South Carolina Sea Grant Consortium

PROJECT REPORT

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Project Title: Structure and Functions of Tidal Freshwater Wetlands on the Cooper River, SC: Effects of Water Management on Succession, Nutrient Cycling, and Fish Habitat

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Objectives: Note any significant changes in objectives below. Otherwise leave blank.

Project Results:

Introduction:

The Santee-Cooper hydroelectric project in 1941 diverted 88% of the discharge from the Santee River into the Cooper River (Williams et al. 1984). In 1985, to reduce the amount of dredging in Charleston harbor, the majority of discharge was rediverted from the Cooper River back to the Santee River. This rediversion reduced the average annual discharge in the Cooper River from 448 cubic meters per second (cms) to 84 cms, dropped the mean water level by 30%, and accelerated the rate of plant succession (SCDHEC, OCRM 2000, Kelley et al. 1990, Kelley and Porcher 1996).

Three major plant groups have been identified in the abandoned rice fields of the Cooper River: (1) submersed aquatic vegetation (SAV) such as coontail *Ceratophyllum demersum*, fanwort *Cabomba caroliniana*, elodea *Egeria densa*, and hydrilla *Hydrilla verticillata*, (2) *Ludwigia* spp.-*Eichornia* spp,-*Polygonum* spp. complex (LEP), and (3) intertidal emergent vegetation (ITEM) such as pickerel weed *Pontederia cordata*, arum *Peltandra virginica*, and giant cutgrass *Zizaniopsis miliacea*. In the Cooper River rice fields, SAV is the dominant form found in early successional stage wetlands with LEP becoming more dominant as succession progresses. The lateral growth of LEP increases the rate of sedimentation allowing for invasion and dominance by ITEM.

The eastern half of Bonneau Ferry (BF) is a 72.3 ha (wetted area at average mid-tide) rice field in an early-successional stage containing SAV (59.5%), ITEM (16.6%), and LEP (13.8%; Figure 1A). It ranges in area from 10.9 ha at an average low tide to 124 ha at an average high tide. Dean Hall (DH) is a 28.6 ha (wetted area at average mid-tide) rice field in a late-successional stage containing ITEM (77.9%), LEP (16.9%), and SAV (3.1%). It ranges in area from 0.02 ha at an average low tide to 59.5 ha at an average high tide. Dean Hall consists of few, deep channels at all tide stages, whereas Bonneau Ferry remains lacustrine at all but the lowest of tide stages (Figure 1B). Tidal amplitude was approximately 0.95 m in both rice fields.

Our objective was to assess fish community structure as a function of the major vegetated habitats in the Cooper River rice fields. To accomplish this objective, we described and compared the fish communities and described energy flow in rice fields of differing vegetation types. Prior to data acquisition, we first evaluated sampling methodology. After a suitable sampling scheme was established, we then established a sampling regime to 1) compare fish communities between two rice fields that differed in relative abundance of aquatic vegetation types and 2) compare fish communities among vegetation types within each rice field. Lastly, to aid in the description of energy flow in the two study rice fields, we calculated production of fish biomass in the two rice fields and collected food habits data on the top predator, largemouth bass.

<u>Sampling Methodology Evaluation</u>:

We evaluated four methods to capture fishes in vegetated habitats: 1) a purse seine, 2) rotenone, 3) drop traps, and 4) boat electrofishing. Previous studies conducted in the Cooper River rice fields used purse seines to evaluate the fish communities (Williams et al. 1984, Homer and Williams 1985, Homer and Williams 1986). However, modifications required to make the use of a purse seine feasible in our two study rice fields were not logistically possible, therefore, we decided against the use of this gear type. Rotenone is a fish toxicant that allows for the collection of nearly all fish within the area sampled, but is expensive, labor intensive, and can elicit negative reactions from the public (Bettoli and Maceina 1996). A drop trap is a mesh or aluminum box that be pushed through the vegetation until it contacts the bottom (Jordan et al. 1997). Electrofishing is an active sampling method that uses an electrical current applied to the water to stun fish, which can then be netted (Reynolds 1996).

We sampled with rotenone twice in channels in Dean Hall and once in an LEP patch in Bonneau Ferry. Block nets were placed around the sampling area and potassium permanganate was applied to the outside of the net to detoxify the rotenone. Fish were immediately collected, identified to species, and enumerated. We captured 23 total species from both rice fields (Table 1). White catfish, *Ameiurus catus*, was the only species to be captured uniquely by this method during the sampling evaluation phase of the project.

We took 38 drop trap samples in BF and DH rice fields during January and February 1999. Twelve samples were taken in SAV, 15 in LEP, and 11 in ITEM. We captured 23 fish species (Table 1), and mosquitofish and least killifish were numerically dominant. Total density (number per m^2) of fish was highest in LEP (mean = 71, sd = 146.3), followed by SAV (mean = 25, sd = 49.5) and ITEM (mean = 18, sd = 43.7).

We established four, 100-m fixed transects in both BF and DH and electrofished each at one of four tide stages between July 1998 and February 1999. Tide stages (TS) were 2-4 (TS1) and 0-2 (TS2) hours prior to high tide and 0-2 (TS3) and 2-4 (TS4) hours after high tide. We captured 29 species and largemouth bass and striped mullet were numerically dominant (Table 1). We conducted a two-way ANOVA to examine the effects of tide stage and rice field on number of fish and number of species collected per transect. After removing an outlier, neither of the main effects (i.e., rice field and tide stage) were significant at *P* # 0.05, nor was the interaction of main effects for number of fish. Number of species was significantly greater in DH than BF (*P* = 0.02) and significantly fewer during TS3 (*P* = 0.03).

Table 1. Fish species captured by three methods, rotenone, drop trap, and electrofishing, in a preliminary evaluation of sampling gears in two Cooper River rice fields. R = rotenone, D = drop trap, and E = electrofishing.

Scientific name	Common Name	Method			Scientific name	Common Name	Method		
		R	D	E			R	D	E
Amia calva	Bowfin			**X**	*Lucania goodei*	Bluefin killifish	**X**	**X**	**X**
Anguilla rostra	American eel	**X**	**X**	**X**	*Lucania parva*	Rainwater killifish	**X**	**X**	**X**
Aphredoderus sayanus	Pirate perch	**X**	**X**	**X**	*Fundulus heteroclitus*	Mummichog	**X**	**X**	
Labidesthes sicculus	Brook silverside			**X**	*Fundulus confluentus*	Marsh killifish		**X**	
Menidia beryllina	Inland silverside	**X**		**X**	*Fundulus chrysotus*	Golden topminnow		**X**	
Strongylura marina	Atlantic needlefish			**X**	*Eucinostomus argenteus*	Spotfin mojarra			**X**
Paralichthys lethostigma	Southern flounder	**X**		**X**	*Gobionellus shefeldti*	Freshwater goby	**X**	**X**	**X**
Lepomis punctatus	Spotted sunfish	**X**	**X**	**X**	*Noturus gyrinus*	Tadpole madtom	**X**	**X**	
Lepomis auritus	Redbreast sunfish	**X**	**X**	**X**	*Ameiurus natalis*	Yellow bullhead			**X**
Lepomis microlophus	Redear sunfish	**X**	**X**	**X**	*Ameiurus catus*	White catfish	**X**		
Lepomis macrochirus	Bluegill	**X**		**X**	*Ictalurus furcatus*	Blue catfish			**X**
Enneacanthus gloriosus	Bluespotted sunfish	**X**	**X**	**X**	*Lepisosteus osseus*	Longnose gar		**X**	**X**
Micropterus salmoides	Largemouth bass	**X**	**X**	**X**	*Morone americana*	White perch			**X**
Dorosoma cepedianum	Gizzard shad			**X**	*Mugil cephalus*	Striped mullet			**X**
Notemigonus crysoleucas	Golden shiner	**X**		**X**	*Myrophis punctatus*	Speckled worm eel		**X**	
Dormitator maculatus	Fat sleeper		**X**	**X**	*Gambusia holbrooki*	Mosquitofish	**X**	**X**	**X**
Eleotris pisonis	Spinycheek sleeper			**X**	*Heterandria formosa*	Least killifish	**X**	**X**	**X**
Esox americanus	Redfin pickerel	**X**	**X**	**X**	*Poecilia latipinna*	Sailfin molly	**X**	**X**	
Esox niger	Chain pickerel	**X**	**X**		*Trinectes maculatus*	Hogchoker	**X**	**X**	

Because the rotenone samples were largely a sub-set of drop trap and electrofishing samples, we decided on a dual sampling method, drop traps to collect small-resident fish species and electrofishing to collect large, mobile fish species. Our final sampling protocol called for bi-monthly sampling for one year. For electrofishing, we established fixed 200-m transects, eight in BF and four in DH. In BF, four transects were randomly placed and four were placed in channels. We sampled each transect with the incoming tide at one of four tide stages (Table 2). For drop traps, we stratified sampling by location (i.e., blocks: up-river, mid-river, and down-river) and vegetation type (SAV, LEP, and ITEM). We took 10 samples from each block in each rice field each sampling month for a total of 30 samples in each rice field. Because preliminary results indicated higher variation in fish numbers in LEP versus SAV and ITEM, we took more samples in LEP. Five samples were taken in LEP, three in SAV, and two in ITEM in each block. Sampling by electrofishing occurred on alternate months from drop trap sampling.

Table 2. Month of sampling of transects 1-4 in Dean Hall (DH) and 1-8 in Bonneau Ferry (BF) for the electrofishing study that examined differences in fish communities between two abandoned rice fields in the Cooper River, South Carolina over four tide stages.

Transect	Tide stage (hours before high tide)			
	3.5	2.5	1.5	0.5
DH-1	April December	August February	October	June
DH-2	June February	April December	August	October
DH-3	October	June	April February	August December
DH-4	August	October	June December	April February
BF-1	April February	August December	October	June
BF-2	October	June February	August December	April
BF-3	June December	October	April	August February
BF-4	August December	April	June February	October
BF-5	June	October	August December	April February
BF-6	April	June February	October	August December
BF-7	October	August	April February	June December
BF-8	August February	April December	June	October

Comparison Between Rice Fields:

Drop trap.–We used a 1-m^2 aluminum drop trap to sample fish from the three vegetation types in each rice field from March 1999 until January 2000. We deployed the drop trap, pushed it into the substrate (until we were confident that no fish could escape from the bottom), removed all vegetation, and used a bar seine (1 m X 1 m, 3.175 mm mesh) to remove all fish. A sample was completed when no fish were found in three consecutive passes. We euthanized captured fish with an overdose of MS-222 and preserved them in 10% formalin. Identification and enumeration were conducted at a later date in the lab. All fish in a sample, up to 30 of the same species, were individually wet weighed to 0.1 mg. Those fish not individually weighed were given the average wet weight of the fish for that species in the same sample. Because the rice fields differed in regards to relative amount of vegetation type, we calculated weighted means for numeric density and biomass density (number and weight, respectively, per square meter). We believe that the weighted mean provides a better estimate of the overall mean density in the rice fields because it takes into account the relative abundance of the vegetation types, but it does not allow for statistical tests because it reduces the degrees of freedom to zero. We performed a repeated-measures ANOVA (Proc Mixed, SAS Institute 1992) testing the effects of rice field and month on mean (un-weighted) numeric and biomass densities of fish.

We collected 12,067 fish representing 27 species from Bonneau Ferry and 4,378 fish representing 25 species from Dean Hall (Table 3). Numerically dominant fish in both rice fields consisted of bluefin killifish *Lucania goodei* (5.6% in BF and 11.4% in DH), rainwater killifish *L. parva* (9.9% in BF and 9.8% in DH), least killifish *Heterandria formosa* (48.0% in BF and 22.2% in DH), and mosquitofish *Gambusia holbrooki* (30.3% in BF and 43.1% in DH). Dean Hall contained more larger bodied fish, such as sunfish (Centrarchidae, 0.74% in BF and 4.3% in DH). Mean weighted numeric densities were approximately 3X higher in BF than in DH, but mean weighted biomass density estimates were nearly equal (Table 4, Figure 2). Thus, BF contained significantly more fish than DH, but DH contained larger fish. The repeated-measures ANOVA showed significantly higher mean numeric densities of fish in BF than DH ($P < 0.01$) and reduced mean numeric densities in March and May 1999 ($P = 0.05$, Figure 2). Mean biomass densities did not significantly differ between rice fields ($P > 0.05$, Figure 2).

Table 3. Number of each fish species captured by drop traps in two Cooper River rice fields, Bonneau Ferry (BF) and Dean Hall (DH), in March 1999 - January 2000.

Scientific name	Common Name (Abbr.)	Rice Field		Scientific name	Common Name (Abbr.)	Rice Field	
		BF	DH			BF	DH
Anguilla rostra	American eel (AEL)	86	40	*Esox niger*	Chain pickerel (CHP)	1	2
Aphredoderus sayanus	Pirate perch (PIP)	1	0	*Lucania goodei*	Bluefin killifish (BFK)	674	501
Menidia beryllina	Inland silverside (ILS)	236	4	*Lucania parva*	Rainwater killifish (RWK)	1,190	429
Paralichthys lethostigma	Southern flounder (SFL)	12	0	*Fundulus chrysotus*	Golden topminnow (GLT)	30	38
Lepomis punctatus	Spotted sunfish (SOS)	77	89	*Fundulus confluentus*	Marsh killifish (MKF)	2	3
Lepomis auritus	Redbreast sunfish (RBS)	0	65	*Fundulus heteroclitus*	Mummichog (MMC)	11	74
Lepomis microlophus	Redear sunfish (RES)	4	8	*Eucinostomus argenteus*	Spotfin mojarra (SMO)	14	0
Lepomis macrochirus	Bluegill (BLG)	2	0	*Gobionellus shefeldti*	Freshwater goby (FWG)	79	74
Enneacanthus gloriosus	Bluespotted sunfish (BLS)	2	20	*Noturus gyrinus*	Tadpole madtom (TPM)	12	8
Enneacanthus obesus	Banded sunfish (BDS)	0	1	*Ameiurus catus*	White catfish (WCF)	2	38
Micropterus salmoides	Largemouth bass (LMB)	4	5	*Lepisosteus osseus*	Longnose gar (LNG)	1	0
Notemigonus crysoleucas	Golden shiner (GLS)	0	1	*Myrophis punctatus*	Speckled worm eel (SWE)	0	3
Elossoma zonatum	Banded pygmy sunfish (BPS)	3	0	*Gambusia holbrooki*	Mosquitofish (MSQ)	3,661	1,888
Dormitator maculatus	Fat sleeper (FAS)	19	107	*Heterandria formosa*	Least killifish (LSK)	5,796	970
Eleotris pisonis	Spinycheek sleeper (SCS)	0	2	*Poecilia latipinna*	Sailfin molly (SFM)	1	0
Esox americanus	Redfin pickerel (RFP)	6	3	*Trinectes maculatus*	Hogchoker (HCK)	141	5

Table 4. Weighted numeric and biomass densities of fish captured by drop traps in two Cooper River rice fields, Bonneau Ferry and Dean Hall, March 1999 - January 2000.

	Weighted Numeric Density (N/m^2)		Weighted Biomass Density (g/m^2)	
Month	Bonneau Ferry	Dean Hall	Bonneau Ferry	Dean Hall
March 1999	9.38	8.65	4.2433	4.8686
May 1999	29.31	6.12	5.8270	7.0437
July 1999	60.19	25.00	8.9844	5.9990
September 1999	100.79	22.36	6.6849	3.5644
November 1999	108.72	13.61	5.1608	7.3968
January 2000	53.84	25.05	6.3737	8.0138
Grand mean	**60.37**	**16.80**	**6.2123**	**6.1477**

Electrofishing.–We established fixed 200 m transects in both wetlands (four stations in DH and eight in BF due to differences in wetland area). Four stations in BF were selected in channels, to be morphologically similar to sites in channelized DH; the other four were selected randomly. Each transect was boat-electrofished during the day every other month from April 1999 through February 2000 at one of four tide stages (Table 2). Only four transects could be completed in one day and each transect was only sampled once per month, therefore, each transect was sampled at only one tide stage per month. We attempted to pick up all stunned fish, which were identified, measured to the nearest 1-mm, and released. Fish whose identities were uncertain were taken to the lab for identification. Fish less than 50 mm TL were deleted from the data-set because they were not efficiently captured by electrofishing. We performed a repeated-measures ANOVA (Proc GLM, SAS Institute 1992) to test the effects of rice field and month on mean catch rates (number/m) of fish.

We captured a total of 29 species from the two study sites; 385 individuals of 21 species from Dean Hall and 262 individuals of 22 species from Bonneau Ferry (Table 5). Largemouth bass was the dominant species in both wetlands (22.3% in BF and 28.6% in DH). Sunfish species, such as largemouth bass, spotted sunfish and redbreast sunfish, were more abundant in Dean Hall compared to Bonneau Ferry. However, redear sunfish was more abundant in BF. Pelagic species, such as inland silverside and golden shiners were more abundant in Bonneau Ferry. The repeated-measures ANOVA showed higher catch rates of fish in DH than BF ($P < 0.01$) and higher catch rates in April ($P < 0.01$, Figure 3).

Table 5. Number of each fish species captured by electrofishing in two Cooper River rice fields, Bonneau Ferry (BF) and Dean Hall (DH), in April 1999 - February 2000. Fish less than 50 mm are not included

Scientific name	Common Name (Abbr.)	Rice Field		Scientific name	Common Name (Abbr.)	Rice Field	
		BF	DH			BF	DH
Amia calva	Bowfin (BFN)	2	10	*Notemigonus crysoleucas*	Golden shiner (GLS)	10	4
Anguilla rostra	American eel (AEL)	29	48	*Dormitator maculatus*	Fat sleeper (FAS)	2	3
Aphredoderus sayanus	Pirate perch (PIP)	1	0	*Eleotris pisonis*	Spinycheek sleeper (SCS)	0	1
Labidesthes sicculus	Brook silverside (BSS)	0	7	*Esox americanus*	Redfin pickerel (RFP)	0	2
Menidia beryllina	Inland silverside (ILS)	27	13	*Esox niger*	Chain pickerel (CHP)	3	0
Strongylura marina	Atlantic needlefish (ANF)	0	1	*Fundulus chrysotus*	Golden topminnow (GLT)	1	0
Paralichthys lethostigma	Southern flounder (SFL)	2	1	*Eucinostomus argenteus*	Spotfin mojarra (SMO)	3	0
Lepomis punctatus	Spotted sunfish (SOS)	17	55	*Gobionellus shefeldti*	Freshwater goby (FWG)	19	3
Lepomis auritus	Redbreast sunfish (RBS)	1	52	*Gobionellus hastatus*	Sharptail goby (STG)	1	0
Lepomis microlophus	Redear sunfish (RES)	38	23	*Ameiurus natalis*	Yellow bullhead (YBH)	0	1
Lepomis macrochirus	Bluegill (BLG)	1	6	*Ameiurus catus*	White catfish (WCF)	2	1
Enneacanthus gloriosus	Bluespotted sunfish (BLS)	0	3	*Ictalurus furcatus*	Blue catfish (BCF)	1	0
Micropterus salmoides	Largemouth bass (LMB)	64	113	*Lepisosteus osseus*	Longnose gar (LNG)	0	2
Dorosoma cepedianum	Gizzard shad (GZS)	1	0	*Mugil cephalus*	Striped mullet (SRM)	36	36
Cyprinus carpio	Common carp (CRP)	1	0				

Comparison Among Vegetation Types:

To examine the relationship between fish and vegetation type, we examined differences in numeric density among vegetation types in each rice field using those fish species common to both rice fields (Bonneau Ferry and Dean Hall). We used a repeated-measures ANOVA (Proc Mixed, SAS Institute 1992) to model the effects of density among vegetation types, months, and blocks in each rice field. Pair-wise comparisons were made with LSMEANS and simple effects of significant interactions were evaluated with the "Slice" option (SAS Institute 1992).

We examined vegetation type preferences of the total fish community and separately for each of the dominant fish species ($N \geq 30$ individuals in both study areas) in each rice field by calculating Ivlev's electivity index (E_i, Krebs 1989) for each vegetation type (i) with the equation

$$E_i = \frac{r_i - n_i}{r_i + n_i},$$

where r_i = the percentage of fish found in vegetation type i and n_i = the percentage of vegetation type i found in the rice field. Percentage of fish was calculated from standing crop estimates in each vegetation type in each rice field. Ivlev's electivity index ranges from -1 to +1 indicating avoidance and selection, respectively, of each vegetation type.

We used canonical correspondence analysis (CCA, ter Braak 1986) using CANOCO software (ter Braak and Šmilauer 1998) to examine fish community similarity among vegetation types within rice fields. Only those species common to both rice fields were used and vegetation types (SAV, LEP, and ITEM) were the measured environmental variables. We weighted samples taken in SAV (x1.708 in BF and x1.642 in DH) and ITEM (x2.216 in BF and x2.289 in DH) to account for unequal sampling effort among vegetation types. We performed a Monte Carlo randomization test of the first axis and of the overall CCA to determine if the ordination results were significant. We used the Procrustes analysis and PROTEST (Jackson 1995) to examine whether fish community differences among vegetation types were similar between rice fields. For this test, low *P*-values indicate high concordance between the two rice field CCA diagrams.

Differences in numeric density among vegetation types were observed in BF ($P < 0.01$), but not in DH ($P = 0.09$). Straight-forward interpretation of the differences among vegetation types in BF was not possible due to the presence of a significant three-way interaction. Within this interaction, significant simple effects for vegetation type were found in the upriver block in July, the downriver block in September, and the downriver block in November (Figure 4). In all three cases, there were higher densities of fish in SAV.

Habitat preferences of the overall fish community showed some differences between rice fields (Table 6). In both rice fields, fish showed a weak selection for SAV and a weak avoidance of ITEM. However, fish showed a moderate selection for LEP in DH, but not in BF.

Table 6. Ivlev's index of electivity for commonly captured fish species inhabiting three vegetation types (SAV = submersed aquatic vegetation, LEP = *Ludwigia* spp.-*Eichornia* spp,-*Polygonum* spp. complex, and ITEM = intertidal emergent vegetation), in two abandoned rice fields, Bonneau Ferry and Dean Hall, of the Cooper River, South Carolina.

	Bonneau Ferry			Dean Hall		
Species	SAV	LEP	ITEM	SAV	LEP	ITEM
American eel	-0.04	0.42	-0.19	0.75	0.65	-1.00
Spotted sunfish	0.13	0.08	-0.47	-0.08	-0.02	0.02
Bluefin killifish	0.15	-0.09	-0.39	0.47	0.18	-0.07
Rainwater killifish	0.14	-0.14	-0.20	0.66	0.41	-0.27
Freshwater goby	0.20	-0.29	-0.71	0.31	-0.04	0.00
Golden topminnow	-0.21	0.15	0.44	0.28	0.19	-0.06
Least killifish	0.17	-0.21	-0.42	0.00	0.29	-0.08
Mosquitofish	-0.10	0.19	0.30	-0.46	0.25	-0.05
Total fish community	0.13	-0.10	-0.17	0.03	0.26	-0.07

There were species-specific differences in habitat utilization (Table 6). American eel was the only species to strongly select for LEP in Bonneau Ferry. Additionally, it selected for SAV, along with four other species, in Dean Hall. Avoidance of ITEM by this species was common in both rice fields, although it was a much stronger avoidance in Dean Hall. Spotted sunfish exhibited near neutral selection to vegetation type, except for avoiding ITEM in Bonneau Ferry. Bluefin killifish, rainwater killifish, and freshwater goby always showed a selection for SAV, but the selection was greater in Dean Hall than Bonneau Ferry. Only golden topminnow and mosquitofish showed a selection for ITEM in Bonneau Ferry and neither showed the same selection in Dean Hall. The two live-bearers, least killifish and mosquitofish, selected for LEP in Dean Hall and neither selected for that type in Bonneau Ferry. Most of these common fish species avoided ITEM in Bonneau Ferry, but exhibited less avoidance for this vegetation type in Dean Hall.

Canonical correspondence analysis showed that fish community structure among vegetation types differed between rice fields (Figure 5). For this analysis, close proximity between a fish and its environment indicate a strong, positive association. In Bonneau Ferry, there was an affinity of fish species for SAV, followed by LEP and ITEM. In Dean Hall, equal numbers of fish species showed an affinity for LEP as SAV. Only two species showed an affinity for ITEM in Dean Hall. The CCA's were significant (P <0.01) for the first and all combined axes for both rice fields. In BF and DH, the first axis explained 96% and 95%, respectively, of the variation in species abundance in relation to vegetation type; the remaining variation was explained by the second axis. The *P*-value from Protest was 0.371, indicating low concordance between ordinations. This reinforces the hypothesis that associations between fish species and vegetation type were not similar between rice fields.

<u>Fish Production</u>:

We calculated total (T) and annual (P) secondary production of fish in each wetland with the Allen curve method (Waters 1977) by plotting density (number/m^2) versus mean wet mass for a mixed-age population. Density for each drop trap sample was based on a sampling area of 1-m^2, whereas density for each electrofishing transect assumed an effective width of 1-m for the electrical field and was based on a sampling area of 200-m^2. We fit the data with a negative exponential function using Sigma Plot software (SPSS Inc. 2000) and calculated the area under the curve through integration to obtain total production for the study interval (Cabral and Marques 1999). Annual production (P) was estimated by dividing total production (T) by the study interval and multiplying the quotient by 365. For drop trap data, we also estimated production on a mean dry weight basis for the total fish community and for the four dominant species (i.e., bluefin killifish, rainwater killifish, least killifish, and mosquitofish). Dry weight was determined for all fish in drop trap samples that were weighed wet in the laboratory. Fish were dried at 60°C in a dessicating oven for at least 24 hrs. Total biomass in each wetland was estimated as mean individual weight multiplied by density for each sampling month. Average biomass (B) was the mean total biomass of fish for the sampling month. Because our estimates for each month and wetland involved multiple days of sampling, time in days was calculated as the average Julian day of sampling for that month. Thus, the study interval was calculated as the average of the Julian sampling days for the first month minus the average of the Julian sampling days for the last month. This resulted in study intervals of 316.3 days in BF and 285.59 days in DH for drop trap data and 300 days in BF and 295 days in DH for electrofishing data. We calculated the P/B ratio by dividing annual production (P) by average biomass (B) (Waters 1977). For all analyses, we assumed constant cohort-to-cohort growth, density, and mortality.

Secondary fish production was less in Bonneau Ferry than Dean Hall (Table 7, Figure 6). For drop trap data, production was nearly double in DH than BF, and nearly 4X higher in DH based on electrofishing data. The same trend was evident using production based on a dry weight basis, with higher production in DH. However, except for electrofishing, average biomass was similar between rice fields. Production per average biomass was higher in Dean Hall than Bonneau Ferry, on wet and dry weight basis, for the small, resident fishes, captured by drop traps but nearly equal for large, mobile fishes captured by electrofishing. Production adjusted for average biomass (P/B) was always higher in Dean Hall suggesting that Dean Hall was the more productive rice field even though it contained lower densities of fish. Capture efficiency based on electrofishing, but not drop traps, may have differed between rice fields. Therefore, we have more confidence in our estimates of fish production based on drop traps compared to electrofishing.

Table 7. Total production (T, g/m^2), annual production (P, g/m^2), average biomass (B, g/m^2), and P/B estimates for fish communities inhabiting two abandoned rice fields, Bonneau Ferry and Dean Hall, of the Cooper River, South Carolina.

Capture method	Weight basis	Total Production (T)	Annual Production (P)	Average biomass (B)	P/B
		Bonneau Ferry			
Drop Trap	wet	15.59	17.99	20.21	0.89
Drop Trap	dry	3.21	3.70	4.32	0.86
Electrofishing	wet	15.59	18.97	7.57	2.51
		Dean Hall			
Drop Trap	wet	25.74	32.90	17.35	1.90
Drop Trap	dry	6.41	8.19	3.94	2.08
Electrofishing	wet	59.25	73.31	27.35	2.68

Table 8. Total production (T, g/m^2), annual production (P, g/m^2), average biomass (B, g/m^2), and P/B ratio estimates for bluefin killifish (BFK), rainwater killifish (RWK), least killifish (LSK), and mosquitofish (MSQ) in two abandoned rice fields, Bonneau Ferry and Dean Hall, of the Cooper River, South Carolina. Weight is dry weight.

Species	Total production (T)	Annual production (P)	Average biomass (B)	P/B
		Bonneau Ferry		
BFK	0.1563	0.1804	0.1505	1.20
RWK	0.7898	0.9114	0.9447	0.96
LSK	0.5332	0.6153	0.3880	1.50
MSQ	0.2640	0.3046	0.4092	0.74
		Dean Hall		
BFK	0.0539	0.0689	0.1176	0.59
RWK	0.3517	0.4495	0.1268	3.54
LSK	0.1162	0.1485	0.0720	2.06
MSQ	0.7083	0.9052	0.3420	2.65

Except for mosquitofish, production of each of the dominant fish species was higher in Bonneau Ferry than Dean Hall (Table 8). However, production adjusted for average biomass (P/B) was higher in Dean Hall for all species except bluefin killifish. These four species, combined, accounted for 54% and 19% of the total small, resident fish production in Bonneau Ferry and Dean Hall, respectively.

<u>Largemouth Bass Food Habits</u>:

Largemouth bass stomach contents were collected from August 1999 through April 2000 to determine the food habits of this top predator in Bonneau Ferry and Dean Hall rice fields. Each rice field was electrofished by boat in areas likely to contain largemouth bass. Acrylic tubes of various sizes were used to extract the gut contents from each fish (Van Den Avyle and Roussel 1980) and each bass was measured to the nearest 1-mm total length. The gut contents were placed in formalin and identified, enumerated, and weighed wet in the lab. Identification of prey items was at the species level for fish and order level for macroinvertebrates.

Overall, 68% of the 368 fish examined contained prey items (Table 9). Prey items were grouped into 23 prey types, consisting mainly of macroinvertebrate orders and fish families.

Table 9. Number of largemouth bass captured for prey use analysis from two abandoned rice fields, Bonneau Ferry and Dean Hall, in the Cooper River, South Carolina.

Date	Number captured	Percent with prey
August 1999	60	72
September 1999	73	62
November 1999	93	65
December 1999	69	71
February 2000	73	79
April 2000	92	59
Total	**368**	**68**

There were marked differences in prey use among months and between rice fields (Figure 7). Amphipods were utilized to the greatest extent during the winter and early spring. Over 80% of fish in DH contained amphipods in February 2000. *Siren* spp. was only utilized in February and members of the fish family Eleotridae (sleepers) were only found in the gut during the winter. Use of crabs and crayfish as prey by largemouth bass peaked in summer, but were utilized year-round. Insects and fish were found in bass stomachs year-round. Crayfish, killifish (Fundulidae and Poeciliidae), and hemipteran insects were found more often in bass captured from Bonneau Ferry than Dean Hall, whereas amphipods, isopods, shrimp (*Palaemonetes* spp.), and crabs were found more often in bass captured from Dean Hall.

Largemouth bass also consumed prey according to size (Figure 8). Small fish consumed shrimp (*Palaemonetes* spp.), hemipteran insects, and killifish (Fundulidae and Poeciliidae). Large fish consumed *Siren* spp., crayfish, crabs, and sunfish (Centrarchidae).

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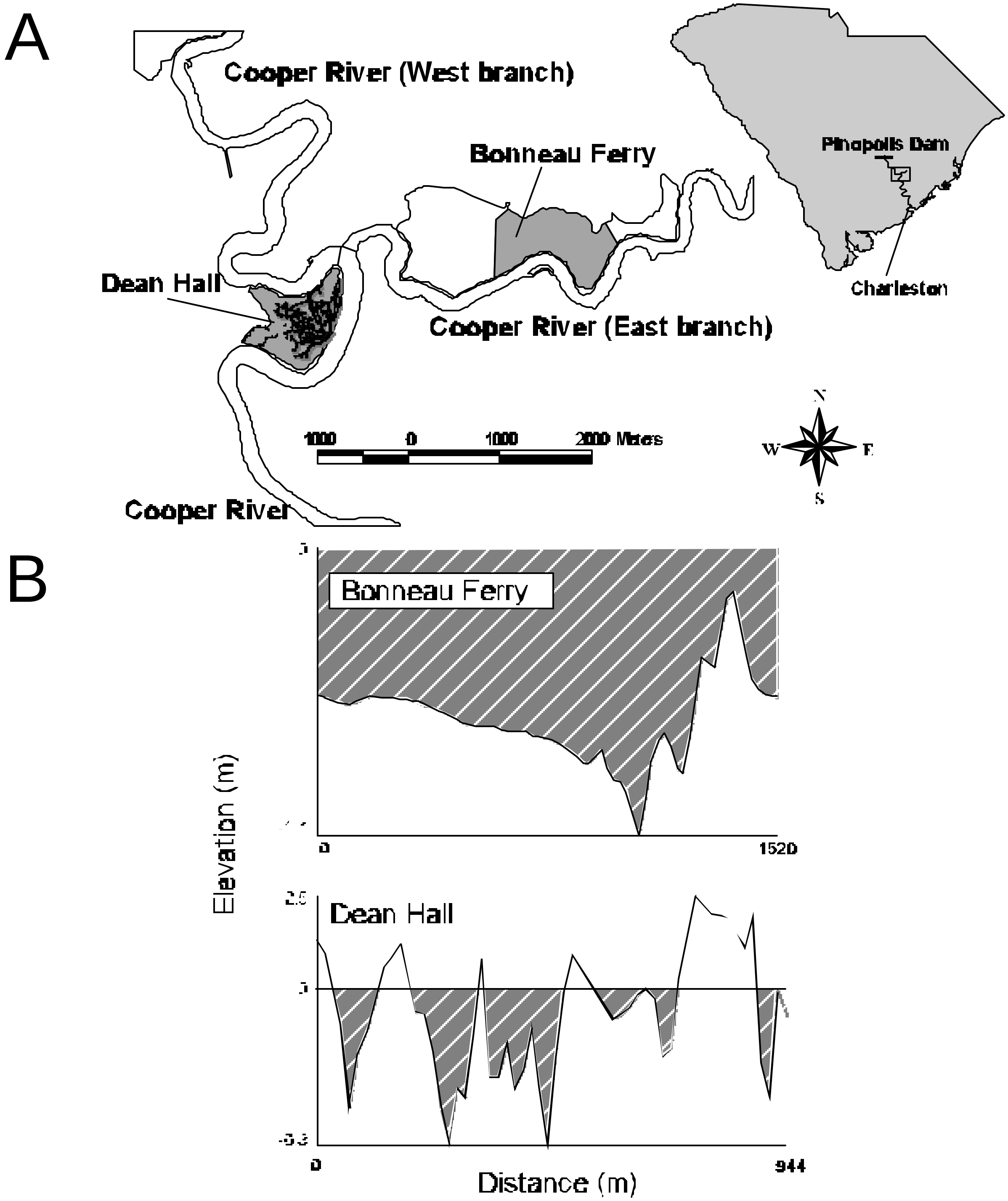
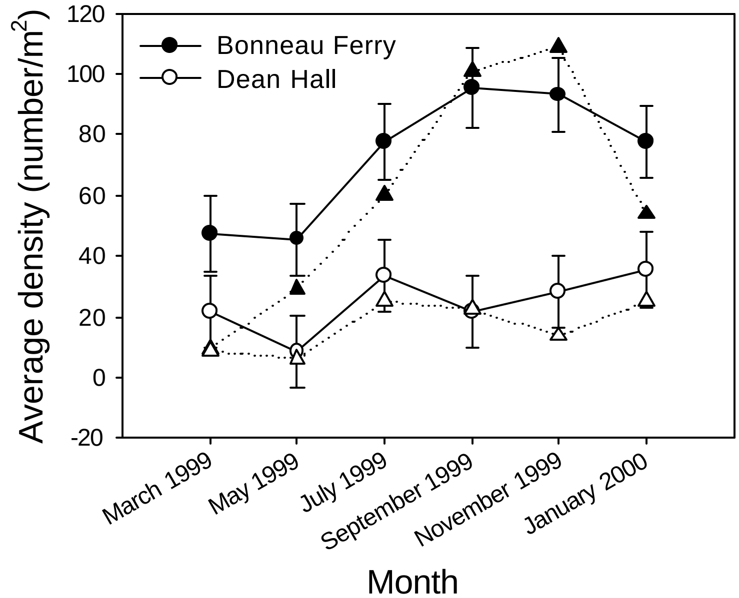


Figure 1. Map of the Cooper River, South Carolina showing the two wetlands, Bonneau Ferry and Dean Hall, that were sampled for differences in fish communities(A) and elevation-profiles illustrating the bottom topography of each wetland in relation to mean water level (B). The shaded area in the elevation-profiles represents the area below mean sea level (0 meters NAVD) and thus submerged.



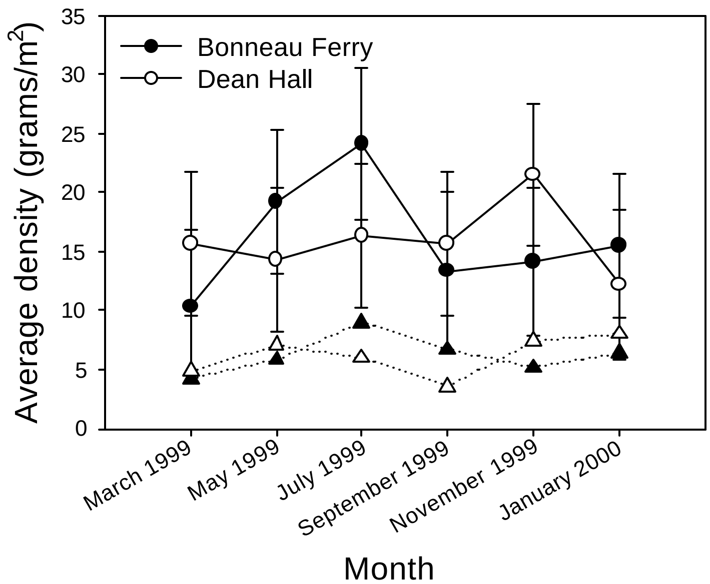


Figure 2. Average bi-monthly numeric (top) and biomass (bottom) density (± 1 SE) of fish captured by drop traps in two rice fields, Bonneau Ferry and Dean Hall, of the Cooper River, South Carolina . Circles are unweighted means and triangles are weighted means.

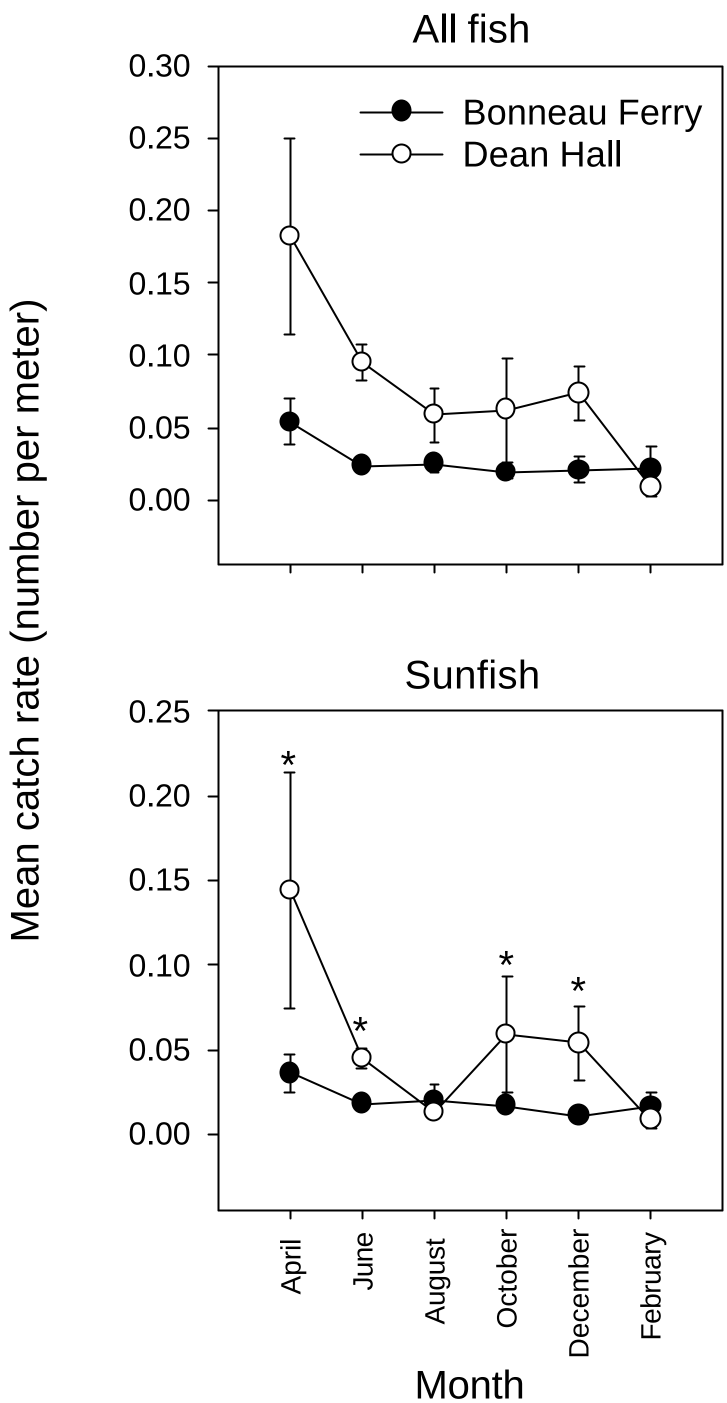


Figure 3. Mean number of total fish and sunfish per meter of electrofishing by month (April 1999 - February 2000) in two rice fields, Bonneau Ferry and Dean Hall, of the Cooper River, South Carolina. Error bars are one standard error about the mean and asterisks indicate significant differences ($\underline{P}$ # 0.05) between rice fields for each month.

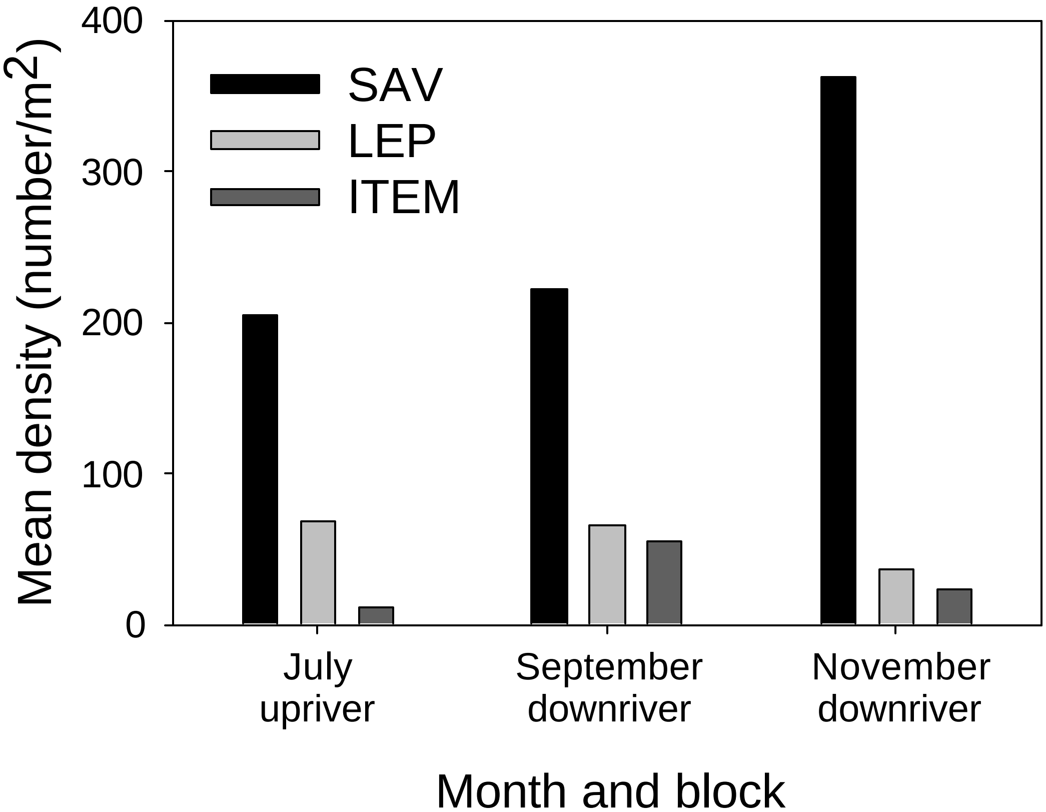


Figure 4. Mean densities of fish among three vegetation types, SAV (submersed aquatic vegetation), LEP (*Ludwigia* spp., *Eichhornia* spp., and *Polygonum* spp. complex), and ITEM (intertidal emergent vegetation) in July, September, and November in the upriver and downriver blocks in Bonneau Ferry rice field of the Cooper River, South Carolina. Only the significant simple effects of vegetation type from the significant 3-way interaction of month, block, and vegetation type obtained from the repeated-measures ANOVA are shown.

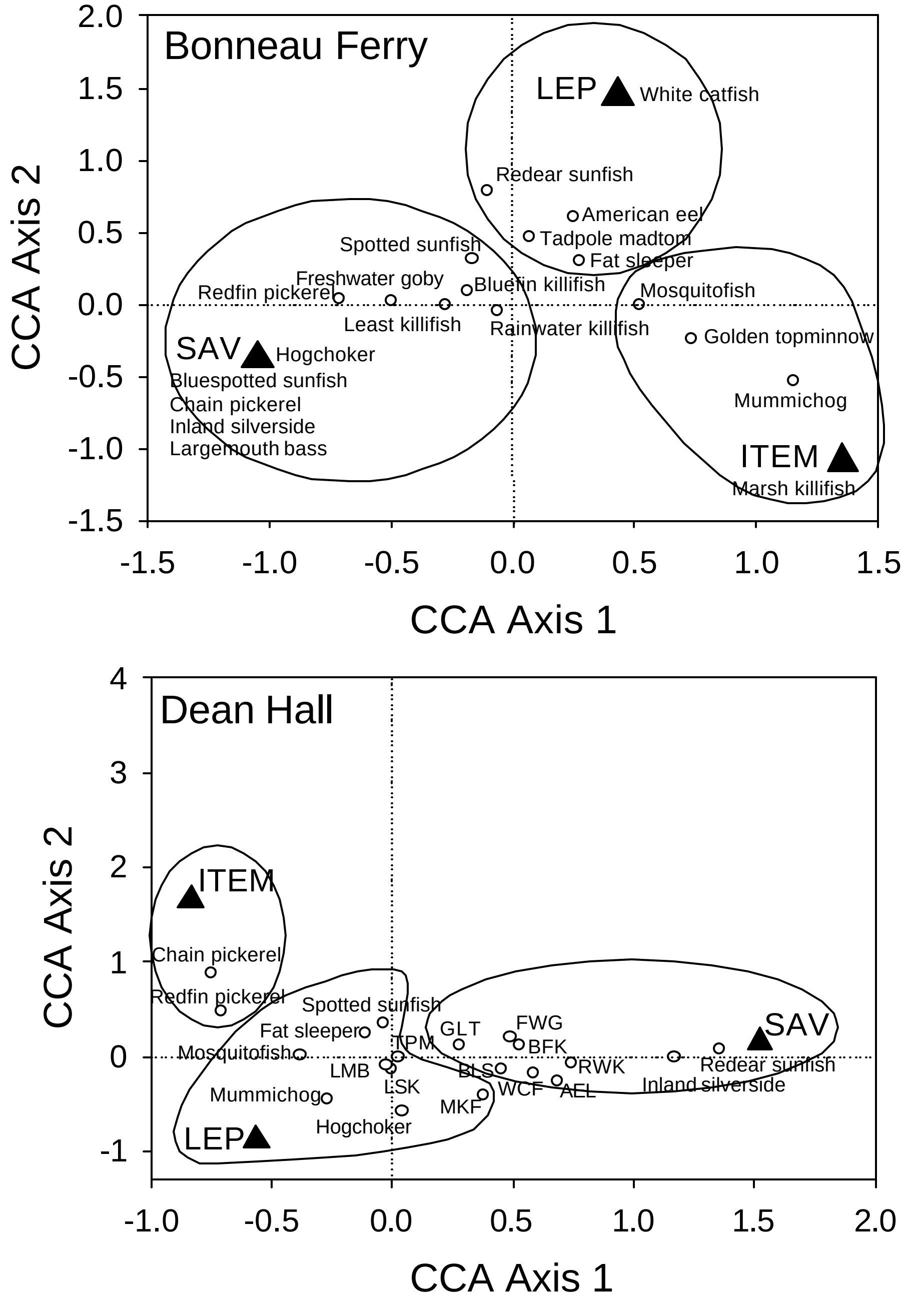


Figure 5. Canonical correspondence analysis diagrams of the relationship between fish community and vegetation type in two rice fields, Bonneau Ferry and Dean Hall, of the Cooper River, South Carolina. Closed triangles denote scores for vegetation type and open circles denote scores for species. SAV = submersed aquatic vegetation, LEP = *Ludwigia* spp., *Eichhornia* spp., and *Polygonum* spp. complex and ITEM = intertidal emergent vegetation. Some species symbols are hidden behind vegetation type symbols. The three letter species codes are found in Table 3.

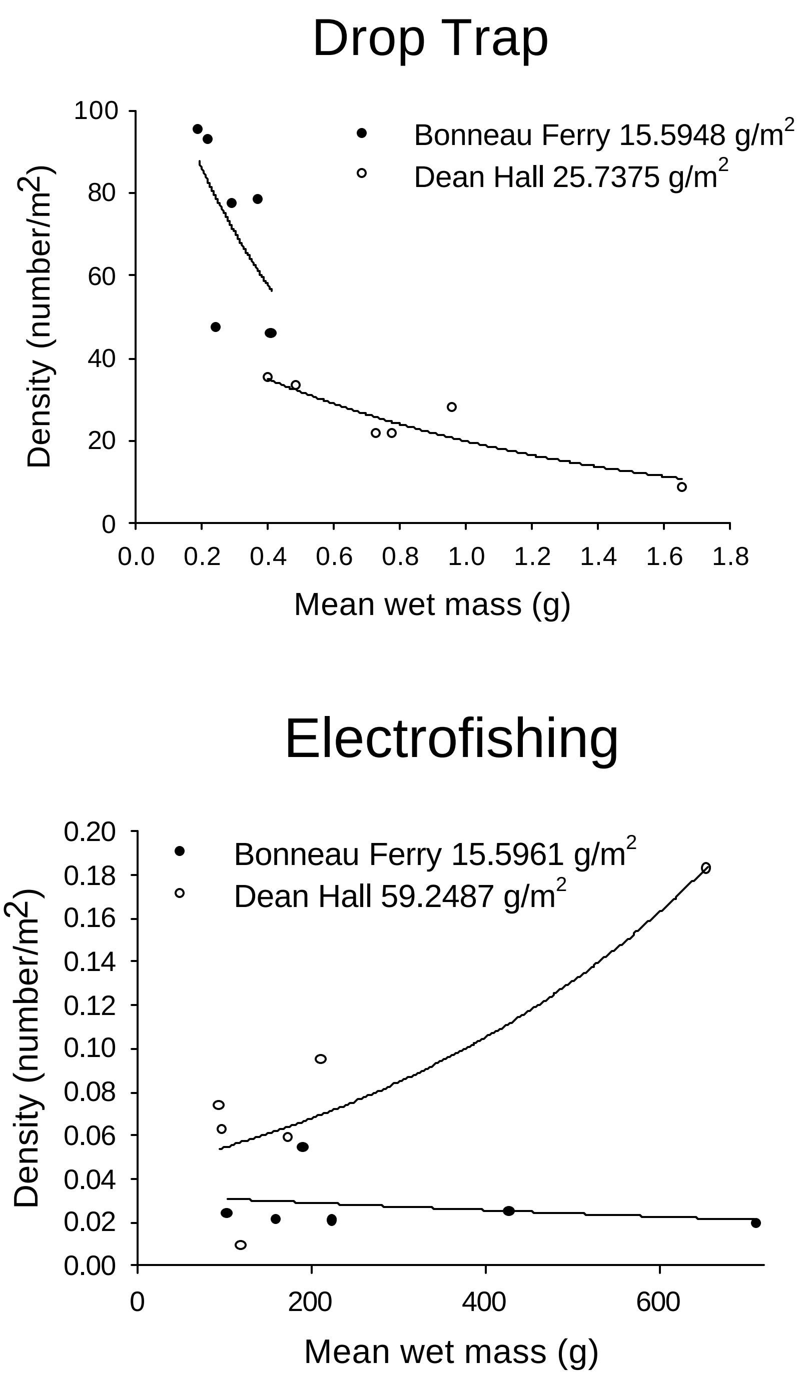


Figure 6. Secondary fish production (grams wet mass/m^2) of small, resident fishes (drop trap) and large, mobile fishes (electrofishing) in two rice fields, Bonneau Ferry and Dean Hall, of the Cooper River, South Carolina.

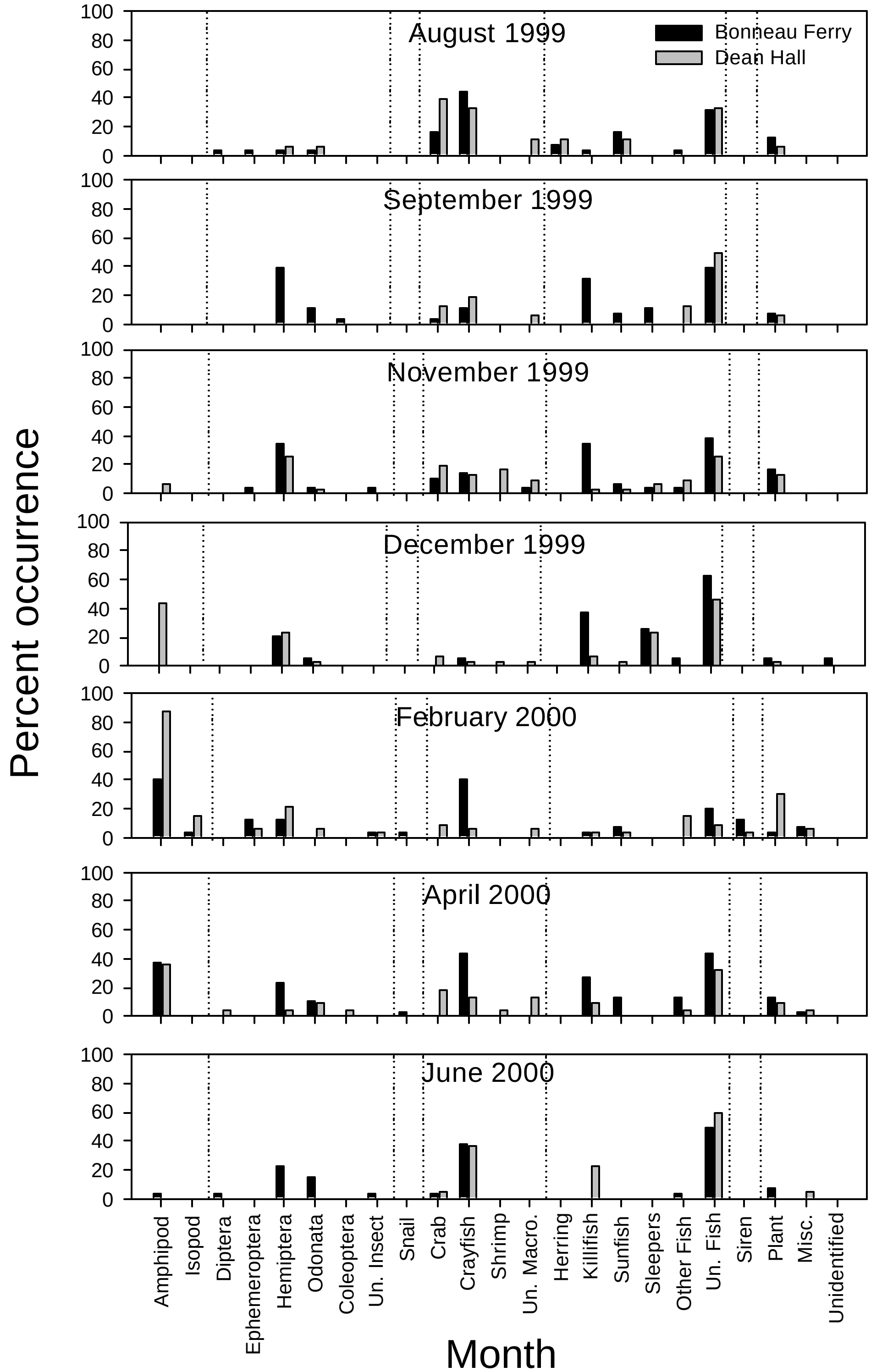


Figure 7. Percent occurrence of prey types in largemouth bass stomachs in two rice fields, Bonneau Ferry and Dean Hall, of the Cooper River, South Carolina.

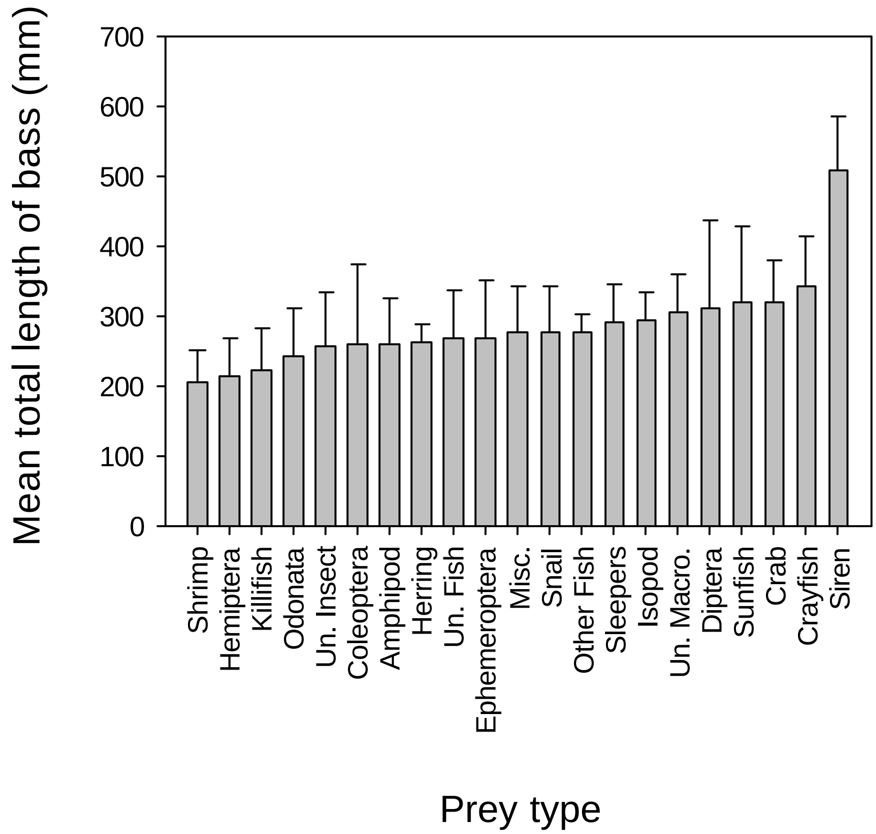


Figure 8. Mean total length of largemouth bass that consumed each prey type in two rice fields, Bonneau Ferry and Dean Hall, of the Cooper River, South Carolina. Error bars are 1 SD.

Additional Comments: none

Benefits: none

Interactions:

Name of Entity	Nature of Interaction
National Science Foundation	M. McManus reviewed a proposal on *Gambusia* reproduction.
SC Sea Grant	M. McManus submitted proposal titled Crayfish in the Tidal Wetlands of the Cooper River, SC: The Interaction Between an Omnivore and Successional Stages.
South Carolina Governor's School for Science and Mathematics	Applied for and received summer intern for 1998.
Aquatic Nuisance Species Conference	M. McManus attended a conference on the growing problem of the spread of aquatic nuisance species in North America in Charleston, SC.
SC Sea Grant	J.S. Bulak and J.M. Long collaborated with J.T. Morris et al. and submitted proposal titled Succession of tidal freshwater wetlands on the Cooper River, SC: ecological functions and management alternatives.
American Fisheries Society	J.M. Long attended a workshop titled Adaptive Sampling of Aquatic Populations at AFS Annual Meeting in 2001.
South Carolina Governor's School for Science and Mathematics	Applied for a summer intern for 2001.
South Carolina Governor's School for Science and Mathematics	Applied for a summer intern for 2002.
American Rivers	J.M. Long received funding in 2002 for a study titled Assessment of modeling the effects of discharge on abandoned rice field structure and function in the Cooper River, South Carolina. $15,282.

Publications:

Journal Articles:

Differences in Fish Communities Between Two Adjacent Freshwater Tidal Wetlands as Determined by Electrofishing–In Review, *Wetlands*.

Other Articles: none

Technical Reports:

McManus, M.G. 1999. Fisheries Investigation in Lakes and Streams - Statewide; Inventory of the fish community of tidal freshwater wetlands of Cooper River. Annual Progress Report, SC Dept. of Nat. Res.

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Presentations:

McManus, M.G. 1998. Structure and functions of tidal freshwater wetlands of the Cooper River, SC. South Carolina Department of Natural Resources Biologist's Meeting. Columbia, SC.

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Long, J.M., J.S. Bulak, L. Rose, and M.G. McManus. 2001. Differences in fish communities between two abandoned rice fields of the Cooper River as determined by electrofishing. South Carolina Chapter American Fisheries Society Annual Meeting. Sunset Beach, NC.

Long, J.M., J.S. Bulak, L. Rose, and M.G. McManus. 2001. Differences in fish communities between two abandoned rice fields of the Cooper River as determined by electrofishing. American Fisheries Society Annual Meeting. Phoenix, AZ.

Planned Publications:

Habitat mediated differences in fish communities in abandoned rice fields of the Cooper River, South Carolina

Comparative ecology and population dynamics of four small resident fish species inhabiting freshwater tidal wetlands of the Cooper River, South Carolina

Bioenergetics and prey use by largemouth bass inhabiting freshwater wetlands of the Cooper River, South Carolina

First occurrence of adult speckled worm eels *Myrophis punctatus* in fresh water in South Carolina

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Students: None

Student Name:______________________ Major:________________
Department/Institution:_____________ Degree:_______________
Actual/Expected Graduation Date:____ Major Professor:______
Thesis Title:____
Current Employer (if applicable):___________________________

Patents and Copyrights: None

Other Products: None

Follow-up:

1) J.M. Long and J.S. Bulak will construct a bioenergetics model of largemouth bass consumption to investigate the effects of predation by this species on other fish species inhabiting two abandoned rice fields, Bonneau Ferry and Dean Hall, of the Cooper River, South Carolina.

Future Efforts (optional):

1) J.M. Long received 4.5 months of funding from American Rivers to investigate river discharge on the fish habitat in the Cooper River rice fields.

2) J.M. Long applied for a 2002 summer intern from the SC Governor's School for Science and Mathematics to investigate differences in food habits and trophic level differences of eastern mosquitofish inhabiting two rice fields differing in vegetation composition.

3) J.M. Long will collaborate with J.T. Morris (USC) to develop a Cooper River rice field succession model. The measures of fish production will be a vital part of this future research.

Comments (optional):

Associate Investigator's (1) Signature: ______________________

Date: ______________________

Associate Investigator's (2) Signature: ______________________

Date: ______________________