FINAL REPORT

SECTION 6

ENDANGERED SPECIES ACT

OKLAHOMA DEPARTMENT OF WILDLIFE CONSERVATION

FEDERAL AID PROJECT E-33

Habitat Requirements of the Arkansas River Shiner, *Notropis girardi*

AUGUST 1, 1994 - AUGUST 7, 1997

FRE-33

FINAL REPORT

STATE: Oklahoma Grant Number E-33

GRANT TYPE: Research

GRANT TITLE: Habitat Requirements of the Arkansas River Shiner, *Notropis girardi*

GRANT DATES: 1 August 1994 - 7 August 1996

ABSTRACT

We report a careful analysis of the microhabitat preferences and some basic life history traits of the Arkansas River Shiner, *Notropis girardi.* Over a 2 year period, seasonal microhabitat samples were taken at 3 localities along the South Canadian River, Cleveland Co., Oklahoma. Microhabitat variables we examined included: depth, temperature, current speed, dissolved oxygen, conductivity, pH, and subjectively defined microhabitat types based on structural and substrate characteristics. Univariate and multivariate analyses indicated that *N. girardi* uses a broad range of microhabitat features which is typical of most of the abundant species in this highly variable Great Plains stream.

We tested the hypothesis that *Notropis girardi* spawns synchronously with major stage rises in total river discharge. We compared the gonadosomatic index (GSI) with the timing of peaks in discharge during the breeding season and found that *N. girardi* is in reproductive readiness throughout the breeding season and may or may not release high numbers of mature ova during stage rises.

During regular microhabitat collections, we examined the gut contents of several individuals. The food habits of this species could not be determined with great precision. It was apparent that the species feeds near the bottom, because most of the contents consisted of biofilm typically found on the outer layers of the sediment. Miscellaneous invertebrate material was also found in the guts, but identification was hampered by abrasion that had occurred inside the gut. Finally, the importance of invertebrates to the diet could not be assessed because it is unclear whether they are pursuing this prey type on the sediment layers or encounter them incidentally when consuming diatoms or other sediment constituents.

I. OBJECTIVE

Identify factors that determine the current distribution of the Arkansas River Shiner, i.e., what specific habitat features must be present for a population of Arkansas River Shiners to persist. This project will also aid in the recovery of this species by providing essential life history information and assist in determining potential reintroduction sites for the species within its historic range.

II. INTRODUCTION

A proposal is currently pending with the United States Fish and Wildlife Service (USFWS) to grant the Arkansas River Shiner protection under the guidelines of the Endangered Species Act of 1973. In order to designate areas of its native range as protected areas for the undisturbed recovery of local populations, more information on the characteristics of the microhabitats that *Notropis girardi* most frequently utilize is required. In accordance with the above requirement, the study in progress is being conducted to provide the USFWS with accurate information about microhabitats and life history of *Notropis girardi*.

III. SUMMARY OF FINDINGS

A. Job Objective 1: Determine which characteristics best describe the microhabitats most frequently used by *Notropis girardi* using univariate and multivariate analyses of habitat variables.

Procedures:

Three localities for study of microhabitat were selected along the South Canadian River in Cleveland Co., Oklahoma where large populations of *Notropis girardi* exist (Table 1). Criteria for site selection also included accessibility and safe wading conditions (under most flow regimes) of the river. Regularly spaced transects across the river were set at least 50 m apart along the bank. Independent seine hauls were taken at regular intervals along each transect (4-6 hauls/transect, for a total of 35-50 hauls/locality) such that no seine haul was closer than 10 m to any other seine haul. At each seine haul site, dissolved oxygen concentration, pH, conductivity, current speed, depth, temperature and the number of *Notropis girardi* and other species present were recorded. In addition, each of the sites was assigned a microhabitat type: (1) *Bank* -- defined as the outer edge of the stream channel, (2) *Island* -- stream edges adjacent to exposed sandbars that separate the main channel, (3) *Sandridge* -- underwater ridges where the current has sculpted the sand into one or more underwater terraces, (4) *Midchannel* -- in open water with no apparent sand structure to offer protection from the fastest currents, (5) *Backwaters* -- regions with mud bottom and little or no flow, and (6) *Pool* -- typically defined in stream ecology as deeper, slower flowing regions of the main channel separated by faster flowing regions. The effects of different substrate types were accounted for by these microhabitat categories. In the South Canadian River, the substrate for bank, island, sandridge, and midchannel is sand; mud is the principal substrate in backwaters and pools (generally slow water microhabitats). With each of the physicochemical variables listed above, as well as the microhabitat variables, individual seine hauls were ordinated using multivariate techniques (canonical correspondence analysis) to compare relative abundances of *Notropis girardi* and other species in each of the microhabitats sampled. Canonical correspondence analysis (CCA) was used instead of principal components analysis (PCA) because the ordination algorithm for CCA includes a weighting of species and sample scores by the relative effects of all environmental variables. Thus, a step similar to overlaying species abundances onto a PCA diagram is performed automatically. This process was repeated for each season (Fall, Winter, Spring, Summer, in that order) for comparison of microhabitat use between and among seasons. Seasons were defined using the standard calendar delineations; fall collections occurred between the Fall Equinox (September 21) and the Winter Solstice (December 21), winter collections occurred between the Winter Solstice and the Spring Equinox (March 21), spring collectons occurred between the Spring Equinox and the Summer Solstice (June 21), and summer collections occurred between the Summer Solstice and the Fall

Equinox. Seasonal effects were of special interest during the breeding season when distinctions were made between adult (>28 mm SL) and juvenile (<28 mm SL) individuals for detection of any ontogenetic differences in microhabitat use. Univariate analyses were typically performed using chi-square tests to determine whether the distribution of *N. girardi* occurred across the *encountered* values of physicochemical variables in proportion to the frequency of sampling in each, or whether proportionally more individuals selected certain regimes of one or more variables.

Results:

Multivariate analysis. Multivariate analysis requires that samples contained at least one individual of at least one species to be included; 704 samples fit this criterion. Canonical correspondence analysis (CCA) produced ordination diagrams illustrated in Figure 1 (1994-95) and 2 (1995-96). In year 1, the environmental variables that were most strongly associated with the species score for *Notropis girardi* were depth, the sandridge and midchannel habitat types, the seasonal influence of winter, and dissolved oxygen. Eigenvalues for the first two multivariate axes were 0.192 and 0.118, respectively, with the sum of canonical eigenvalues equal to 0.421 and the unconstrained eigenvalues equal to 2.974. All of these values indicate a weak relationship of environmental parameters (in general) to species distributions although a substantial percentage of the variation in the species-environment relationship was explained (47.8% and 29.3%, respectively). Higher eigenvalues would indicate greater robustness of the multivariate ordinations. In year 2, current and midchannel habitats were the only environmental parameters associated with the distribution of adult *N. girardi.* Here, eigenvalues for the first two axes were similar (0.245 and 0.069, respectively) but the variation explained was substantially greater (64.1% and 18.1%, respectively).

The only factors strongly associated with the distribution of juvenile *Notropis girardi* in year 1 were current, conductivity (TDS), and island habitat types. In year 2 of the study, juveniles were apparently influenced by backwater habitat types .

Important factors indicated by multivariate analyses are summarized in Table 2. The only factor in common between both years of the study was the midchannel habitat type. Thus, there is a high amount of variability in the distribution of *Notropis girardi* at our sampling localities.

Multiple Regression. We constructed a model of important variables by multiple regression analysis. In this model, dissolved oxygen ($p = 0.042$), temperature ($p < 0.001$), and pH ($p = 0.044$) were the variables significantly related to the abundance of *Notropis girardi*. The entire model was statistically significant, but is not a strong predictor of abundance ($p < 0.001$, $F = 6.929$, $r^2 = 0.07$), accounting for only 7% of total variance in abundance. The regression equation was (Abundance = 0.52(Current) - 0.284(Temperature) + 0.101(Dissolved Oxygen) + 0.092(pH) + 0.013(Conductivity) - 0.018(Depth).

Habitat Associations. The discrete microhabitat types designated at the beginning of the study (bank, island, sandridges, backwaters, midchannel, and pools) were analyzed separately for abundance across all seasons, localities and both years of the study. Contingency tests indicated that bank habitat contained significantly more *N. girardi* than the others ($p < 0.01$ by table); islands and sandridges also contained a greater proportion of individuals than predicted by the null hypothesis (Table 3). Seasonally, adults selected bank and backwaters habitats in the winter and remained in islands and sandridges during the fall, spring and summer (Table 4, Figure 3). Juveniles (Table 5, Figure 4), in contrast with adults, had their greatest abundance in backwaters, but, were also significantly found in bank and sandridge habitats.

Univariate Relationships. Table 3 summarizes the results of chi-square goodness-of-fit tests across categories of individual physicochemical variables across all sampling seasons and localities for both years of the study. Conductivity, temperature and dissolved oxygen were associated with distributions of *Notropis girardi* that differed from those predicted by the null hypothesis. Temperatures in which proportionally more *N. girardi* occurred were 7-18 degrees C. However, analysis by season and locality showed that temperature was important in the winter when the coldest microhabitats were avoided and late spring/early summer when the warmest microhabitats were avoided (Table 4, Figure 5). Conductivity values in which proportionally more individuals were observed were 1000-1300 umhos and proportionally fewer individuals were found when conductivity was greater than 1300 except in the summer when the distribution ranged up to 1600 umhos. With respect to microhabitat selection, however, the relative uniformity of conductivity values within a given locality resulted in a lack of statistical significance when the chi-square analysis was performed on a single locality (Table 4, Figure 6). Furthermore, in both the combined and seasonal analyses, neither extreme in the range of conductivity encountered in the study (650-2200 umho) likely exceeds the physiological tolerance of this species, but specific physiological tolerance studies would be useful to verify this conclusion. Dissolved oxygen values of 10-13 mg/l resulted in a statistically significant selection by *N. girardi* (Table 3, Figure 7) but again the effect was discontinuous in all seasons except fall (10.1-11.0 mg/l) indicating that this effect is not biologically significant. Neither the combined nor the seasonal analyses showed an effect of pH on the distribution of *N. girardi* ($p > 0.95$; Table 3, 4; Figure 8).

The effects of individual variables on the distribution of juveniles are summarized in Table 5. Temperatures in which juveniles were found ranged from 25-36 degrees centigrade, typical of the shallower habitats (backwaters, bank) that are usually selected. There were categories of dissolved oxygen, pH and conductivity that seemed to harbor more juveniles, but again, this effect was inconsistent by sampling localities during the breeding season (Table 5, Figure 9). Furthermore, when there was a significant distribution, the values for which there was apparent selection were discontinuous for all three variables.

Depth and current were considered likely to exert a combined influence on the microhabitat distribution of *Notropis girardi*. The importance of natural flow regimes indicated by other studies (e.g., Bestgen et al., 1989) as well as the association of current speed with the species score for *N. girardi* in the CCA ordination diagram were the basis for this consideration. Sixteen resource states were defined by combinations of depths and current speeds as shown in Table 6 and Table 7. The proportion of total samples taken in each resource state was then compared with the proportion of the total number of *N. girardi* in each. A chi-square test across all combinations of depth and current speed in which samples were actually taken demonstrated that the distribution of *Notropis girardi* deviated from that predicted by a random distribution (p <

0.01 by table). The categories that contained a greater number of individuals than predicted by the null hypothesis were resource states defined by depths of 0-50 cm and current speeds of 0-100 cm/s. However, on a season by season basis, this distribution often appears discontinuous (Table 6). A chi square test was also used to determine whether juveniles were distributed across these same resource states differently than the adults. This was done by calculating the expected juvenile abundances from the actual proportions of adults that occurred in each rather than the proportions of samples because juveniles are absent from the sampling during all but the late spring and summer samples. Juveniles differed from adults with respect to the depth and current speed interaction by selecting shallow water more frequently than adults (Table 5, 7). Occasionally, however, juveniles can be found in faster water as indicated by the appearance of a greater number of individuals than predicted in current speeds of 75-100 cm/s.

B. Job Objective 2: Compare the gonadosomatic index with flow regimes encountered during the breeding season (approximately April-September) to determine whether changes in flow patterns influence the reproductive cycles of *Notropis girardi*.

Procedures:

At sampling locality #1 (Table 1), 10-15 individuals were collected roughly every 10 days during the breeding season. Females (N = 87) were examined in the laboratory to determine the reproductive condition and the gonadosomatic index (GSI) of males and females during different flow regimes encountered during the breeding season. Instead of using egg counts, reproductive condition was scored using a subjective index (adapted from Heins, 1985) that ranged from 0 to 3 (for the characteristics defined by each category, see Table 8). This index was used primarily for females. Sex ratios were calculated for each month during the breeding season for which *Notropis girardi* individuals were sampled. All reproductive condition data were compared to the peaks in stream flow that occurred during the breeding season. The collections made in 1995 with respect to GSI were problematic and are not reported here because extremely high flows during parts of the reproductive season prevented some of the regular sampling. Specimens for 1996 were frozen prior to analysis to prevent the exposure of both somatic and gametic components to any fixation or preservation chemicals that can alter the composition of gametes in particular.

Results:

General Observations. Previous studies (Moore, 1944) have indicated that *Notropis girardi* reaches maturity when individuals reach a standard length (SL) of 28 mm. We collected individuals that were 30 mm SL and greater and we found that no individuals were in reproductive readiness until reaching 32-33 mm SL. All males that were examined had reduced testes and never appeared as though spawning efforts were imminent. Spawning habitat could not be defined because individuals were occasionally difficult to locate and samples for a given day during the breeding season contained individuals from several microhabitats.

Gonadosomatic Index (GSI). Figure 10 shows the GSI versus daily stream discharge in cubic feet per second (cfs). Peak gonadal mass, as a function of body mass, occurred on about day 40 of the sampling period (mid-May). However, discharge demonstrated 3 peaks of varying size at about day 80 (mid-late June), day 100 (early July), and day 125 (early August). It is important to note that GSI values ranged from 0.035-0.07 in all samples between May and August. Furthermore, GSI values were depressed in April and late August samples and the overall pattern indicates that peak reproductive efforts occur even in the absence of major stage rises. Although peak flow conditions cannot be completely excluded by these results, the timing of reproduction in *Notropis girardi* is likely influenced by other factors such as temperature, photoperiod, or chemical cues.

Reproductive condition. In support of the above conclusions, Figure 11 shows that in May, June and July, a substantial proportion of individuals are in peak reproductive condition (Type 3) indicating a more or less continuous potential to engage in fertilizations regardless of flow conditions. In females with Type 3 eggs, release of eggs appeared imminent. All males collected had greatly reduced testes indicating that spawning had already occurred. The increase in Type 0 and Type 1 females in late July and August indicates that (1) females had exhausted gametes by that time and (2) the number of juveniles that had not yet reached reproductive maturity increased in abundance.

Sex Ratios. With the exception of the month of April, the populations sampled in this part of the study were heavily female biased (Figure 12) and in some cases, samples consisted entirely of females. The apparent deficiency in abundance of males indicates that, in spite of the relatively consistent readiness of females, actual reproductive events could be limited by the availability of males. More research into the reproductive biology of this species is required to determine whether the lack of males is significant. Possible questions to pursue include: (1) Is there selection for a limited number of males with favorable characteristics? (2) Are males isolated in distribution during the breeding season in special microhabitats (e.g., those that might make favorable dispersal or nursery areas) not sampled in this part of the study? (3) Are males reproductively ready at smaller sizes earlier in the reproductive season and then not present after spawning?

C. Job Objective 3: Analyze foraging periodicity and the type, size, and number of prey items for variation in the ability to acquire food in the various habitats sampled.

Procedures:

During regular collections for the microhabitat study, individuals were collected and preserved for analysis of diet composition and foraging periodicity. In addition, two 24 hour collections (3 hour intervals) were made to detect nocturnal foraging, if present. Time of day, locality, and microhabitat (seine haul) were noted. From these data we attempted to determine (1) the type and relative frequency of abundant prey items, (2) whether *Notropis girardi* forage more actively at certain times of the day, and (3) whether the microhabitats that support large numbers of *Notropis girardi* also tend to be the microhabitats where gut fullness is greatest. The gut fullness index (GFI) was quantified by dividing the mass of gut contents by body mass. Relative importance of food items was then calculated as a proportion of the mass of the gut contents alone.

Results:

Foraging Periodicity. Figure 13 illustrates the mean (+SE) gut fullness across a 24-hour period. In general, gut fullness increases in the morning and peaks in late afternoon (approx. 1500 h) and slowly declines after dusk; however, this pattern is not statistically significant ($N = 51$, $p = 0.063$ by Kruskall-Wallis). Gut fullness was also high in the early morning, but this was due to two individuals with extremely full guts.

Food Preferences: Examination of gut contents demonstrated that *Notropis girardi* contained primarily sand/sediment, detritus and incidental invertebrate prey. Gross analysis indicates that dynamics within the gut result in the abrasion of invertebrate prey by sand particles and solid detritus. As a consequence, identification of invertebrate items is impossible; nor were we able to determine whether invertebrates are incidental or whether they are essential to the nutrient requirements of *N. girardi*. Figure 14 gives the relative proportions (by weight) of items examined in the guts of ($N = 42$) *N. girardi*. Organic detritus and sand were the two primary components of the diet and invertebrates, algae and biofilm (organic layer on top of the sediment) were relatively minor components. Thus the best that can be said is that *N. girardi* is likely a generalist feeder in which no particular invertebrate dominated the diet.

IV. RECOMMENDATONS

From the results presented here, it is clear that *Notropis girardi* uses a diverse array of riverine microhabitats within the annual cycle; no specific physicochemical feature of microhabitat is exclusively used by this species and it ranges widely throughout most of the available microhabitats in the South Canadian River. In central to east central Oklahoma, where this research was conducted, *Notropis girardi* maintains viable populations in river reaches characterized by shallow, moderately high flowing water, backwaters, banks and braided channels. Therefore, the continued success of this species will likely be ensured by efforts to avoid drastic changes in the present conditions of the river. In particular, activities that change the channel configuration and reduce the diversity of available microhabitats in the South Canadian River should be avoided. For example, channelization, sand mining on a massive commercial scale, dredging, etc., should be avoided and an effort should be made to ensure the continued existence of backwaters, open main channels, and island microhabitats.

Although we could neither confirm nor reject the hypothesis that *Notropis girardi* spawned during stage rises, this species is in reproductive readiness during much of the early summer. Because reproduction may still be tied to flow, actions to ensure the continued free flow of the river should be taken. Our results indicate that shallow microhabitats such as backwaters may be important to certain life stages of this species. Even if elevated flows do not initiate reproduction in this species, they do promote maintenance of backwaters and should be considered important to the maintenance of the species.

We recommend that specific studies be conducted with respect to the physiological tolerance of *Notropis girardi* to some of the seemingly important physicochemical parameters such as temperature and current speed. With these data, biologically meaningful limits can be set for the regulation of protected habitats. With respect to the reproductive biology, we suggest experiments to determine the specific behavioral mechanism for spawning events and to examine the reasons for skewed sex ratios in this species. Furthermore, factors affecting the survival of juveniles should be examined more closely. Although our study did not detect a selectivity for specific temperature regimes, it is possible that the number of juveniles recruited into the adult population may be dependent upon the degree of survival of some physiological or ecological bottleneck in the late summer.

There is a growing awareness (Schlosser, 1991, 1995) that the aquatic "landscape" (i.e., all of the features of the riverine environment present) is important to species. Thus, if most or all of the available habitats are being used during the life cycle of *Notropis girardi*, the entire "landscape" of the South Canadian River should be maintained through continued flow, allowing peaks and avoiding "no flow" conditions as much as possible.

V. LITERATURE CITED

Bestgen, K. R., S. P. Platania, J. E. Brooks, and D. L. Propst. 1989. Dispersal and life history traits of *Notropis girardi* (Cypriniformes: Cyprinidae) introduced into the Pecos River, New Mexico. *Am. Midl. Nat.* 122: 228-235.

Heins, D. C. 1985. Life history traits of the Florida sand darter, *Ammocrypta bifascia*, and comparisons with the Naked sand darter, *Ammocrypta beani*. Amer. Midl. Nat. 113:209-223.

Moore, G. A. 1944. Notes on the early life history of *Notropis girardi*. Copeia 1944:209-214.

Schlosser, I. J. 1991. Stream fish ecology -- a landscape perspective. Bioscience 41:704-712.

Schlosser, I. J. 1995. Critical landscape attributes that influence fish population dynamics in headwater streams. Hydrobiologia 303:71-81.

V. SIGNIFICANT DEVIATIONS: None

VI. PREPARED BY: ______________________

Karl M. Polivka, Graduate Research Assistant
William J. Matthews, Job Leader
University of Oklahoma (Dept. of Zoology and Biological Station)

DATE: 10 February 1997

VII. APPROVED BY: ______________________

Harold Namminga, Federal Aid Coordinator
Oklahoma Department of Wildlife Conservation
Oklahoma City, Oklahoma 73105

APPENDIX 1 -- FIGURE CAPTIONS

Figure 1. Ordination diagram for canonical correspondence analysis of samples taken in 1994-95. Eigenvalues for the two axes represented are 0.192 (horizontal) and 0.118 (vertical). Species abbreviations are given in Appendix 2; environmental variable abbreviations are given in Appendix 3.

Figure 2. Ordination diagram for canonical correspondence analysis of samples taken in 1995-96. Eigenvalues for the two axes represented are 0.245 (horizontal) and 0.069 (vertical). Species abbreviations are given in Appendix 2; environmental variable abbreviations are given in Appendix 3.

Figure 3. Seasonal associations of adult *Notropis girardi* with subjectively defined microhabitat categories. For each category, the difference between the observed number of individuals and the expected number of individuals (based on sampling frequency) is plotted on the ordinate. Significance applies to a chi-square test of independence (sample sizes: N = 551, fall; N = 1565, winter; N = 764, spring; N = 500, summer).

Figure 4. Seasonal associations of juvenile *Notropis girardi* with subjectively defined microhabitat categories. For each category, the difference between the observed number of individuals and the expected number of individuals (based on sampling frequency) is plotted on the ordinate. Significance applies to a chi-square test of independence (N = 1950).

Figure 5. Seasonal associations of adult *Notropis girardi* with defined ranges of temperature encountered during the study. For each category, the difference between the observed number of individuals and the expected number of individuals (based on sampling frequency) is plotted on the ordinate. Significance applies to a chi-square test of independence (sample sizes: N = 551, fall; N = 1565, winter; N = 764, spring; N = 500, summer). [* = inconsistent -- not repeatable at an individual locality; ** = discontinuous -- statistically significant distribution over a discontinuous set of values]

Figure 6. Seasonal associations of adult *Notropis girardi* with defined ranges of conductivity encountered during the study. For each category, the difference between the observed number of individuals and the expected number of individuals (based on sampling frequency) is plotted on the ordinate. Significance applies to a chi-square test of independence (sample sizes: N = 551, fall; N = 1565, winter; N = 764, spring; N = 500, summer). [* = inconsistent -- not repeatable at an individual locality; ** = discontinuous -- statistically significant distribution over a discontinuous set of values]

Figure 7. Seasonal associations of adult *Notropis girardi* with defined ranges of dissolved oxygen encountered during the study. For each category, the difference between the observed number of individuals and the expected number of individuals (based on sampling frequency) is plotted on the ordinate. Significance applies to a chi-square test of independence (sample sizes: N = 551, fall; N = 1565, winter; N = 764, spring; N = 500, summer). [* = inconsistent -- not repeatable at

an individual locality; ** = discontinuous -- statistically significant distribution over a discontinuous set of values]

Figure 8. Seasonal associations of adult *Notropis girardi* with defined ranges of pH encountered during the study. For each category, the difference between the observed number of individuals and the expected number of individuals (based on sampling frequency) is plotted on the ordinate. Significance applies to a chi-square test of independence (sample sizes: N = 551, fall; N = 1565, winter; N = 764, spring; N = 500, summer). [* = inconsistent -- not repeatable at an individual locality; ** = discontinuous -- statistically significant distribution over a discontinuous set of values]

Figure 9. Seasonal associations of juvenile *Notropis girardi* with defined ranges of environmental variables encountered during the study. For each category, the difference between the observed number of individuals and the expected number of individuals (based on sampling frequency) is plotted on the ordinate. Significance applies to a chi-square test of independence (N = 1950). [* = inconsistent -- not repeatable at an individual locality; ** = discontinuous -- statistically significant distribution over a discontinuous set of values]

Figure 10. Gonadosomatic index (GSI) and daily discharge (cubic feet per second) plotted for each day of the reproductive season in 1996. Mean GSI values (range = 0.035-0.07) for a given sampling date are reported for that day (N = 87). The beginning and end of each month of the sampling period is given to orient the numbers assigned on the abscissa to each day of the sampling period.

Figure 11. The proportion of individuals assigned to each reproductive condition category (see Table 8) during each month of the sampling period. Values for all sampling occasions in a given month were pooled for this analysis (N = 87).

Figure 12. Sex ratios for each month of the sampling period. All individuals from each sampling occasion were pooled for this analysis (N = 87).

Figure 13. Mean stomach fullness index (SFI) for a 24-hour interval. No significant differences were found (N = 41, p = 0.063 by Kruskall-Wallis).

Figure 14. Gross approximation of dietary composition of N = 42 individuals (inverts = invertebrate prey items).

APPENDIX 2 -- SPECIES ABBREVIATIONS IN ORDINATION DIAGRAMS

notgir	*Notropis girardi*	Arkansas River shiner
juvgir	juvenile *N. girardi*	juvenile Ark. River shiner
gamaff	*Gambusia affinis*	mosquitofish
hybpla	*Hybognathus placitus*	plains minnow
cyprub	*Cyprinodon rubrofluviatilis*	Red River pupfish
pimvig	*Pimephales vigilax*	bullhead minnow
notstr	*Notropis stramineus*	sand shiner
carcar	*Carpiodes carpio*	river carpsucker
ictpun	*Ictalurus punctatus*	channel catfish
funzeb	*Fundulus zebrinus*	plains killifish
notath	*Notropis atherinoides*	emerald shiner
cyplut	*Cyprinella lutrensis*	red shiner

Table A2-1. Complete collection results, as number of individuals per species, for samples analyzed in this report. Seasons are pooled across the entire sampling period, August 1994-August 1996 (fall = fall, wint = winter, spri = spring, summ = summer) and data are reported for each sampling locality, N (e.g., fall-N).

Season	cyplut	hybpla	notath	notgir	gamaff	funzeb	pimvig	carcar	notstr	ictpun	cyprub	juvgir
fall-1	1443	3	38	103	0	0	6	0	6	0	0	0
fall-2	80	2	11	16	0	12	0	0	0	0	5	0
fall-3	217	4	72	432	0	0	0	0	1	1	0	3
wint-1	46	12	21	623	0	0	0	0	0	0	4	0
wint-2	112	10	49	216	0	0	0	0	1	0	0	0
wint-3	602	7	15	726	0	0	0	0	0	0	1	0
spri-1	1753	18	150	460	0	2	20	1	3	2	6	1
spri-2	1232	13	148	52	25	1	3	2	0	0	0	7
spri-3	869	18	61	252	130	0	38	8	0	0	0	226
summ-1	1648	8	51	275	96	0	33	74	3	9	0	618
summ-2	1585	2	13	95	42	0	7	12	3	2	0	577
summ-3	2247	46	75	130	122	0	8	1	0	2	0	518

APPENDIX 3 -- Abbreviations of environmental variables used in multivariate ordinations.

current	current speed
TDS	conductivity
Temp	temperature
isld	island microhabitat type
sndrdg	sand ridge microhabitat type
bkwtr	backwater microhabitat type
bank	bank microhabitat type
midch	midchannel microhabitat type
pool	pool microhabitat type
DO	dissolved oxygen
pH	pH

Table 1. Legal description of the sampling localities where all fieldwork was conducted in this study

Locality	SE	Section	Township	Range	County
1	SE/4	2	8N	3W	Cleveland
2	SE/4	18	8N	2W	Cleveland
3	SE/4	6 and 7	6N	1W	Cleveland

(Locality 1 - SE 24th Ave., Norman; Locality 2 - South Jenkins, Norman; Locality 3 - Lexington/Purcell Bridge)

Table 2. Environmental parameters associated with the abundance of juvenile and adult *Notropis girardi* in canonical correspondence analysis (X= associated with distribution).

Factor	Year 1		Year 2	
	Adults	Juveniles	Adults	Juveniles
current		X	X	
depth	X			
dissolved oxygen	X			
conductivity		X		
pH				
temperature				
sandridges				
banks				
islands		X		
pools				
midchannels	X		X	
backwaters				X

Table 3. Results of chi square tests across all sampling occasions of the influence of individual physicochemical variables on microhabitat selection by adult *Notropis girardi.*

Factor	Significant effect?	Associations
Temperature	Yes ($p < 0.01$)	7-18 degrees C
pH	No	----------
Conductivity	Yes ($p < 0.01$)	1000-1300 mmho
Dissolved Oxygen	Yes ($p < 0.01$)	10.0-13.0 mg/l
Depth + Current	Yes ($p < 0.01$)	0-50 cm depth; 0-100 cm/s current
Habitat Type	Yes ($p < 0.01$)	Bank, island, sandridge, midchannel

Table 4. Results of chi square tests at the individual season + locality level of the influence of individual physicochemical variables on microhabitat selection by adult *Notropis girardi*.

Factor	Significant effect?	Associations
Temperature	Yes ($p < 0.01$)	avoids temp.< 9-12 degrees C in winter avoids temp.> 31 degrees C in late spring
pH	inconsistent	----------
Conductivity	inconsistent	1000-1300 mmho (1600 in summer), but not repeatable by locality
Dissolved Oxygen	discontinuous	-----------
Depth + Current	Yes ($p < 0.01$)	0-50 cm depth; 0-100 cm/s current
Habitat Type	Yes ($p < 0.01$)	"bank" and "backwaters" in winter, "island" and "sandridge" in fall, spring, summer

Table 5. Results of chi square tests of the influence of individual physicochemical variables on microhabitat selection by juvenile *Notropis girardi.*

Factor	Significant effect?	Associations
Temperature	Yes ($p < 0.01$)	25-36 degrees C
pH	inconsistent	8.6-9.0, but not repeatable
Conductivity	inconsistent	1000-1300 mmho, 1600-2200 mmho, but not repeatable by locality
Dissolved Oxygen	discontinuous	7.0-8.0, 13.1-14.0, 15.1-16, 17.1-18.0
Depth + Current	Yes ($p < 0.01$)	0-50 cm depth (esp. 0-25 cm) 0-100 cm/s current
Habitat Type	Yes ($p < 0.01$)	Bank, sandridge, backwaters

inconsistent = not repeatable at the scale of one locality
discontinuous = statistically significant, but distribution occurs in several discontinuous values of the given variable

Table 6. The seasonal distribution of adult *Notropis girardi* individuals with respect to defined categories of the combinations of depth and current speed shown. Values represent the difference between the number of individuals observed and the expected number of individuals (based on sampling frequency) in each category. For all seasons, $p<0.01$ by chi-square test of independence.

FALL — **Current (cm/s)**

Depth (cm)	0-25	26-50	51-75	76-100
0-25	-35	2	21	X
26-50	-37	53	26	-3
51-75	X	-13	-5	-1
76-100	X	X	-7	X

WINTER — **Current (cm/s)**

Depth (cm)	0-25	26-50	51-75	76-100
0-25	108	-102	27	X
26-50	38	-189	-75	191
51-75	X	3	X	X
76-100	X	X	X	X

SPRING — **Current (cm/s)**

Depth (cm)	0-25	26-50	51-75	76-100
0-25	-60	-38	-6	X
26-50	130	23	-3	2
51-75	-9	-6	-22	3
76-100	X	-8	X	X

SUMMER — **Current (cm/s)**

Depth (cm)	0-25	26-50	51-75	76-100
0-25	-25	62	-37	-5
26-50	9	1	-12	-6
51-75	-4	-5	17	14
76-100	X	-5	-5	X

Table 7. The seasonal distribution of juvenile *Notropis girardi* individuals with respect to defined categories of the combinations of depth and current speed shown. Values represent the difference between the number of individuals observed and the expected number of individuals (based on sampling frequency) in each category. For all seasons, $p<0.01$ by chi-square test of independence.

		Juvenile Current (cm/s)			
		0-25	26-50	51-75	76-100
Depth (cm)	0-25	110	132	-16	X
	26-50	-237	-24	226	-179
	51-75	13	-23	-16	11
	76-100	X	X	X	X

Table 8. Conditions for classification of reproductive conditon in *Notropis girardi*.

Stage	Condition
0	Ovaries small, undeveloped ova usually not present or small, few in number and transparent.
1	Ovaries developed with numerous developing, but still immature ova, or mostly spent ova with a few mature ova in the distal part of the ovaries
2	Mature ova becoming translucent, but moderate in size and number
3	Ovaries extremely large, filling most of the body cavity and distending the abdomen. Completely mature ova, large, very numerous (> 100)

(adapted from Heins, 1985)

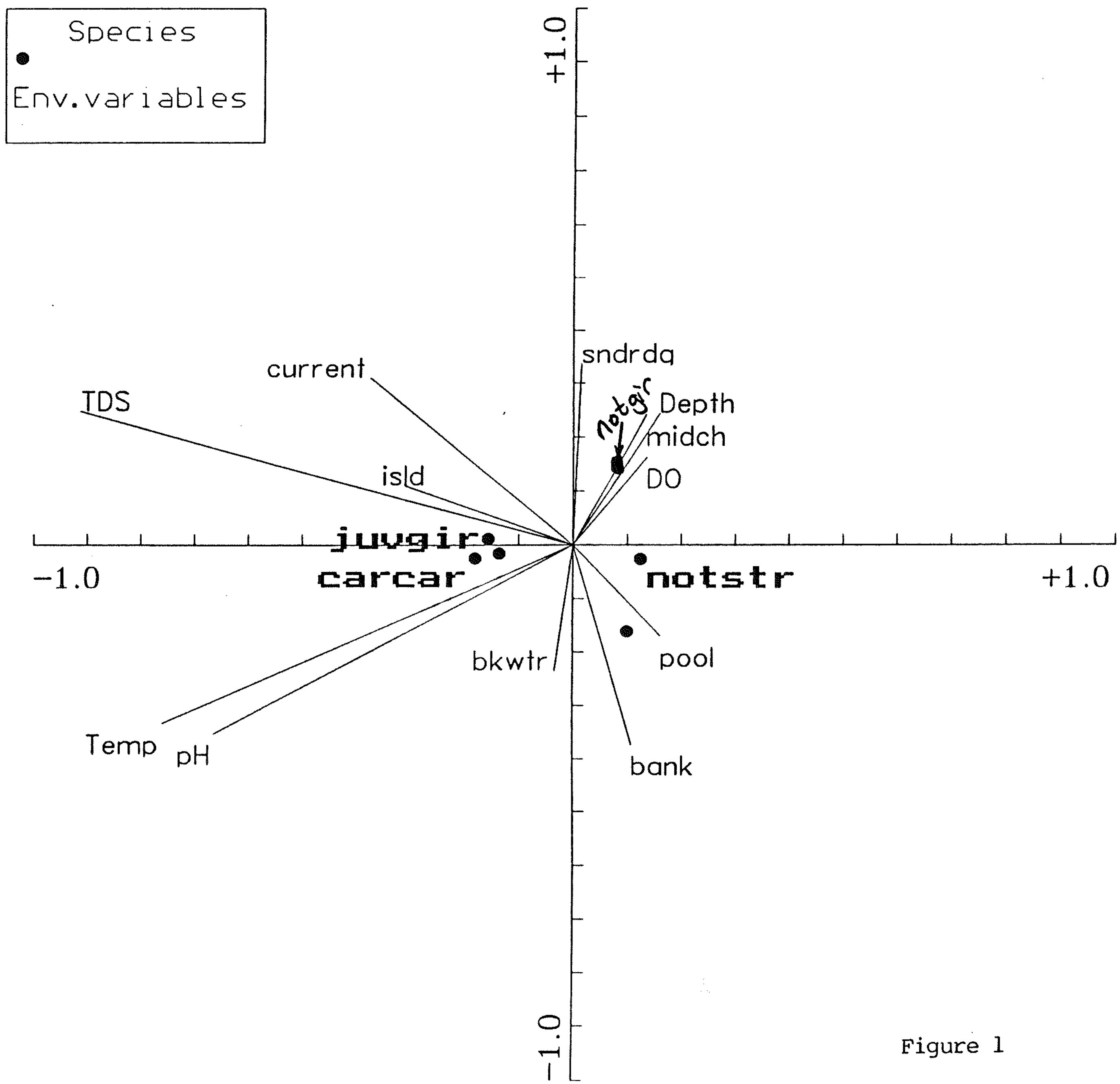
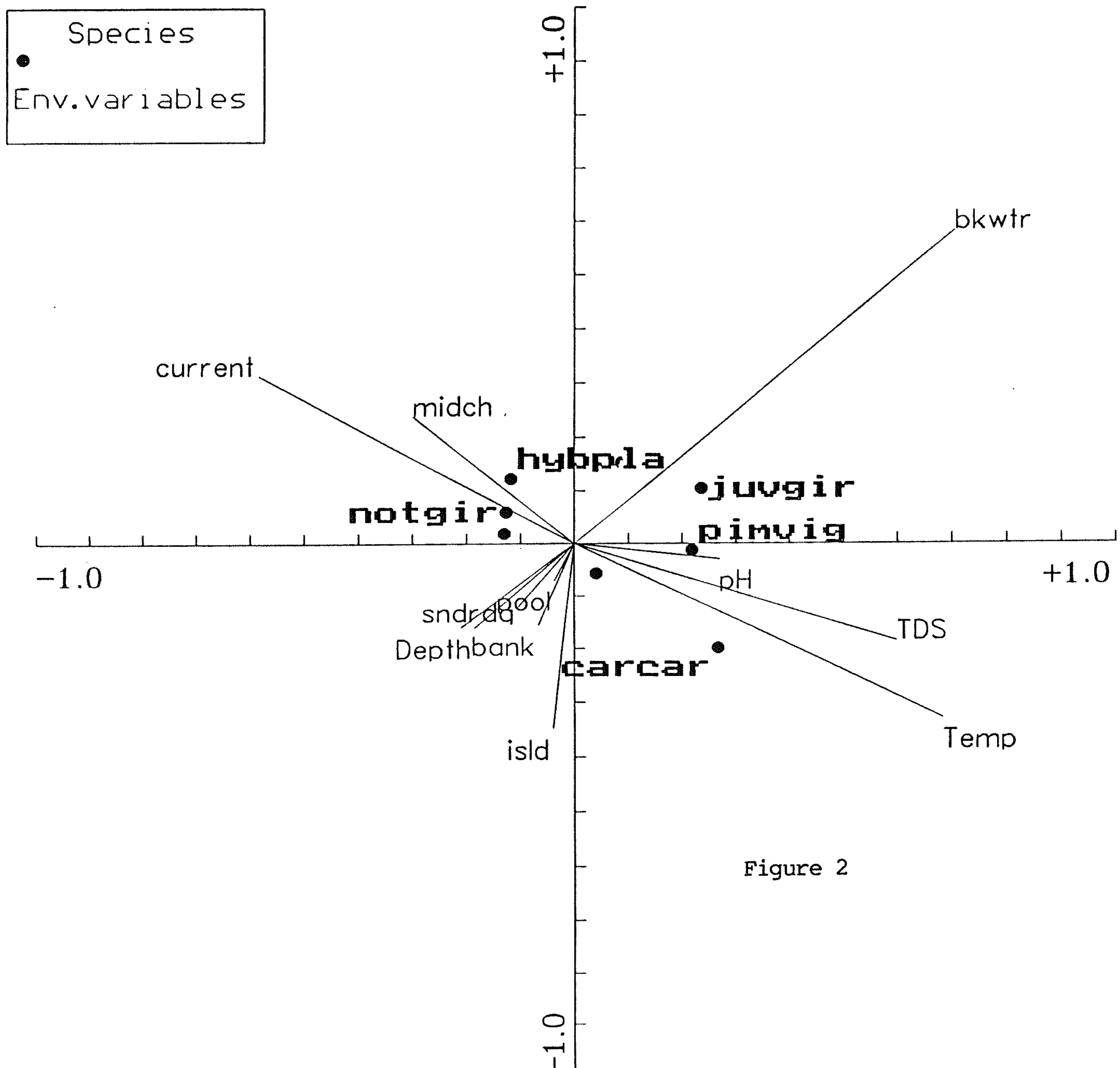

Species
Env.variables
+1.0
-1.0
-1.0
+1.0
current
TDS
isld
sndrdq
Depth
midch
DO
juvgir
carcar
notstr
bkwtr
pool
Temp
pH
bank

Figure 1



Species
Env.variables
+1.0
-1.0
+1.0
-1.0
bkwtr
current
midch
hybpla
juvgir
notgir
pimvig
pH
pool
sndrdg
Depthbank
TDS
carcar
isld
Temp

Figure 2

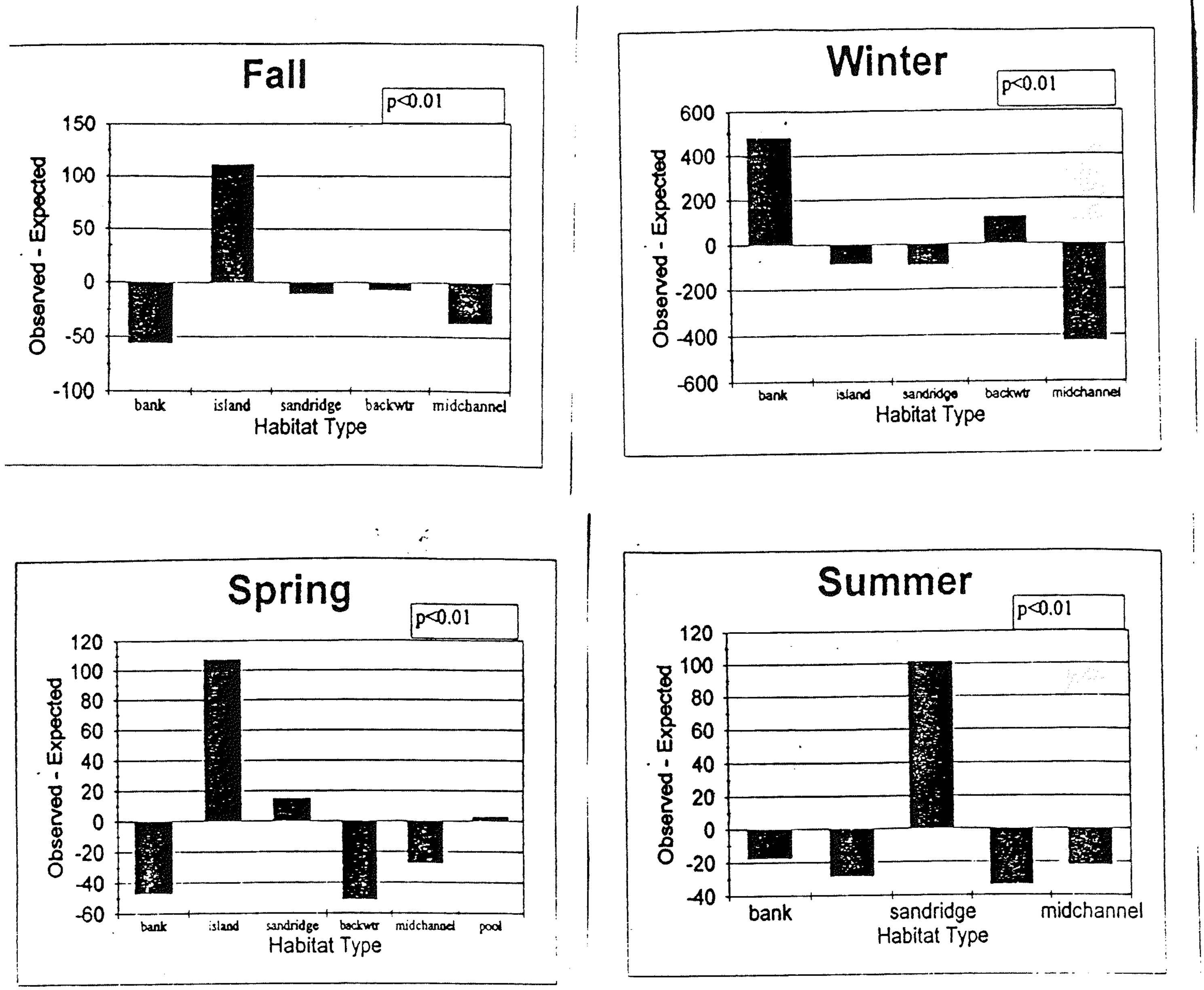

Fall
p<0.01
150
100
50
0
-50
-100
Observed - Expected
bank
island
sandridge
backwtr
midchannel
Habitat Type
Winter
p<0.01
600
400
200
0
-200
-400
-600
Observed - Expected
bank
island
sandridge
backwtr
midchannel
Habitat Type
Spring
p<0.01
120
100
80
60
40
20
0
-20
-40
-60
Observed - Expected
bank
island
sandridge
backwtr
midchannel
pool
Habitat Type
Summer
p<0.01
120
100
80
60
40
20
0
-20
-40
Observed - Expected
bank
sandridge
midchannel
Habitat Type

Figure 3

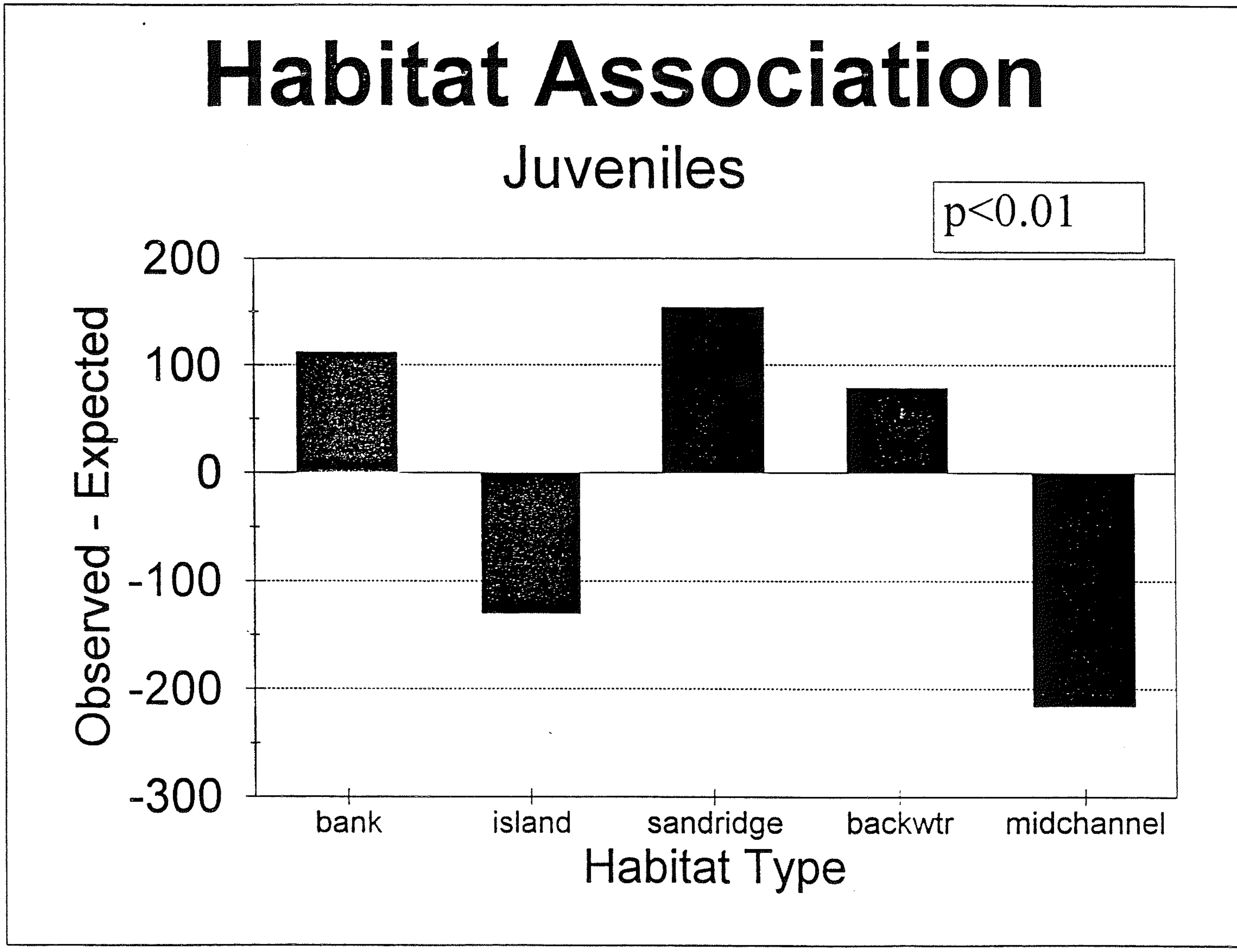

Habitat Association
Juveniles
p<0.01
200
100
0
-100
-200
-300
Observed - Expected
bank
island
sandridge
backwtr
midchannel
Habitat Type

Figure 4

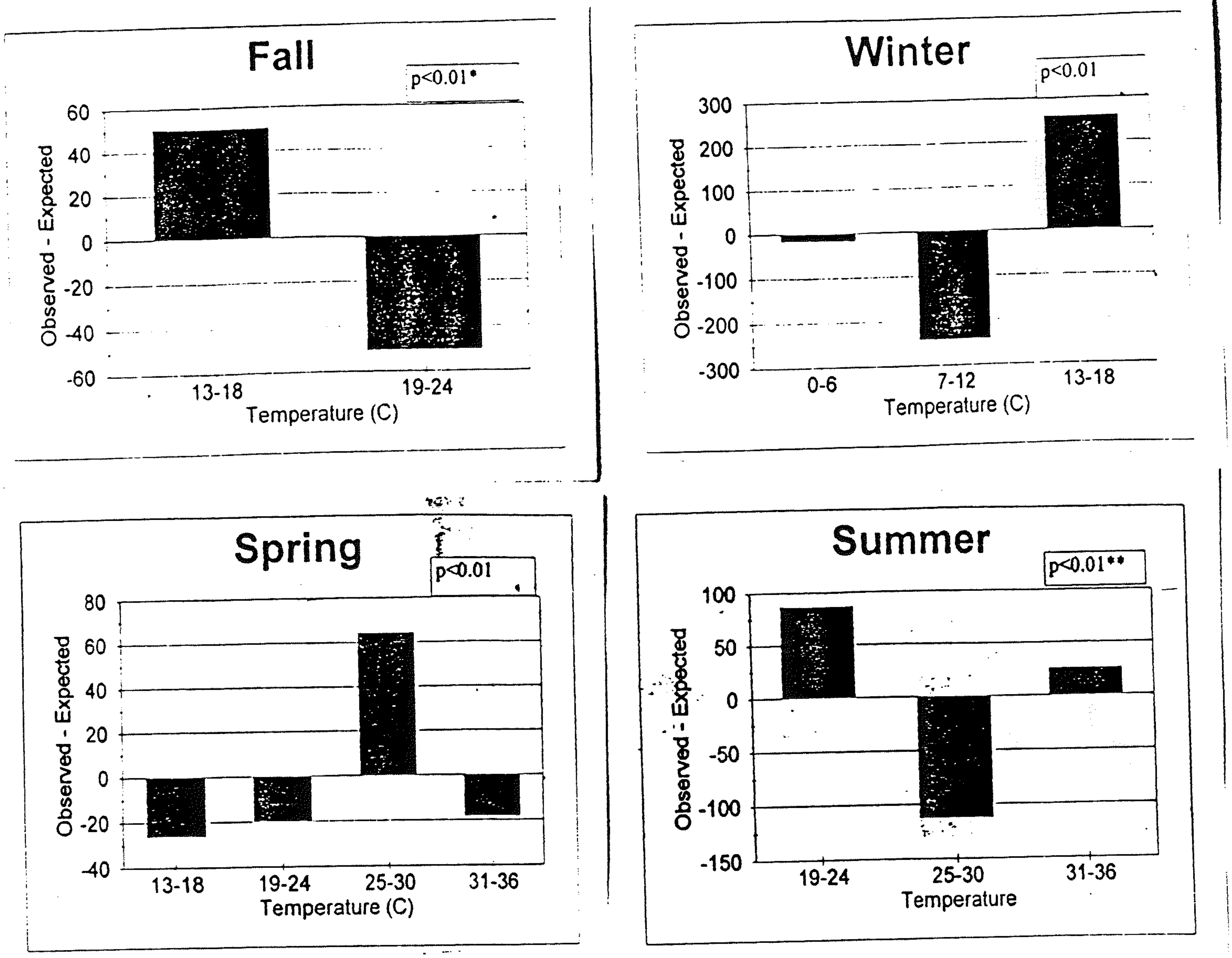

Fall
p<0.01*
60
40
20
0
-20
-40
-60
Observed - Expected
13-18
19-24
Temperature (C)
Winter
p<0.01
300
200
100
0
-100
-200
-300
Observed - Expected
0-6
7-12
13-18
Temperature (C)
Spring
p<0.01
80
60
40
20
0
-20
-40
Observed - Expected
13-18
19-24
25-30
31-36
Temperature (C)
Summer
p<0.01**
100
50
0
-50
-100
-150
Observed - Expected
19-24
25-30
31-36
Temperature

Figure 5

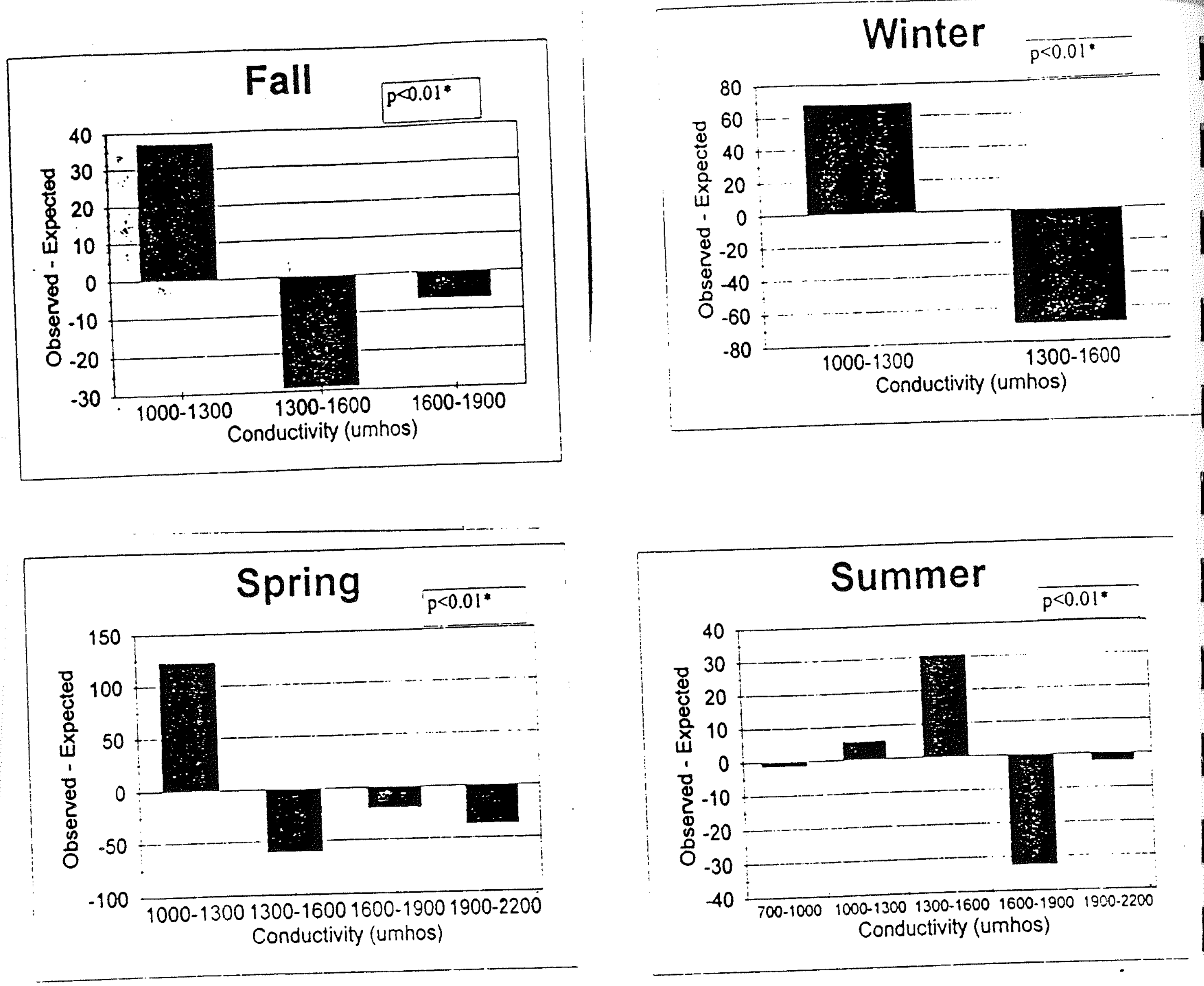
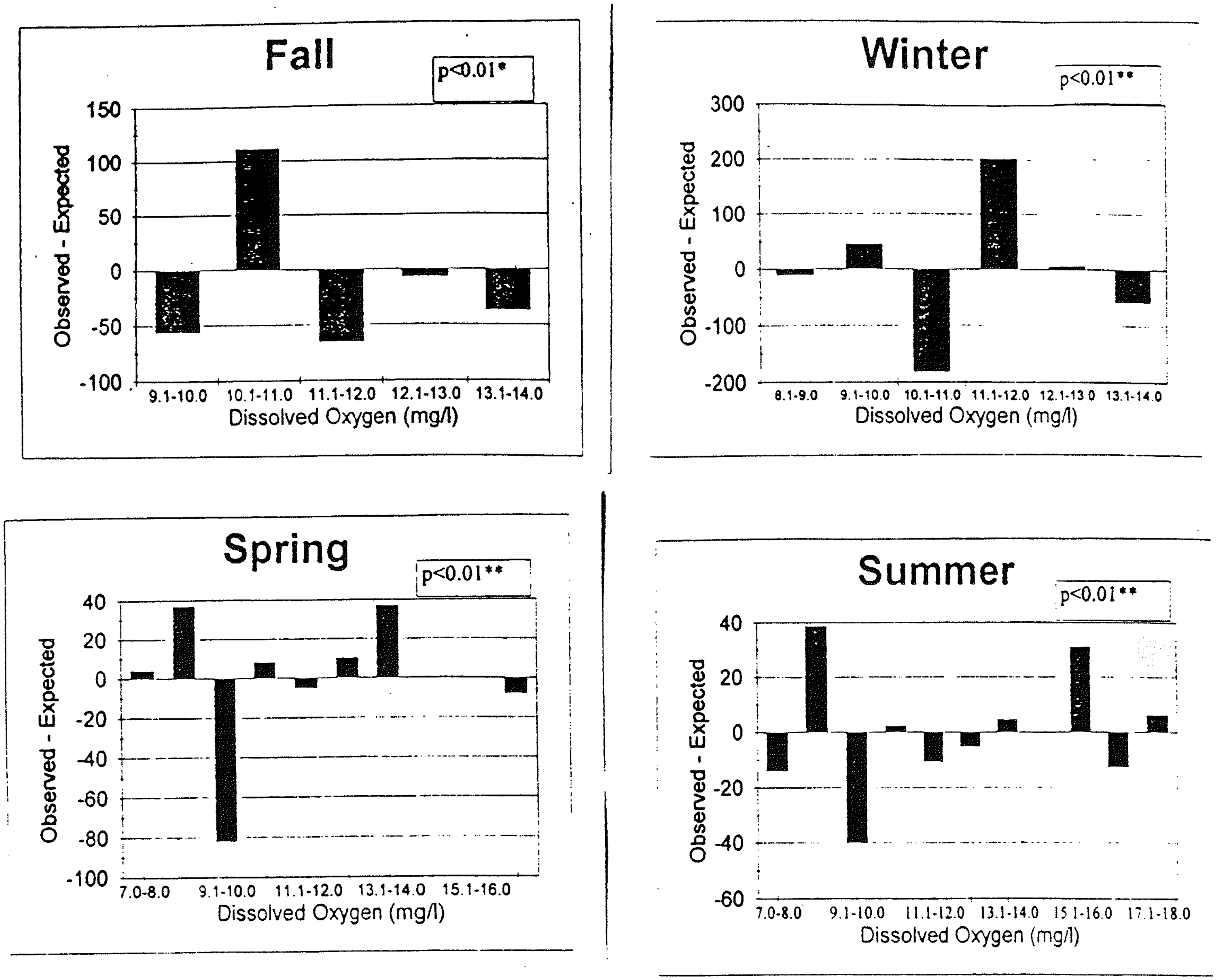

Fall
p<0.01*
Observed - Expected
40
30
20
10
0
-10
-20
-30
1000-1300
1300-1600
1600-1900
Conductivity (umhos)
Winter
p<0.01*
80
60
40
20
0
-20
-40
-60
-80
1000-1300
1300-1600
Spring
p<0.01*
150
100
50
-50
-100
1900-2200
Summer
700-1000

Figure 6



Fall
p<0.01*
150
100
50
0
-50
-100
Observed - Expected
9.1-10.0
10.1-11.0
11.1-12.0
12.1-13.0
13.1-14.0
Dissolved Oxygen (mg/l)
Winter
p<0.01**
300
200
100
0
-100
-200
Observed - Expected
8.1-9.0
9.1-10.0
10.1-11.0
11.1-12.0
12.1-13.0
13.1-14.0
Dissolved Oxygen (mg/l)
Spring
p<0.01**
40
20
0
-20
-40
-60
-80
-100
Observed - Expected
7.0-8.0
9.1-10.0
11.1-12.0
13.1-14.0
15.1-16.0
Dissolved Oxygen (mg/l)
Summer
p<0.01**
40
20
0
-20
-40
-60
Observed - Expected
7.0-8.0
9.1-10.0
11.1-12.0
13.1-14.0
15.1-16.0
17.1-18.0
Dissolved Oxygen (mg/l)

Figure 7

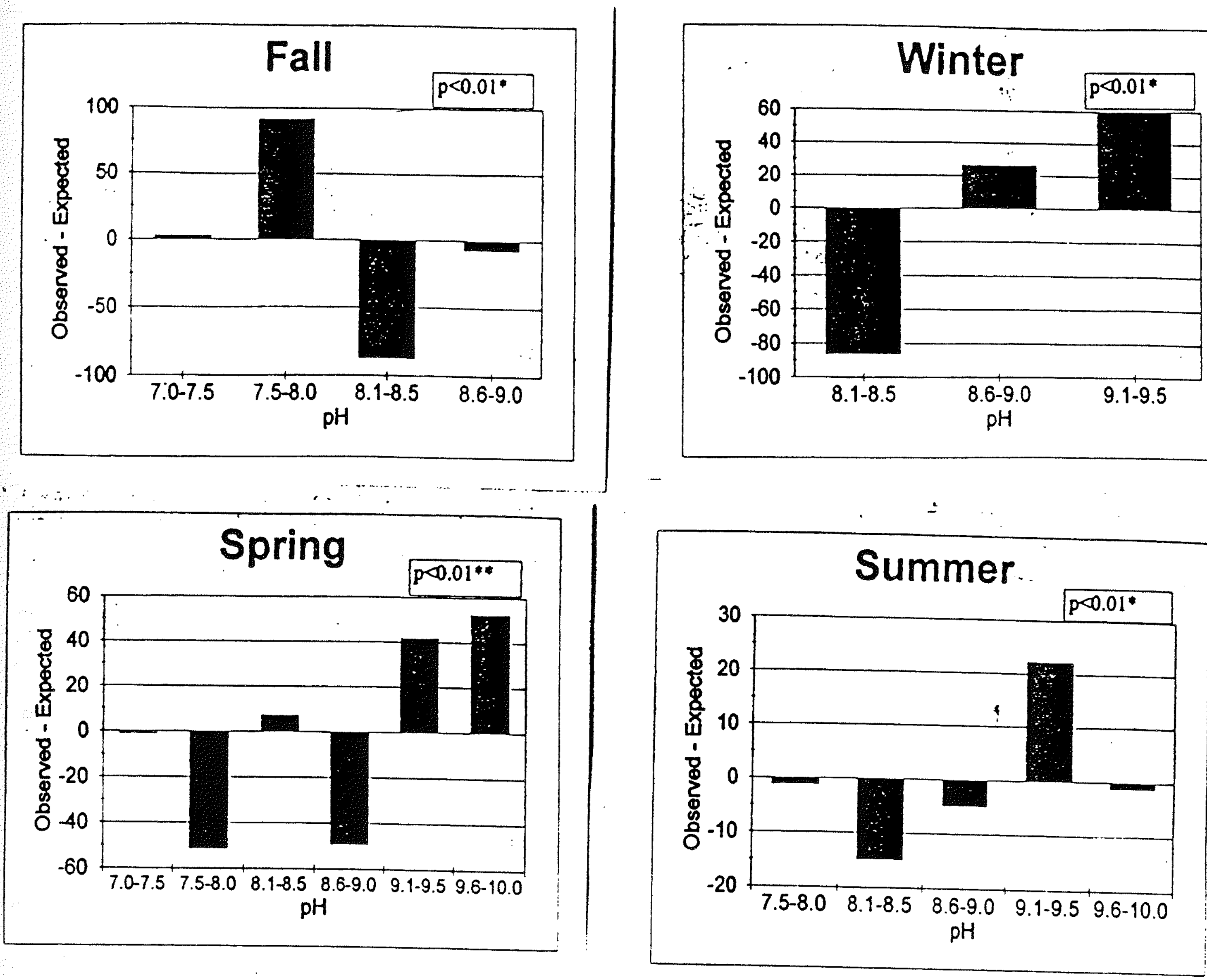

Fall
p<0.01*
100
50
0
-50
-100
Observed - Expected
7.0-7.5
7.5-8.0
8.1-8.5
8.6-9.0
pH
Winter
p<0.01*
60
40
20
0
-20
-40
-60
-80
-100
Observed - Expected
8.1-8.5
8.6-9.0
9.1-9.5
pH
Spring
p<0.01**
60
40
20
0
-20
-40
-60
Observed - Expected
7.0-7.5
7.5-8.0
8.1-8.5
8.6-9.0
9.1-9.5
9.6-10.0
pH
Summer
p<0.01*
30
20
10
0
-10
-20
Observed - Expected
7.5-8.0
8.1-8.5
8.6-9.0
9.1-9.5
9.6-10.0
pH

Figure 8

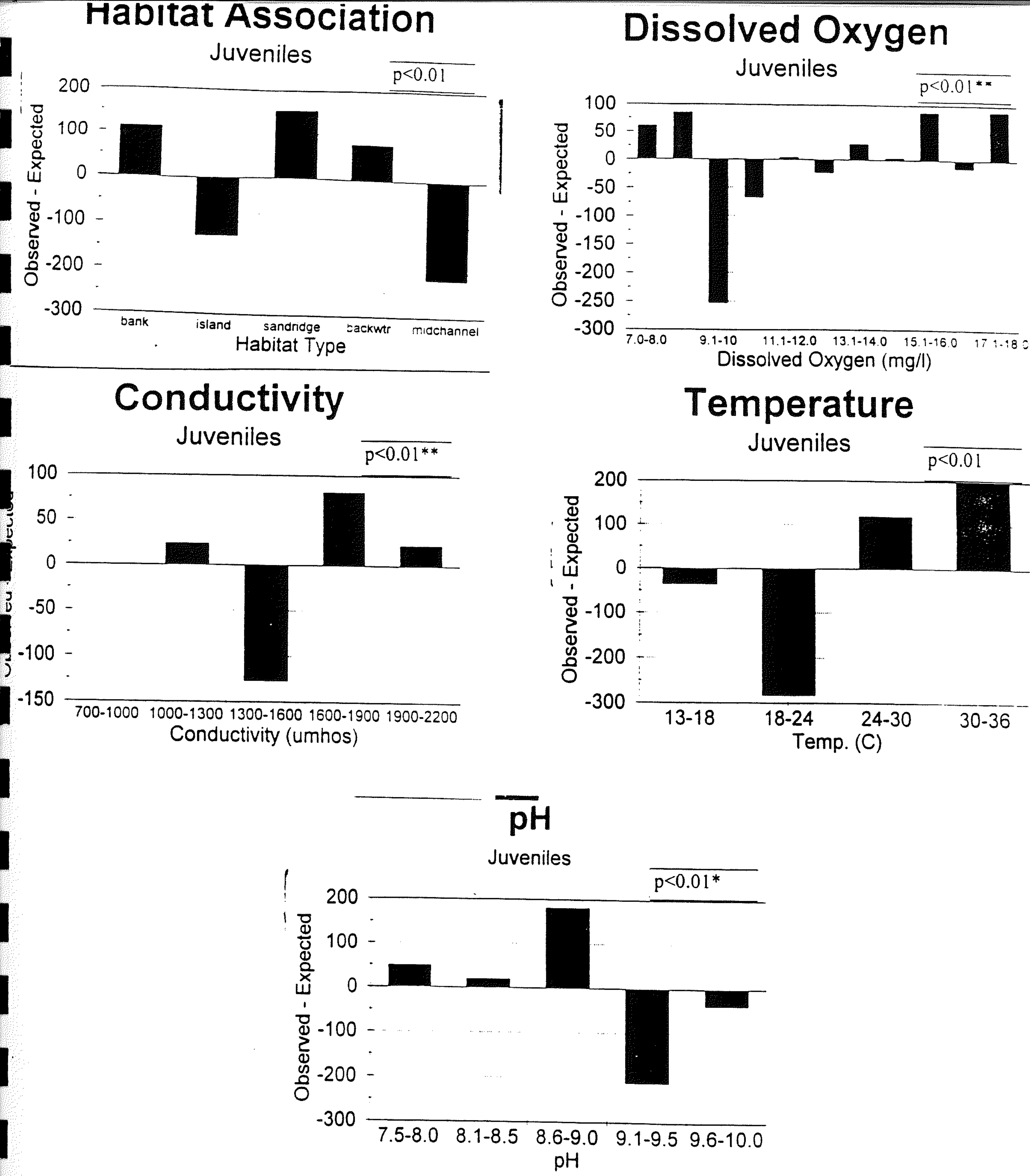

Habitat Association
Juveniles
p<0.01
Observed - Expected
200
100
0
-100
-200
-300
bank
island
sandridge
backwtr
midchannel
Habitat Type
Dissolved Oxygen
Juveniles
p<0.01**
Observed - Expected
100
50
0
-50
-100
-150
-200
-250
-300
7.0-8.0
9.1-10
11.1-12.0
13.1-14.0
15.1-16.0
17.1-18.0
Dissolved Oxygen (mg/l)
Conductivity
Juveniles
p<0.01**
100
50
0
-50
-100
-150
700-1000
1000-1300
1300-1600
1600-1900
1900-2200
Conductivity (umhos)
Temperature
Juveniles
p<0.01
Observed - Expected
200
100
0
-100
-200
-300
13-18
18-24
24-30
30-36
Temp. (C)
pH
Juveniles
p<0.01*
Observed - Expected
200
100
0
-100
-200
-300
7.5-8.0
8.1-8.5
8.6-9.0
9.1-9.5
9.6-10.0
pH

Figure 9

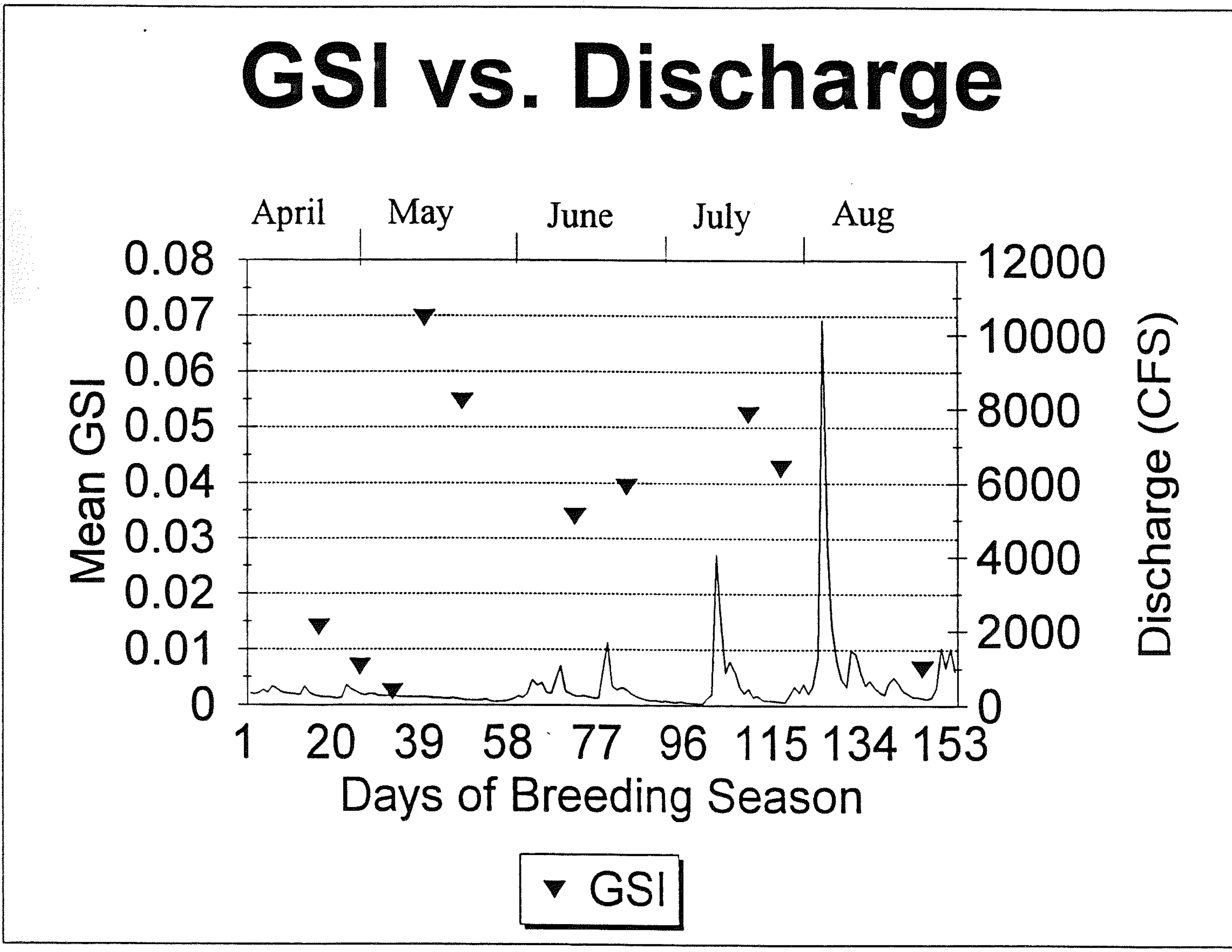

GSI vs. Discharge
April
May
June
July
Aug
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
Mean GSI
12000
10000
8000
6000
4000
2000
0
Discharge (CFS)
1
20
39
58
77
96
115
134
153
Days of Breeding Season
GSI

Figure 10

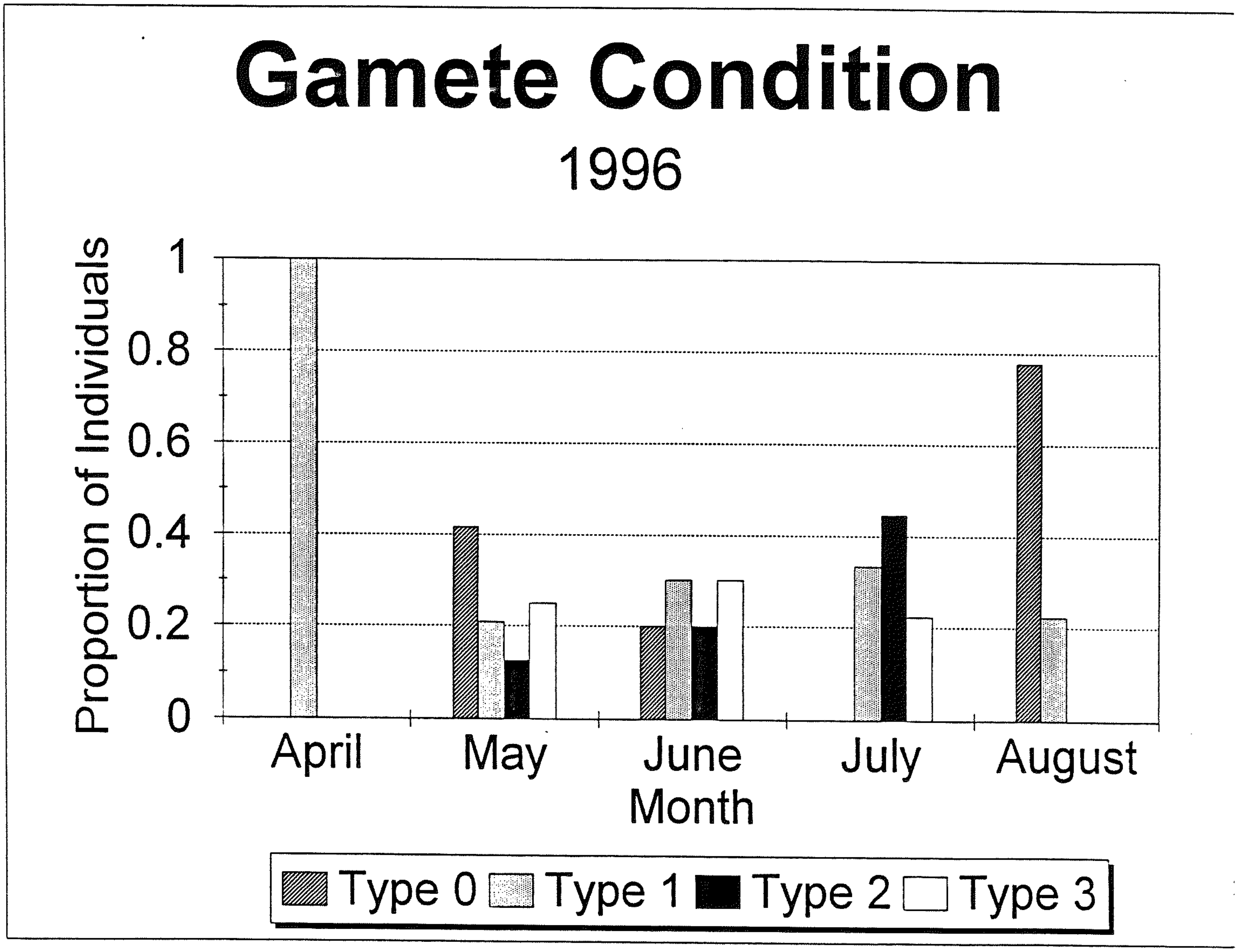
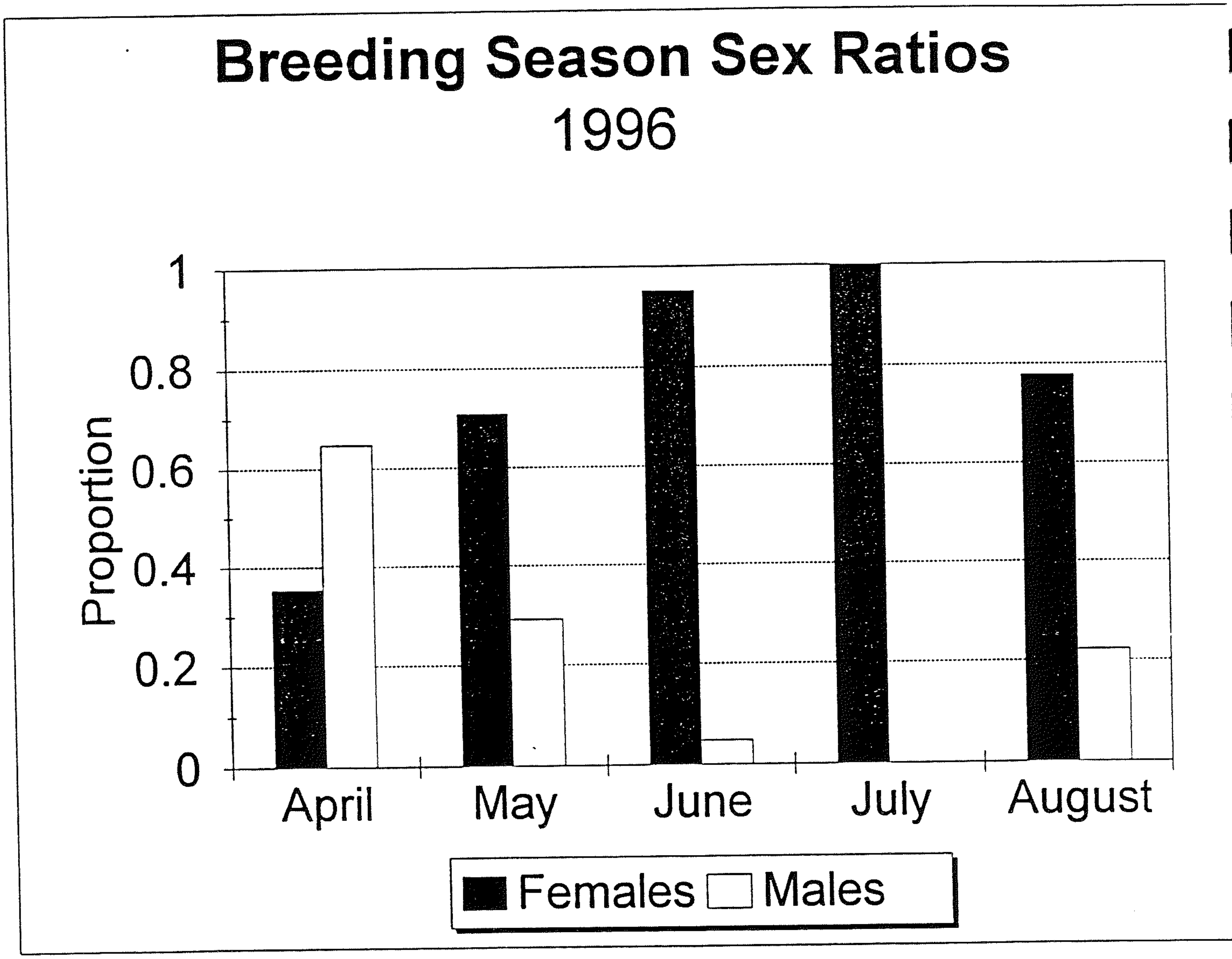

Gamete Condition
1996
Proportion of Individuals
1
0.8
0.6
0.4
0.2
0
April
May
June
July
August
Month
Type 0
Type 1
Type 2
Type 3

Figure 11



Breeding Season Sex Ratios
1996
Proportion
1
0.8
0.6
0.4
0.2
0
April
May
June
July
August
Females
Males

Figure 12

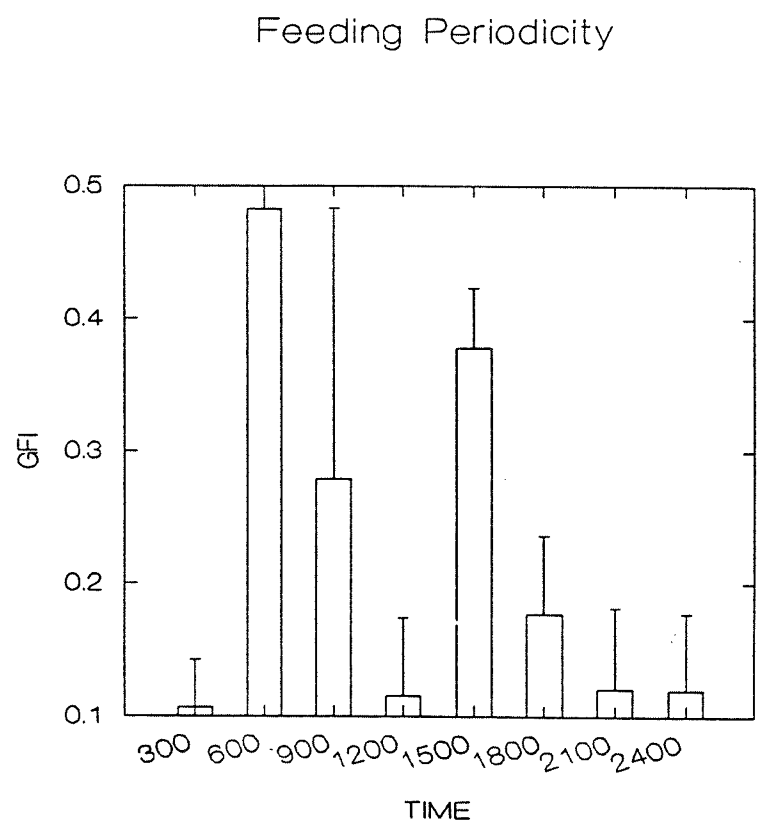

Feeding Periodicity
0.5
0.4
0.3
0.2
0.1
GFI
300
600
900
1200
1500
1800
2100
2400
TIME

Figure 13

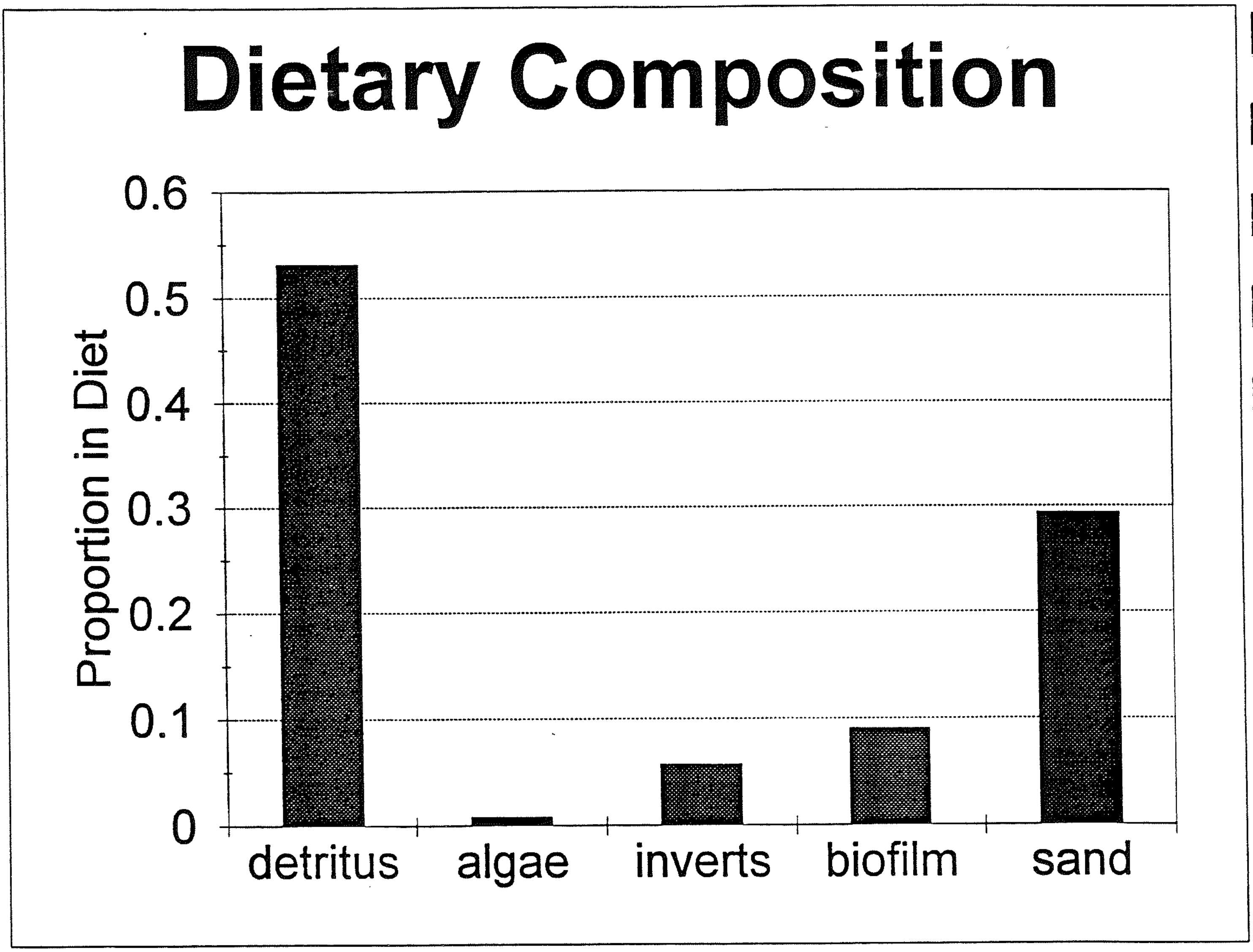

Dietary Composition
Proportion in Diet
0.6
0.5
0.4
0.3
0.2
0.1
0
detritus
algae
inverts
biofilm
sand

Figure 14