams are misrepresented because of dependence on precipitation and groundwater data in calculating the presence of temporary streams (Nadeau and Rains, 2007).

Headwater types

Wetlands were both the most common headwater source in Florida (2924) and had the widest geographic coverage, followed by seeps (2305), lakes (265) and springs (50), with the source of 285 headwaters unclassified because of unclear headwater origin (Figure 3—interpolated from these totals). Seeps were found at the highest average elevation (45 m), followed by lakes (31 m), wetlands (27 m) and springs (12 m) (Figure 4). Latitude, longitude and elevation were statistically significant predictors of locations for specific headwater types ($p < 0.0001$) (Figure 5). The greatest contributors to total headwater stream length were wetland headwaters (2762 km), followed by seeps (2389 km), lakes (251 km), and springs (28 km). Spring-fed headwater streams were statistically shorter ($p < 0.0001$) on average (557 m) than first-order streams originating from other headwater types, which ranged in average length from 929 (unclassified) to 1036 m (seep). Lake and seep headwaters produced nearly equal average stream lengths based on flow regime, while streams of spring and wetland origin were dominantly perennial.

Wetlands. Wetland headwaters were found in high densities throughout the state, except for the approximately 7000 km^2 area of central Florida lacking headwater streams (portions of Marion, Citrus, Sumter, Lake, Hernando, and Pasco counties) (Figure 3). Wetland headwaters had both the broadest distribution of any headwater type (31.00 N to 27.41 N latitude, 80.64 W to 87.57 W longitude) (Figure 4) and the widest elevational distribution (0–91 m, $\mu = 27$ m) (Figure 5). Streams originating from wetland headwaters were more often perennial than temporary (1625 vs 1299) with average first-order stream lengths of 1022 m (perennial) and 847 m (temporary) (Figure 6).

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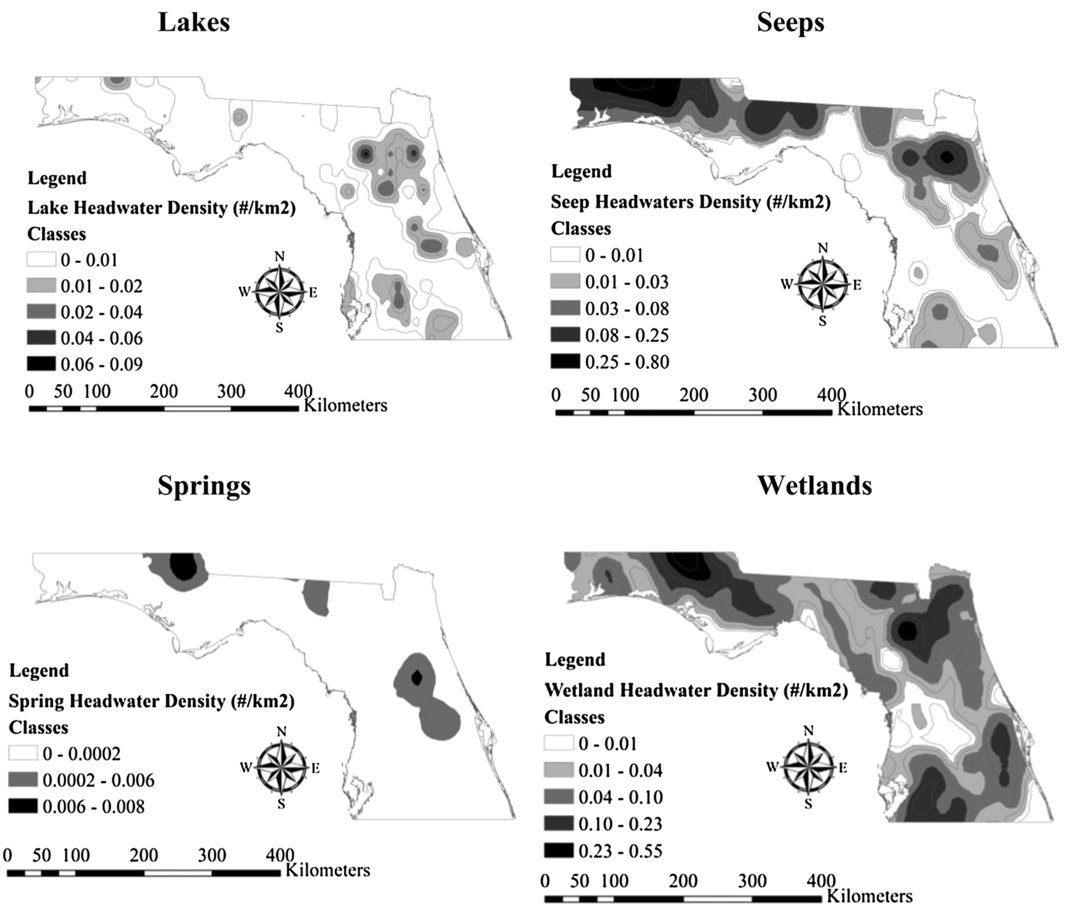

Figure 3. Distribution and density (#/km^2) of headwater types in Florida

Seeps. Seeps were most numerous in the panhandle, north-east/north-central (Alachua, Bradford, Clay, Duval, Marion, Putnam and Union counties), and west-central (Hillsborough, Polk, Manatee and Hardee counties) regions of the state (Figure 3). Their distribution ranged from 31.00 N to 27.42 N and 80.56 W to 87.60 W longitude (Figure 4) at elevations of 0–94 m ($\mu = 45$ m) (Figure 5). As mentioned earlier, seeps were found at the highest average elevation of any headwater type, and their outlet streams were characterized as temporary more often than perennial (1575 and 730) with average lengths of 1028 m (temporary) and 1054 m (perennial) (Figure 6).

Lakes. Lake headwaters occurred in greater densities in the north-east and north-central (Alachua, Bradford, Clay, Duval, Marion, Putnam and Union counties), east-central (Seminole and Lake counties) and west-central (Hillsborough, Polk and Highlands counties) portions of the Florida peninsula (Figure 3). They were found from 30.99 N to 27.42 N latitude and 80.53 W to 87.58 W longitude (Figure 4) at elevations from sea level to 85 m ($\mu = 27$ m) (Figure 5). More first-order streams emerging from lakes were classified as perennial than temporary (183 to 82) with average lengths of 989 m (perennial) and 857 m (temporary) (Figure 6).

Springs. Springs displayed the lowest abundance and density of any headwater type (Figure 3). They were located from 30.95 N to 27.93 N latitude and 81.24 W to 86.18 W (Figure 4) and had the lowest elevational distribution of all headwater types surveyed, from sea level −37 m ($\mu = 2$ m) (Figure 5). Springs were mostly located within regions of low elevation and karst topography as a result of their connection with surficial or the Floridan aquifers (Schmidt, 1997). Spring headwater streams were overwhelmingly perennial (48 and 2), with average lengths of 570 m (Figure 6). The two temporary spring-fed streams recorded were 250 m in length and probably highly dependent on surficial aquifer and rainfall contributions.

Unclassified headwater type. Unclassified headwaters were found from 30.99 N to 27.42 N latitude and 80.53 W to 87.51 W longitude at elevations from 2 to 85 m ($\mu = 31$ m). Most were located at low to mid elevation making it difficult to define headwater type if not clearly designated. Unclassified headwaters gave rise to more temporary (170) than perennial streams (115), with average stream lengths of 932 m (temporary) and 925 m (perennial).

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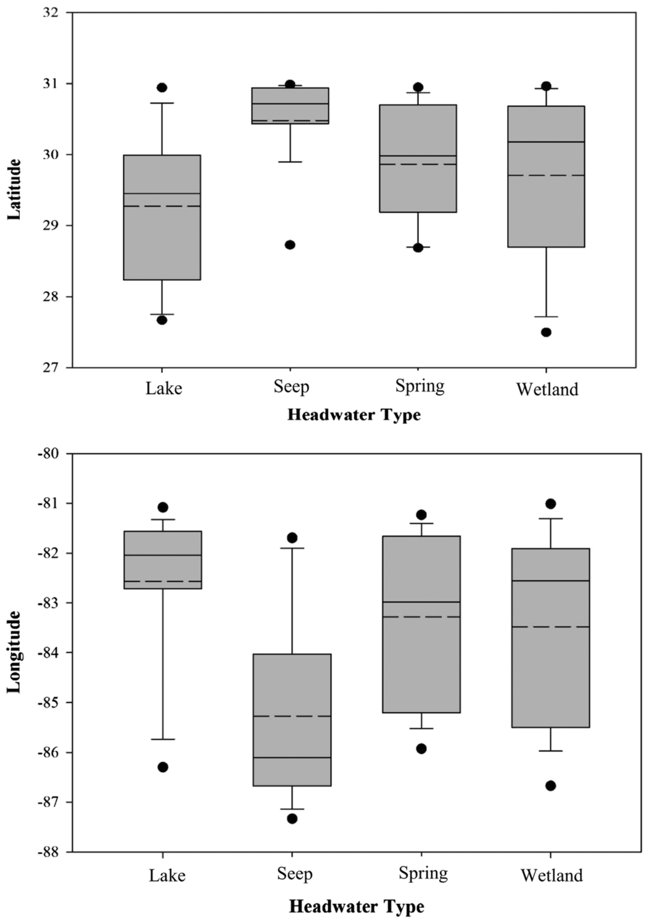

Figure 4. Distribution of headwater types in Florida by latitude and longitude. The solid bar is the median value, dashed line is the mean, box represents the 25th–75th percentile, whiskers are the 10th and 90th percentiles and dots indicate outliers at the 5th and 95th percentiles

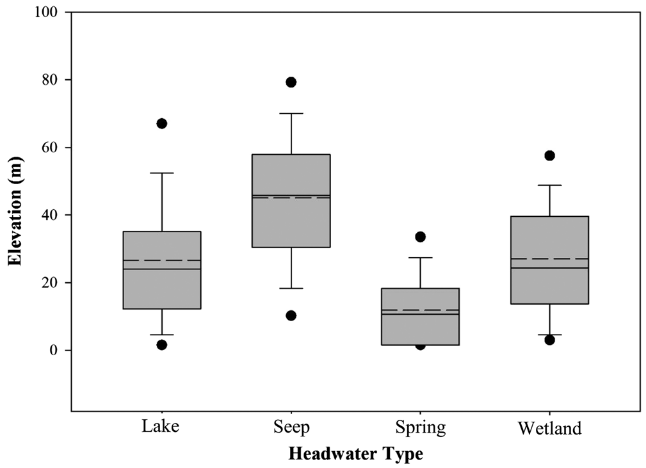

Figure 5. Distribution of headwater types in Florida by elevation (m) above MSL. The bar is the median value, dashed line is the mean, box represents the 25th–75th percentile, whiskers are the 10th and 90th percentiles and dots indicate outliers at the 5th and 95th percentiles

Upland vegetation surrounding headwaters

Wetlands were the dominant stream headwaters in grassland/prairie (89), hardwood forests (136), and pine flatwoods (1301) (Figure 7). Seeps were dominant in forests of longleaf pine and xerophytic oaks (989) and those of mixed hardwood and pines (855), which are characteristic vegetation of both the panhandle along the western highlands and the Tallahassee Hills, and the central region of the peninsula. Finally, lake headwaters were found mostly in forests with longleaf pine and xerophytic oaks (86) and pine flatwoods (80), and spring headwaters (47) were not associated with any particular vegetation unit (Figure 7).

Stream conservation and management

The number of headwater streams joining per length of river channel (drainage density) is expected to parallel increasing complexity of stream networks within their watershed landscapes (Benda *et al*., 2004). Four groups of Florida rivers were identified through cluster analysis of drainage densities (Figures 8 and 9). Group 1 consisted of six rivers with the lowest drainage densities (0.30–1.39 streams/km main channel), all were coastal rivers of peninsular Florida and, with one exception, draining to the Gulf of Mexico. Seven of the eight rivers (group 2) with intermediate drainage densities (1.77–3.04 streams/km main channel) were located in peninsular Florida. Only three of the 12 rivers comprising the two groups (groups 3 and 4) with the greatest drainage densities (5.16–9.37 and 15.49–16.96 streams/km main channel, respectively) were not located in the Florida panhandle.

Because headwater systems have a close terrestrial–aquatic relationships, low thresholds of impacts exist to disturbances of surrounding lands (Gomi *et al*., 2002; Saunders *et al*., 2002; Fisher *et al*., 2004; Lowe and Likens, 2005; Meyer *et al*., 2007). The first grouping (0.30–1.39), with low headwaters/river length ratios, is sensitive to conservation needs, as proportionally few places exist for breeding and refugia. If affected, the number of these areas would drastically decrease, altering the biotic integrity of the system. The second grouping is somewhat transitional in nature, bridging the gap between the rivers with low ratios to those with higher ratios (1.77–3.04). These rivers will need a broad-based conservation approach to ensure that headwaters and their associated watersheds are protected. The third (5.16–9.37) and especially the fourth (15.49–16.96) groupings, including rivers with the highest headwater/stream length ratios, are sensitive to changes in watershed land use and nutrient release. With high densities of headwaters in these watersheds, land use changes will affect a larger

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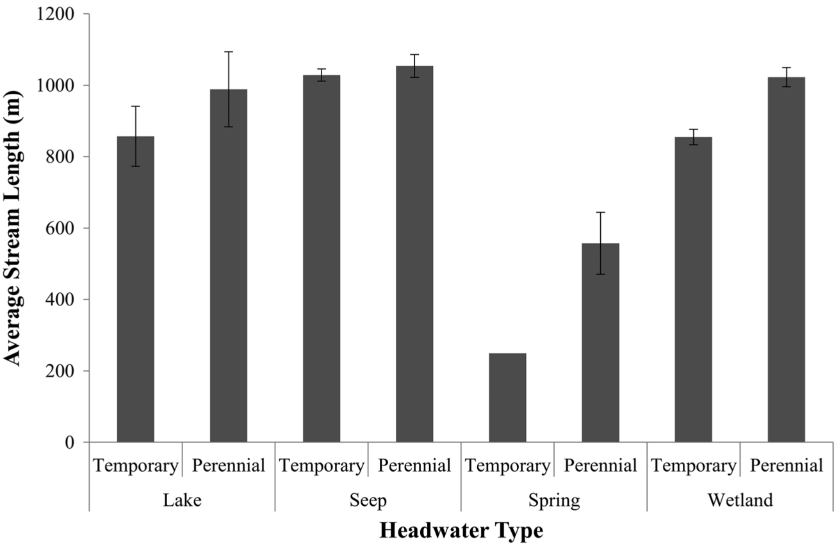

Figure 6. Flow regime and average stream length (m) by headwater type with standard error. Bars represent standard error

proportion of headwaters that can contribute to both point source and non-point source pollution (Bedient *et al.*, 1978), as well as impact possible areas of high biodiversity.

Over the past decade, conservation science has begun to shift emphasis from individual species and species guilds to a more holistic approach to understanding the context of species within the broader landscape and changing environment (Poiani *et al.*, 2000). Lowe and Likens (2005) likened stream network structure to that of a human lung, with the finest branches, the alveoli of lungs or the headwaters of streams, being of utmost importance to the functioning of the whole network. Haggett and Chorley (1969) characterized stream networks as a series of linear segments joining at nodes and ultimately leading to a single outlet for the network. The shortest distance along a stream channel between nodes is termed the network distance (Ganio *et al.*, 2005).

Recognizing the importance of network structure, Benda *et al.* (2004) proposed the network dynamics hypothesis to relate spatial arrangement of tributaries in a lotic network to stochastic watershed processes and associated spatiotemporal patterns of stream habitat heterogeneity. Critical to fauna metapopulations is to identify 'key hot spots', such as headwaters and network nodes, where localized impacts

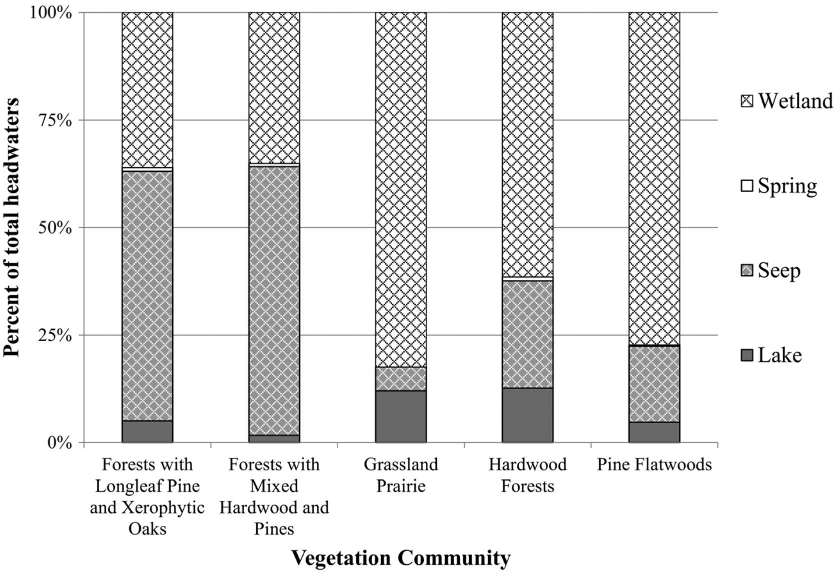

Figure 7. Relationship of vegetation community type with percentage of total number of headwaters

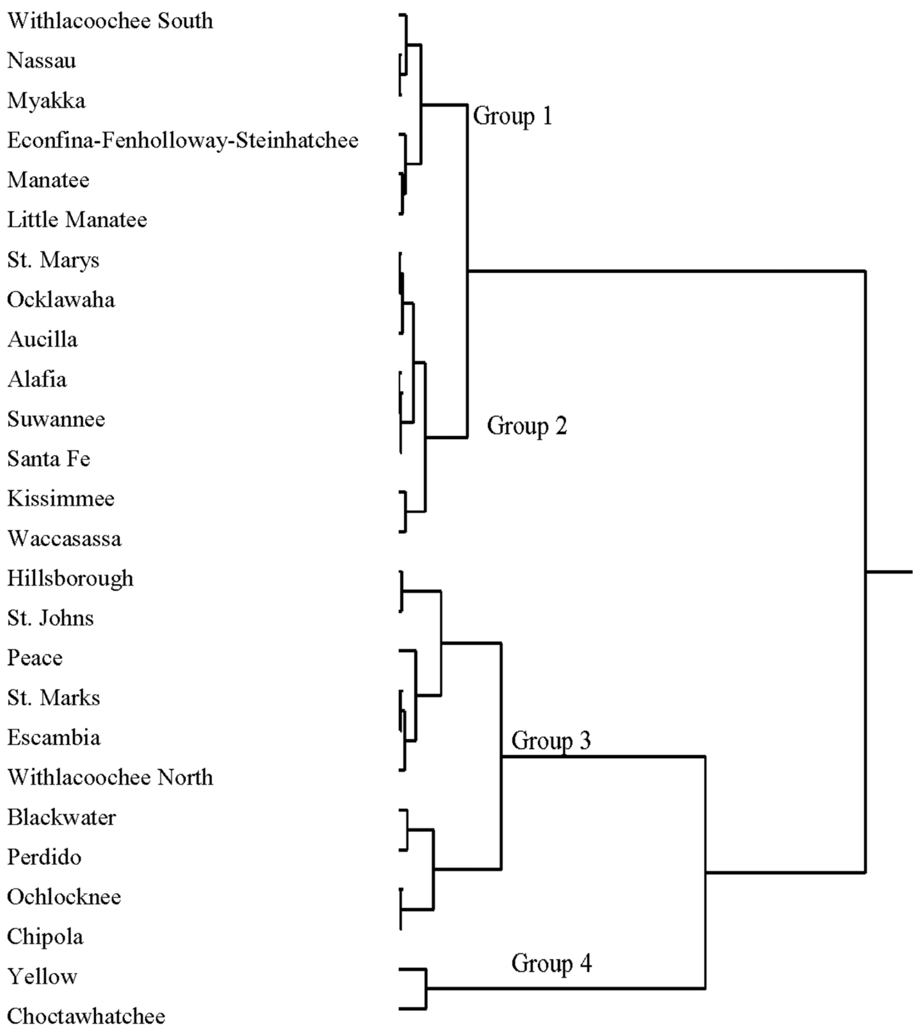

Figure 8. Cluster analysis of the number of headwaters/km main channel of the major rivers of Florida. Headwater count and river length measurement extended beyond Florida to include whole watersheds

will have serious consequences for both upstream and downstream connectivity and potential for species' extirpation or extinction of endemics (Fagan, 2002; Lowe *et al.*, 2006). Even though the overland distance between adjacent headwaters can be minimal in highly dendritic stream networks, metapopulations can be very isolated, which is associated with long intermodal stream channel lengths.

The Florida panhandle is one of five richest biodiversity hot spots in North America, with more frogs and snakes of any comparably sized area on the continent (Blaustein, 2008). It is also third globally for the number of turtle species. Reflecting endemism and limited species distributions, conservation of mussels and fish in pandhandle streams is of special concern (Hoehn, 1998; Blaustein, 2008; Rowell and Mackenzie, 2012; Gruver and Murphy, 2013). Of the 259 river sub-basins in Florida surveyed for the distribution of 31 species of rare, threatened and endangered fish, a vast majority of the basins of concern were in the panhandle (Hoehn, 1998). The importance of the panhandle for conservation of aquatic and semi-aquatic biota has been attributed to elevation refugia from sea level rise in the Pleistocene (Blaustein, 2008) and the greatest complexity of Florida river networks. Highly complex dendritic river networks, as found in the panhandle, not only provide abundant species refugia at headwaters, but close terrestrial proximity of headwaters increases their susceptibility to all scales of local and regional urban development agriculture. While headwaters and stream nodes have adjusted to episodic natural disturbances, including the high frequency of direct hurricane landfalls in the area, altered hydrology and associated sediment and nutrient to headwater streams can potentially alter habitat at stream nodes, effectively blocking up and downstream biotic

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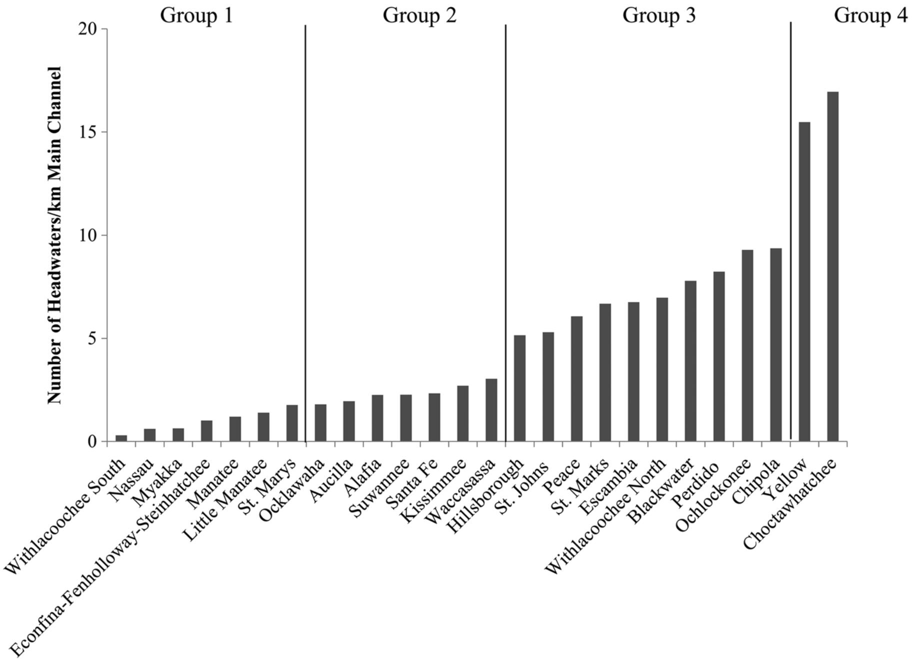

Figure 9. The ratio of the number of the headwaters/km main channel for the major rivers of Florida. Headwater count and river length measurement extended beyond Florida to include whole watersheds of transboundary waters

connectivity, thus imperiling critical habitat for threatened and endangered species of fish and mussels.

At the other extreme of stream density patterns in Florida, the nearly 7000 km^2 area in central Florida essentially lacking headwaters might become a dispersal bottleneck for aquatic biota seeking climate change refugia farther north. Coenen and Crisman (2014) documented an approximate 40 km northward shift in the southern limit of the warm temperate zone between 1970 and 2010, from its former position along the I-4 population corridor. Northward movement by warm temperate and subtropical biota in response to additional climate warming and altered precipitation is threatened by the large portion of north central Florida lacking streams and the closing window of north–south conservation corridors along streams through the rapidly expanding and infilling urban development along I-4.

CONCLUSIONS

Headwaters and their associated streams face an uncertain future within the state of Florida. This study has established a baseline for future conservation/management plans to protect streams of great ecological importance from expanding population growth. Even though headwaters were more concentrated in panhandle, average stream lengths were similar among headwater stream categories and regions of the state. Wetland headwaters were the dominant headwater type and had the widest distribution; springs were very rare; while seep and lakes were abundant but predominantly located in the panhandle and peninsular regions of the state, respectively.

Finally, the drainage densities (number of headwaters per river length (km)) of major rivers in Florida were examined. Cluster analysis defined four main groups of watersheds, ranging from low to high drainage densities. In the two groups with the lowest drainage densities, only 12 of the 14 rivers were located in peninsular Florida, while 9 of the 12 rivers with higher drainage densities in groups 3 and 4 were in the panhandle. Because of high concentrations of headwater streams, high biodiversity and endemism of fauna, and the presence of many rare and endangered species, conservation of the panhandle streams in Florida is greatly needed. Another density pattern determined through this study was the 7000 km^2 area in the central region of the state that is basically void of headwater streams. Because of the 40 km movement north of the northern boundary of the subtropics over the past 40 years (Coenen and Crisman, 2014), this 'void' area could act as a dispersal barrier as aquatic species migrate in response to climate change.

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