Temporal and Spatial Trends in Fish Communities Inhabiting Two Freshwater Tidal Wetlands of the Cooper River, South Carolina

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Abstract: From April 1999 through February 2000, we electrofished fixed transects in two freshwater tidal wetlands of the Cooper River, South Carolina, to examine how spatial and temporal variation in these habitats influenced fish community composition. The Dean Hall site consisted of a collection of tidal creeks with intertidal, emergent vegetation and large fluctuations in submersed habitat due to tide. The Bonneau Ferry site was lacustrine, dominated by submergent vegetation, and fluctuated very little with the tide. We found 34 total species. Most were a species of Centrarchidae (41%) or an estuarine migrant (27%). Abundance and species richness varied among months, with a peak in April and June. Differences in fish community structures were noted between wetlands with Dean Hall generally containing a more specious, but variable, community whereas Bonneau Ferry contained a more stable fish community with slightly fewer species. Moreover, the Dean Hall fish community tended to be predominated more by Centrarchidae species whereas Bonneau Ferry contained more estuarine migratory species. Our results fill a void in the understanding of fish communities in southeastern U.S. wetlands by targeting the large-bodied fishes and add to the understanding of seasonal diversity in these systems. Moreover, our results underscore the need to study a diversity of wetland types to best discover fish community dynamics within a river system.

Key words: abandoned rice fields, species diversity, community stability, electrofishing

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The abandoned rice fields of the Cooper River, South Carolina, are unique habitats of the Southeastern United States (Odum et al. 1984), represent nearly all of the littoral area of the river, and are used by many fish species for residency, spawning, and nursery areas (Williams et al. 1984). The rediversion of approximately 80% of

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the water to the Santee River in 1985 has been implicated in recent habitat changes in these rice fields (Kelley et al. 1990, Kelley and Porcher 1996, South Carolina Department of Health and Environmental Control, 2000) elevating management concerns (Odum et al. 1984, Oswald 1997). Some rice field owners are considering impoundment so that the fields will remain lacustrine (Oswald 1997), which would have the added consequence of closing them to fish migration with the river. Others will likely allow their fields to remain fallow and open to fish migration, but these fields will also likely continue to undergo habitat changes, converting through vegetation succession from relatively deep lacustrine habitats to relatively shallow intertidal ones. For example, from 1973 to 1994, open water habitat in the Cooper River decreased 36% whereas intermediate and late succession stage habitats increased 82% and 31% respectively (J. Morris, University of South Carolina, unpublished data). Regardless of the management strategy (active versus passive), these changes will have implications for the fish community that resides and reproduces in these habitats.

While many studies of fish have been conducted in the Cooper River wetlands in response to the rediversion of 1985 (Williams et al. 1984, Homer and Williams 1985, Thomas et al. 1992, Eversole et al. 1994), information is still lacking regarding how fish communities respond to the environmental variation of these wetlands. Specifically, none of these studies have utilized gear efficient for capturing large-bodied fish species, thus under-representing their contribution to the fish community. Williams et al. (1984) and Homer and Williams (1985) used purse seines to examine fish communities and Thomas et al. (1992) and Eversole et al. (1994) focused their studies on blueback herring *(Alosa aestivalis)* distribution using gill nets and egg traps. A fuller knowledge of under-represented species is essential in order to make credible, scientific-based management decisions regarding these wetlands.

Our objective for this study was to examine temporal trends and relationships between measured environmental variables and the fish community in two abandoned rice fields using a method (i.e., electrofishing) effective at capturing relatively large mobile fishes. We examined monthly trends in abundance, species richness, and species diversity to discover relationships between environmental variables and fish communities in two wetlands with differing habitat.

Study Area

Our two study sites were located approximately 2 km apart at the confluence of the West and the East branch of the Cooper River, South Carolina and differed in their habitat, which is an interaction of vegetation type, succession stage, and resultant morphology of submersed areas. The eastern half of Bonneau Ferry is a predominately lacustrine 72.3-ha wetland with a relatively flat bottom and containing mostly submerged aquatic vegetation (SAV; 59.5%) (J. Kelley, The Citadel, unpublished data). The amount of submersed area fluctuates little with the tidal cycle, typically <5%. Dean Hall is a 28.6-ha wetland containing mostly intertidal emergent vegetation (ITEM; 77.9%) (J. Kelley, The Citadel, unpublished data). It consists of a few deep and narrow channels at all tide stages with tall vegetation surrounding the channels making it a collection of small streams with bi-directional flow depending on tide. Dean Hall can lose >60% of its submersed area during tidal fluctuations. During our study, tidal amplitude was approximately 0.95 m in both wetlands.

Methods

We established fixed 200-m transects in both wetlands, seeking to uniformly cover each wetland from upstream to downstream in relation to the adjacent Cooper River. Four transects were in Dean Hall and eight were in Bonneau Ferry to account for the difference in area between wetlands. Due to its morphology, transects in Dean Hall were constrained to be within narrow tidal creek channels with well-defined, substrate borders (i.e., old dike walls). Because of this constraint, electrofishing efficiency was probably greater in Dean Hall than in Bonneau Ferry, which contained mostly open-water habitats. To minimize this effect, four transects in Bonneau Ferry were located in channels with vegetated borders, to be similar to the Dean Hall transects. The remaining transects in Bonneau Ferry were located over relatively flat bottom, without vegetative borders, typically with a carpet of dense SAV underneath. However, one transect in Bonneau Ferry had a vegetative border, but was not located over a channel. Each transect was boat-electrofished against the incoming tide during the day every other month from April 1999 through February 2000 at varying tide stages. Electrofishing output at 566 pulsed-DC volts ranged from 1.5 to 2 amps. We attempted to pick up all stunned fish, which were identified, measured to the nearest 1 mm, and released. Fish of uncertain identity were taken to the lab for positive identification. After sampling, we measured water depth at the ends of each transect, and at every 50 m in between, to the nearest 0.3 cm. We measured water temperature and conductivity (μS/cm) with a YSI model 30 meter at the end of each transect immediately after sampling. Presence of riverine conditions, substrate and vegetative borders, and SAV carpet were assessed visually at each transect and given the same binomial score regardless of the time of sampling. Time since low tide was calculated for each sample as the difference in hours between the beginning time of the sample and the most recent predicted low tide time listed in the National Oceanographic and Atmospheric Administration's (NOAA) tide predictor website *(http://www.co-ops.nos.noaa.gov/)* for 1999 and 2000. The table that we used in this study may no longer be available via the website as it is periodically updated by removing out-of-date tables.

We used a variety of statistical methods to examine trends in fish community composition and environmental variation. Differences in fish abundance and species richness between transect types (i.e., flat versus channel) in Bonneau Ferry were examined and no further consideration of transect type was made for subsequent analyses when no differences were found. Mean abundance, species richness, and measured environmental variables (i.e., temperature, conductivity, and water depth) was assessed among months and between wetlands with a factorial ANOVA (Proc GLM; SAS 1992) and LSMEANS (SAS 1992) for post-hoc pairwise comparisons. Fish abundance and species richness values were normalized with a $\log_{10}$ (n+1) transformation. The Simpson's diversity index (1-D; Krebs 1989), interpreted as the probability that two individuals chosen at random will be different species, was calculated for each month and wetland and was visually inspected for trends. High values for 1-D demonstrates that abundance is evenly distributed among species, indicating high species evenness. Canonical correspondence analysis (CCA; ter Braak 1986) was used to examine the association between measured environmental variables and fish community composition and was performed with CANOCO software (ter Braak and Smilauer 1998). Canonical correspondence analysis is a direct ordination technique that orders species according to measured environmental variables and has been used to discover how a variety of environmental variables affect fish species distribution and community composition (Gelwick et al. 2001). The measured environmental variables at each transect included water temperature, conductivity, average depth, time since low tide, presence of riverine conditions, presence of channel, presence of substrate border (i.e., dike wall), presence of vegetative border, and presence of dense SAV carpet. Because rare fish can strongly influence the CCA, we only ordinated those species that were represented by $>1\%$ of the total catch. We used CANOCO to perform a Monte Carlo randomization test of the first axis, and all combined axes, to determine the significance of the ordination. All statistical tests were evaluated at $P \leq 0.05$.

Results

We captured 930 individuals representing 34 species (Table 1) but noted temporal and site differences in community structure and environmental variables. We did not detect any differences in abundance (ANOVA, channel type, $F_{1,36} = 1.09$, $P = 0.30$) or species richness (ANOVA, channel type, $F_{1,36} = 1.38$, $P = 0.25$) between transect types in Bonneau Ferry, so no further differentiation of transect types were made. Numerical abundance was greater in Dean Hall than Bonneau Ferry (ANOVA, wetland, $F_{1,60} = 12.95$, $P < 0.01$) and mean species richness was higher in Dean Hall in April, June and December (ANOVA, wetland*month, $F_{5,60} = 2.41$, $P = 0.04$), but similar at other times (Fig. 1). In both wetlands, abundance and species richness peaked in spring/early summer, decreased in late summer, and increased again in fall. Temperature was significantly higher in Bonneau Ferry in February (ANOVA, wetland*month, $F_{5,60} = 3.48$, $P < 0.01$), conductivity was always higher in Dean Hall (ANOVA, wetland, $F_{1,60} = 18.77$, $P < 0.01$), and depth of sampling was greatest in August and October (ANOVA, month, $F_{5,60} = 6.58$, $P < 0.01$) (Table 2; Fig. 2).

There was a tendency for the community structure to fluctuate more in Dean Hall than in Bonneau Ferry. The Dean Hall fish community ranged from 2 total species in February to 20 in June (Table 3) whereas the range in Bonneau Ferry was from 8 in February to 16 in October (Table 4). Additionally, species diversity as measured by Simpson's index fluctuated more in Dean Hall, ranging from 0.49 in February to 0.87 in June and October. In Bonneau Ferry, Simpson's diversity index ranged between 0.79 in December to 0.86 in August.

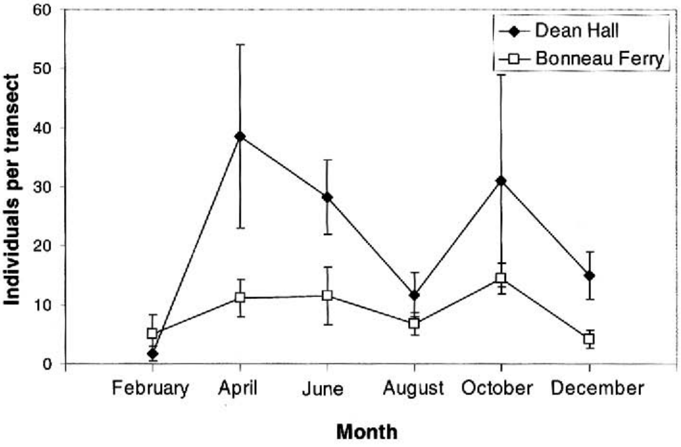
Though species composition varied temporally, differences between wetlands were also noted (Table 3, 4). In both wetlands, centrarchids were the dominant taxa, comprising 52% and 29% of the total catch in Dean Hall and Bonneau Ferry, respec-

Table 1. Scientific and common names of fish species captured by electrofishing in two wetlands of the Cooper River, South Carolina. Names are grouped by family.

Scientific name	Common name
Amiidae	
Amia calva	Bowfin
Anguillidae	
Anguilla rostrata	American eel
Aphredoderidae	
Apredoderus sayanus	Pirate perch
Atherinidae	
Labidesthes sicculus	Brook silverside
Menidia beryllina	Inland silverside
Belonidae	
Strongylura marina	Atlantic needlefish
Bothidae	
Paralichthys lethostigma	Southern flounder
Centrarchidae	
Lepomis punctatus	Spotted sunfish
Lepomis auritus	Redbreast sunfish
Lepomis microlophus	Redear sunfish
Lepomis macrochirus	Bluegill
Enneacanthus gloriosus	Bluespotted sunfish
Micropterus salmoides	Largemouth bass
Clupeidae	
Dorosoma cepedianum	Gizzard shad
Cyprinidae	
Cyprinus carpio	Common carp
Notemigonus crysoleucas	Golden shiner
Eleotridae	
Dormitator maculatus	Fat sleeper
Eleotris pisonis	Spinycheek sleeper
Esocidae	
Esox americanus	Redfin pickerel
Esox niger	Chain pickerel
Fundulidae	
Lucania goodei	Bluefin killifish
Lucania parva	Rainwater killifish
Fundulus chrysotus	Golden topminnow
Gerreidae	
Eucinostomus argenteus	Spotfin mojarra
Gobbiidae	
Gobionellus shufeldti	Freshwater goby
Gobionellus hastatus	Sharptail goby
Ictaluridae	
Ameirus natalis	Yellow bullhead
Ameirus catus	White catfish
Ictalurus furcatus	Blue catfish
Lepisosteidae	
Lepisosteus osseus	Longnose gar
Mugilidae	
Mugil cephalus	Striped mullet
Poeciliidae	
Gambusia holbrooki	Mosquitofish
Heterandria formosa	Least killifish
Poecilia latipinna	Sailfin molly

tively. Within this family, largemouth bass was the most abundant species at both sites. However, the predominance of centrarchids was more prevalent in Dean Hall (with seven species) than in Bonneau Ferry (five species). Moreover, redbreast sunfish, which was the predominant species in Dean Hall in April, was collected only once in Bonneau Ferry. Migratory estuarine species also showed spatial and temporal patterns in abundance. From April through August, migratory estuarine species often were the predominant species, with a similar number in each wetland (eight species), but some were found in only one wetland. For example, Atlantic needlefish was only captured in Dean Hall whereas sharptail goby was only captured in Bonneau Ferry.

Canonical correspondence analysis (CCA) revealed two main trends: variation in species according to habitat type and variation in species according to temperature (Fig. 3). The first two canonical axes of the CCA explained 39.1% and 21.9%, respectively, of the variation in the species-environment relation. The first canonical axis (eigenvalue = 0.32) was related to habitat, with species showing associations with open water (i.e., that with SAV carpet) versus channels (those with riverine con-



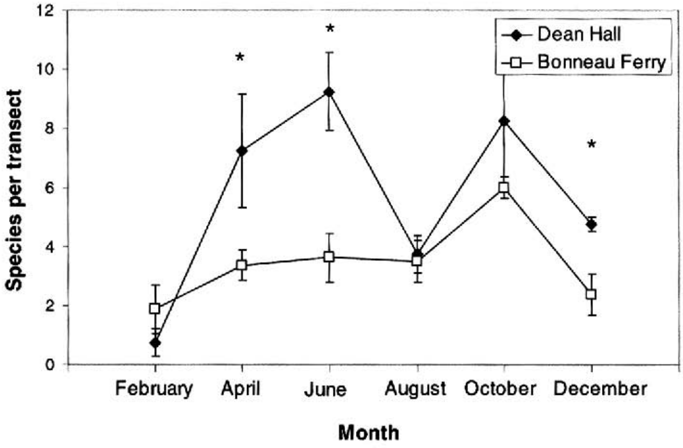


Figure 1. Mean number of individuals (top graph) and species (bottom graph) per transect among months in two wetlands of the Cooper River, South Carolina. Error bars are one standard error about the mean. An asterisk indicates significant differences between wetlands.

ditions, high conductivities, and substrate borders and those with vegetated borders). This axis also relates to differences between wetlands because Dean Hall had substrate border channels and higher conductivities whereas Bonneau Ferry was the only wetland to have SAV carpet. The second canonical axis (eigenvalue = 0.18) was related to seasonal variation, with seasonal migrants occurring mostly during warmer weather and Centrarchidae present during colder weather. The CCA was significant for the first ($P < 0.01$), and all combined ($P < 0.01$), axes.

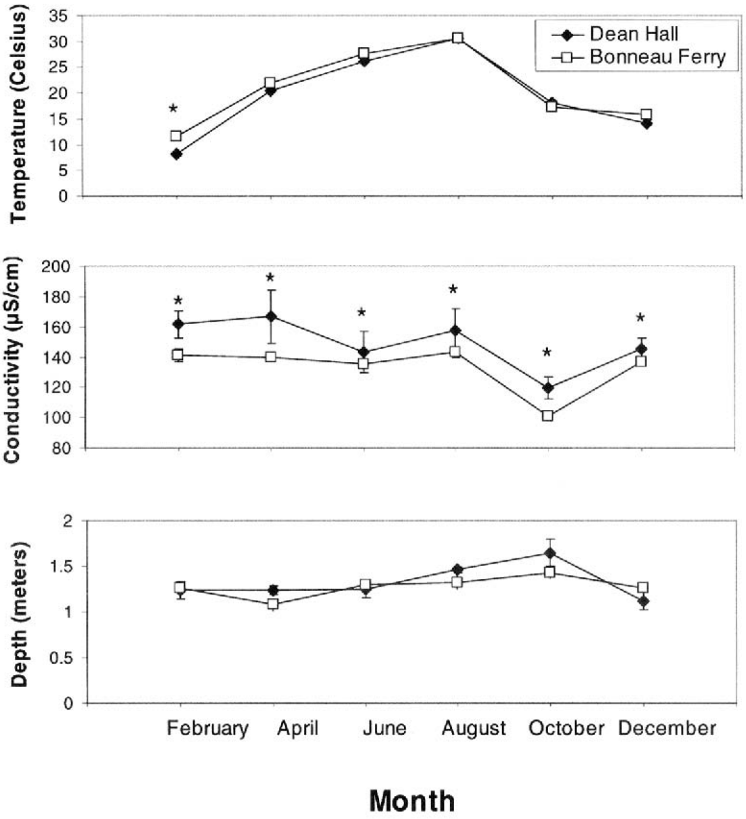


Figure 2. Trends in temperature, depth, and conductivity of electrofishing transects in two wetlands of the Cooper River, South Carolina.

Discussion

Temporal change in the environment was one of the primary factors affecting the fish community composition in these two wetlands. Increased abundances of Centrarchidae and estuarine species contributed the most to seasonal diversity in spring/early summer. Most likely, these changes reflected their spawning activity (Odum et al. 1984, Jenkins and Burkhead 1993) and, thus, increased abundance during this time. In a previous Cooper River sampling effort using purse seines, Williams et al. (1984) reported spring as the season with highest numerical abundance and summer as the season with the greatest number of species whereas Homer and Williams (1985) found the highest abundance and species richness in summer (July and August). Odum et al. (1984) generalized fall or winter as the time of peak seasonal diversity and abundance of fishes in freshwater wetlands of the southeast, but their summary was based on only two studies conducted in Georgia. The more

Table 2. Summary of environmental variables measured at electrofishing transects in two wetlands of the Cooper River, South Carolina from April 1999 through February 2000. Variables with an asterisk were not tested for differences.

	Transect							
	1	2	3	4	5	6	7	8
Variable	Bonneau Ferry							
Mean temperature (°C)	21.02	20.87	20.45	20.95	20.92	20.00	21.68	20.12
Mean conductivity (µS/cm)	133.07	131.28	133.93	136.37	131.28	136.08	133.28	128.33
Mean depth (m)	1.23	1.17	1.43	1.20	1.39	1.28	1.30	1.21
Mean time since low tide (h)*	3.67	4.00	4.00	3.83	4.33	4.17	4.33	3.67
Presence of channel*	1	0	1	1	1	0	0	0
Presence of riverine conditions*	0	0	0	0	0	0	0	0
Presence of vegetated border*	1	1	1	1	1	0	0	0
Presence of substrate border*	0	0	0	0	0	0	0	0
Presence of SAV carpet*	0	0	0	0	0	1	1	1
	Dean Hall							
Mean temperature (°C)	19.12	19.73	19.78	19.77	NA[1]	NA	NA	NA
Mean conductivity (µS/cm)	134.95	145.68	149.17	166.37	NA	NA	NA	NA
Mean depth (m)	1.30	1.29	1.25	1.46	NA	NA	NA	NA
Mean time since low tide (h)*	3.83	3.67	4.50	4.50	NA	NA	NA	NA
Presence of channel*	1	1	1	1	NA	NA	NA	NA
Presence of riverine conditions*	1	1	1	1	NA	NA	NA	NA
Presence of vegetated border*	0	0	0	0	NA	NA	NA	NA
Presence of substrate border*	1	1	1	1	NA	NA	NA	NA
Presence of SAV carpet*	0	0	0	0	NA	NA	NA	NA

1. NA = not applicable.

specific data collected from the Cooper River support spring and summer as the time of greatest seasonal fish diversity in this system.

It was interesting to note differences in community structure and stability between the two wetlands concurrent with differing habitats. Dean Hall, with its collection of small tidal streams and tidally fluctuating habitat, could be described as the wetland with more diverse and more edge habitat, both of which have been shown to increase fish abundance (Rozas and Odum 1987, Gunderson and Loftus 1993, Minello et al. 1994, Peterson and Turner 1994). Moreover, stream-like habitat in tidal wetlands has been shown to positively affect Centrarchidae species (Trebitz and Nibblelink 1996, Gelwick et al. 2001). Specifically, the fact that redbreast sunfish, which is characterized as a stream inhabitant (Aho et al. 1986), was found in Dean Hall in numerous instances but only once in Bonneau Ferry, along with twice as many Centrarchidae species, verifies the influence of tidal streams on this group. In contrast, the habitat in Bonneau Ferry could be described as more stable because it changes less as the water level fluctuates with the tide, which has been shown to influence fish community stability (Weaver et al. 1996). Whether or not open wetlands like Bonneau Ferry generally contain more stable fish communities cannot be answered by our study because we did not replicate our study across many wetland types. Further research is needed to best answer these questions.

Table 3. Number of individuals, number of species, and Simpson's diversity index (1-D), by month, in the Dean Hall wetland of the Cooper River, South Carolina, as determined by electrofishing. Species with an asterisk were considered "estuarine." Species are sorted in descending order of total abundance.

	Month					
Species	February	April	June	August	October	December
Largemouth bass	3	38	15	10	16	32
Spotted sunfish	0	34	4	1	4	14
Redbreast sunfish	0	44	5	0	1	2
American eel*	0	2	31	11	1	3
Mosquitofish	0	0	16	0	25	0
Striped mullet*	0	8	9	21	0	0
Bluefin killifish	0	4	8	0	22	0
Rainwater killifish	0	2	6	0	17	1
Redear sunfish	4	3	5	1	5	5
Inland silverside*	0	1	1	0	16	1
Bowfin	0	6	3	1	0	0
Brook silverside	0	0	2	0	5	0
Bluegill	0	4	1	0	1	0
Golden shiner	0	0	1	0	4	0
Least killifish	0	0	1	0	4	0
Fat sleeper*	0	0	1	0	2	1
Bluespotted sunfish	0	2	1	0	0	0
Freshwater goby	0	3	0	0	0	0
Longnose gar	0	0	1	0	0	1
Redfin pickerel	0	2	0	0	0	0
Atlantic needlefish*	0	0	0	1	0	0
Golden topminnow	0	0	0	0	1	0
Spinycheek sleeper*	0	0	0	1	0	0
Southern flounder*	0	0	1	0	0	0
White catfish	0	0	1	0	0	0
Yellow bullhead	0	1	0	0	0	0
Total abundance	7	154	113	47	124	60
N species	2	15	20	8	15	9
% Centrarchidae	100	81	29	26	26	88
% estuarine	0	9	38	72	15	8
Simpson's Diversity (1-D)	0.49	0.80	0.87	0.70	0.87	0.65

Electrofishing by boat has long been known to be biased toward collecting larger fish (Reynolds 1996). Moreover, Meador and McIntyre (2003) found boat electrofishing to be better at collecting certain families of fish (Catastomidae, Centrarchidae, Cyprinidae, and Ictaluridae) over others. We found evidence of family-level bias in our study because Centrarchidae was a predominant member of the fish fauna when electrofishing was the collection method whereas drop traps resulted in Poeciliidae and Fundulidae to be predominant (Morris et al. 2002). Furthermore, Williams et al. (1984) and Homer and Williams (1985) found species of Moronidae and Fundulidae to be predominant in a nearby wetland when purse seines were the collection method. As a result, our study complements these other studies by targeting those species whose collection was negatively biased with previous methods.

The fact that we found differences in fish communities and community stability

Table 4. Number of individuals, number of species, and Simpson's diversity index (1-D), by month, in the Bonneau Ferry wetland of the Cooper River, South Carolina, as determined by electrofishing. Species with an asterisk were considered "estuarine." Species are sorted in descending order of total abundance.

	Month					
Species	February	April	June	August	October	December
Largemouth bass	8	10	6	14	14	12
Mosquitofish	0	0	30	2	12	0
Inland silverside*	5	19	1	10	5	0
Rainwater killifish	0	1	13	3	22	0
Redear sunfish	7	15	3	2	3	8
Striped mullet*	7	22	3	4	0	1
American eel*	0	2	17	7	0	3
Least killifish	0	0	2	0	26	0
Bluefin killifish	1	0	1	3	21	1
Freshwater goby*	0	16	5	0	0	0
Spotted sunfish	7	3	3	4	0	1
Golden shiner	4	0	5	4	2	0
Bowfin	0	0	1	0	1	1
Chain pickerel	1	0	0	0	0	2
Spotfin mojarra*	0	0	0	0	3	0
Fat sleeper*	0	0	0	1	1	0
Golden topminnow	0	0	0	0	2	0
Southern flounder*	0	0	1	0	0	1
White catfish	0	0	1	0	1	0
Blue catfish	0	0	0	1	0	0
Bluegill	0	0	0	0	1	0
Common carp	0	0	0	0	1	0
Gizzard shad	0	1	0	0	0	0
Pirate perch	0	0	0	0	0	1
Redbreast sunfish	0	0	0	0	0	1
Sailfin molly	0	0	0	0	1	0
Sharptail goby	0	0	0	0	0	1
Total abundance	40	89	92	55	116	33
N species	8	9	15	12	16	12
% Centrarchidae	55	31	13	36	16	67
% estuarine	30	66	29	40	8	18
Simpson's Diversity (1-D)	0.84	0.82	0.83	0.86	0.85	0.79

between habitat types that characterize these wetlands underscores the importance of maintaining a diversity of habitat types within an ecosystem. Other studies have shown differences in fish community composition between vegetated and unvegetated areas (Whitfield 1988, Lubbers et al. 1990, West and King 1996), between different types of submerged vegetated areas (Duffy and Baltz 1998), and between plant forms (Chick and McIvor 1994, Xie et al. 2000). Ultimately, we cannot generalize beyond our two study wetlands because we did not replicate wetland type in our study. However, our study provides some of the first data that suggests how wetland type can influence fish community structure in this system and future studies can be designed to take advantage of this knowledge.

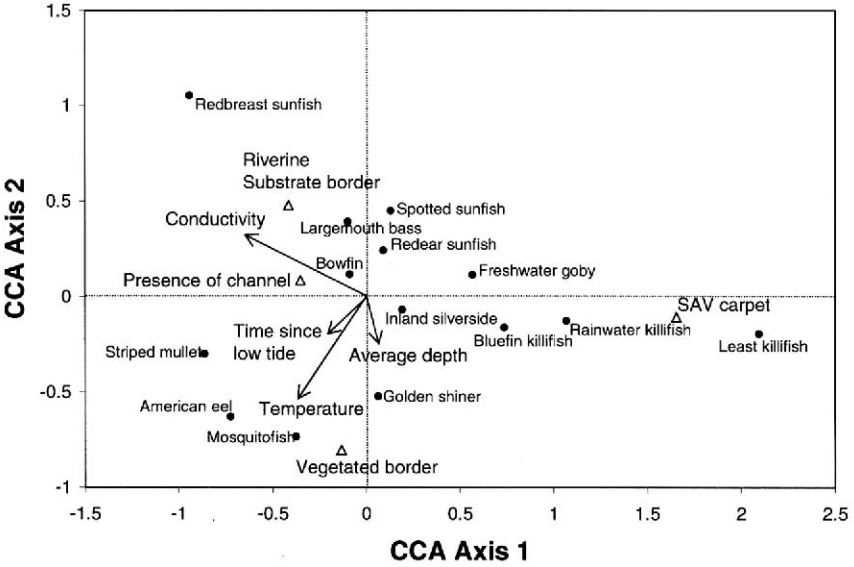


Figure 3. Canonical correspondence analysis diagram of fish species inhabiting two wetlands of the Cooper River, South Carolina. Closed circles denote species scores, open triangles denote centroids of categorical environmental variables, and arrows represent continuous environmental variable scores.

How these wetlands are managed in the future will have consequences for the fish communities that use these habitats. Managing for open water habitats versus allowing the fields to remain fallow and become increasingly dominated by intertidal emergent vegetation (Kelley and Porcher 1996) will be a factor determining fish community composition, especially impacting estuarine migratory species such as inland silversides and freshwater gobies. Additionally, our data suggest that wetland types may vary in their value to fish depending on seasons, making heterogeneity of wetland types important to the overall ecology of the river basin. Future research that incorporates replicates of many wetlands types is needed to best assess how wetland habitat affects fish community composition.

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