A Meta-Analysis and Synthesis of Existing Information on Higher Trophic Levels In Florida Bay (Model Validation and Prediction)

Final Report on Year 2 of a Two-Year Project
Cooperative Agreement #IA5280-9-9030

To
Everglades National Park
40001 State Road 9336
Homestead, FL 33034

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Darlene Johnson, Joan A. Browder, Doug Harper, and Steven Wong
Southeast Fisheries Science Center
National Marine Fisheries Service
75 Virginia Beach Drive
Miami, Florida 33149

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Introduction

In Yr-1 work, models for 11 dominant forage species in Florida Bay were developed to determine major factors determining the density of these species (Johnson et al. 2002). Environmental variables (not including time lags of the same variable) were tested for their ability to explain variation in species density. Salinity and an index of freshwater flow were among the variables tested because these factors can be linked to water management strategies. Yr-2 work consisted of validation of those models using data from a year not used to develop the models and an application demonstrating the potential use of these models predictively to evaluate alternative water management decisions. The demonstration presented in this report supercedes a previous demonstration, prepared for the CESI Workshop, that was performed before model validation. The validation analysis led to a modification of the prediction method. (Note: The 11 species we discuss include the genus *Eucinostomus* spp., which consists of at least two species that are found in Florida Bay and are difficult to distinguish, especially as juveniles. For simplicity and readability we include this genus in the group of 11 taxa that we refer to collectively as "species". Both scientific names and common names for all eleven taxa are given in Appendix Table A-1.)

Improvement in the ecological condition of Florida Bay is a major goal of the Comprehensive Everglades Restoration Project (CERP), yet very few models are available to predict ecological responses to proposed water management changes. The demonstration project proposed a set of models to collectively provide an estimate of the response of Florida Bay's forage fish community to changes in water flow and salinity. A major objective of CERP is to create a freshwater flow regime that benefits the natural communities of native plants and animals of South Florida, including the estuaries. One might suppose that the most supportive water regime would be the one resulting from the system's natural response to rainfall (i.e., without canals and structures), and the general approach of CERP is to develop a hydrologic system that will mimic the natural one. This effort will be assisted by water management models that can simulate water depths and flows under various water management scenarios. Predictive power must be extended to include the response of natural ecosystems to hydrologic predictions in order to ensure that biological systems will benefit from this effort.

The forage community in Florida Bay might be an ideal indicator of ecological response to change in water management for several reasons. This group consists of small species that are easily caught and relatively short-lived and will respond quickly to environmental conditions. The abundance of forage species is probably an indication of the relative abundance of the predator fish that depend upon them for prey but whose abundance cannot be determined as accurately.

The models developed in this project can potentially represent the forage community as a whole because the forage community consists primarily of the 11 species covered by the models. These 11 species comprised 87% of the throw trap samples by number for 1984-1986 (Sogard et al. 1989) and 87.5% for 1994-1996 (Matheson et al. 1999). For the trawl samples, the 11-species group comprised 86.4% of the 1980's and 89% of the 1990's samples collected by the Beaufort Laboratory (Thayer et. 1987); Thayer et al. 1999). The group comprised 73.6% of the seine samples and 65.5% of the trawl samples collected by FMRI during the 1990's (excluding all invertebrates except pink shrimp). During the 1970's the 11-species group comprised 63.5% of the samples (combined trawl and seine results) for the western Bay, 91.5% of the samples in the central Bay, and 38.7% of the samples for the eastern Bay (Schmidt 1979). This summary was derived from raw data for FMRI and from reports for Schmidt, Beaufort, Sogard, and Matheson's studies.

Models of the 11 forage species provide a means to evaluate ecological responses to freshwater flow, rainfall, and resulting salinity through correlative relationships evident in an extensive database compiled from several studies. The models demonstrate a link between salinity and biological responses and identify salinity optima for individual species and the 11-species forage community as a whole. These models of forage fish density were developed based on three decades of historic data. The data include wet and dry years and years of moderate conditions that might provide a good baseline from which to evaluate species responses. The cumulative model results have the potential to be linked to the output of water management models to determine the potential effect of water management strategies on the Florida Bay ecosystem.

These models also demonstrate a link between seagrass communities and forage species. Because seagrass type and seagrass density were included in the models as variables, the models are able to evaluate secondary effects of shifts in seagrass communities. For instance, the models could be used to predict how the 75:25 (*Thalassia:Halodule*) proposed seagrass targets might affect fish communities.

The forage fish models also could be used to help interpret the results from monitoring programs. Because of year-to-year variation in rainfall, it will be difficult to determine, with data for just a few years, whether monitoring results are due to rainfall variation or a change in water management. The forage fish models could potentially be used to help distinguish differences due to water management from those due to differences in rainfall.

Methodology

Data Sources and Development

Environmental and habitat variables that might influence the density of forage species in time and space were compiled for possible inclusion in the models. Potential independent variables were acquired from forage fish studies in which they were measured as part of routine sampling or were obtained from separate sources. The full set of variables considered for use in the models is given in Appendix A, Table A-1. The footnote to Table A-1 provides the rationale for consideration of each variable or type of variable.

Three general types of variables were used in model development, validation, and prediction: spatial (that were assumed to be the same across months and years), temporal (assumed to be the same for all basins), and spatial/temporal (specific to each basin and time period). Spatial variables included seagrass type (*Thalassia, Halodule, Syringodium,* mixed, and none), seagrass density (dense, moderately dense, moderate, moderately sparse, and sparse), depth, and tidal amplitude were estimated for each basin in Florida Bay. Temporal variables were considered the same for all basins and included temperature, rainfall, freshwater flow, sea level, and a wind vector variable that combined direction and intensity. Salinity was the only variable for which both spatial and temporal information existed. Insufficient information was available to represent monthly or yearly differences in the spatial variables or spatial differences in the temporal variables, although such variation may occur.

Seagrass type and seagrass density for each basin were estimated from average values derived from the data of Durako, Fourqueran, Powell et al., and Matheson (unpublished data described in Johnson et al. 2002). For some basins in which no seagrass data were available from these sources, qualitative data from FMRI studies were used to predict seagrass type and density. For those remaining basins in which no seagrass data were available, a nearest neighbor approach was used to assign seagrass information. Seagrass type and density used in the models are presented in Appendix A (Tables A-2-A-3). The relative quality of seagrass information used in basin predictions is indicated as bold (good- data came from that habitat), regular print (moderate- data came from another habitat within basin), and italic (poorest-data estimated from adjacent basin). See the Yr-1 Final Report (Johnson et al. 2002) for details of the methods used to produce the map of seagrass density used to develop the models.

Basin depths by habitat were estimated by averaging basin and habitat specific depth data from the forage fish trawl databases (Appendix A, Table A-4). For basins lacking depth information, depth was imputed using *transcan*, an SPLUS routine in the HMISC library, which imputed missing values based on habitat type (bank, basin, channel, mainland shoreline, island shoreline), region (northeast, Atlantic, Gulf, and interior), and depth for other basins. The r^2 for predicting missing depths was 0.74. Appendix A, Tables A-5 and A-6, show model results and final values.

Tidal amplitude was estimated using GIS techniques and ArcView to plot station locations and assigning them to tidal amplitude bands based on a cover of tidal amplitude contours derived from Smith (1997) (Appendix A, Table A-7). Rainfall was obtained from Kevin Kotun (ENP), flow was obtained from Carolyn Price (USGS.) Wind speed and direction were obtained from the NOAA Molasses Reef buoy. Sea Level was obtained from the NOAA tide table website Sources and treatment of temporal data are more fully described in the Yr-1 Final Report (Johnson et al. 2002). Salinity for each of the basins was obtained from monthly salinity maps generated for each time period.

Model Development

The models were developed as part of the Yr-1 work and are more fully described in the Yr-1 Final Report (Johnson et al. 2002). Some details of the methods are repeated here to facilitate understanding the Yr-2 work, which is based on the models. Some additional information about the models not included in the Yr-1 report has been added to this report.

Three decades of data from three gear types were used to develop models for 11 dominant forage species of Florida Bay (*Lucania parva, Eucinostomus spp., Lagodon rhomboides, Syngnathus scovelli, Opsanus beta, Hippocampus zosterae, Anchoa mitchelli, Gobiosorobustum, Floridichthys carpio, Microgobius gulosus,* and *Farfantepenaeus duorarum*). These species were chosen by consensus by the major researchers who had conducted field studies in Florida Bay as species that might respond to changes in salinity. Statistical models were developed using the generalized additive modeling (GAM) approach with SPLUS statistical software (Mathsoft [now Insightful] 1999) and the Hmisc Library (Harrell 2001). The *areg.boot* routine in Harrell's Hmisc Library adds substantially to the GAM capability within SPLUS. GAM is a nonparametric generalization of multiple linear regression. Scatterplot smoothers (Chambers et al. 1983) in GAM replace least square fits in regression (Swartzman et al. 1992). GAM models are specified by the user as in multiple regression models, i.e., with a dependent variable and a set of proposed independent variables, which may consist of categorical variables and continuous variables. In our case, variables such as salinity and temperature were the continuous variables and physical habitat and seagrass cover characteristics were categorical variables.

GAM models had several advantages for this application. The GAM approach is used on fishery survey data to develop indices of abundance that are not biased by patchy animal distributions (Swartzman et al. 1992). GAM models also can be used to reduce bias from sampling designs that are unbalanced in time and space. The GAM approach is able to resolve complex relationships between variables and to separate sources of variation among many dependent variables. GAM provides a theoretically rigorous foundation for developing models that are not linear. Models are built that conform to the shape of the data using a smoothing technique that reflects local trends while allowing trends over the entire space and time to be observed if they exist. Algorithms are available that will determine the most appropriate transformations of dependent and independent variables, therefore avoiding the need to define these transformations in advance. We used the AVAS (Additivity and Variance Stabilization) algorithm of the *areg.boot* routine in the Hmisc Library. With AVAS, the most appropriate transformation to ensure a constant variance of residuals is forced by an algorithm that, at the same time, maximizes r^2 (Harrell 2001). The AVAS algorithm was developed by Tibshirani (Hastie and Tibshirani 1990).

The AVAS algorithm is powerful but can result in overfitting (i.e., r^2 can be greatly inflated when one fits too many predictive variables), a problem that can be overcome with the Efron bootstrap (Harrell 2001), which is built into the Hmisc Library routine. Bootstrapping randomly samples the original data set with replacement, creates a new data set with the same number of observations, and reruns the analysis on the new data set. The bootstrap estimates the optimism (bias) in the apparent r^2, which is subtracted from the apparent r^2 for a more reliable estimate.

Bootstrapping is used in GAM in other important ways. The bootstrap is used to compute confidence limits for all estimated transformations. All steps involved in fitting the additive models are repeated fresh for each re-sample. Bootstrapping is used to estimate the effect of changing one predictor while holding other variables constant. The ordinary bootstrap, also built into the Hmisc Library routine, is used to estimate the standard deviation of difference in two possibly transformed estimates (for two values of X), assuming normality of such differences (Harrell 2001). The *summary* method for *areg.boot* computes bootstrap estimates of standard errors differences in predicted responses (on the original scale) for selected levels of each predictor against the lowest requested level of the predictor. The *plot* function using this procedure gives a predicted transformed Y as a function of each X, holding other X's constant. AVAS standardizes all transformed values using a mean of 0 and a variance of 1.

In development of the 11 models, cluster analysis techniques were used to screen potential independent variables to prevent collinearity. The general approach was to use only one independent variable from a cluster of variables representing stratification in time or space. For example, only one rainfall indicator at a time was used in a model run since the rainfall variables formed a cluster. The most logical predictor (based on those commonly cited in the literature or suggested in other studies) within each cluster was used in the model. Analyses were conducted with the full set of independent variables selected in the screening process to avoid the possible bias caused by stepwise selection (Harrell 2001).

Standardized density, an index of abundance, is the model result. Plotted output of the GAM models predict standardized densities with respect to each factor while holding the other factors constant. This allows the effect of each variable to be examined individually. For significance testing within each variable, each category of a categorical variable is evaluated as significant or not significant against the first category of the series (the default of *areg.boot*). Significance testing of continuous variables is performed by testing against the median of the first 10-percentile (rounded off to the nearest whole number), rather than the lowest value available (choosing extreme values resulted in the models not converging).

Model Validation

A validation analysis of the forage fish models was conducted using trawl data (216 unique samples, no replicate samples) collected by Allyn Powell (NMFS, Beaufort Laboratory) in March, May, July, September, November of 2000 and January 2001. Predictions were made using each of the 11 models produced with the original data set (Johnson et al. 2002) and data on temperature, salinity, seagrass type, and seagrass density that were collected with fish sampling (the validation data). Predictions corresponding in time and space to the validation data were made with the GAM models within SPLUS and Hmisc using the *predict* function of *areg.boot*.

Either mean or median values can be predicted. The mean of the untransformed response (i.e., untransformed mean density) is estimated by computing the arithmetic mean of *ginverse(lp + residuals*), where *ginverse* is the inverse of the nonparametric transformation of the response and is obtained by reverse linear interpolation, *lp* is the linear predictor for an individual observation on the transformed scale, and *residuals* is the entire vector of residuals estimated from the fitted model, on the transformed scales (n residuals for n original observations). The median of the untransformed response is *ginverse(lp + median(residuals)).*

Fish density was predicted for each data point in the validation data set. The predictions were then compared to observed densities from the validation data set. Comparisons were also made of predictions and observations averaged by basin. Comparisons were made using plots and regression analyses. Significant relationships were assumed for equations with $p<0.1$.

Density predictions for April and August of 1995 were available from the model application demonstration and were also compared to available observations. Because the 1995 data were used to develop the models, this cannot be considered a validation exercise, but the comparison does provide useful information for evaluation of the models.

Model Application

Models were used to predict densities of the 11 species in a dry (April) and wet (August) season in an extreme dry (1990) and an extreme wet (1995) year. Salinity and freshwater flow differed substantially among the four periods and served as a proxy of changes that might occur under alternative water management designs. A previous set of predictions was prepared for the CESI Workshop (Johnson and Browder 2002) and was based on model means. When our subsequent model validation analysis, described above, indicated that, for all but two species, predictions based on medians were more closely aligned to observations than predictions based on means, we redid the predictions using medians for the other nine species. Prediction methods based on means and medians were described in the validation section.

The number of hectares of each habitat within each basin was calculated using GIS techniques and ArcView. Predicted densities (numbers/hectare) were converted to numbers per basin by habitat. The numbers per habitat were summed to calculate numbers of each species within Florida Bay. Numbers were converted to biomass using monthly median weights for each species using data from Schmidt (1970's) and from Powell et al. (1980's and 1990's).

As an index of community composition, we adapted the eveness measure to our use. As described by Krebs (1989), evenness is as follows:

$$J' = H'/H'max.$$

where H' is the Shannon-Wiener function, $H' = \sum p_i \log p_i$, where $p = n_i/N$, n is the number of individuals of species i and N is the total number of individuals of all species. $H'max = \log_e S$, where S is the number of species. H'max is the maximum possible H'. We calculated this index based on the output of our 11 models, and S was limited to 11. As we have applied it, this index can only be used to compare the predicted distributions of the 11 modeled species among the strata of our models and under the various conditions examined with the 11 models. It seems useful for this purpose, as we see variation that provides perspective on species composition, but our results with respect to this evenness measure should not be used to compare Florida Bay with other systems.

Results

Model Development

The 11 forage species models produced in Yr-1 work are shown in Appendix B, Table B-1. The intercept and regression coefficients of the standardized transformed variables of each model are given in Appendix B, Table B-2. In ordinary least squares regression, the regression coefficients of standardized independent variables indicate the relative sensitivity of the dependent variable to the various independent variables of a given model. This interpretation should be viewed with caution with respect to GAMs, however. Alzola and Harrell (2000) state that, because the independent variables are transformed, the regression coefficients of GAMs may not be meaningful. Sample size and coefficients of determination (r^2) of the GAM models are given in Appendix B, Table B-3. To evaluate the independent explanatory power of the independent variables, we conducted single variable GAMs for each species and variable (Appendix B, Table B-4. We conducted ANOVAs of the untransformed dependent variable in relation to the untransformed independent variables to evaluate the relative importance of these variables to forage species densities (Appendix B, Table B-5). Note that the ANOVAs could be affected by lack of balance in the overall design (unlike the GAMs, which avoid imbalance).

Model Validation

Our original predictions for the validation exercise were based on means. Subsequent examination of maximum predicted values in relation to maximum values in the observed data (the Powell et al. trawl data for 2000-2001) indicated that the mean-based predictor over-predicted densities for nine of the 11 species. Some predictions were an order of magnitude larger than the observed. Only predictions for *Lagodon* and *Eucinostomus* were of a reasonable order of magnitude. We, therefore, redid the predictions based on medians and found that maximum values were on the same scale as observations for the other nine species. Furthermore, a linear regression of observed vs. predicted produced a higher r^2 than that produced by the mean-based predictor for the nine species. A limitation of using the median-based predictor, however, was that density predictions were not made for many points that were covered by the mean-based predictor. The median-based predictor is more limited by lack of replicates than the mean-based predictor. This may be because a mean can be determined from one data record (although it may not be very meaningful), but at least two data records are required to determine a median. Based on our comparison of prediction methods, the mean-based predictor was used to predict *Lagodon* and *Eucinostomus* densities and a median-based predictor was used to predict densities of the other nine species.

Table 1 shows the final linear regression results (r^2 and p-value) for each species and for the 11 species combined. The r^2s of the predictive models also are shown for comparison purposes. The highest r^2s for the linear regression between the predicted and observed values were found for *Lagodon* (0.33), *Farfantepenaeus* (0.21), *Syngnathus* (0.21), *Gobiosoma* (0.18), and *Eucinostomus* (0.15), and the lowest r^2s were for *Floridichthys*, (0.03), *Hippocampus* (0.05), *Microgobius* (0,05), *Opsanus* (0.06), and *Lucania* (0.07). The p-values were significant for all species. The r^2 for the total of all the species using the mixed (mean for *Lagodon* and *Eucinostomus* and median for the rest) was 0.15 compared to the total for the mean (0.05) and the median (0.11). Missing values in the median-based predictions were replaced by zeros for running the above regressions of predicted vs. observed. In many cases these values dropped out entirely because they were paired with missing data in the observed.

Figure 1 shows the observed 11-species total density versus the predicted species total density (total of all 11 species) for individual points, while Figure 2 shows the pattern after one exceptionally high observed value (in Basin 43) was eliminated. Figure 3 shows the observed 11-species total versus predicted species total averaged by basin and month. Figure 4 shows the observed 11-species total versus the predicted species total averaged by basin. The r^2 values for the 11- species total values were slightly improved by averaging within basins, but, of the predictions for individual species, only the *Anchoa* r^2 values were improved by grouping by basin (Table 2). The validation data set lacked replicate samples, which potentially weakened the correlation with the predictions. This is especially the case because of the many data points (i.e., site and time) in the validation data set with a density of zero for one, more, or all species.

The r^2 of 10 species (not *Opsanus*) was substantially improved by adding "region" (as a categorical variable) to the linear regression (note that region was not a variable in the models) (Table 3). The r^2 value for the combined 11-species increased from 0.15 to 0.23. For the individual species, the lower r^2 values rose from (0.03-0.07) to (0.18-0.59), while the higher r^2 values rose from (0.15-0.33) to (0.18-0.45). Figures 5-16 show observed vs. predicted density plotted by region. It did not improve the individual species regression models (i.e., the r^2 was relatively poor) (Table 3) to separate the data by regions, probably because the sample size was so low. Region was not included as a variable in our GAM models to avoid masking the influence of spatial variables such as salinity, seagrass, and tidal amplitude. The response of the validation equations to the addition of region suggests that there was regional variation in faunal densities not adequately accounted for by our spatial variables.

Table 1. Results (r^2s and p-values) of linear regressions of predicted vs. observed density from 2000-2001 validation data and r^2s of the models used to make the predictions.

Species	Statistic used	R^2	P-value	Model R^2
Anchoa	median	0.10	2.98×10^{-6}	0.15
Eucinostomus	mean	0.15	7.0×10^{-9}	0.36
Farfantepenaeus	median	0.21	1.14×10^{-12}	0.42
Floridychthys	median	0.03	0.0068	0.30
Gobiosoma	median	0.18	5.5×10^{-11}	0.09
Hippocampus	median	0.05	0.0007	0.10
Lagodon	mean	0.33	0	0.23
Lucania	median	0.07	0.0001	0.25
Microgobius	median	0.05	0.0005	0.19
Opsanus	median	0.06	0.00034	0.34
Syngnathus	median	0.21	1.41×10^{-12}	0.10
Total	mean(2), med(9)	0.15	1.13×10^{-6}	
Total	all mean	0.05	0.0011	
Total	all median	0.11	1.13×10^{-6}	

Figure 1. Predicted 11-species total vs observed 11-species total for 2000-2001 trawl data (individual points).

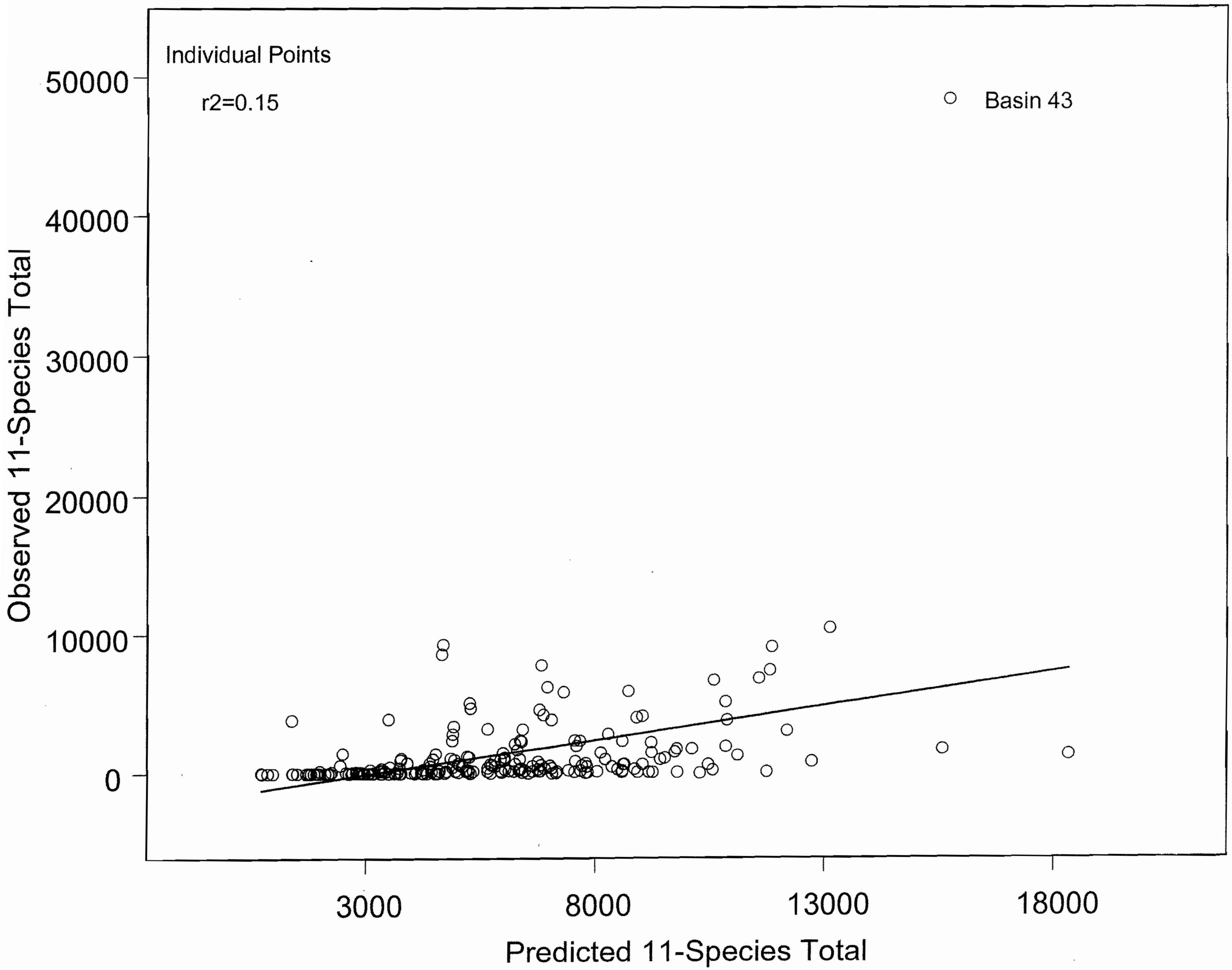
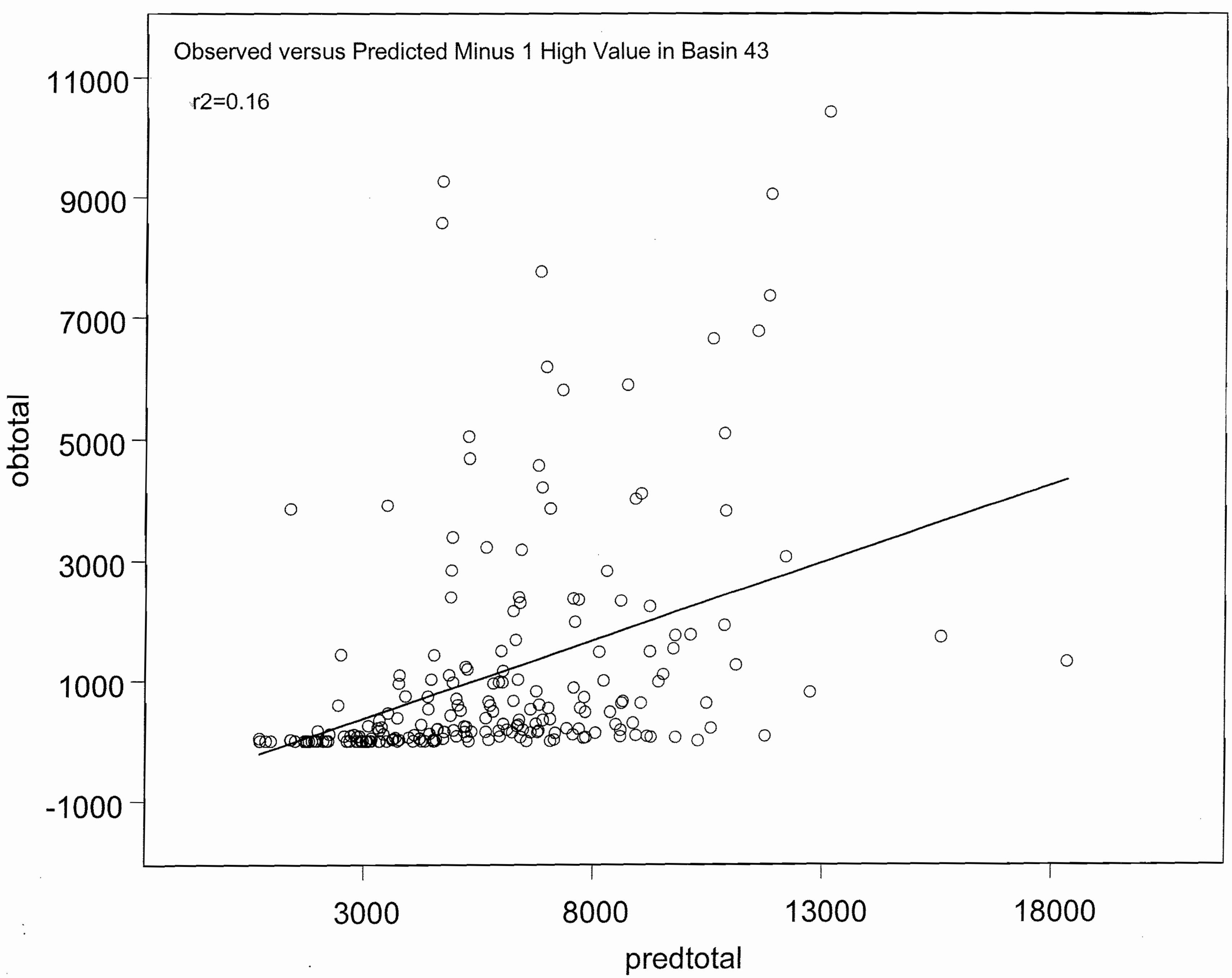
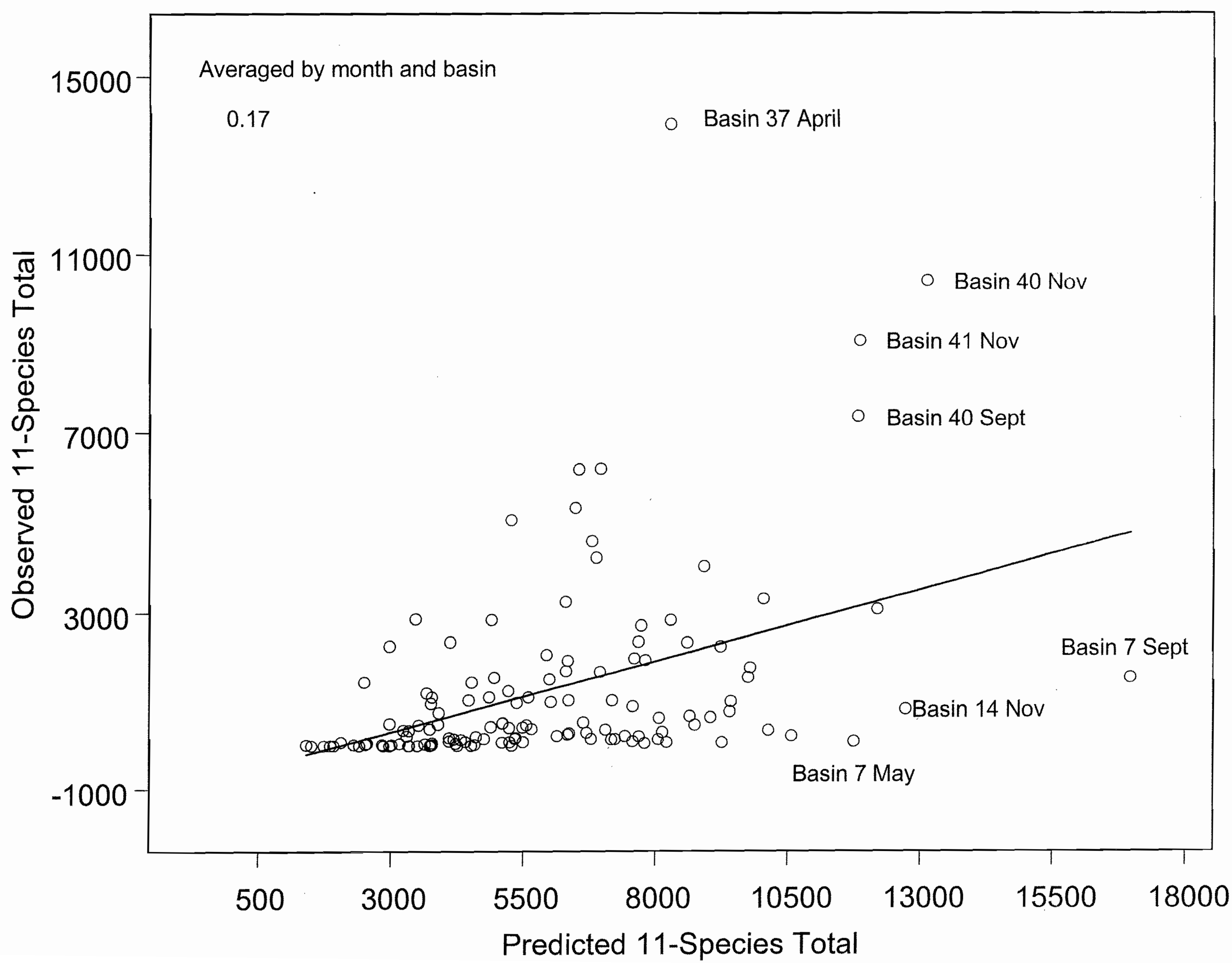

Individual Points
r2=0.15
Basin 43
50000
40000
30000
20000
10000
0
3000
8000
13000
18000
Observed 11-Species Total
Predicted 11-Species Total

Figure 2. Predicted 11-species total vs observed 11-species total for 2000-2001 trawl data (individual points) minus the highest outlier (Basin 43).



Observed versus Predicted Minus 1 High Value in Basin 43
r2=0.16
11000
9000
7000
5000
3000
1000
-1000
obtotal
3000
8000
13000
18000
predtotal

Figure 3. Predicted 11-species total vs observed 11-species total for 2000-2001 trawl data (averaged by month and basin).



Averaged by month and basin
0.17
Basin 37 April
Basin 40 Nov
Basin 41 Nov
Basin 40 Sept
Basin 7 Sept
Basin 14 Nov
Basin 7 May
15000
11000
7000
3000
-1000
Observed 11-Species Total
500
3000
5500
8000
10500
13000
15500
18000
Predicted 11-Species Total

Figure 4. Predicted 11-species total vs observed 11-species total for 2000-2001 trawl data (averaged by basin).

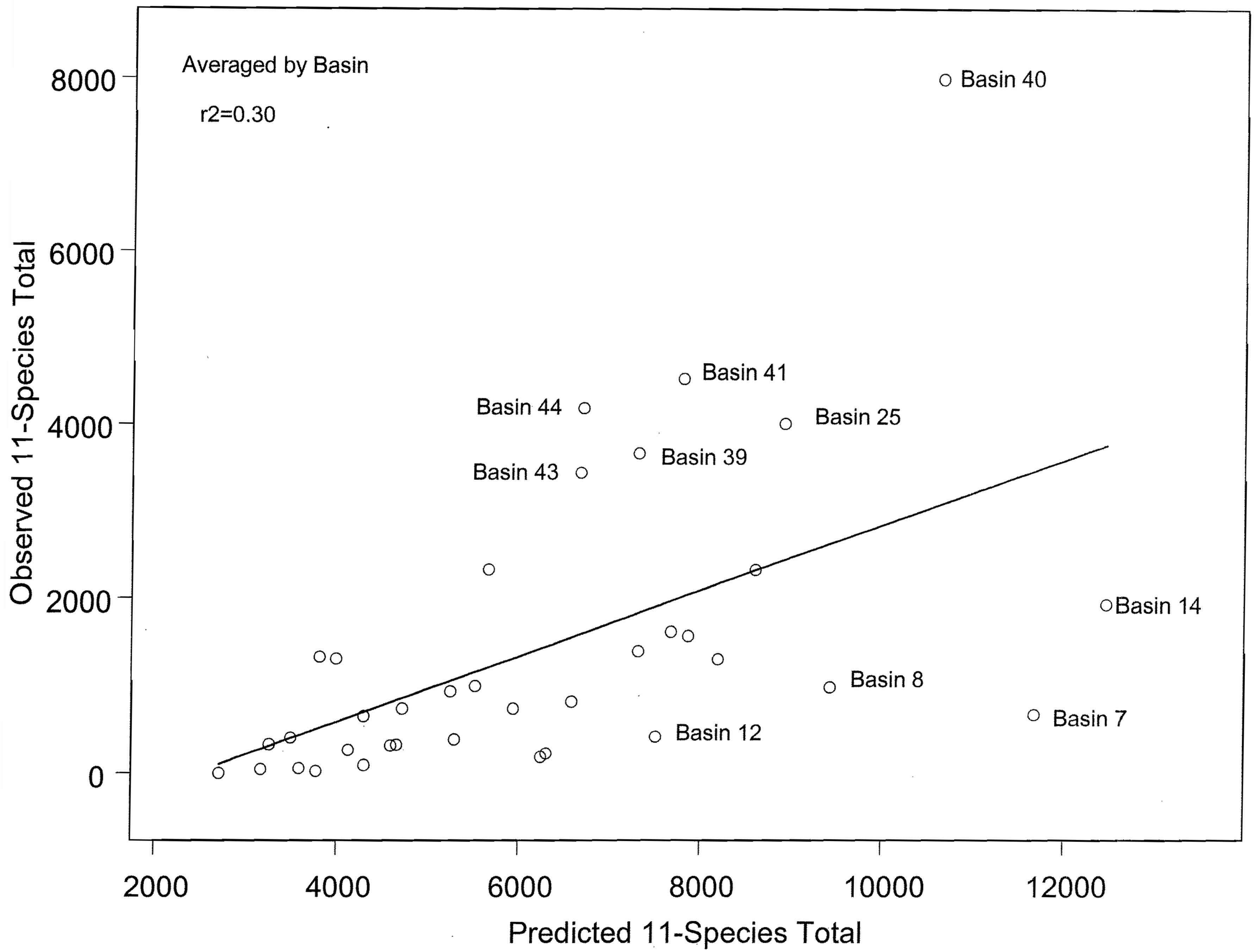
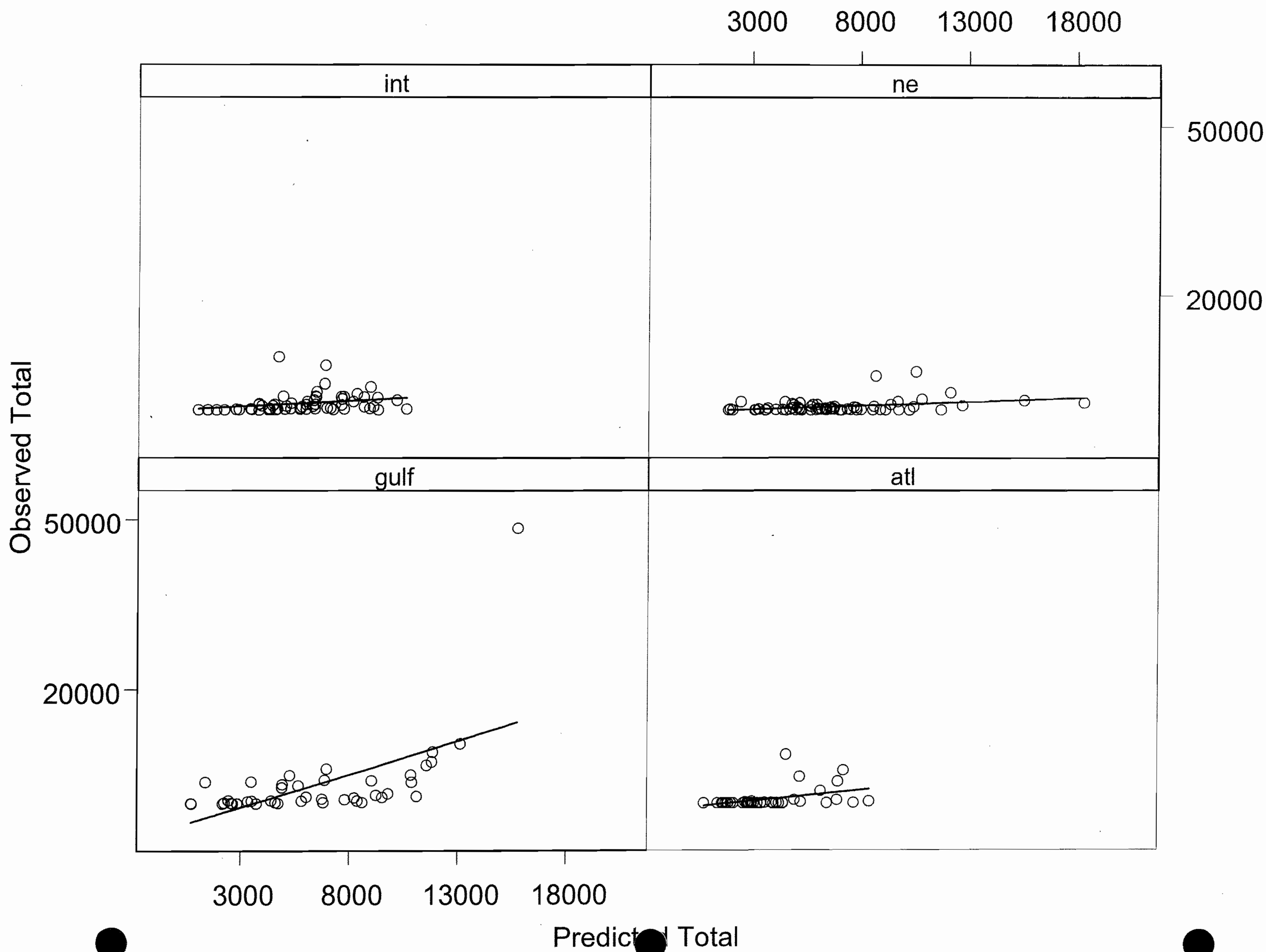

Averaged by Basin
r2=0.30
Basin 40
Basin 41
Basin 44
Basin 25
Basin 39
Basin 43
Basin 14
Basin 8
Basin 7
Basin 12
8000
6000
4000
2000
0
2000
4000
6000
8000
10000
12000
Observed 11-Species Total
Predicted 11-Species Total

Table 2. Results (r2) of three linear regressions to compare predicted and observed values from 2000-2001 validation data. (The first compares predicted and observed of individual samples, the second compares prediced and observed values averaged by basin, and the third uses only data with at least two replicates.

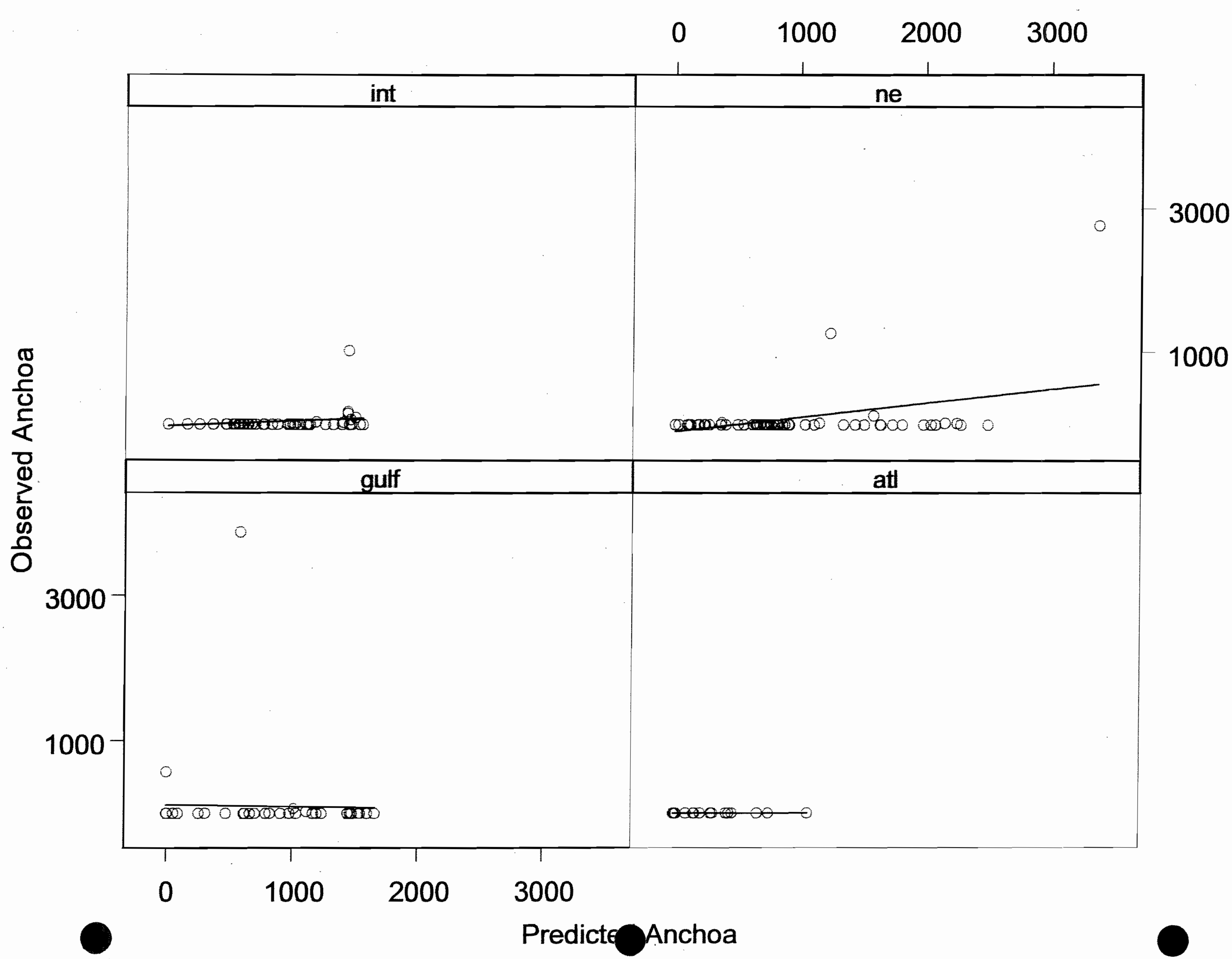
Taxa	2000-2001 data for Individual samples	2000-2001 data averaged by basin	2000-2001 data (only samples with replication)
Anchoa	0.10	0.13	0.02
Eucinostomus	0.18	0.15	0.20
Farfantepenaeus	0.21	0.21	0.13
Floridichthys	0.07	0.003	0.11
Gobiosoma	0.18	0.15	0.20
Hippocampus	0.05	0.03	0.01
Lagodon	0.28	0.27	0.30
Lucania	0.07	0.003	0.001
Microgobius	0.05	0.03	0.02
Opsanus	0.06	0.02	0.09
Syngnathus	0.21	0.11	0.24
Total	0.15	0.17	0.07

Figure 5. Predicted 11-species total vs observed 11-species total for 2000-2001 trawl data by major regions of Florida Bay (Atlantic, gulf, interior, and northeast).



int
ne
gulf
atl
Observed Total
Predicted Total
3000
8000
13000
18000
50000
20000

Figure 6. Predicted *Anchoa mitchelli* vs observed for 2000-2001 trawl data by major regions of Florida Bay (Atlantic, gulf, interior, and northeast).



int
ne
gulf
atl
Observed Anchoa
Predicted Anchoa
0
1000
2000
3000

Figure 7. Predicted *Gobiosoma robustum* vs observed for 2000-2001 trawl data by major regions of Florida Bay (Atlantic, gulf, interior, and northeast).

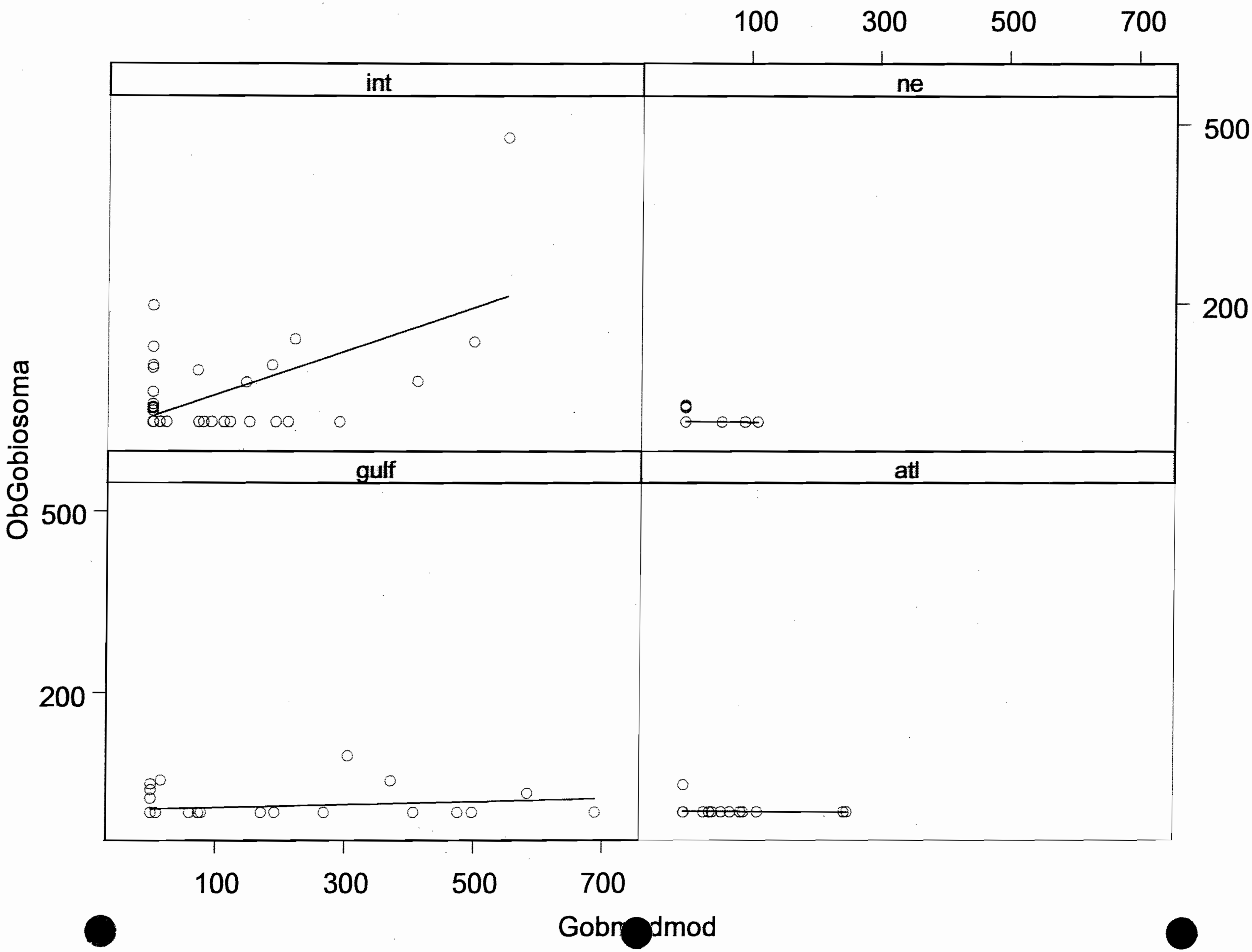
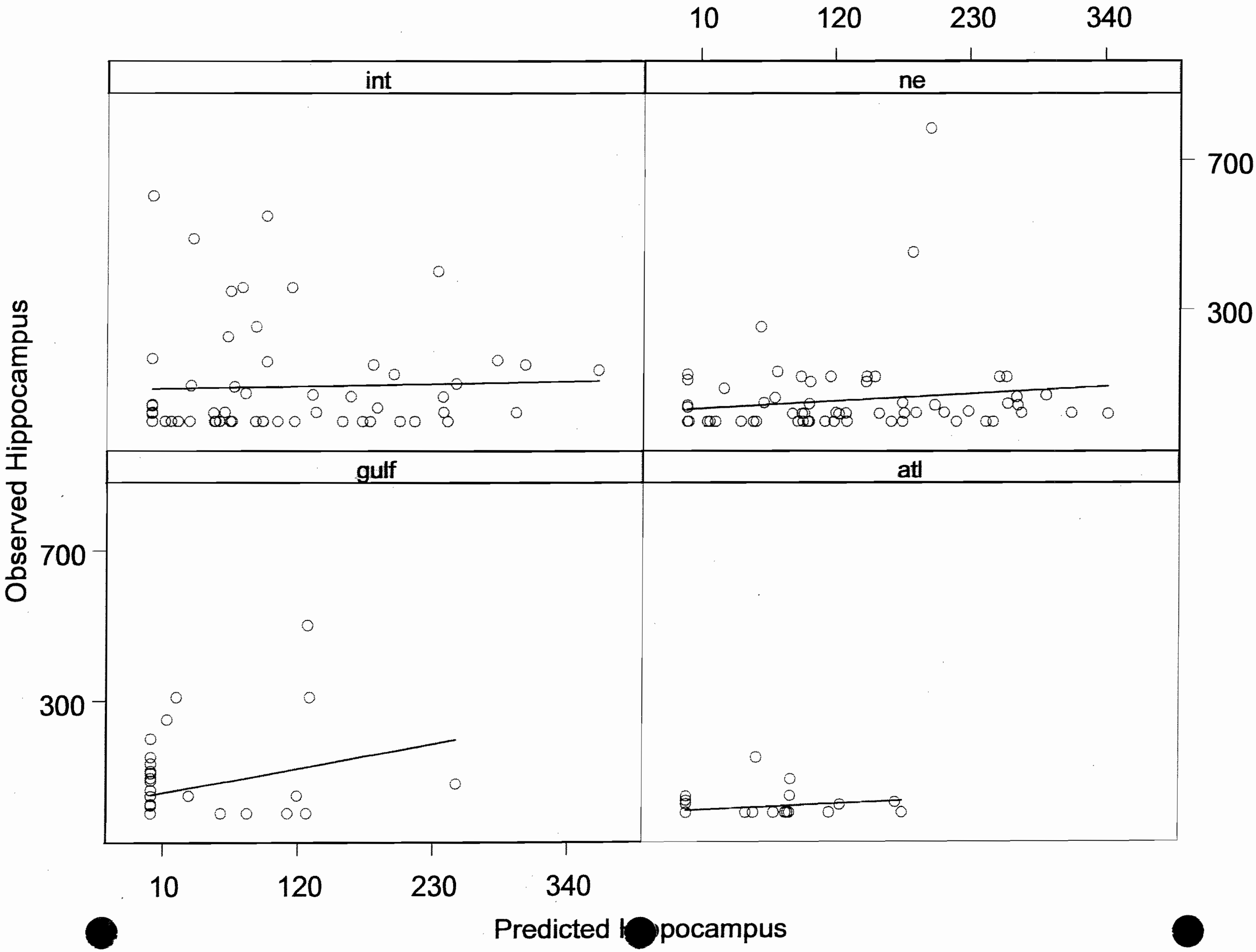
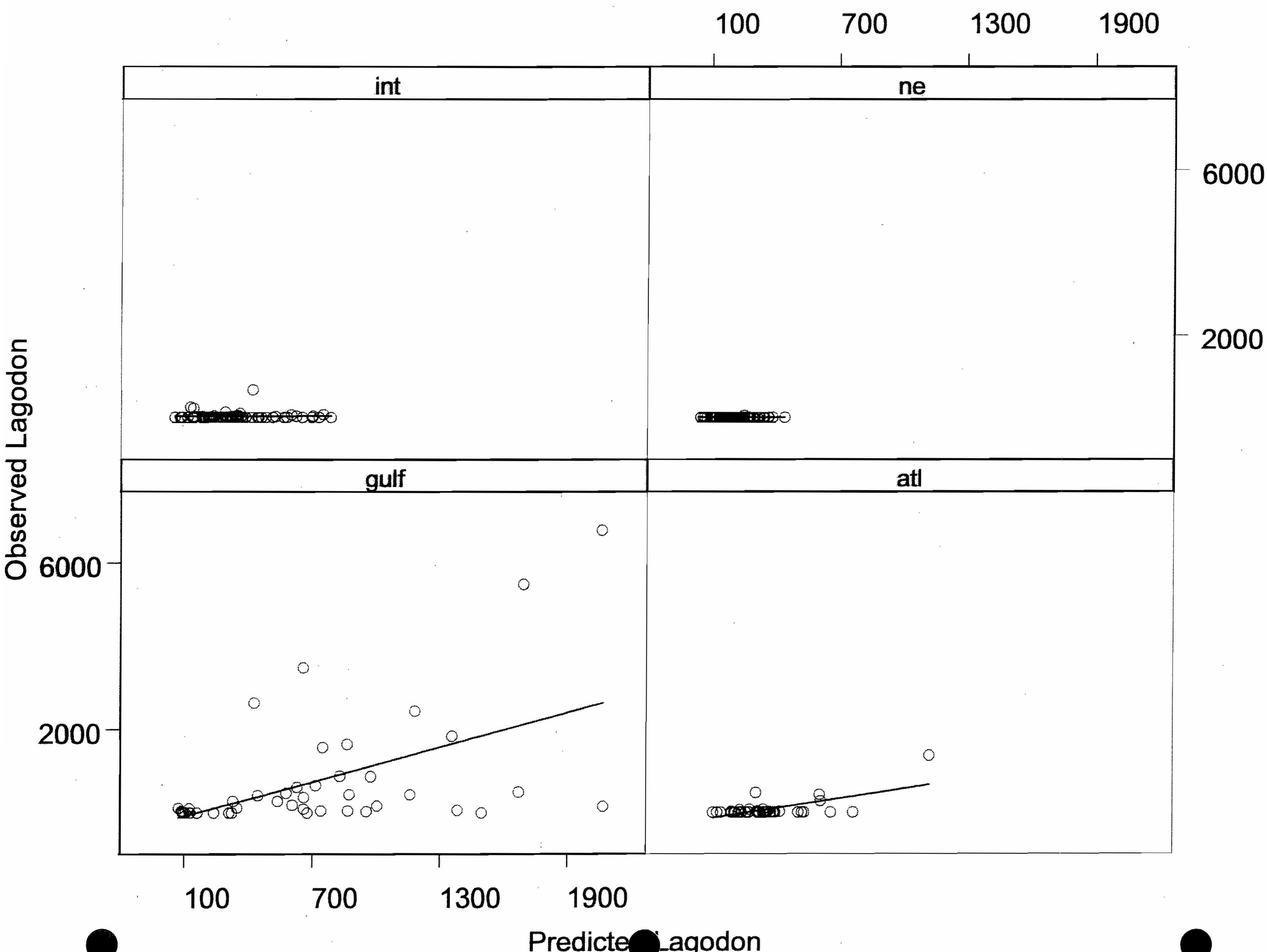

int
ne
gulf
atl
100
300
500
700
500
200
ObGobiosoma
Gobmodmod

Figure 8. Predicted *Hippocampus zostera* vs observed for 2000-2001 trawl data by major regions of Florida Bay (Atlantic, gulf, interior, and northeast).



int
ne
gulf
atl
10
120
230
340
700
300
Observed Hippocampus

Figure 9. Predicted *Lagodon rhomboides* vs observed for 2000-2001 trawl data by major regions of Florida Bay (Atlantic, gulf, interior, and northeast).



int
ne
gulf
atl
100
700
1300
1900
6000
2000
Observed Lagodon
Predicted Lagodon

Figure 10. Predicted *Lucania parva* vs observed for 2000-2001 trawl data by major regions of Florida Bay (Atlantic, gulf, interior, and northeast).

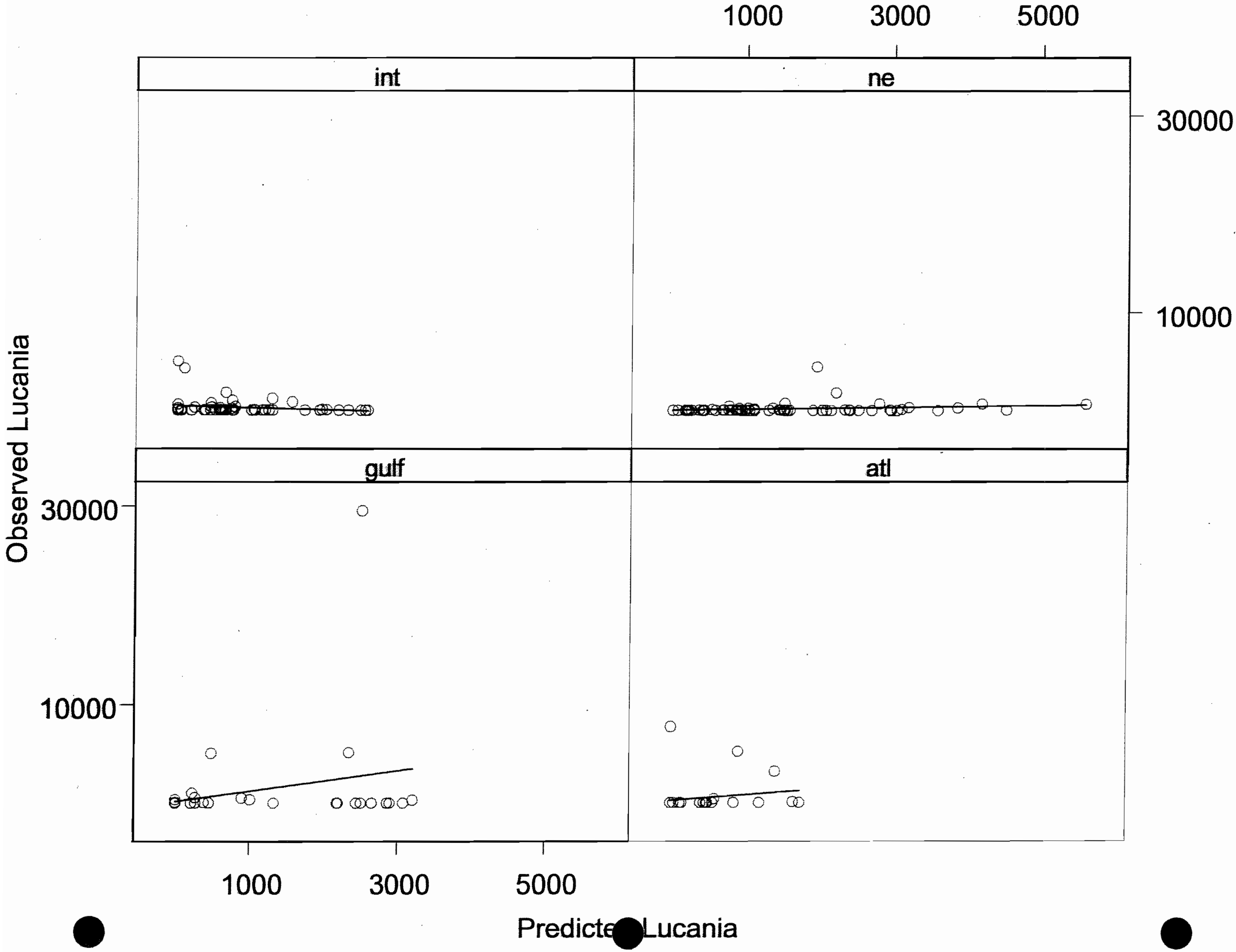

int
ne
gulf
atl
1000
3000
5000
30000
10000
Observed Lucania
Predicted Lucania

Figure 11. Predicted *Microgobius gulosus* vs observed for 2000-2001 trawl data by major regions of Florida Bay (Atlantic, gulf, interior, and northeast).

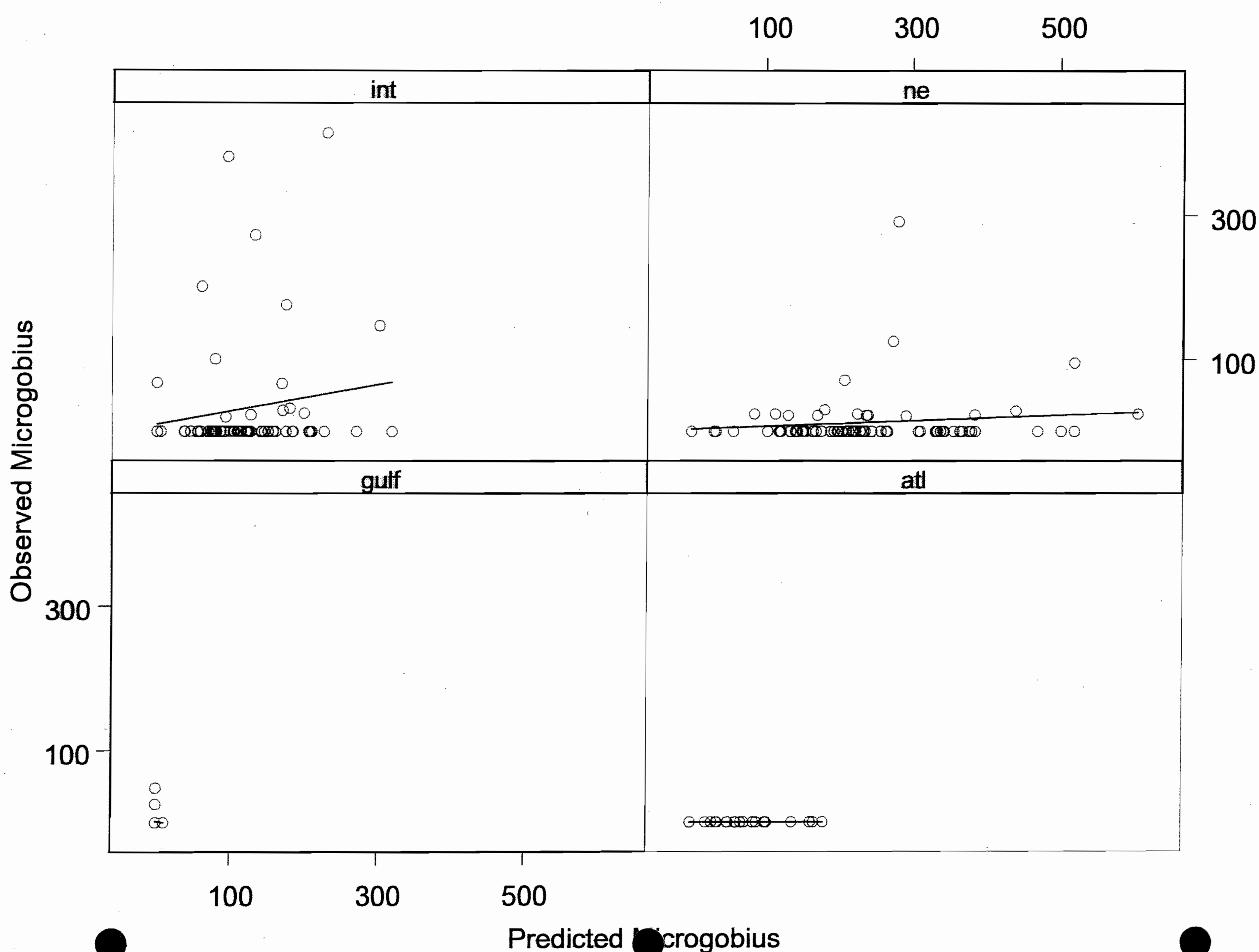
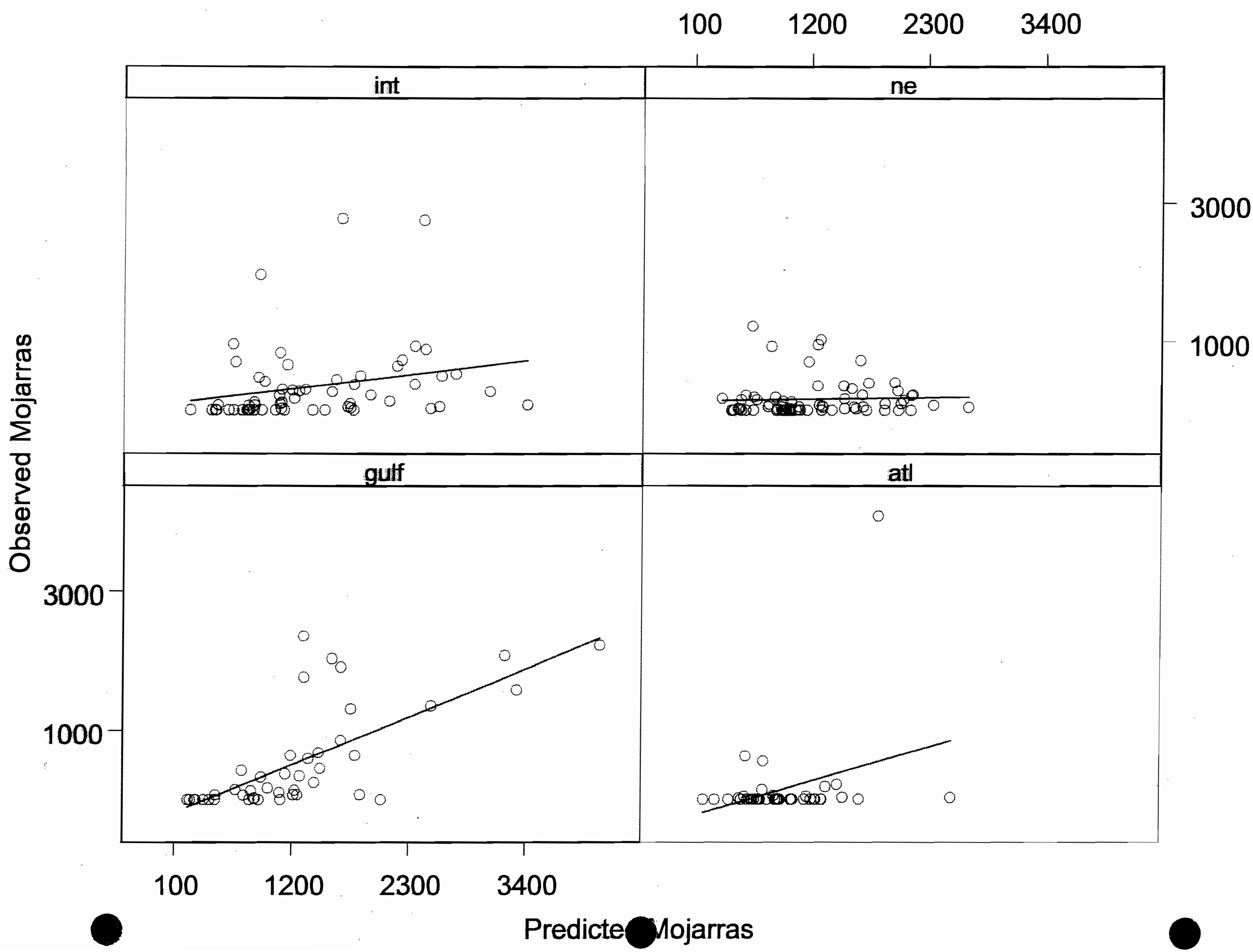
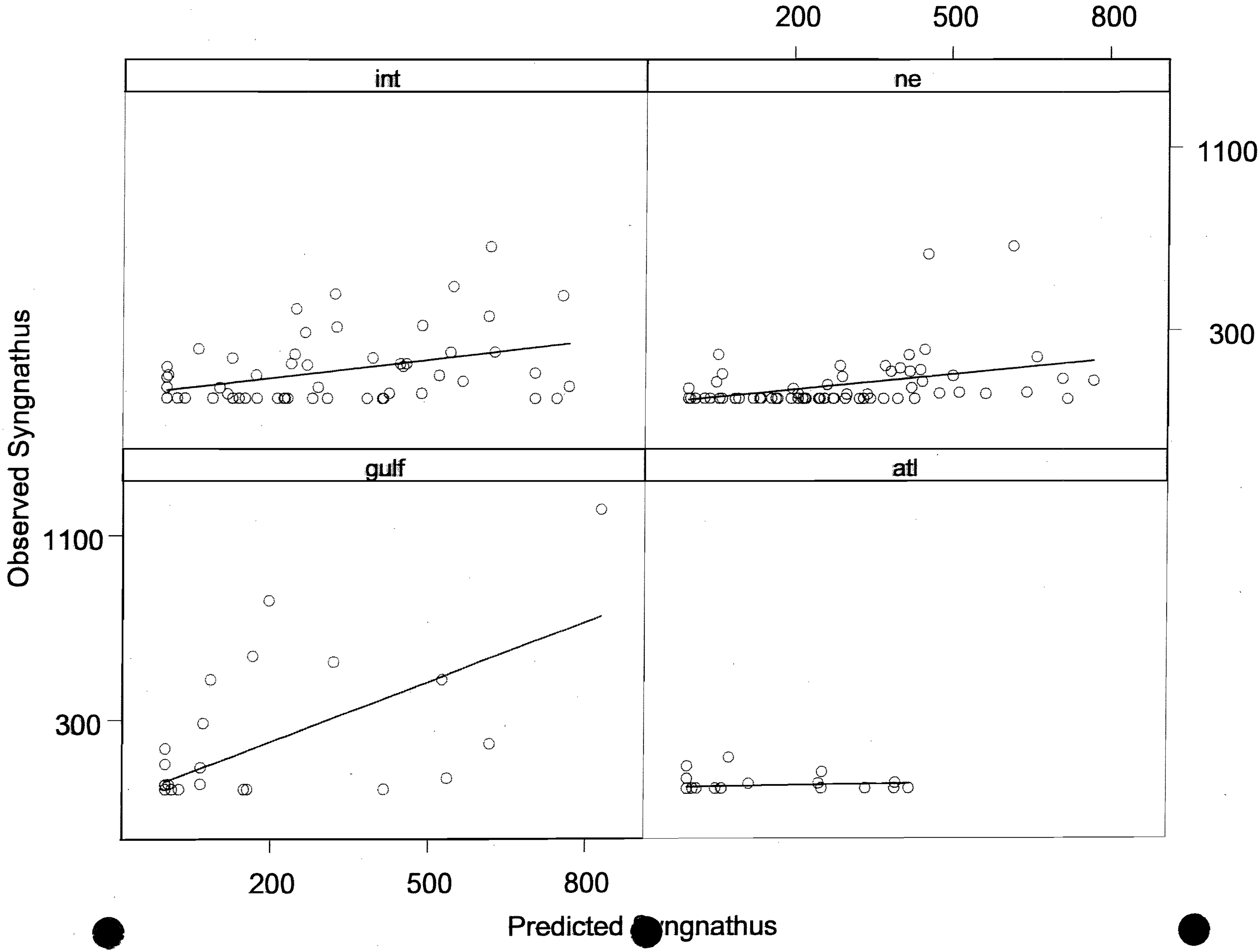

int
ne
gulf
atl
100
300
500
Observed Microgobius
Predicted Microgobius

Figure 12. Predicted *Eucinostomus spp.* (mojarras) vs observed for 2000-2001 trawl data by major regions of Florida Bay (Atlantic, gulf, interior, and northeast).



int
ne
gulf
atl
100
1200
2300
3400
3000
1000
Observed Mojarras
Predicted Mojarras

Figure 13. Predicted *Syngnathus scovelli* vs observed for 2000-2001 trawl data by major regions of Florida Bay (Atlantic, gulf, interior, and northeast).



int
ne
gulf
atl
200
500
800
1100
300
Observed Syngnathus
Predicted Syngnathus

Figure 14. Predicted *Farfantepenaeus duorarum* vs observed for 2000-2001 trawl data by major regions of Florida Bay (Atlantic, gulf, interior, and northeast).

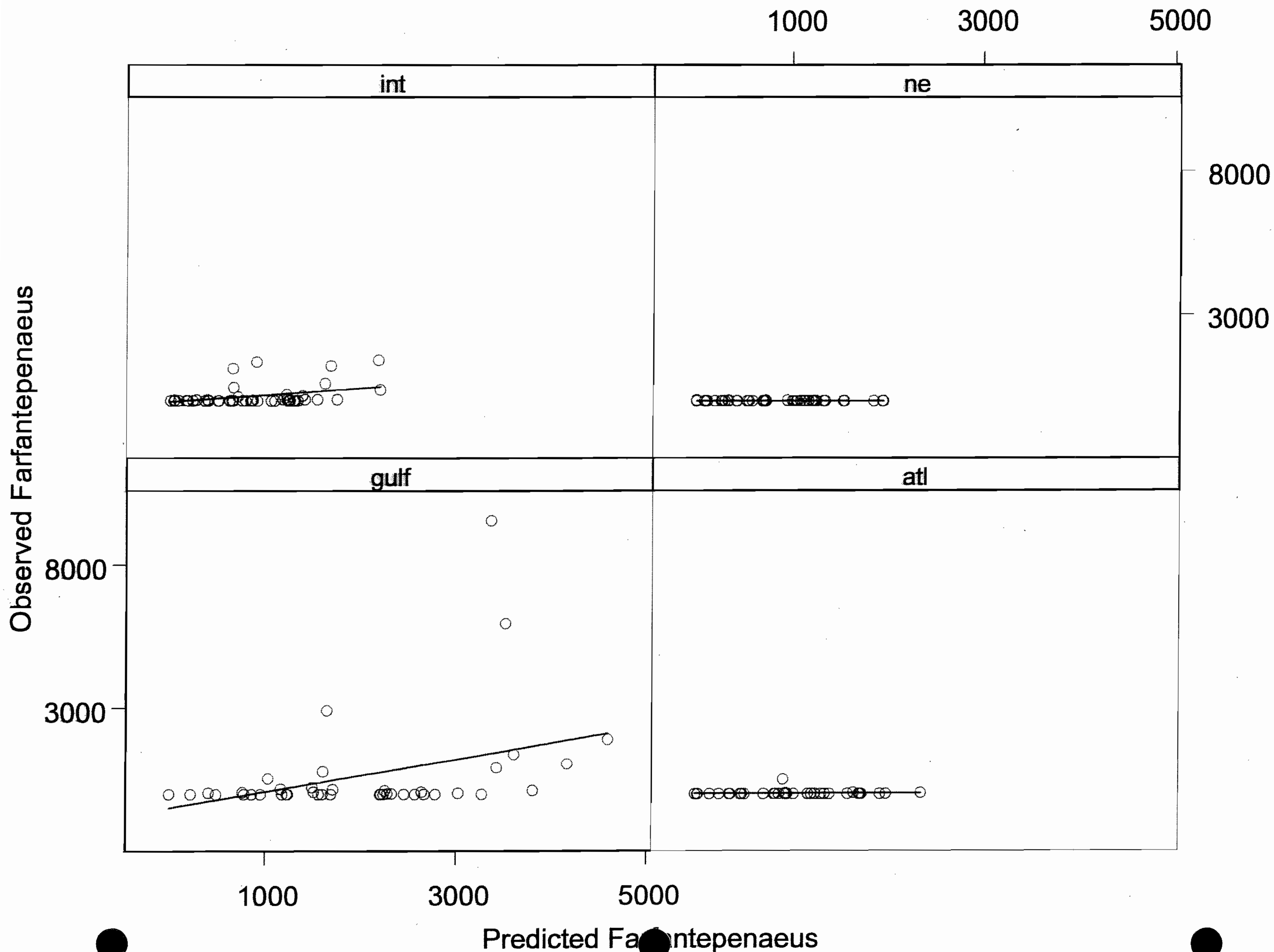
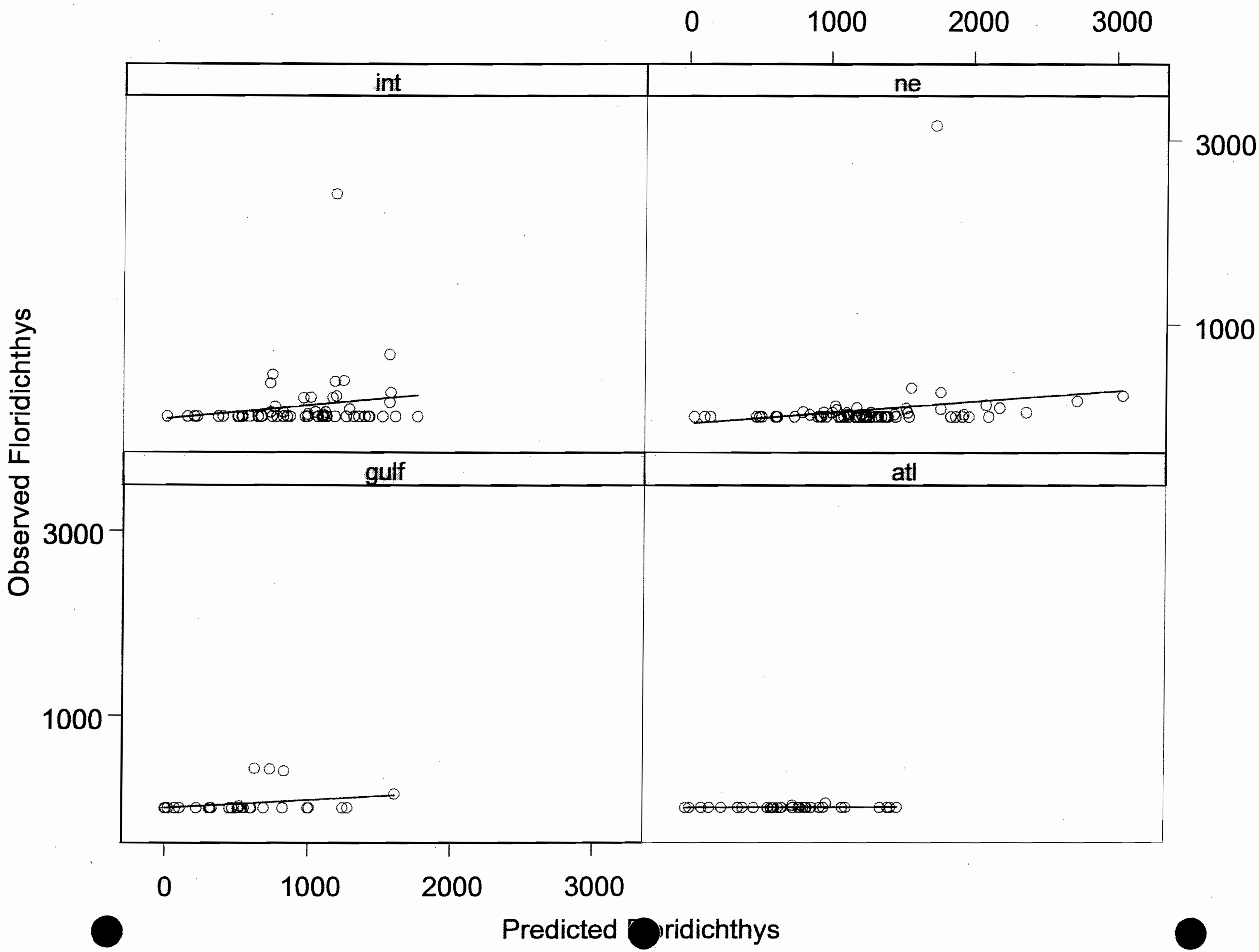
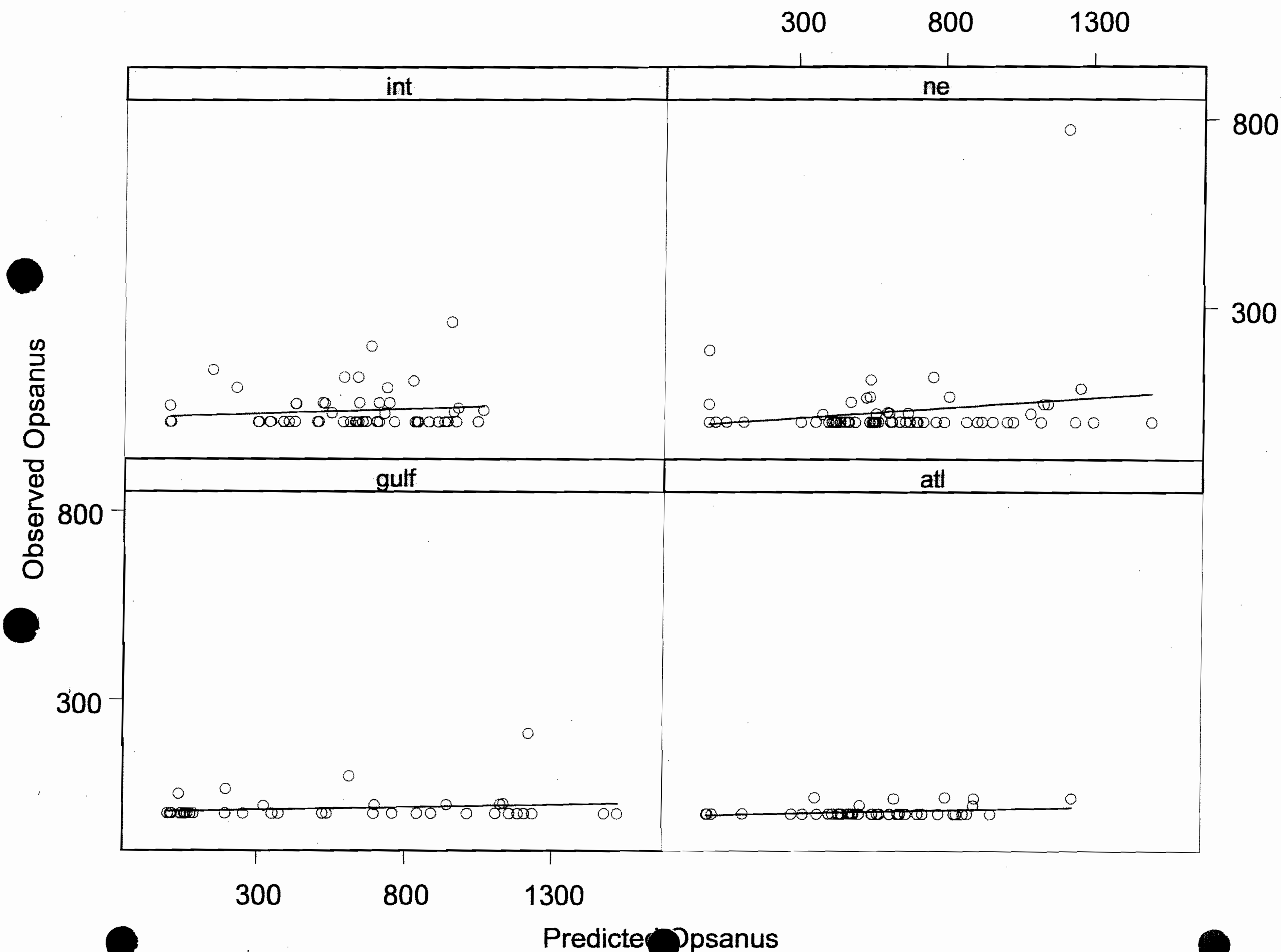

int
ne
gulf
atl
1000
3000
5000
8000
3000
Observed Farfantepenaeus
Predicted Farfantepenaeus

Figure 15. Predicted *Floridichthys carpio* vs observed for 2000-2001 trawl data by major regions of Florida Bay (Atlantic, gulf, interior, and northeast).


int
ne
gulf
atl
Observed Floridichthys
Predicted Floridichthys
0
1000
2000
3000
1000
3000



int
ne
gulf
atl
Observed Opsanus
Predicted Opsanus
300
800
1300

Figure 16. Predicted *Opsanus beta* vs observed for 2000-2001 trawl data by major regions of Florida Bay (Atlantic, gulf, interior, and northeast).

Table 3. Results (r^2) of linear regression of linear regression of predicted versus observed density from 2000-2001 validation data with region added to the regression equation as an explaining categorical variable, and r^2s of separate linear regressions of predicted versus observed density for each region.

Species	baywide observed vs predicted with "region" r2	linear regression of observed versus predicted for each region ne r2	Atlantic r2	interior r2	gulf r2
Number of observations	207	69	44	60	43
Anchoa	0.1	0.1700	all zeros	0.0800	0.0005
Eucinostomus	0.15	0.0020	0.090	0.0600	0.49
Farfantepenaeus	0.21	0.0003	0.005	0.1900	0.145
Floridichthys	0.07	0.0300	0.020	0.0300	0.1
Gobiosoma	0.18	0.0020	0.004	0.3600	0.05
Hippocampus	0.05	0.0200	0.070	0.0010	0.09
Lagodon	0.28	0.0040	0.430	0.0001	0.26
Lucania	0.07	0.0400	0.030	0.0300	0.07
Microgobius	0.05	0.0100	all zeros	0.0200	0.001
Opsanus	0.06	0.0400	0.120	0.0200	0.04
Syngnathus	0.21	0.1500	0.020	0.1700	0.43

Comparison of predicted to observed from 1995 data

Predictions of faunal densities were made for August and April of 1995 as part of our model application demonstration. These are discussed in the next section. We used the predictions to make a second comparison of predicted to observed faunal densities. Because the models were developed from a database that included 1995 data, this comparison is not a validation exercise. Nevertheless, it provides perspective on the predictions and seems more appropriate in this part of the report than in the next section. Figure 17 shows the relationship between predicted and observed total density (of all 11 species) averaged (over habitat and the two time periods, April and August), by basin, for 1995. The r^2 value of the linear regression of predicted vs. observed total faunal density (all 11 spedies) was 0.34 (Table 4), higher than the r^2 for the validation study (Table 2). With respect to the individual model statistics, the relationships of predicted to observed density were signficant ($p<0.1$) for eight species (all but *Farfantepenaeus, Gobiosoma,* and *Syngnathus*). The r^2 values were higher than the averaged basin r^2 values in the validation study for the eight species (Table 2).

Figure 17. Predicted numbers per hectare (by basin) of 11-species forage community vs observed for April and August 1995.

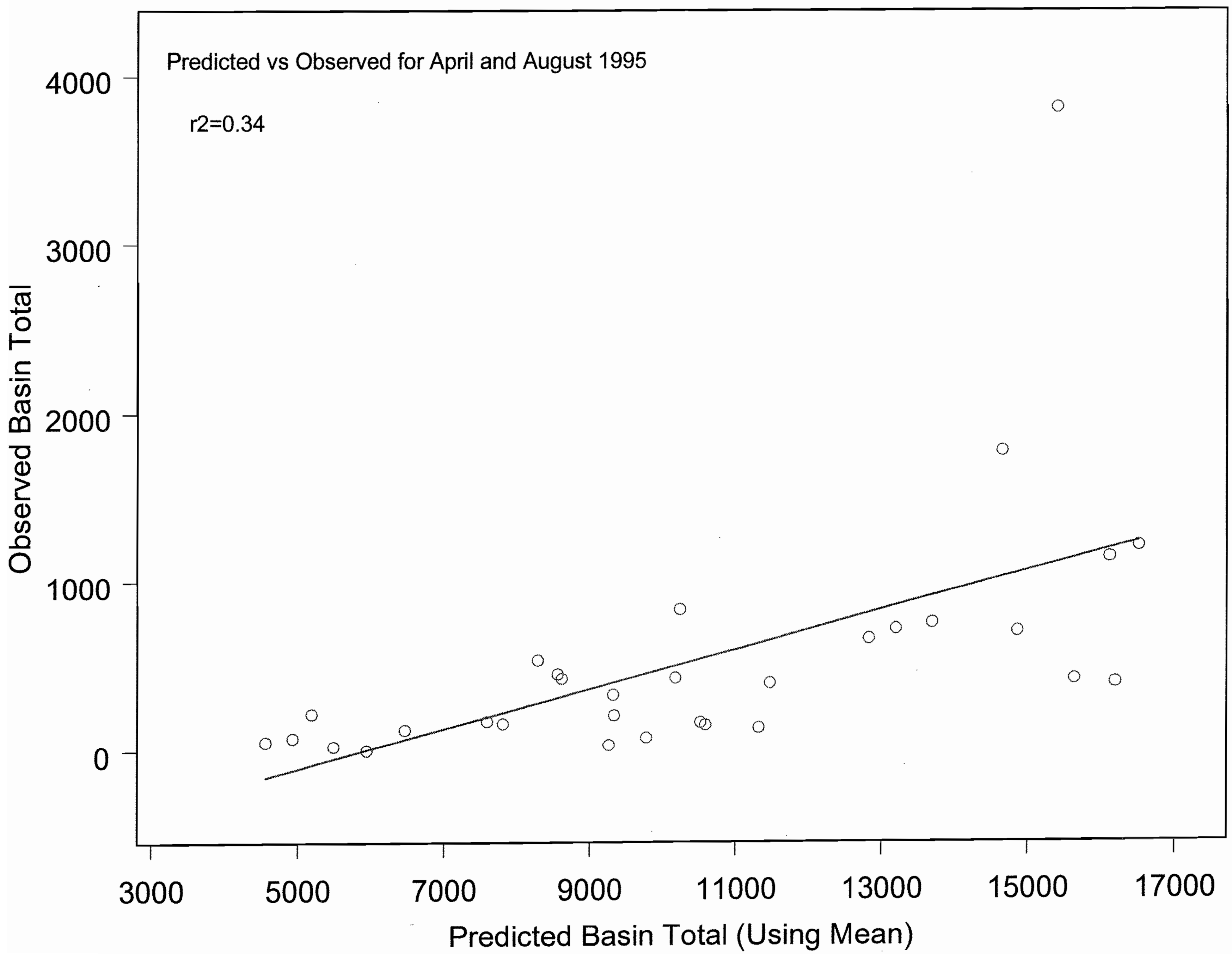

Predicted vs Observed for April and August 1995
r2=0.34
Observed Basin Total
4000
3000
2000
1000
0
3000
5000
7000
9000
11000
13000
15000
17000
Predicted Basin Total (Using Mean)

Table 4. Results (r2 and p-value) of linear regression between predicted and observed density from 1995 data, averaged by basin (n=30).

Taxa	Statistic	r2	p-value
Anchoa	median	0.21	0.0088
Eucinostomus	mean	0.70	5.25 x 10-9
Farfantepenaeus	median	0.06	0.1867
Floridichthys	median	0.68	9.4 x 10-9
Gobiosoma	median	0.04	0.2578
Hippocampus	median	0.13	0.05
Lagodon	mean	0.31	0.0012
Lucania	median	0.15	0.03
Microgobius	median	0.44	0.00005
Opsanus	median	0.11	0.065
Syngnathus	median	0.07	0.1374
Total	mean(2), med(9)	0.34	0.0006

Model Application

The project objective was to determine whether the density of certain individual species or the combined density of all 11 species might serve as a performance measure to evaluate water management alternatives. To help evaluate the potential usefulness of the models as predictors, we predicted the response of the forage fish community to conditions of wet and dry seasons of an extreme wet year and an extreme dry year. Observations from a wet year and a dry year were selected in lieu of output from hydrologic or hydrodynamic models since output from a hydrodynamic model is not yet available. Salinity maps produced for each time period are shown in Figures 18-21. The salinity map for 1995 was based on more data than that for 1990 and is therefore probably more reliable.

Figures 22-60 and Tables 5 and 6 show how differences in salinity and freshwater flow may affect the forage species community in terms of numbers, biomass, and species composition, any or all of which could serve as performance measures. First the predictions are presented in

Figure 18. Salinity map of Florida Bay for April 1990.

April 1990 Salinity

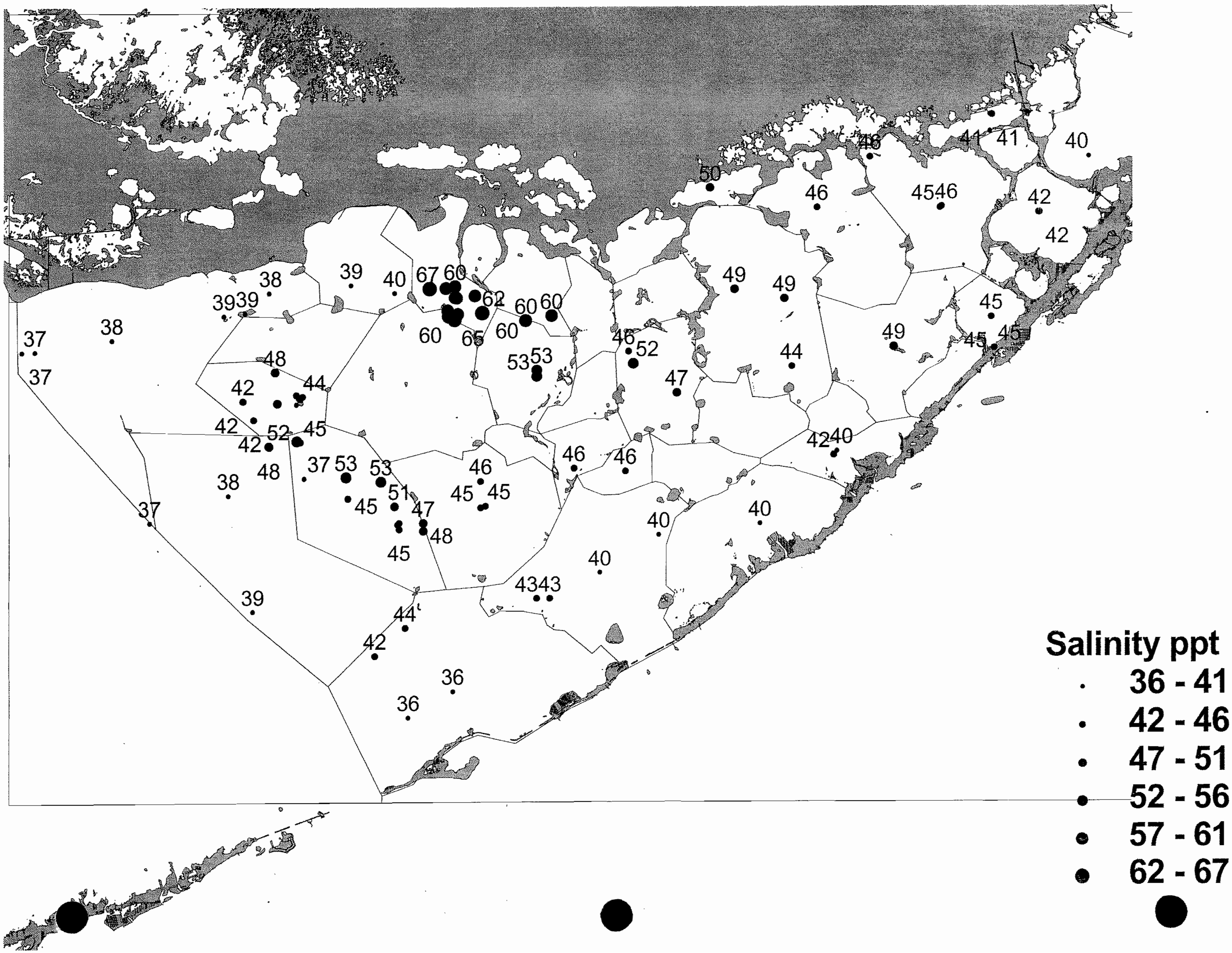


Figure 19. Salinity map of Florida Bay for August 1990.

August 1990 Salinity

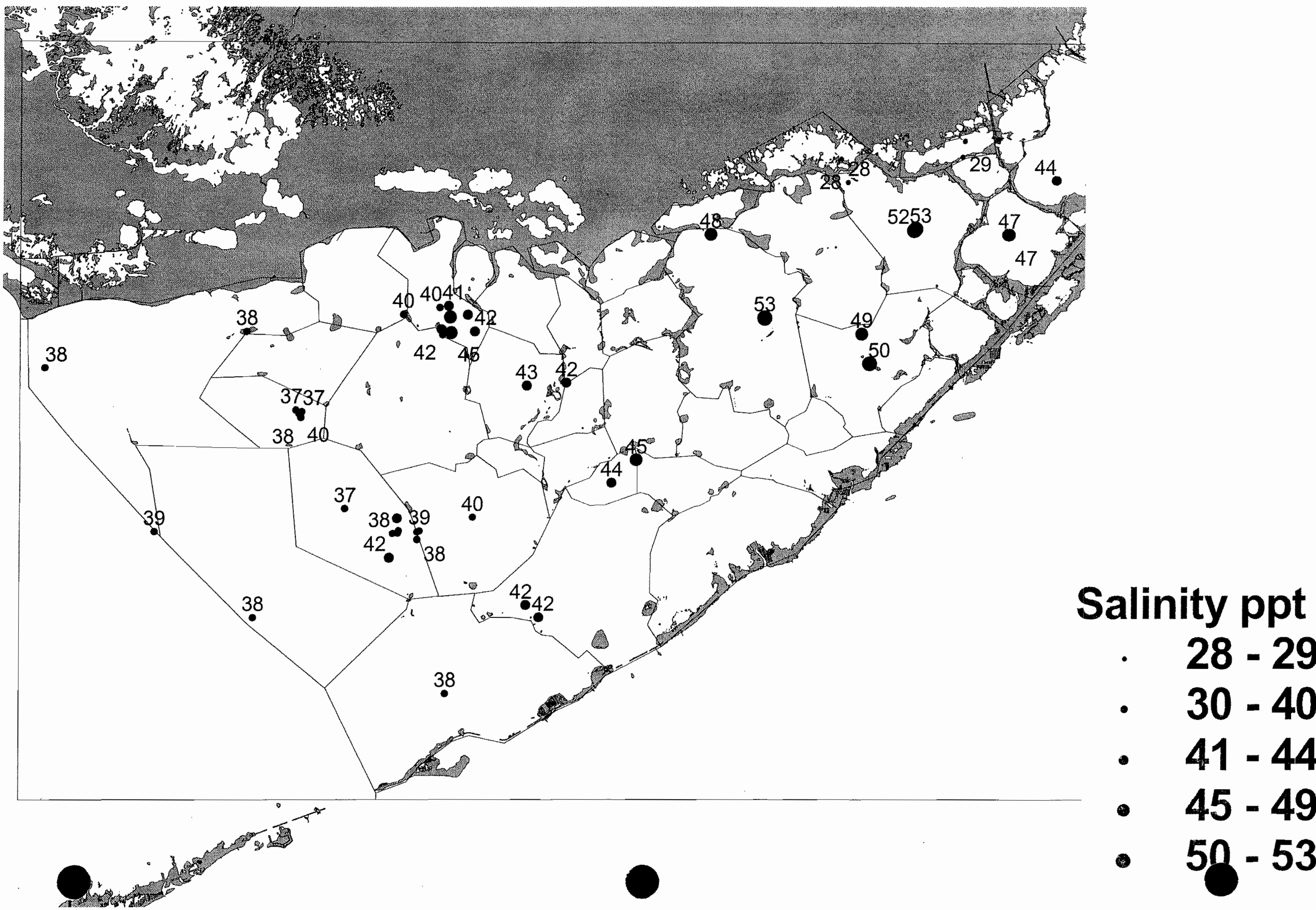


Figure 20. Salinity map of Florida Bay for April 1995.

April 1995 Salinity

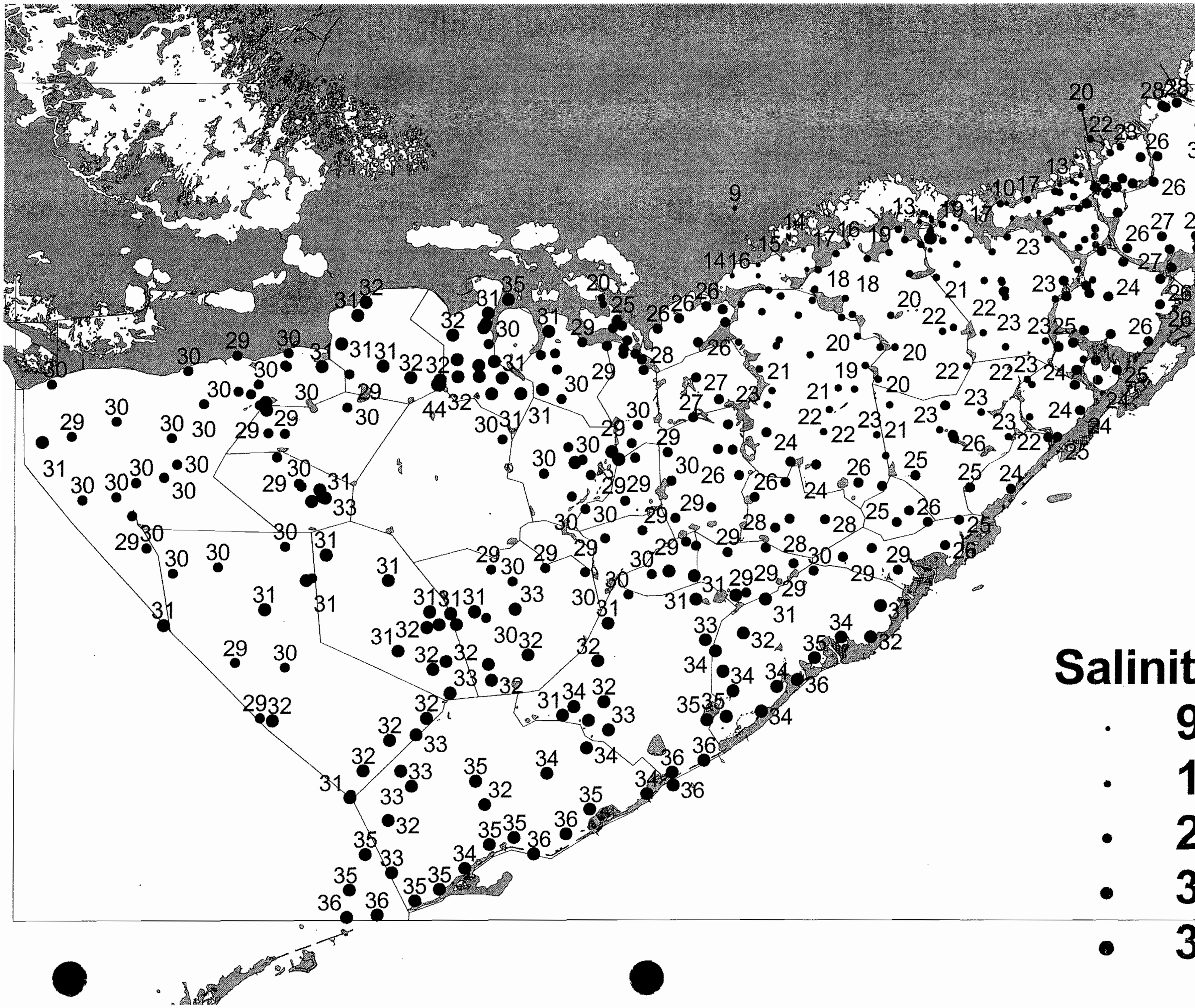
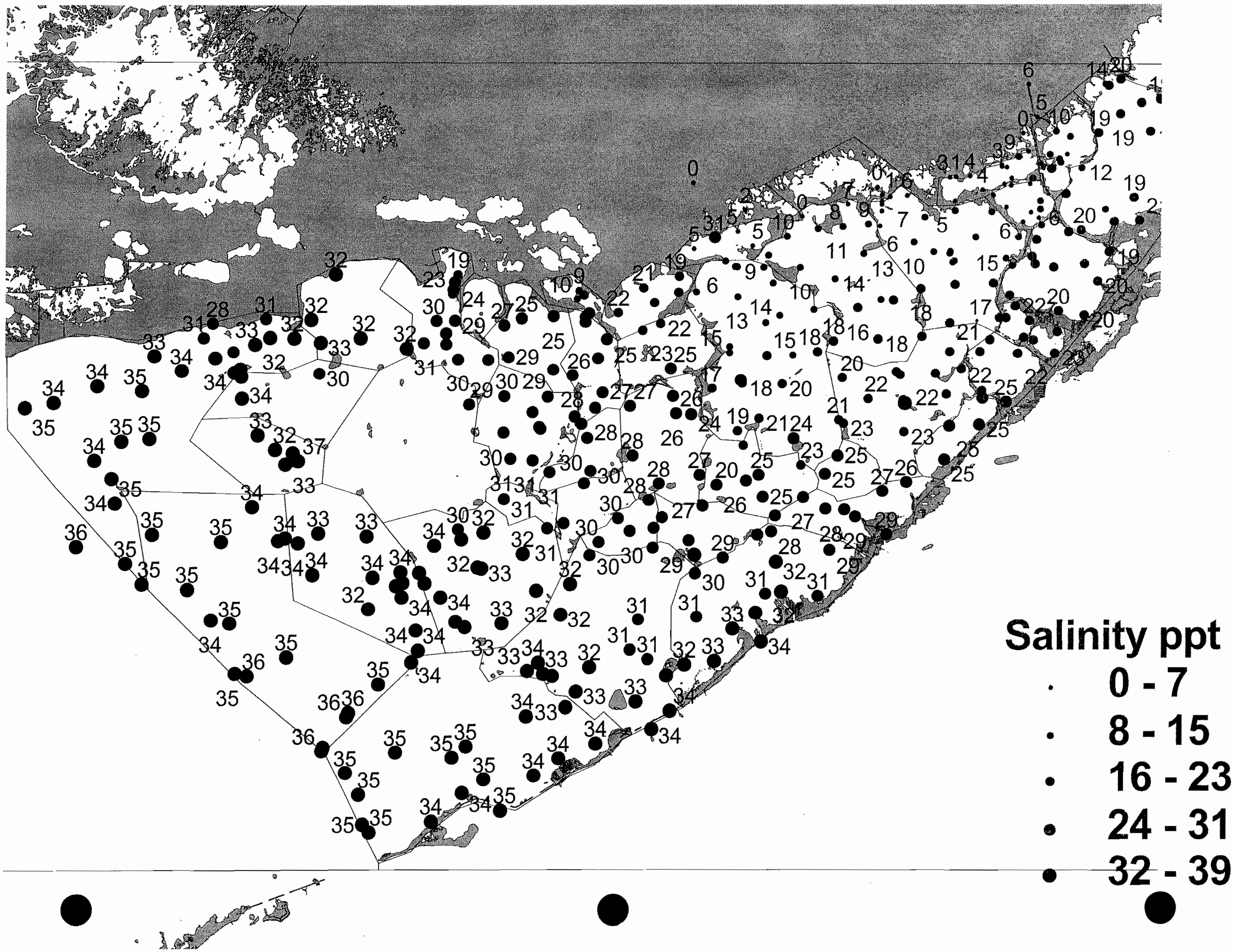


Figure 21. Salinity map of Florida Bay for August 1995.

August 1995 Salinity



general terms. Then predictions are presented in terms of species, habitat, and geography. Seasonal patterns of spawning may affect the seasonal abundance of some or all of the species. Therefore, it is most appropriate to compare dry season to dry season and wet season to wet season for the two years.

Predictions of faunal density were based on trawl gear because trawl gear made up the greatest proportion of our samples. Predictions were made for the five habitat types (bank, basin, channel, island shoreline, mainland shoreline). The basin habitat is the most important habitat in Florida Bay, comprising about 78.5% of Bay area, followed by bank, which comprises about 20% (Appendix A, Table A-8). The combined channel, island shoreline, and mainland shoreline habitat make up less 2% of the area of the Bay.

General Synopsis (Bay-Wide Patterns)

Figure 22 shows the total number of individuals of all 11 species, as predicted by the 11 individual species models. The prediction of bay-wide total abundance could potentially be used as an index of the response of the forage community, as represented by the 11 forage species in the model, to a change in conditions. Models predict that bay-wide abundance has a seasonal component and would be higher during wet seasons (August) than dry seasons (April). Predicted abundance of the 11 species was slightly higher in the wet year (1995) than the dry year (1990). The highest predicted abundance was during the wet season of the wet year (August 1995). The total predicted abundance during April 1995 (dry season, wet year) was 1.05 times higher than in April 1990 (dry season, dry year), and the total predicted abundance during August 1995 (wet season, wet year) was 1.07 times higher than in August 1990 (wet season, dry year). Thus overall abundance of the 11 species community changed between extreme conditions.

Predicted response differed by species. Figure 23 shows the predicted response of each species. The predicted Bay abundance of *Lucania, Eucinostomus, Floridichthys,* and *Farfantepenaeus* showed a seasonal effect with highest numbers in August. However, highest predicted numbers of *Lucania* were in August of the wet year, whereas highest predicted numbers of the other three species were in August of the dry year. Highest predicted numbers of *Microgobius, Gobiosoma, Anchoa, Syngnathus*, and *Hippocampus* occurred during the wettest period, August 1995. The predicted abundance of *Lagodon* was highest during the driest period, April 1990. The predicted abundance of *Opsanus* was highest during times of intermediate conditions: wet season/dry year followed by dry season/wet year.

Species Density by Habitat Type

Figures 24-35 show predicted bay-wide responses of forage species to wet and dry years (by wet and dry seasons) by habitat. Patterns of density for the combined 11 species were similar across all habitats. The highest predicted total forage species numbers occurred in August 1995. The basin followed by the mainland shoreline habitat had the greatest predicted density,

Figure 22. Bay-wide total predicted number of all 11 modeled species of the forage community for dry (April) and wet (August) seasons of 1990 (extreme dry year) and 1995 (extreme wet year).

Predicted numbers of 11 forage species in Florida Bay for 1990 (dry year) and 1995 (wet year).

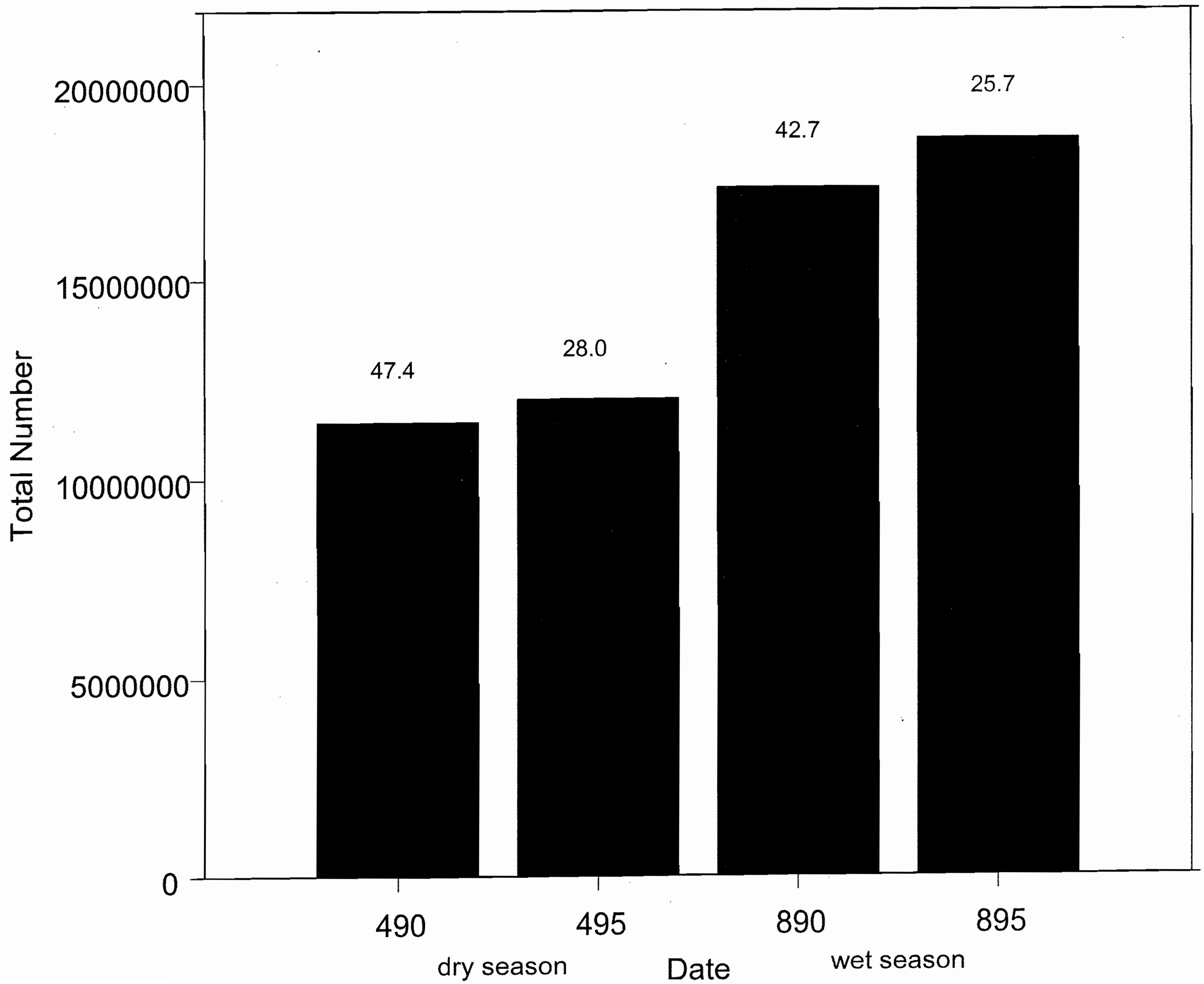
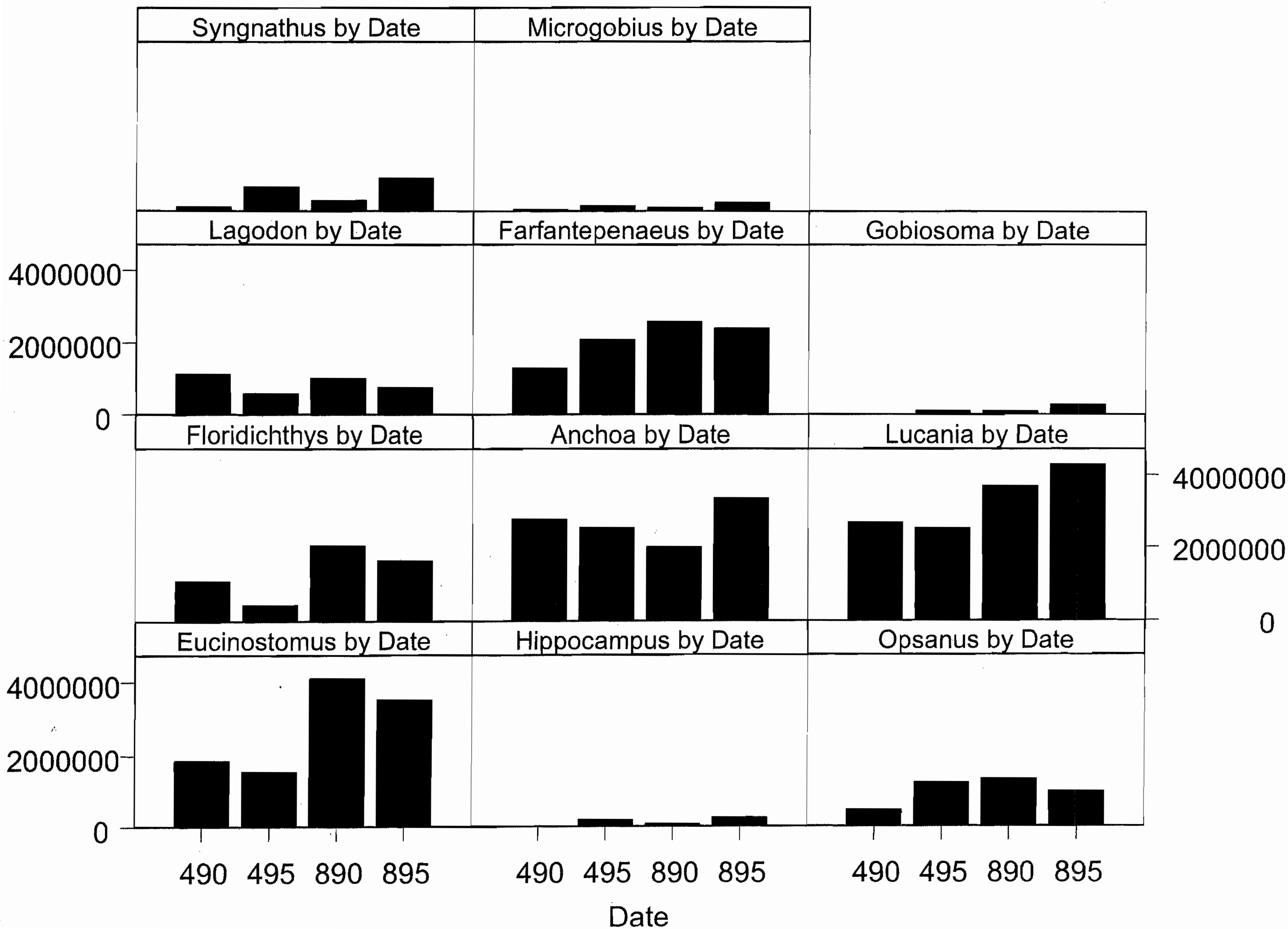


Figure 23. Bay-wide total predicted number of each species of the forage community for dry (April) and wet (August) seasons of 1990 (extreme dry year) and 1995 (extreme wet year).



Syngnathus by Date
Microgobius by Date
Lagodon by Date
Farfantepenaeus by Date
Gobiosoma by Date
Floridichthys by Date
Anchoa by Date
Lucania by Date
Eucinostomus by Date
Hippocampus by Date
Opsanus by Date
4000000
2000000
0
490 495 890 895
Date

and the bank habitat had the lowest predicted density (Figure 24). All habitats were predicted to have higher density in August than in April, and 1995 was predicted to have higher faunal density than 1990 for both seasons.

The individual species responses were habitat dependent (Figures 25-35). Table 5 summarizes predicted responses to habitat (averaged across both seasons and years of the predictions, April and August, 1990 and 1995). Predicted density was highest in the basin and mainland shoreline habitats and lowest on banks. Highest predicted density of *Anchoa* was in the channel followed by basin habitats and lowest predicted density was on banks (Fig. 25). *Eucinostomus* predicted densities were highest in island and mainland shoreline habitats and lowest in channels (Fig. 26). Predicted densities of *Farfantepenaeus* were highest in island shorelines and basins and lowest in channels (Fig. 27). *Floridichthys* predicted densities were highest on banks, mainland shorelines, and island shorelines and lowest in basins and channels (Fig. 28). Predicted densities of *Gobiosoma* were highest in the mainland shoreline habitat and lowest in the island shoreline (Fig. 29). *Hippocampus* predicted densities were highest along island shorelines and lowest around mainland shorelines (Fig. 30). Predicted densities of *Lagodon* were similar in all habitats with highest in basin and channel habitats (Fig. 31). *Lucania* predicted densities were highest in basin and channel habitats and lowest on banks and island shorelines (Fig. 32). Predicted densities of *Microgobius* were in channels and basins and lowest on banks and island shorelines (Fig. 33). *Opsanus* predicted densities were highest in basin and channel habitats and lowest on banks (Fig. 34). Predicted densities of *Syngnathus* were highest on bank and mainland shoreline habitats and lowest in channels and basins (Fig. 35).

Table 5. Predicted number/hectare of 11-species by habitat type (averaged over the four periods of predictions (April and August of 1990 and 1995).

Habitat	Bank	Basin	Channel	Island	Mainland	Average
Anchoa	581	1,867	2,222	967	1,211	1,370
Farfantepenaeus	759	1,090	580	1,137	995	912
Floridichthys	1,388	867	852	1,346	1,370	1,165
Gobiosoma	67	84	87	9	116	72
Hippocampus	108	95	133	169	7	102
Lagodon	416	494	469	414	425	444
Lucania	262	2,954	1,876	165	1,164	1,284
Microgobius	48	120	127	49	111	91
Mojarra	1,750	1,633	793	2,287	2,329	1,759
Opsanus	125	805	722	177	243	414
Syngnathus	547	271	292	360	422	378
Total	6,050	10,280	8,152	7,079	8,394	7,991

Figure 24. Predicted Bay-wide average density of individual forage species by habitat for dry (April) and wet (August) seasons of 1990 (extreme dry year) and 1995 (extreme wet year).

Predicted Average Densities of 11 Forage Species by Habitat for April (dry season) and August (wet season) for 1990 (dry year) and1995 (wet year). Calculated using median.

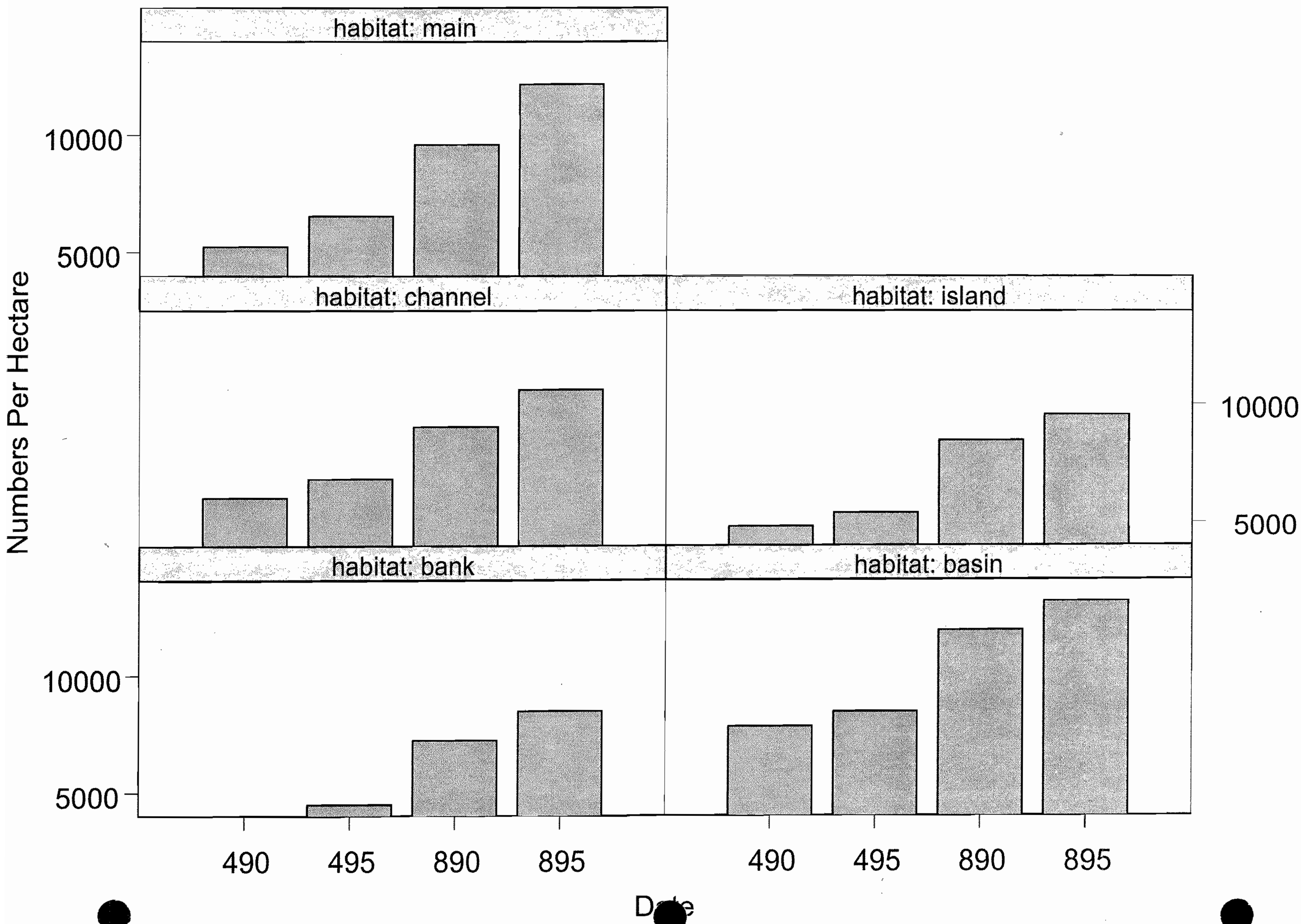


Figure 25. Predicted number per hectare of *Anchoa mitchelli* by habitat for dry (April) and wet (August) seasons of 1990 (extreme dry year) and 1995 (extreme wet year).

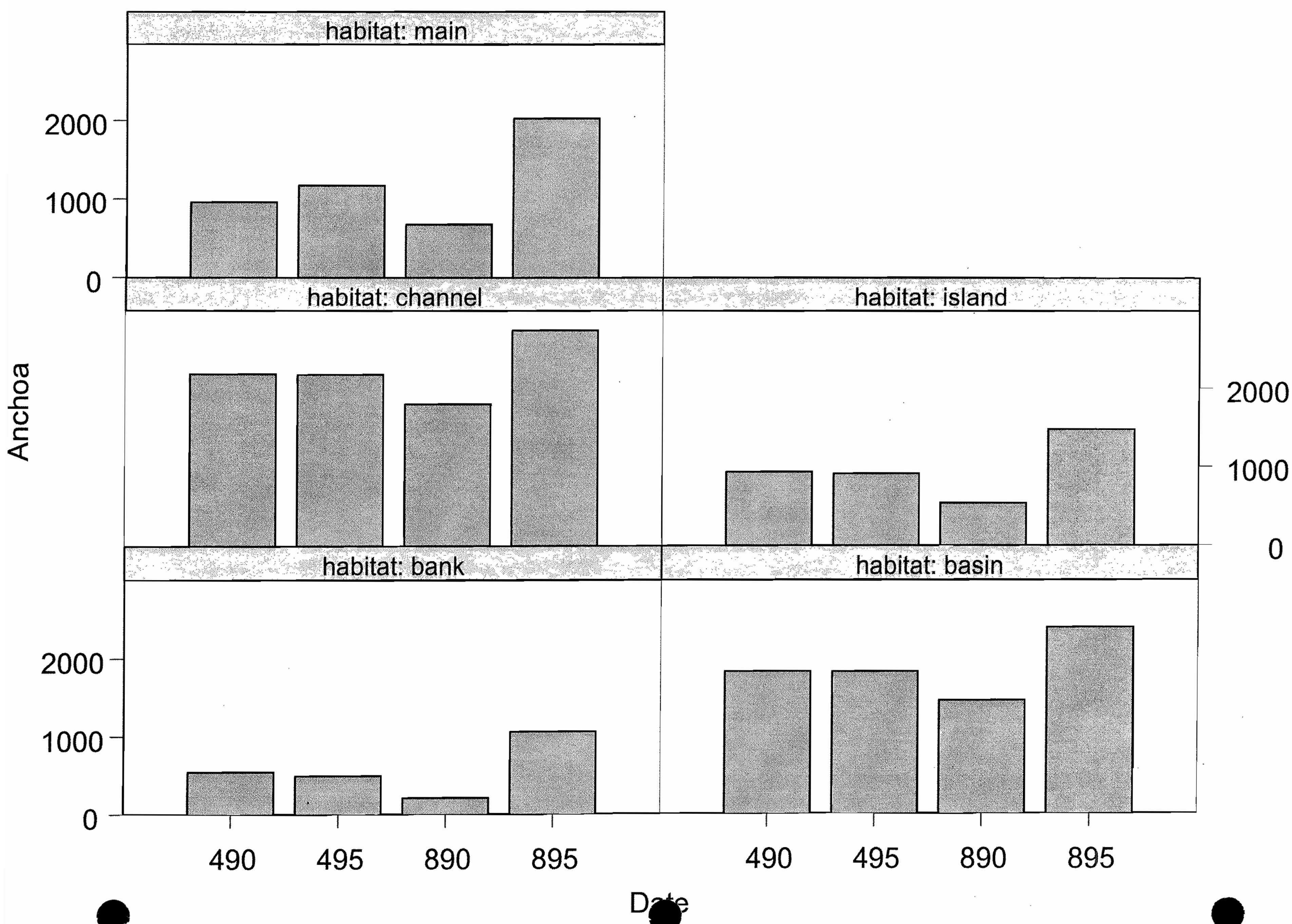

habitat: main
habitat: channel
habitat: island
habitat: bank
habitat: basin
Anchoa
2000
1000
0
490
495
890
895
Date

Figure 26. Predicted number per hectare of *Eucinostomus spp.* by habitat for dry (April) and wet (August) seasons of 1990 (extreme dry year) and 1995 (extreme wet year).

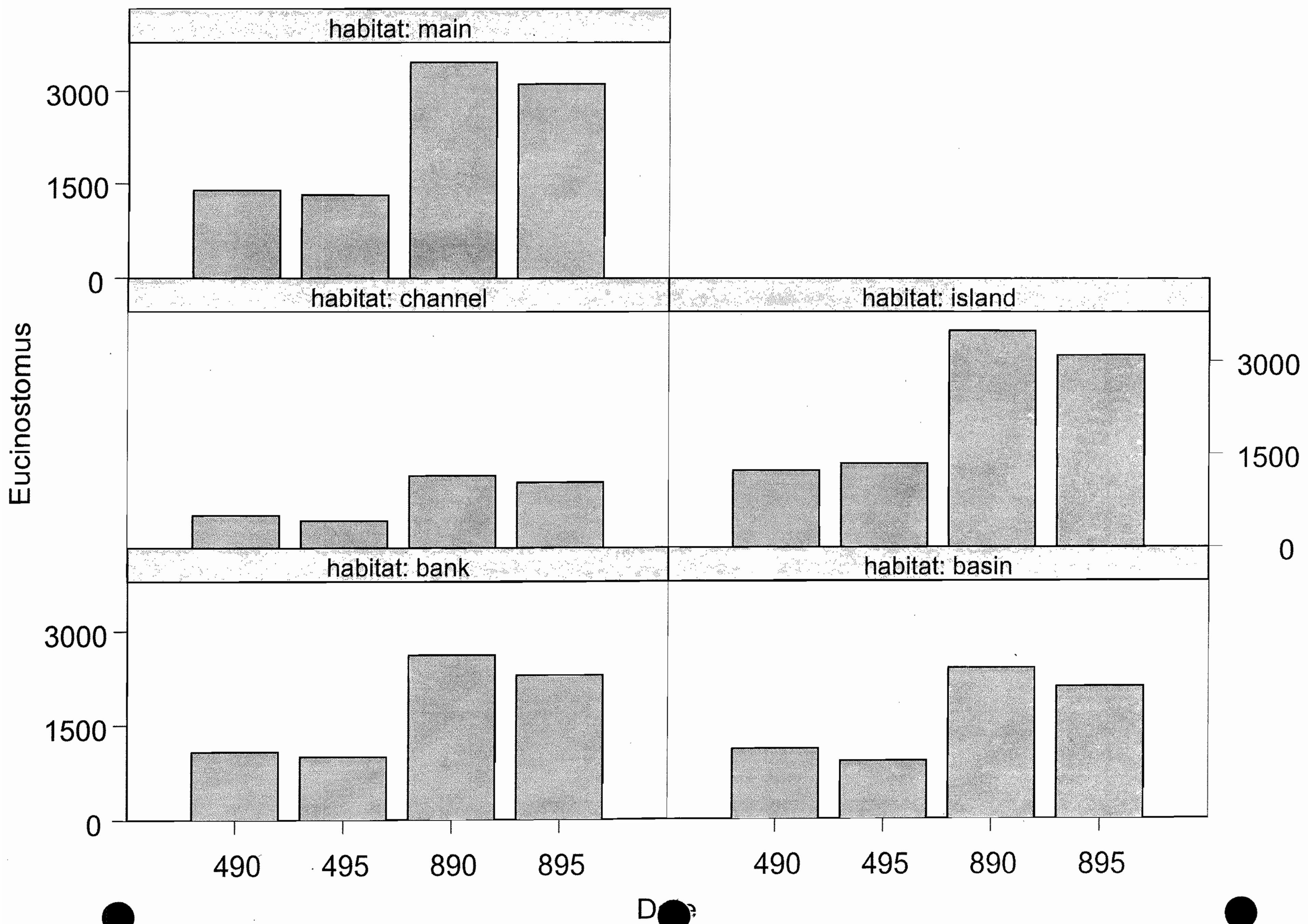
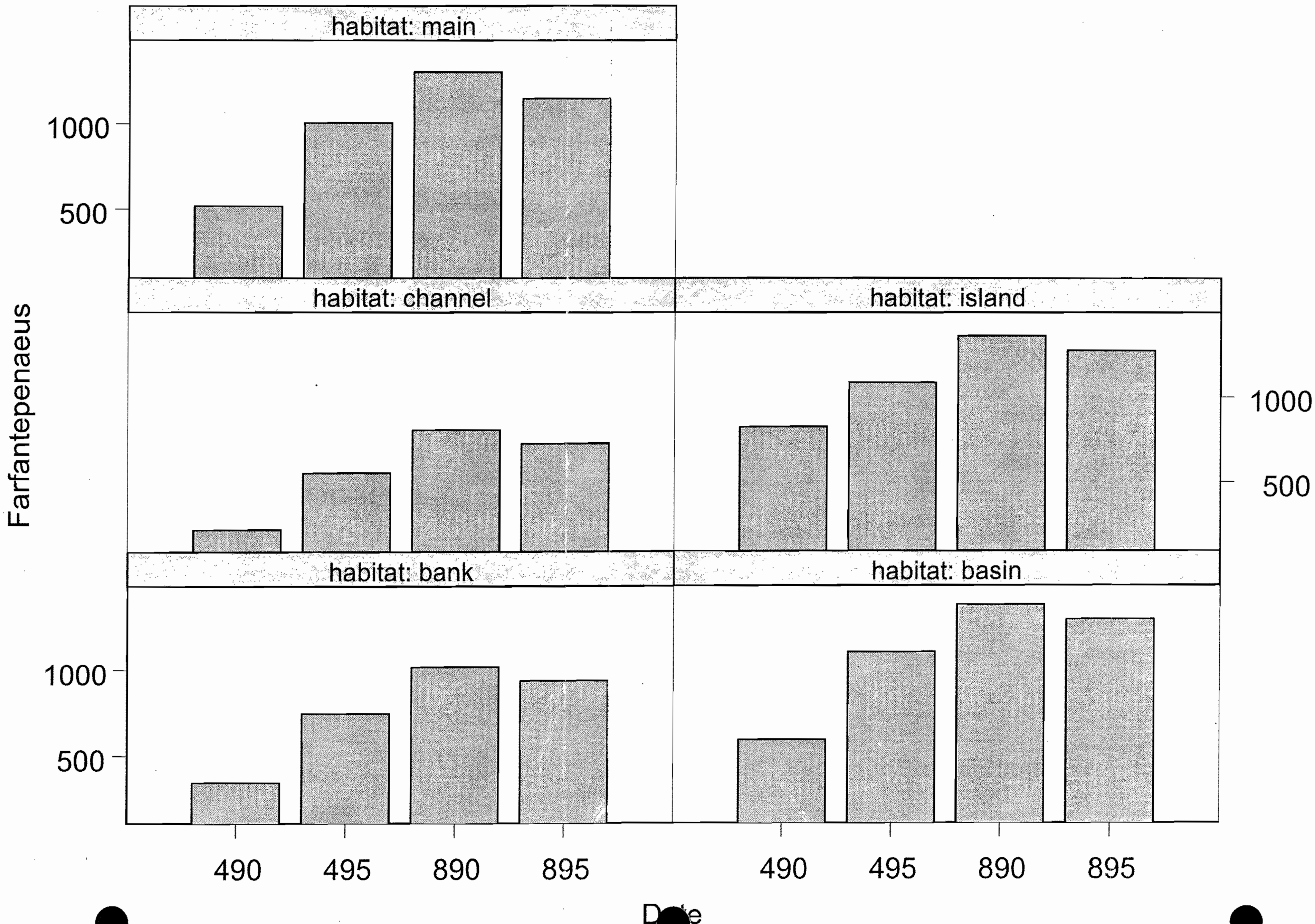

habitat: main
habitat: channel
habitat: island
habitat: bank
habitat: basin
Eucinostomus
3000
1500
0
490
495
890
895

Figure 27. Predicted number per hectare of *Farfantepenaeus duorarum* by habitat for dry (April) and wet (August) seasons of 1990 (extreme dry year) and 1995 (extreme wet year).



habitat: main
habitat: channel
habitat: island
habitat: bank
habitat: basin
1000
500
490
495
890
895
Farfantepenaeus

Figure 28. Predicted number per hectare of *Floridichthys carpio* by habitat for dry (April) and wet (August) seasons of 1990 (extreme dry year) and 1995 (extreme wet year).

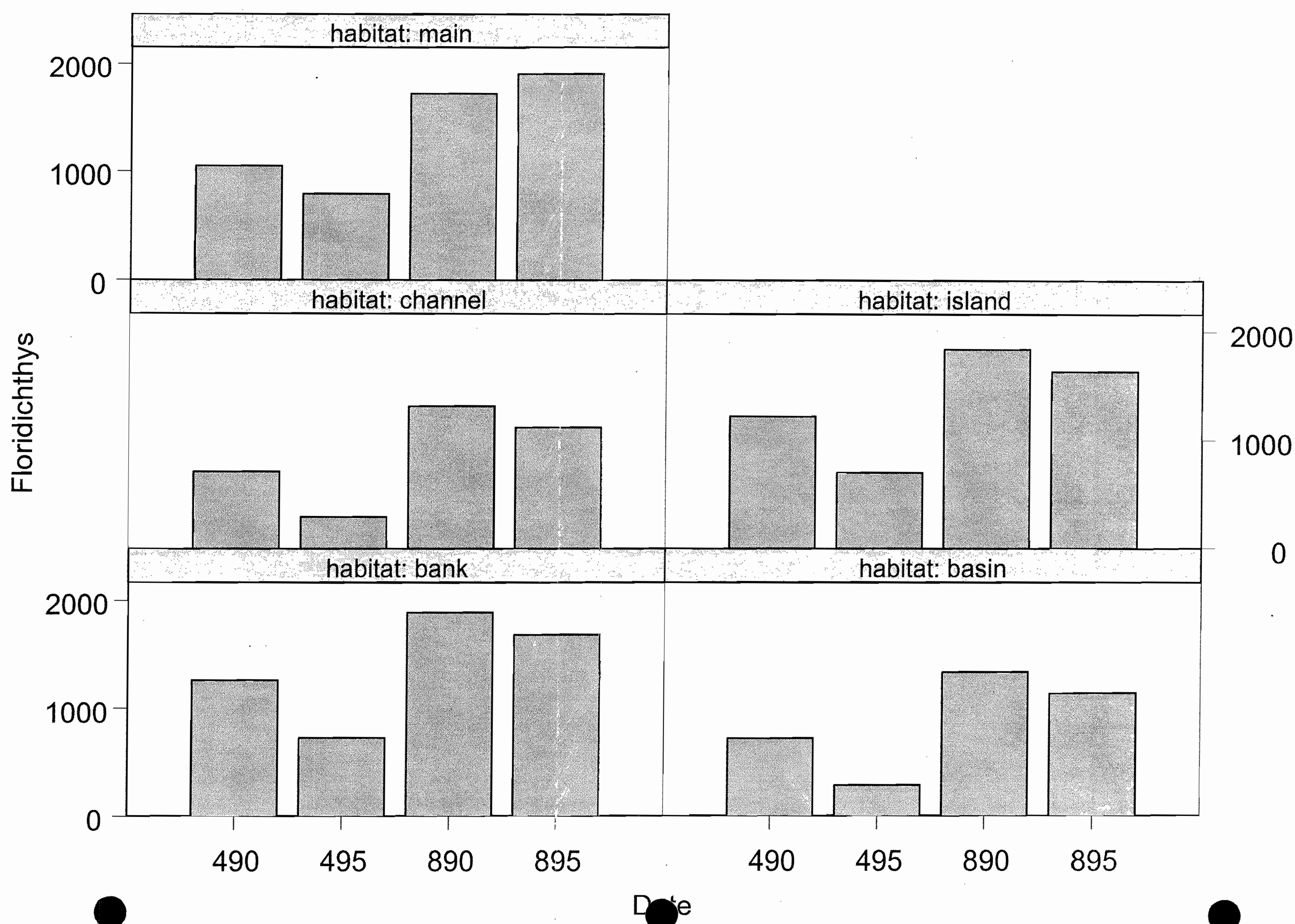

habitat: main
habitat: channel
habitat: island
habitat: bank
habitat: basin
Floridichthys
0
1000
2000
490
495
890
895
Date

Figure 29. Predicted number per hectare of *Gobiosoma robustum* by habitat for dry (April) and wet (August) seasons of 1990 (extreme dry year) and 1995 (extreme wet year).

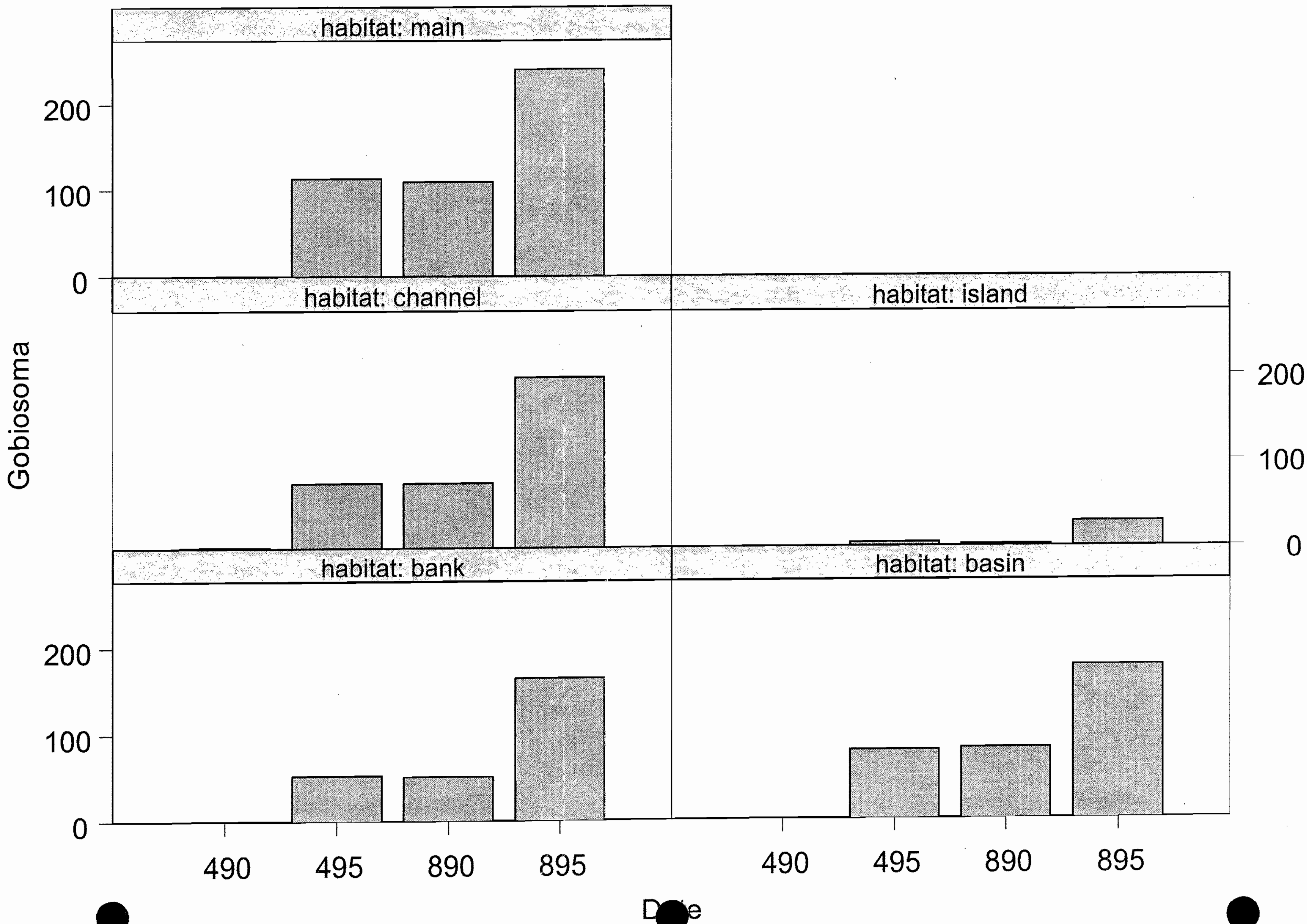

habitat: main
habitat: channel
habitat: island
habitat: bank
habitat: basin
Gobiosoma
200
100
0
490
495
890
895

Figure 30. Predicted number per hectare of *Hippocampus zostera* by habitat for dry (April) and wet (August) seasons of 1990 (extreme dry year) and 1995 (extreme wet year).

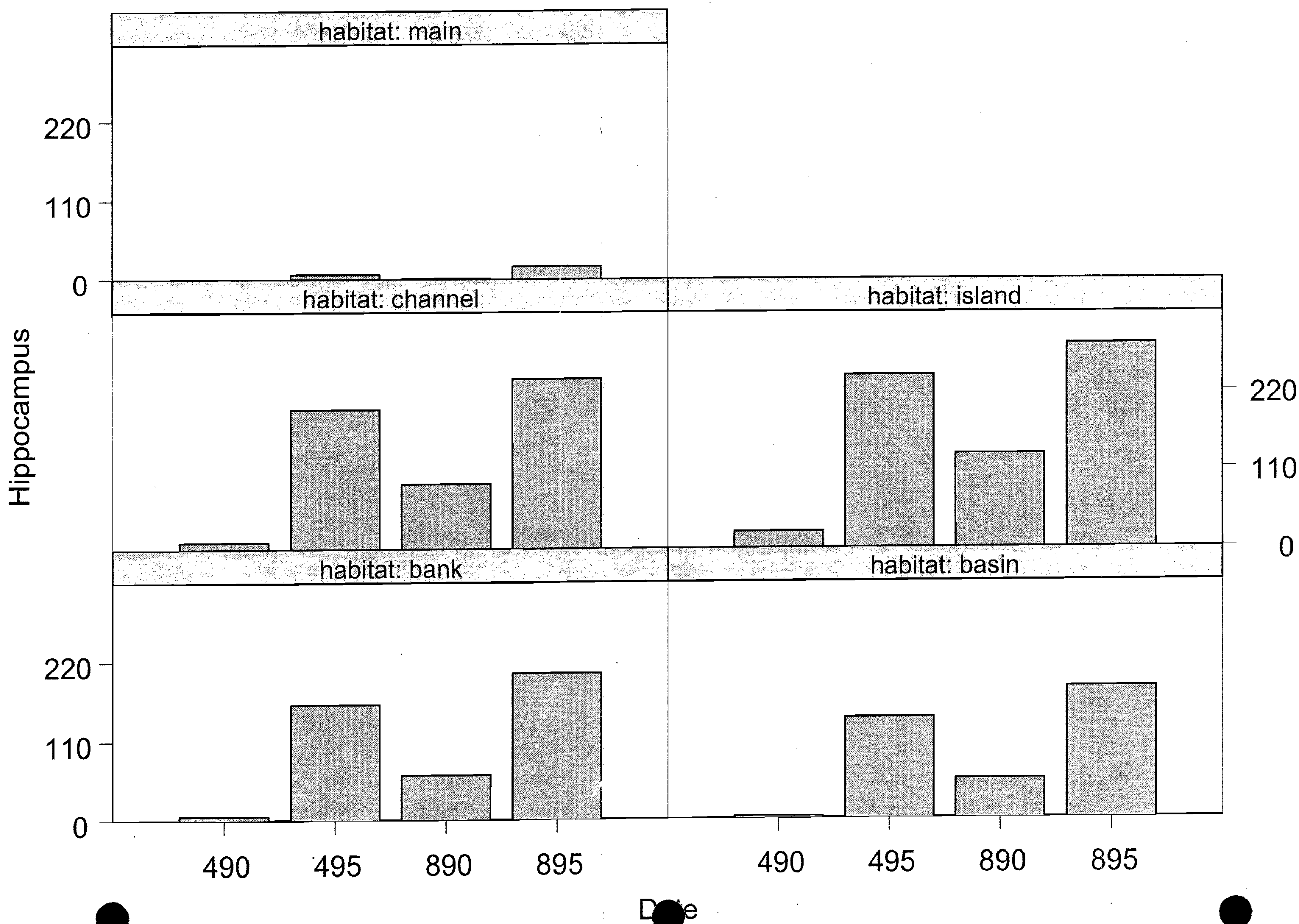

habitat: main
habitat: channel
habitat: island
habitat: bank
habitat: basin
Hippocampus
220
110
0
490
495
890
895
Date

Figure 31. Predicted number per hectare of *Lagodon rhomboides* by habitat for dry (April) and wet (August) seasons of 1990 (extreme dry year) and 1995 (extreme wet year).

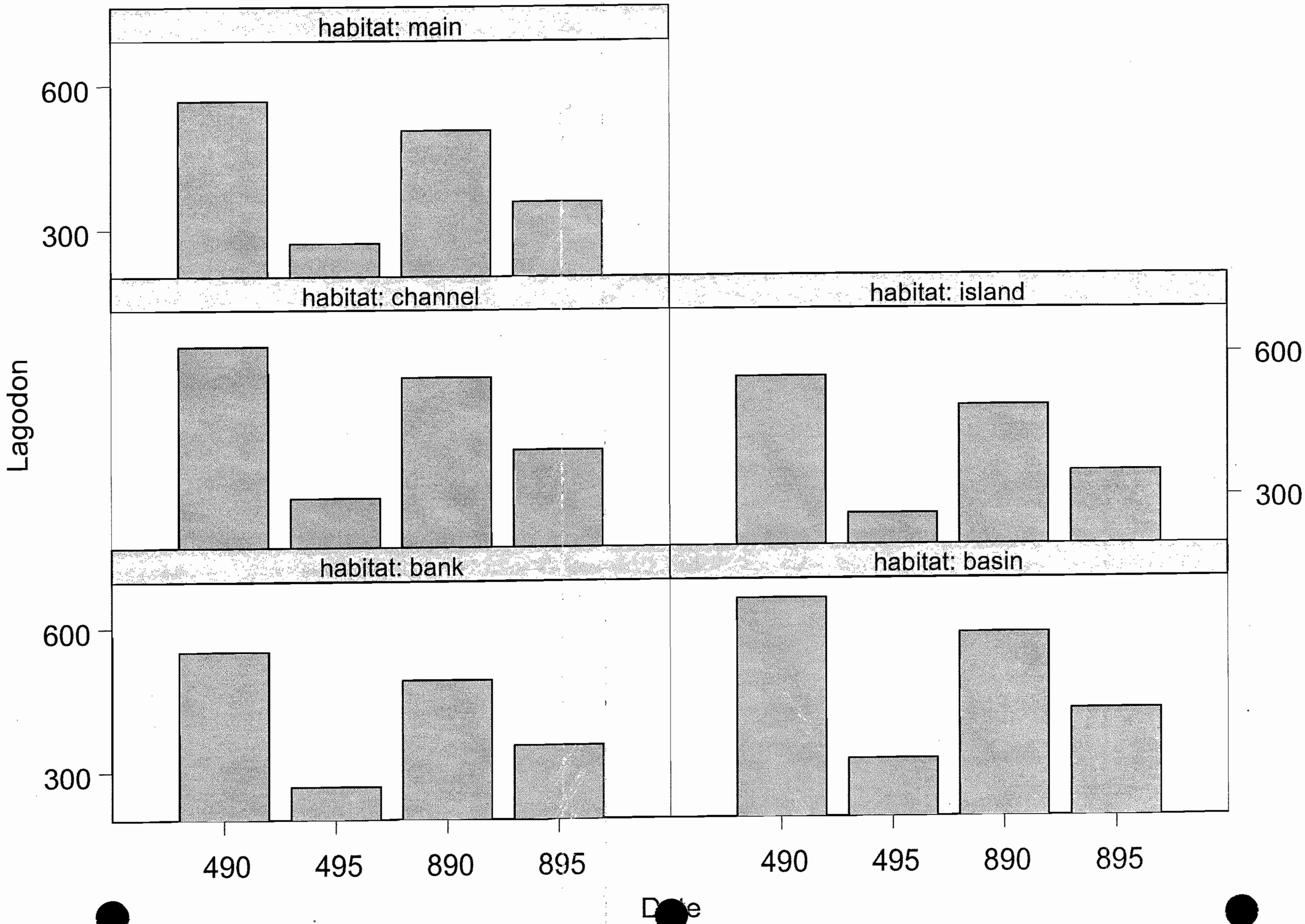

habitat: main
habitat: channel
habitat: island
habitat: bank
habitat: basin
Lagodon
600
300
490
495
890
895
Date

Figure 32. Predicted number per hectare of *Lucania parva* by habitat for dry (April) and wet (August) seasons of 1990 (extreme dry year) and 1995 (extreme wet year).

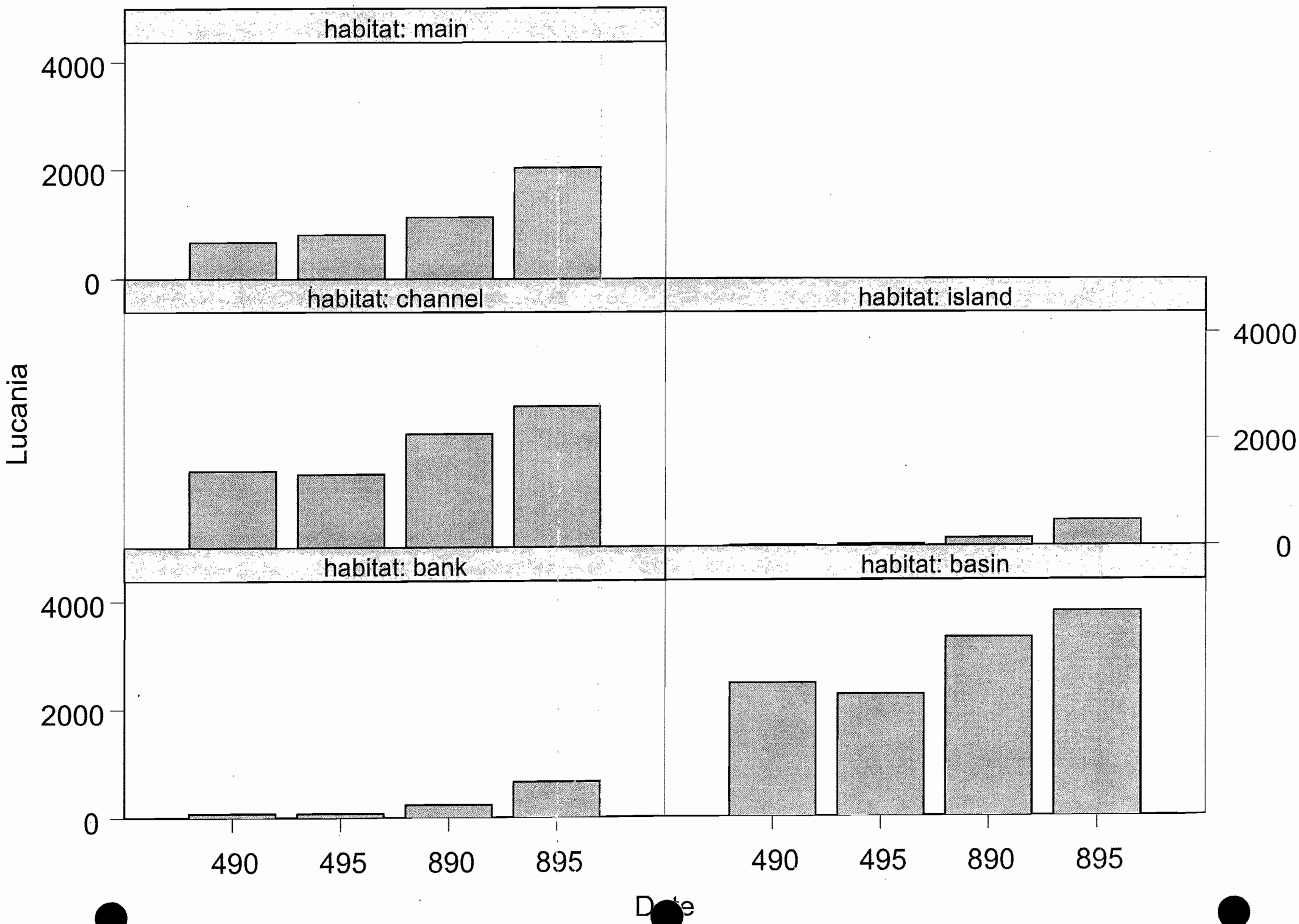
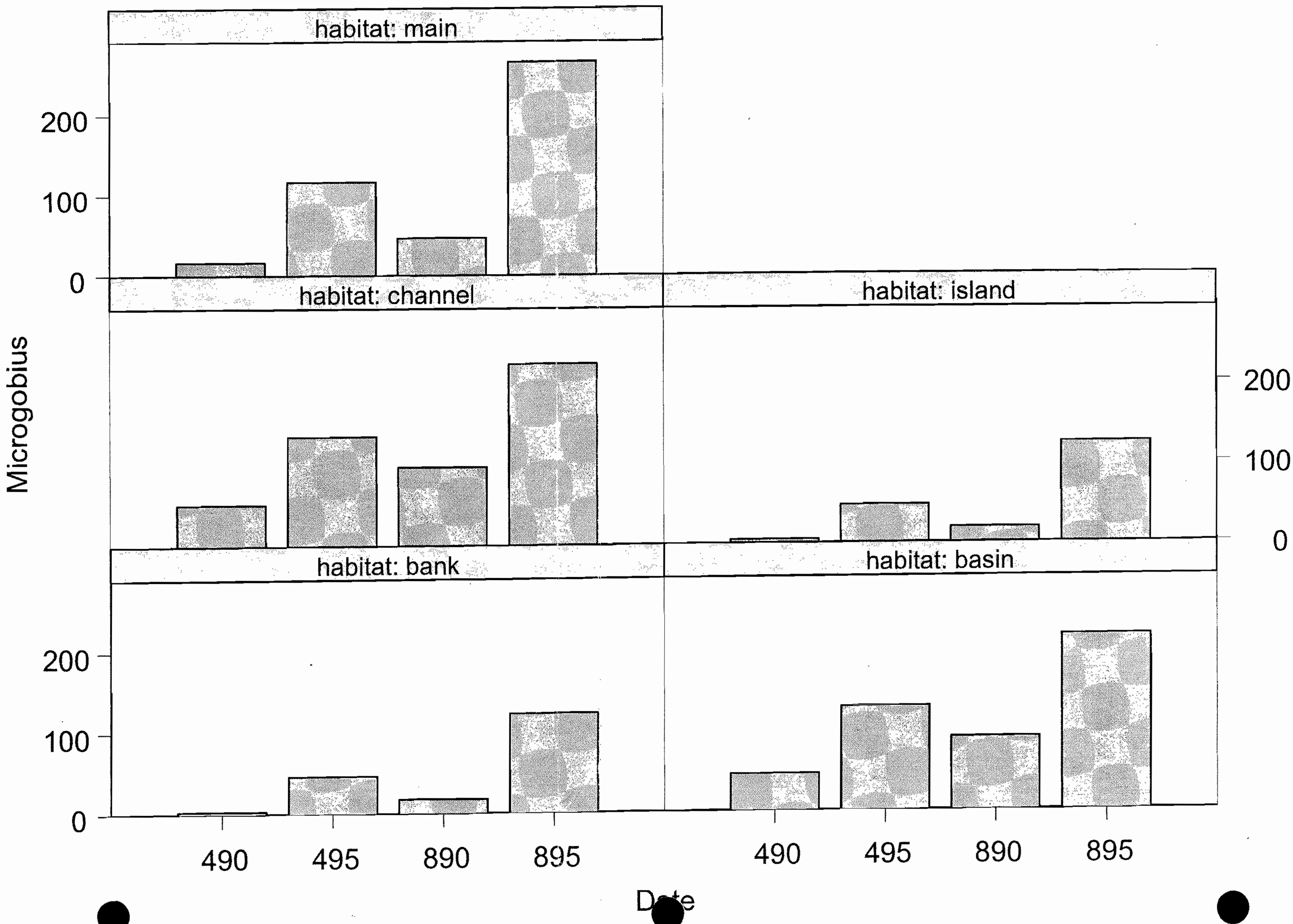

habitat: main
habitat: channel
habitat: island
habitat: bank
habitat: basin
Lucania
Date
0
2000
4000
490
495
890
895

Figure 33. Predicted number per hectare of *Microgobius gulosus* by habitat for dry (April) and wet (August) seasons of 1990 (extreme dry year) and 1995 (extreme wet year).



habitat: main
habitat: channel
habitat: island
habitat: bank
habitat: basin
Microgobius
0
100
200
490
495
890
895
Date

Figure 34. Predicted number per hectare of *Opsanus beta* by habitat for dry (April) and wet (August) seasons of 1990 (extreme dry year) and 1995 (extreme wet year).

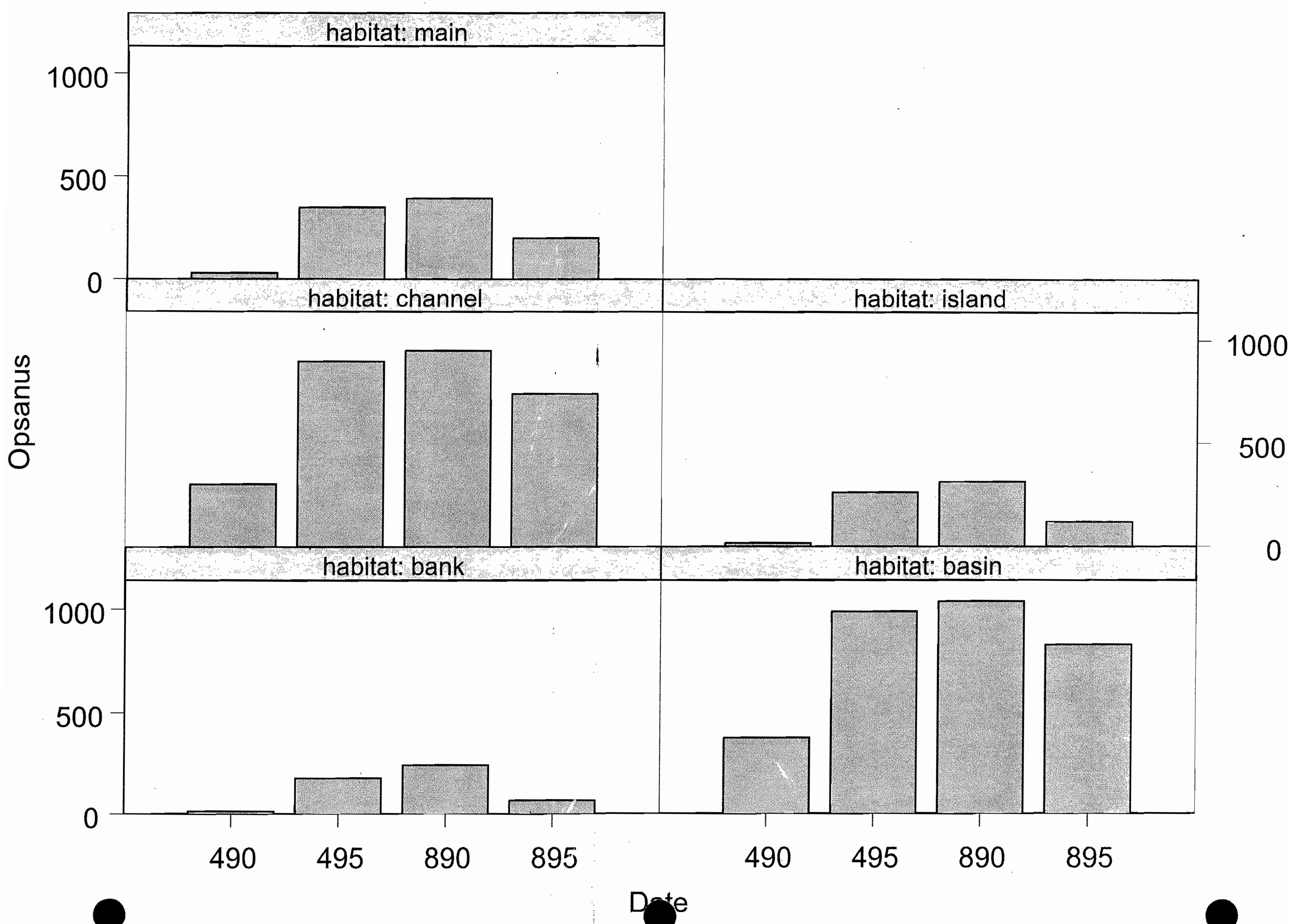
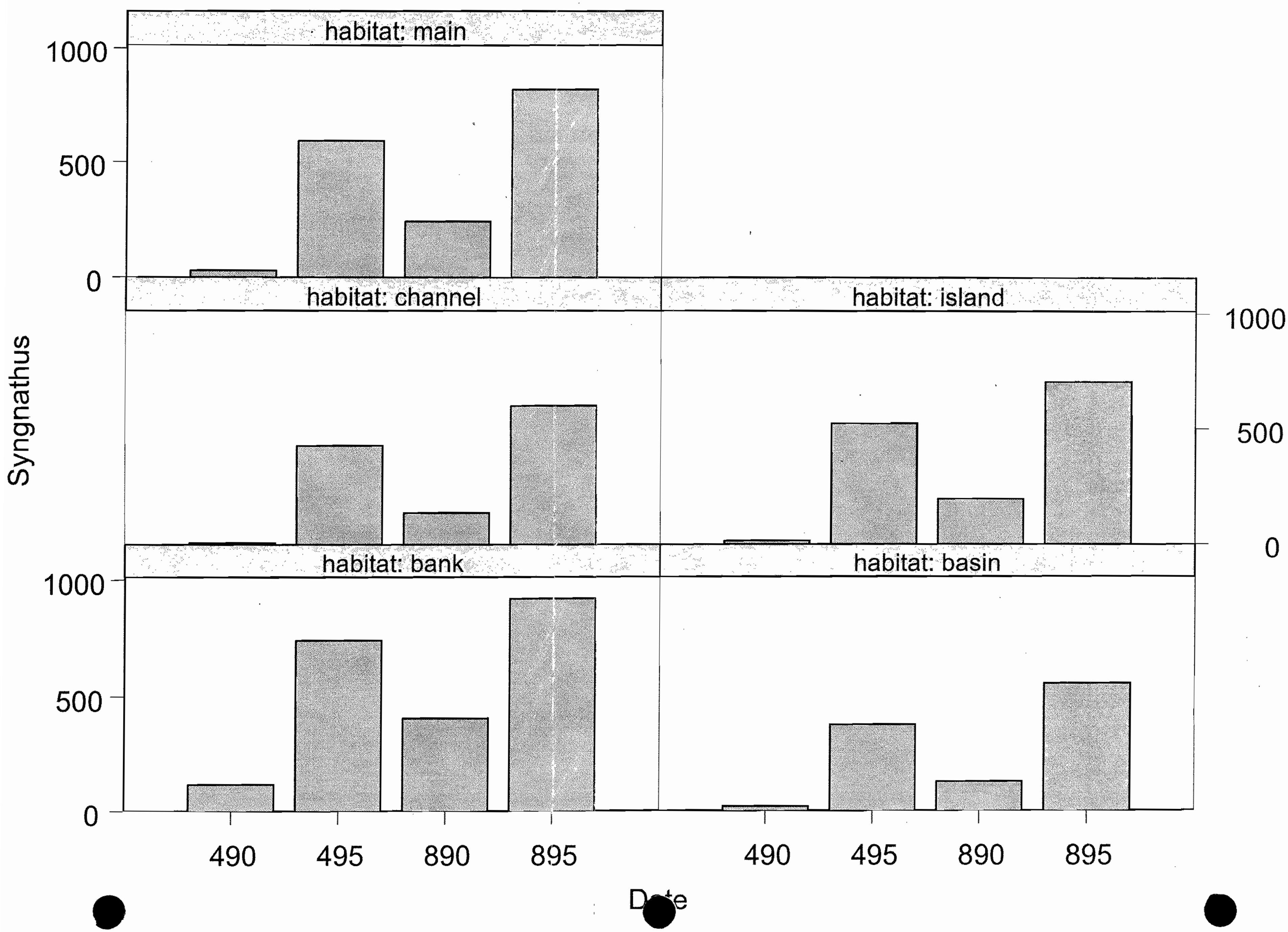

habitat: main
habitat: channel
habitat: island
habitat: bank
habitat: basin
Opsanus
1000
500
0
490
495
890
895
Date

Figure 35. Predicted number per hectare of *Syngnathus scovelli* by habitat for dry (April) and wet (August) seasons of 1990 (extreme dry year) and 1995 (extreme wet year).


habitat: main
habitat: channel
habitat: island
habitat: bank
habitat: basin
Syngnathus
1000
500
0
490
495
890
895

Species Composition

Figure 36 shows the predicted species composition (percent of total number) for the entire Bay for the four time intervals. Species composition by habitat (predicted numbers/hectare) for the four time intervals is shown in Figures 37-41.

On a Bay-wide basis, there were no major changes in predicted species composition among the four time periods. Four taxa were consistently dominant in terms of percent composition during all time periods: *Farfantepenaeus, Anchoa*, *Eucinostomus*, and *Lucania*. The relative importance of the individual species varied seasonally. *Eucinostomus* were more important in April than in August. *Opsanus* and *Floridichthys* were most important during the driest period. Percent composition of *Syngnathus* was higher in both seasons of the wet year.

Differences in predicted percent composition were more noticeable on a habitat basis. In the bank habitat, the predicted highest ranking dominants during the driest period were *Floridichthys, Eucinostomus*, *Lagodon*, and *Anchoa*, while the wettest period was characterized by *Eucinostomus*, *Floridichthys, Anchoa, Farfantepenaeus,* and *Syngnathus* (Figure 37). Predicted species composition was more even in the wetter periods (year and season). Dominants were more important in dryer periods.

Lucania, Anchoa, and *Eucinostomus* were dominants during all periods in the basin habitat (Figure 38). The importance of *Farfantepenaeus, Opsanus*, and *Floridichthys* varied between periods, with the first two species more important in the dry season/wet year when *Floridichthys* predicted numbers were reduced.

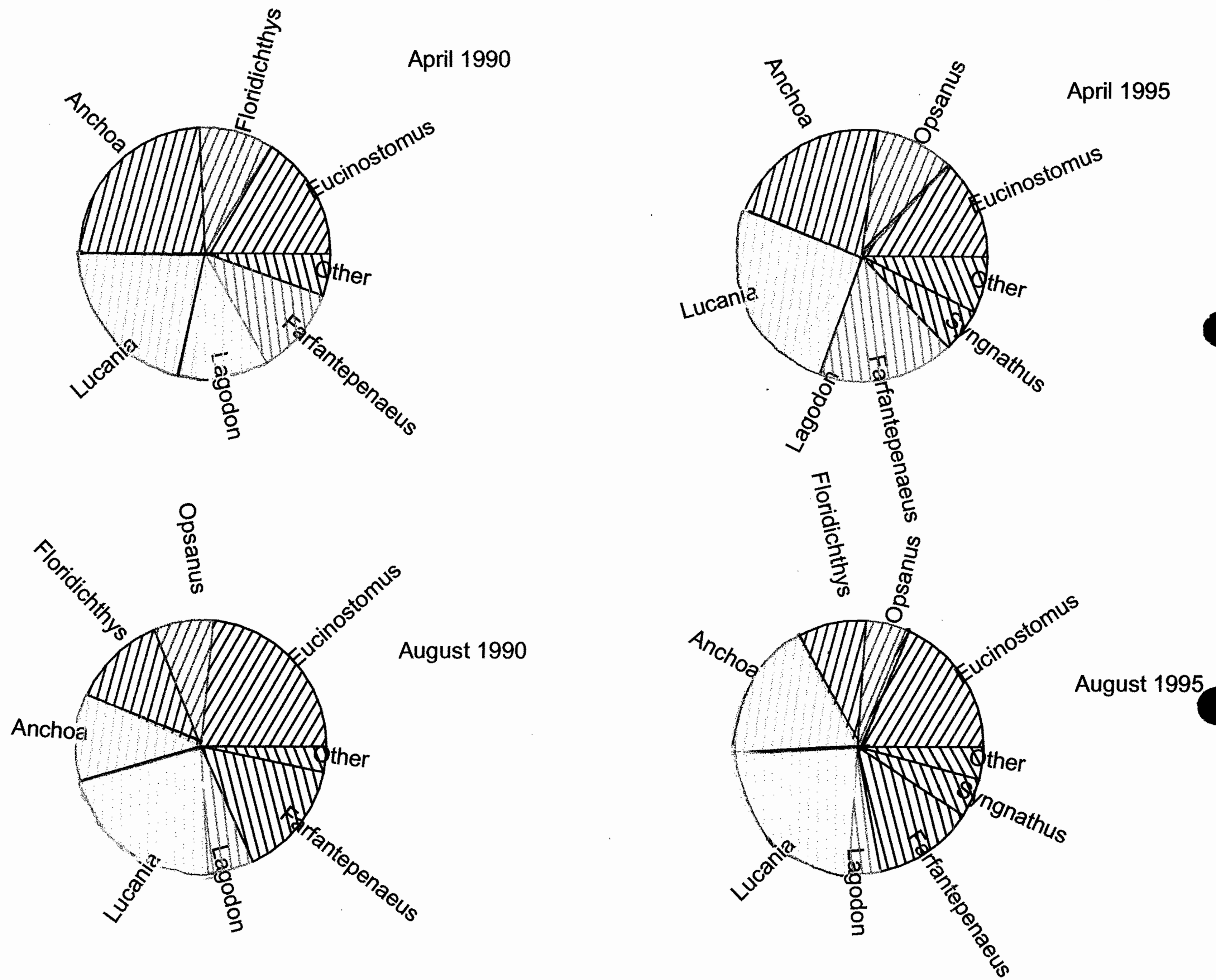
In the channel habitats, *Lucania* and *Anchoa* were predicted dominants during all time periods (Figure 39). *Floridichthys* were least important and *Opsanus* more important during April of the wet year. *Lagodon* was most important and *Opsanus* least important during the dry season/dry year. *Syngnathus* was more important during the wet year than the dry year.

In the island shoreline habitat, *Eucinostomus*, *Floridichthys,* and *Farfantepenaeus* were important during all time periods (Figure 40). *Syngnathus* was more important in the wet years for both seasons. *Anchoa* was important in all time periods with reduced numbers during August of the dry year. *Lagodon* was most important during the driest period. *Lucania* was predicted to be unimportant in this habitat.

In the mainland shoreline habitat, six species (*Eucinostomus*, *Floridichthys, Anchoa, Lucania, Lagodon*, and *Lagodon*) were predicted to be important in the driest period (Figure 41). *Lagdon* became less important during other time periods and was replaced in dominance by *Syngnathus* during April 1995. The other five species were more important during the wet year.

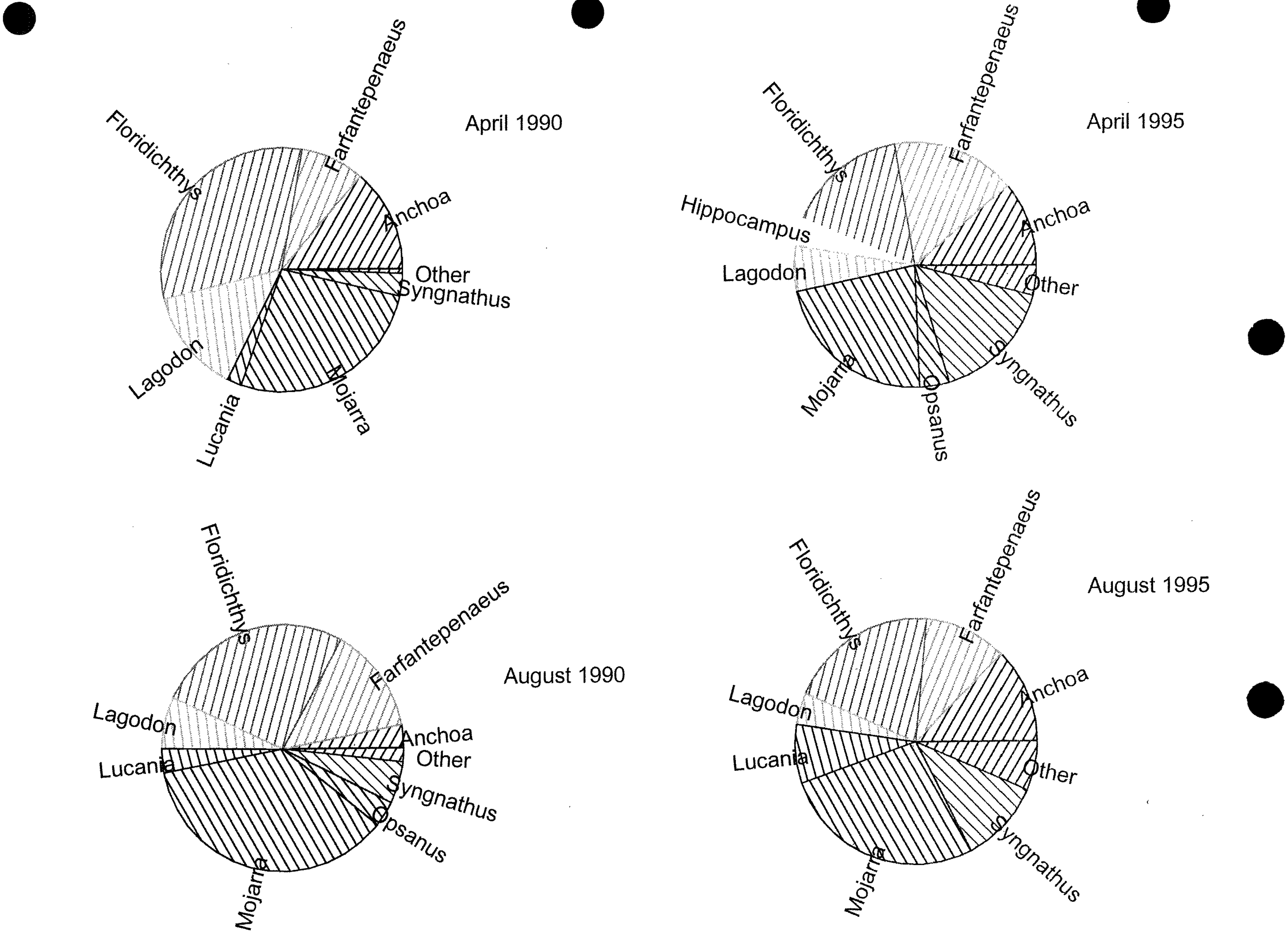
Basin habitat is the most important habitat in the Bay in terms of area. Basin habitat comprises 78% of Bay area and the bank habitat comprises 21% (Appendix A, Table A8). The

Figure 36. Predicted species composition (percent of total number/hectare) for the entire Florida Bay for dry (April) and wet (August) seasons of 1990 (extreme dry year) and 1995 (extreme wet year).



Percent Composition by Number in Florida Bay

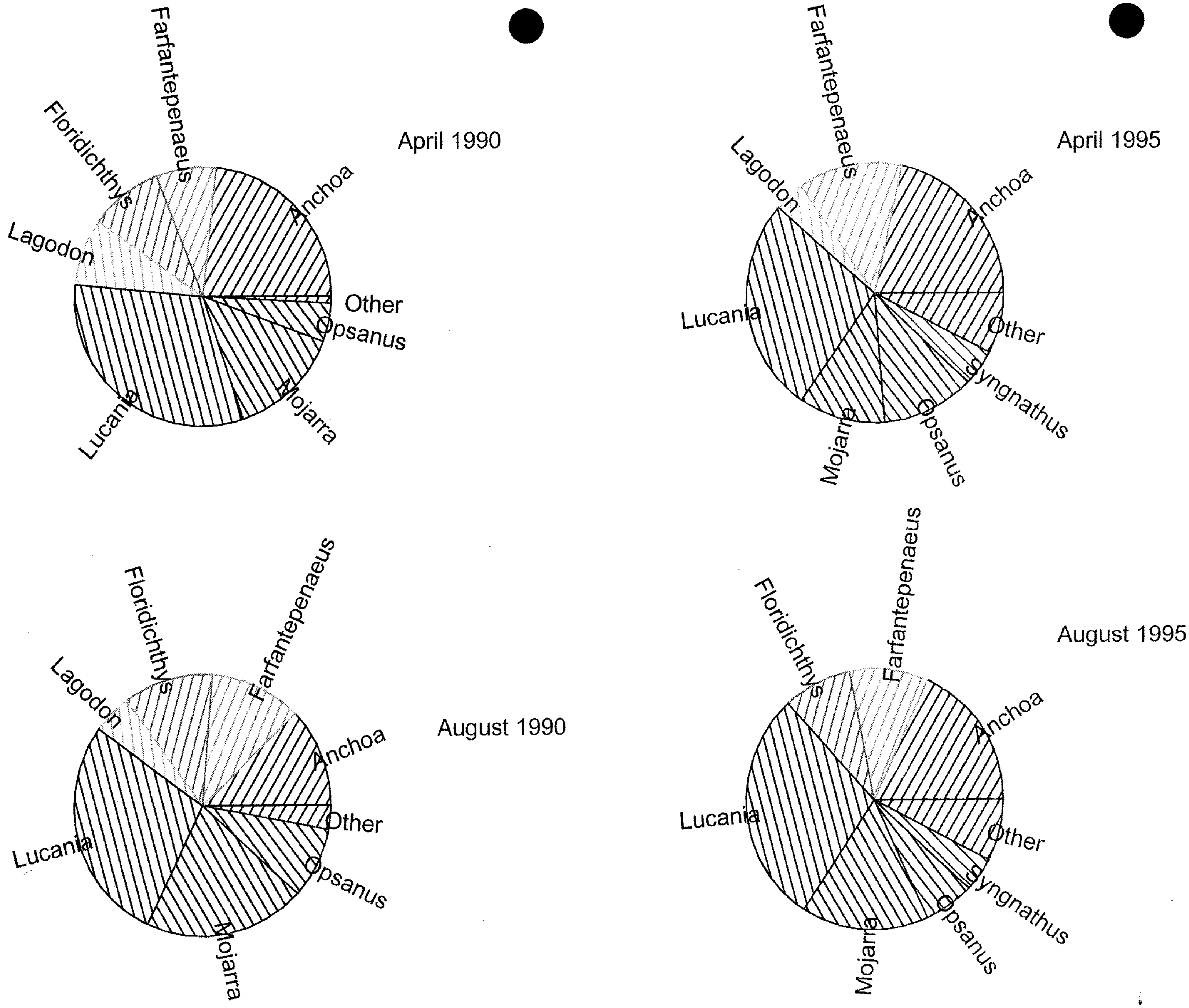
Figure 37. Species composition (percent of total number/hectare) for bank habitat for dry (April) and wet (August) seasons of 1990 (extreme dry year) and 1995 (extreme wet year).



BANK HABITAT

By Number

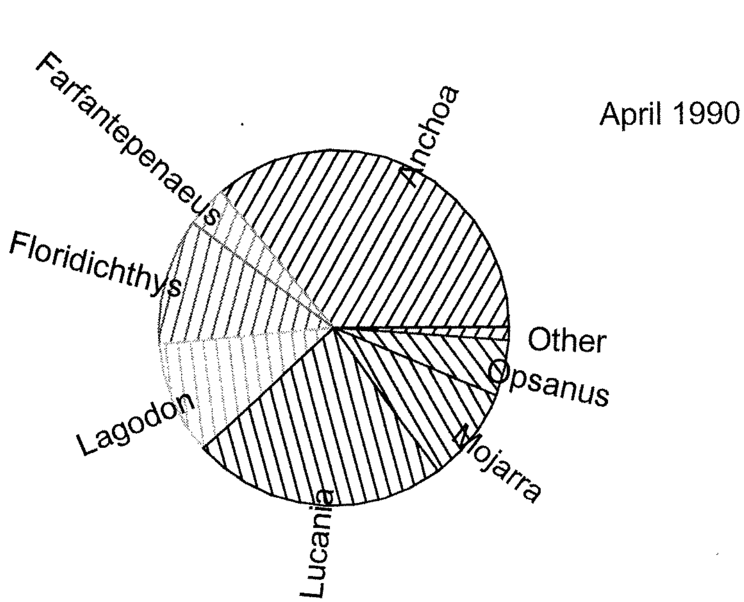
Figure 38. Species composition (percent of total number/hectare) for basin habitat for dry (April) and wet (August) seasons of 1990 (extreme dry year) and 1995 (extreme wet year).

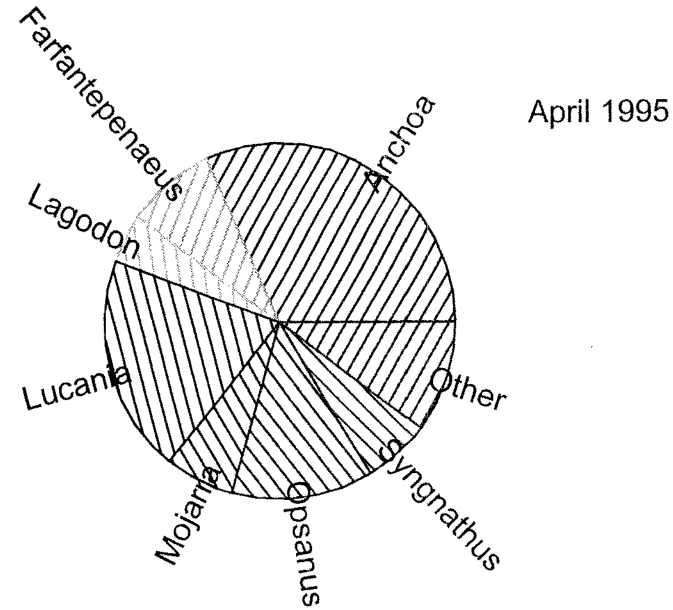


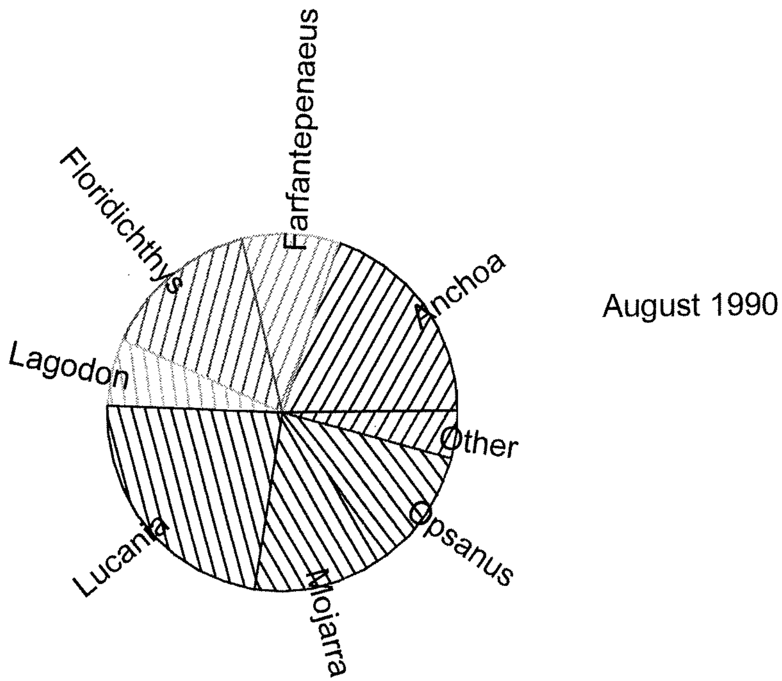
BASIN HABITAT

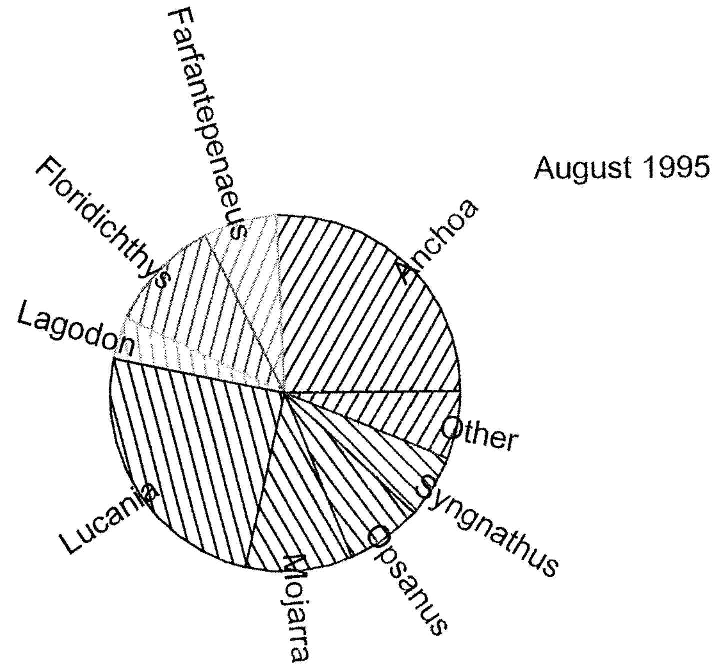
By Number

Figure 39. Species composition (percent of total number/hectare) for channel habitat for dry (April) and wet (August) seasons of 1990 (extreme dry year) and 1995 (extreme wet year).





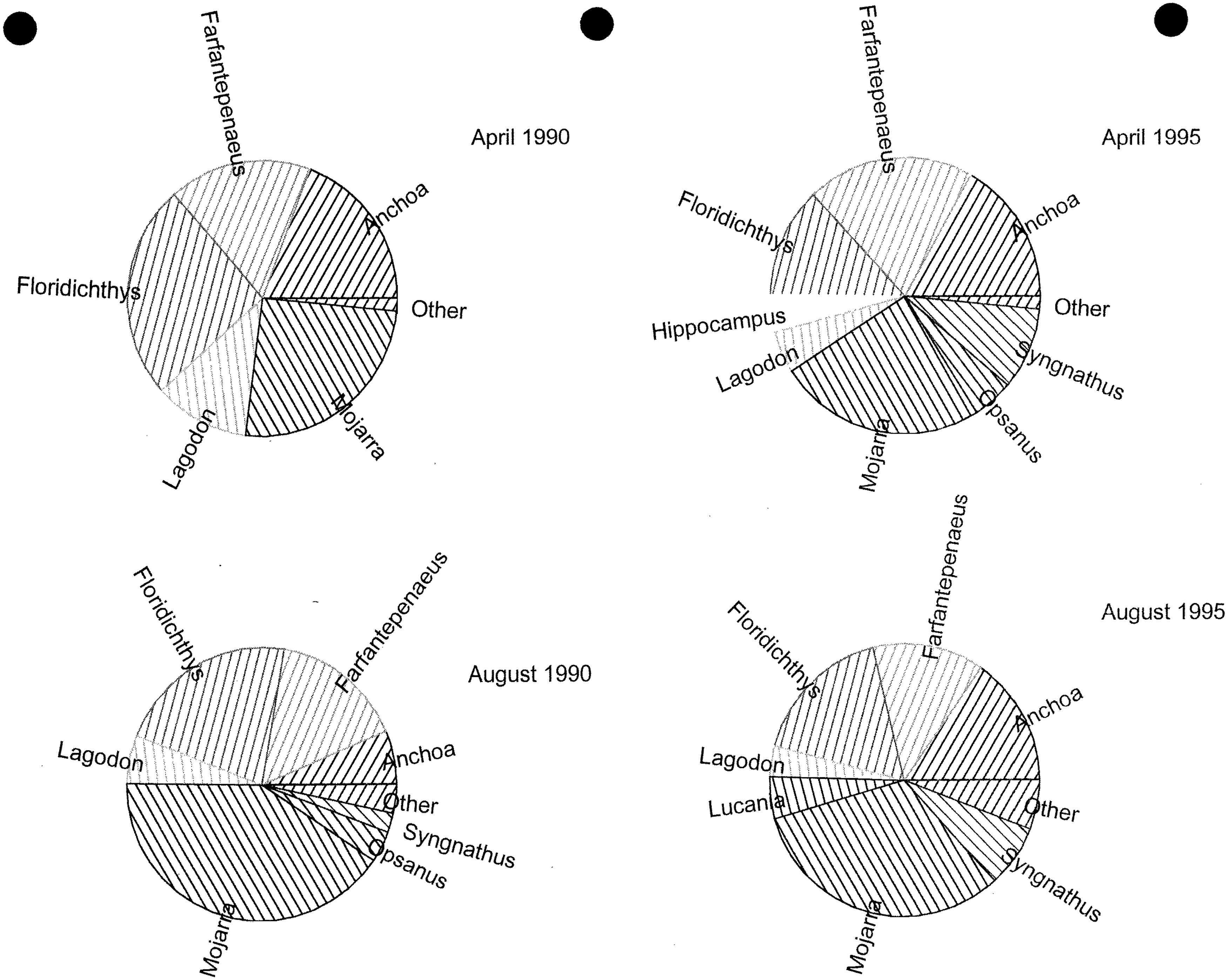




CHANNEL

By Number

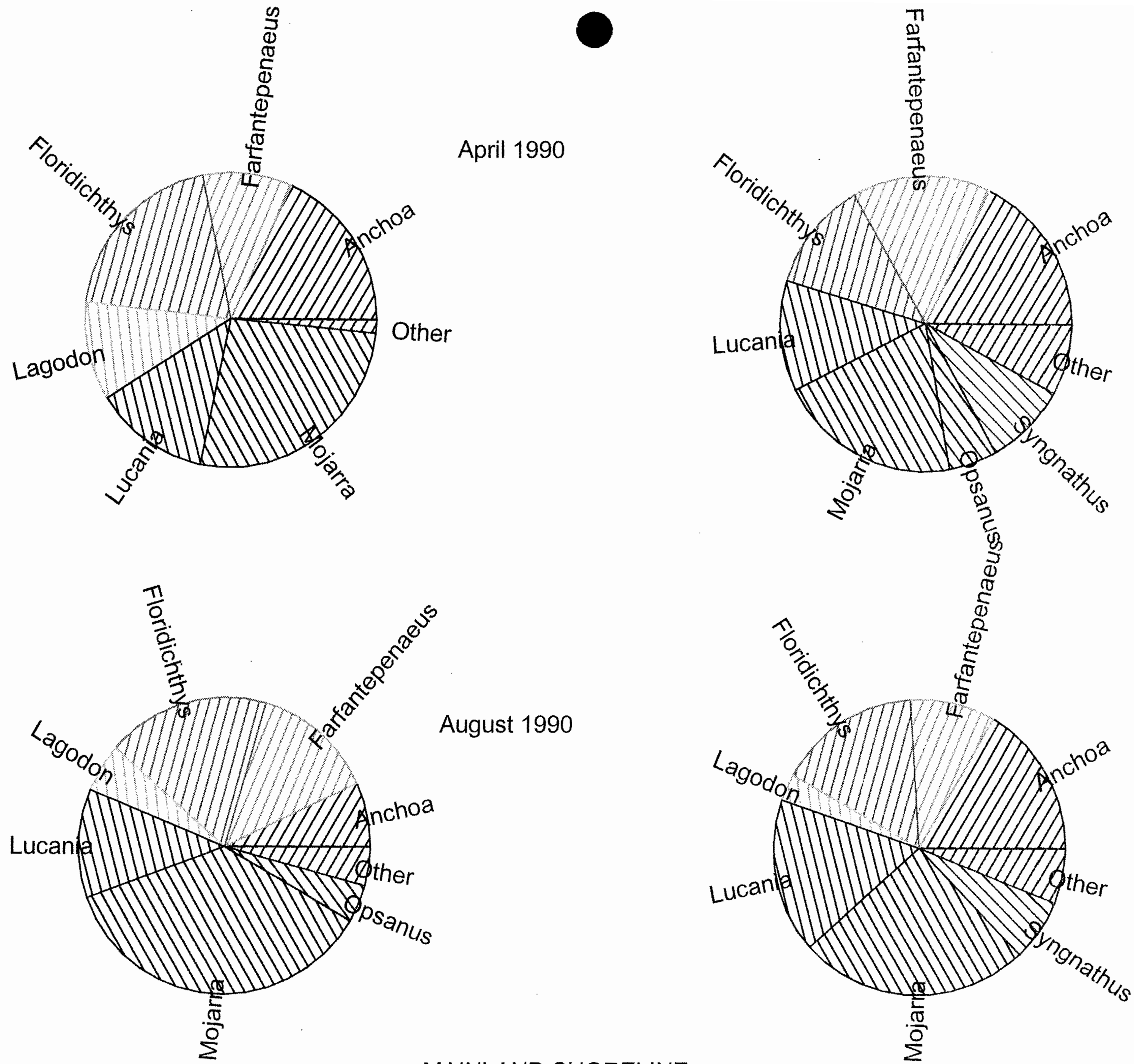
Figure 40. Species composition percent of total number/hectare) for island shoreline habitat for dry (April) and wet (August) seasons of 1990 (extreme dry year) and 1995 (extreme wet year).



ISLAND SHORELINE

By Number

Figure 41. Species composition (percent of total number/hectare) for mainland shoreline habitat for dry (April) and wet (August) seasons of 1990 (extreme dry year) and 1995 (extreme wet year).



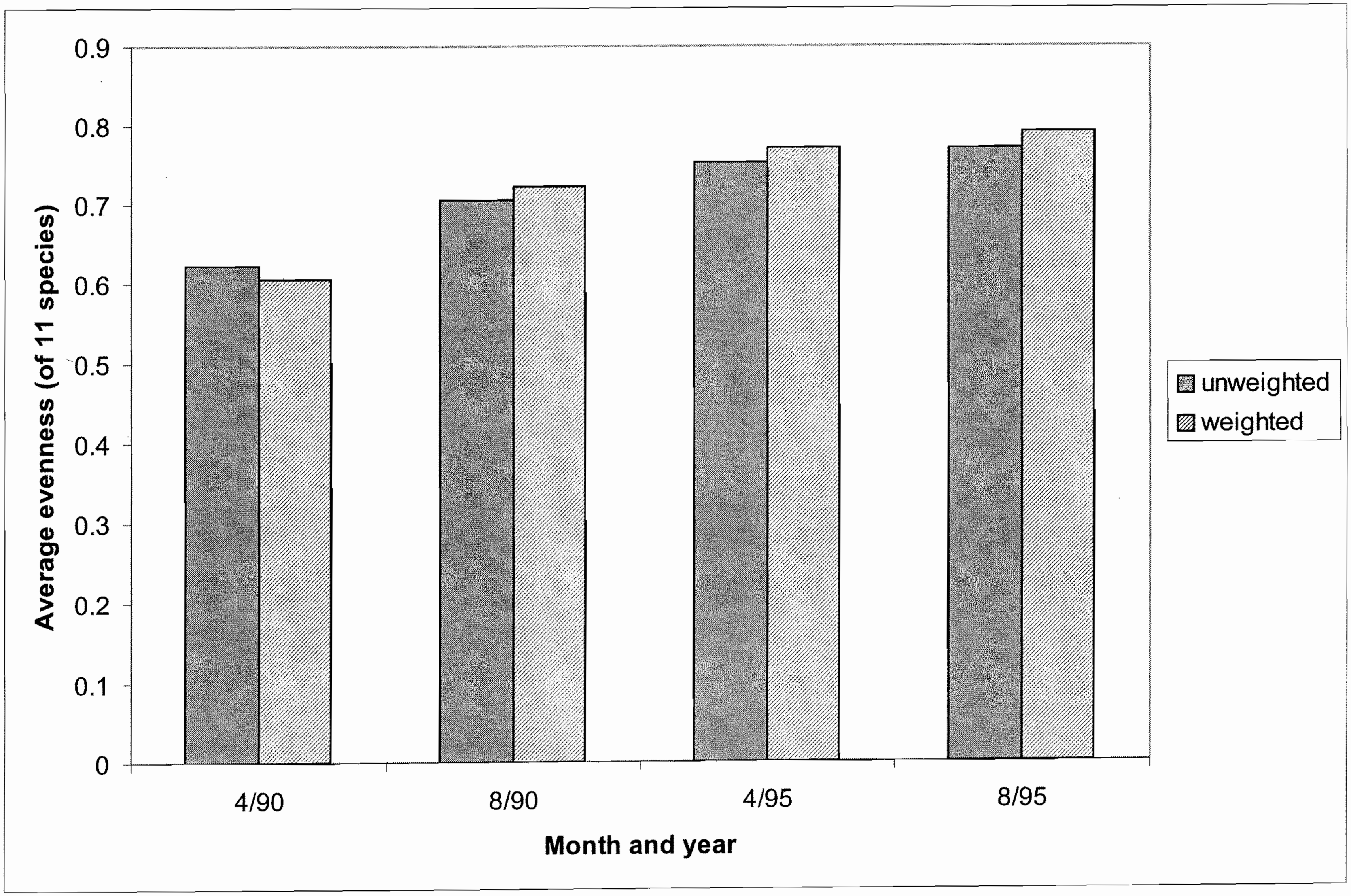
MAINLAND SHORELINE

By Number

Figure 42. Species evenness for a dry (April) and a wet (August) season of an extreme dry (1990) and extreme wet (1995) year.

Figs 41-48 are missing also!

98



Average evenness (of 11 species)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
4/90
8/90
4/95
8/95
Month and year
unweighted
weighted

Figure 43. Species evenness of 11-species community for four main habitat types.

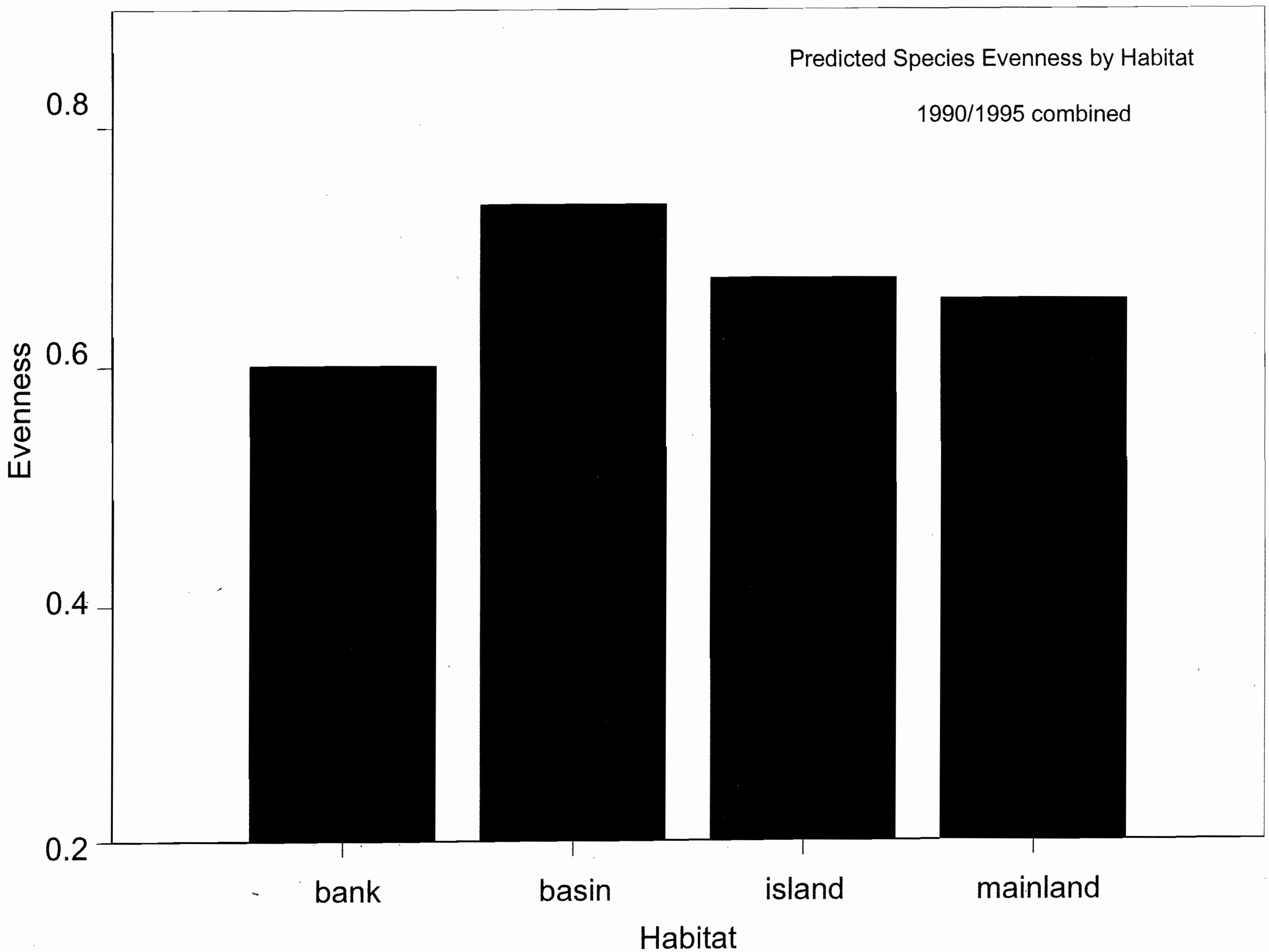

Predicted Species Evenness by Habitat
1990/1995 combined
Evenness
0.8
0.6
0.4
0.2
bank
basin
island
mainland
Habitat

Figure 44. Species evenness of 11-species community by salinity category (basin habitat).

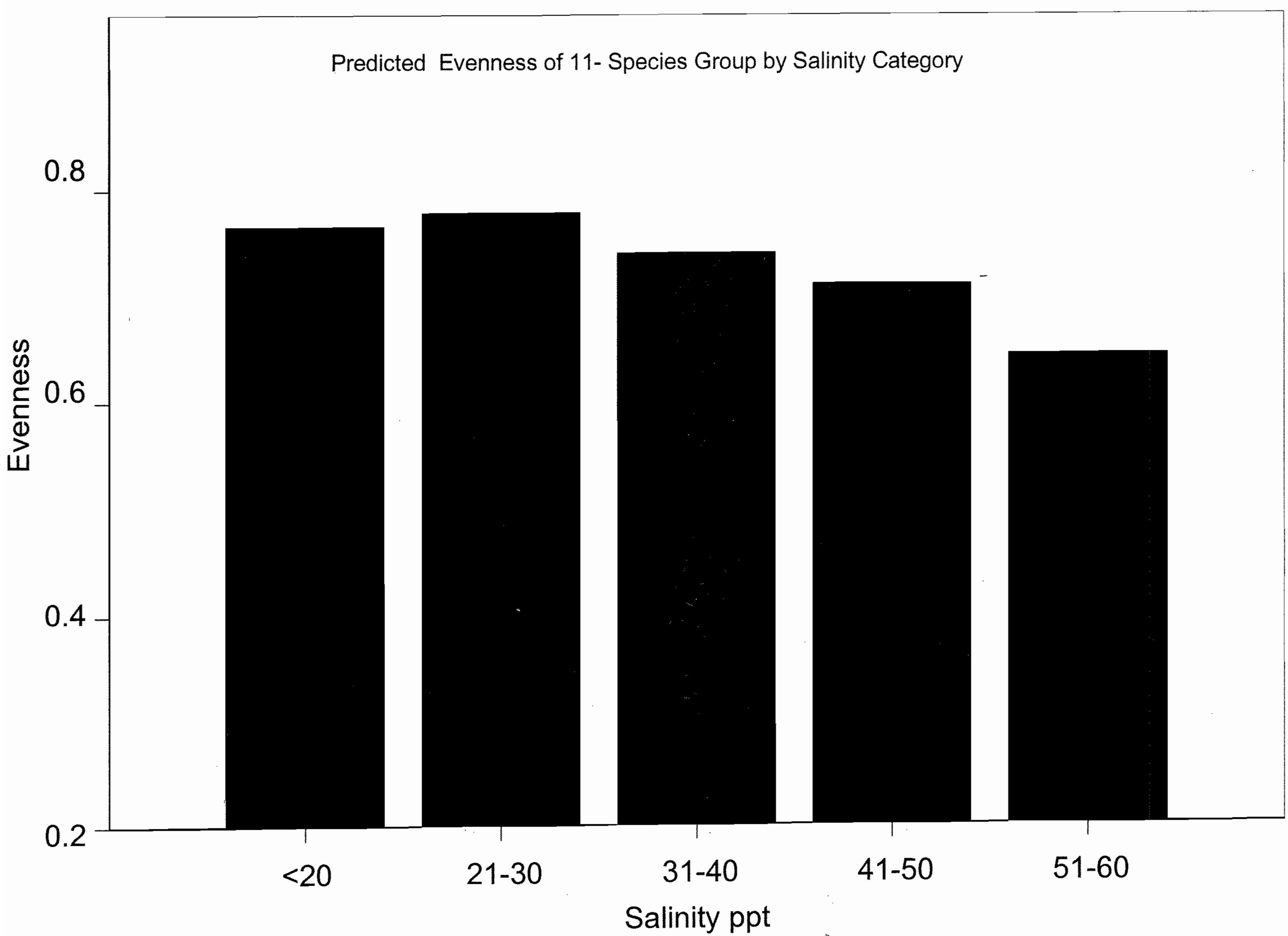
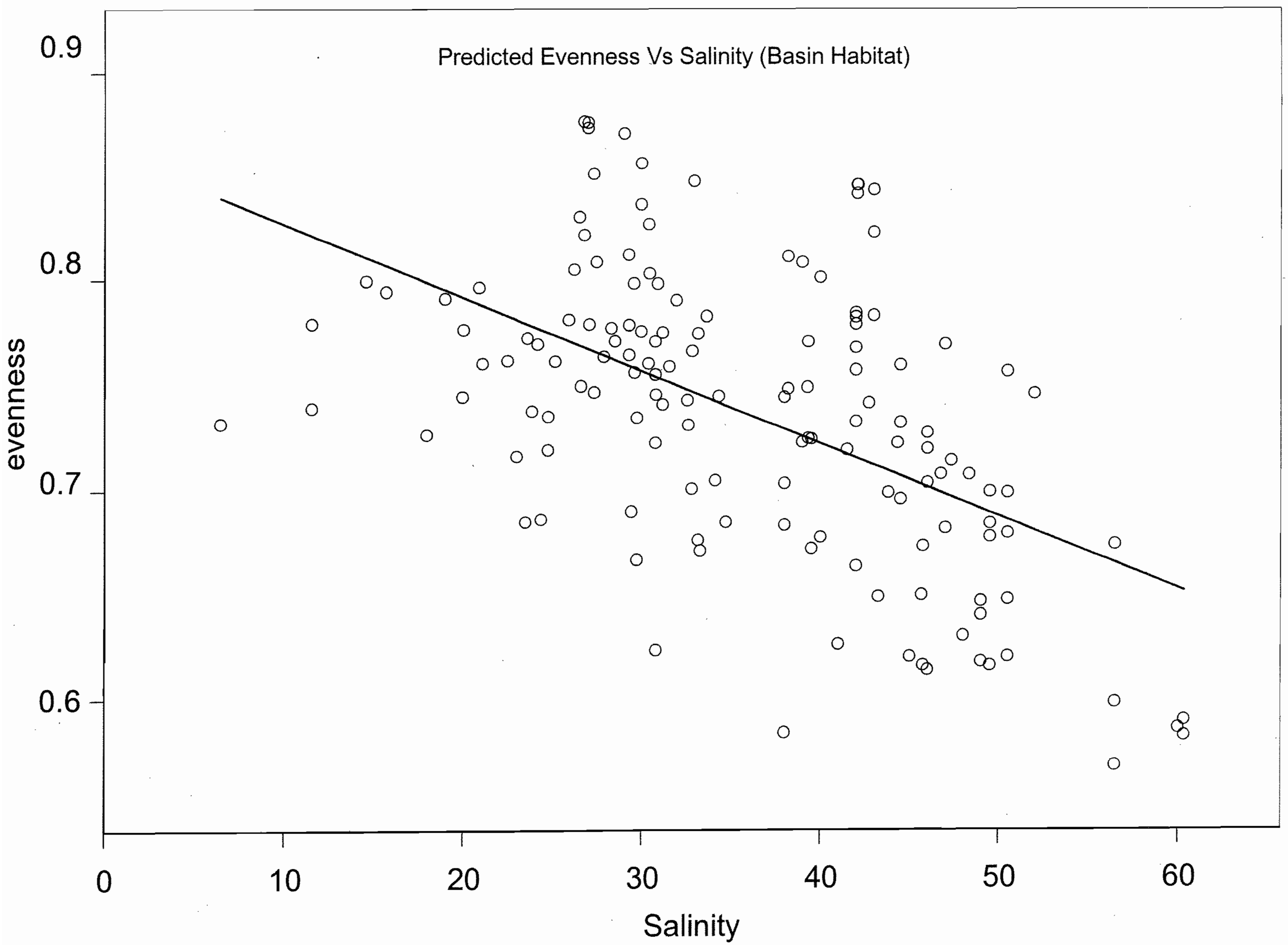

Predicted Evenness of 11- Species Group by Salinity Category
Evenness
0.8
0.6
0.4
0.2
<20
21-30
31-40
41-50
51-60
Salinity ppt

Figure 45. Species evenness for 11-species community versus salinity for basin habitat.



Predicted Evenness Vs Salinity (Basin Habitat)
0.9
0.8
0.7
0.6
evenness
0
10
20
30
40
50
60
Salinity

Figure 46. Species composition by biomass for the entire Florida Bay for dry (April) and wet (August) seasons of 1990 (extreme dry year) and 1995 (extreme wet year).

Predicted Species Composition by Biomass

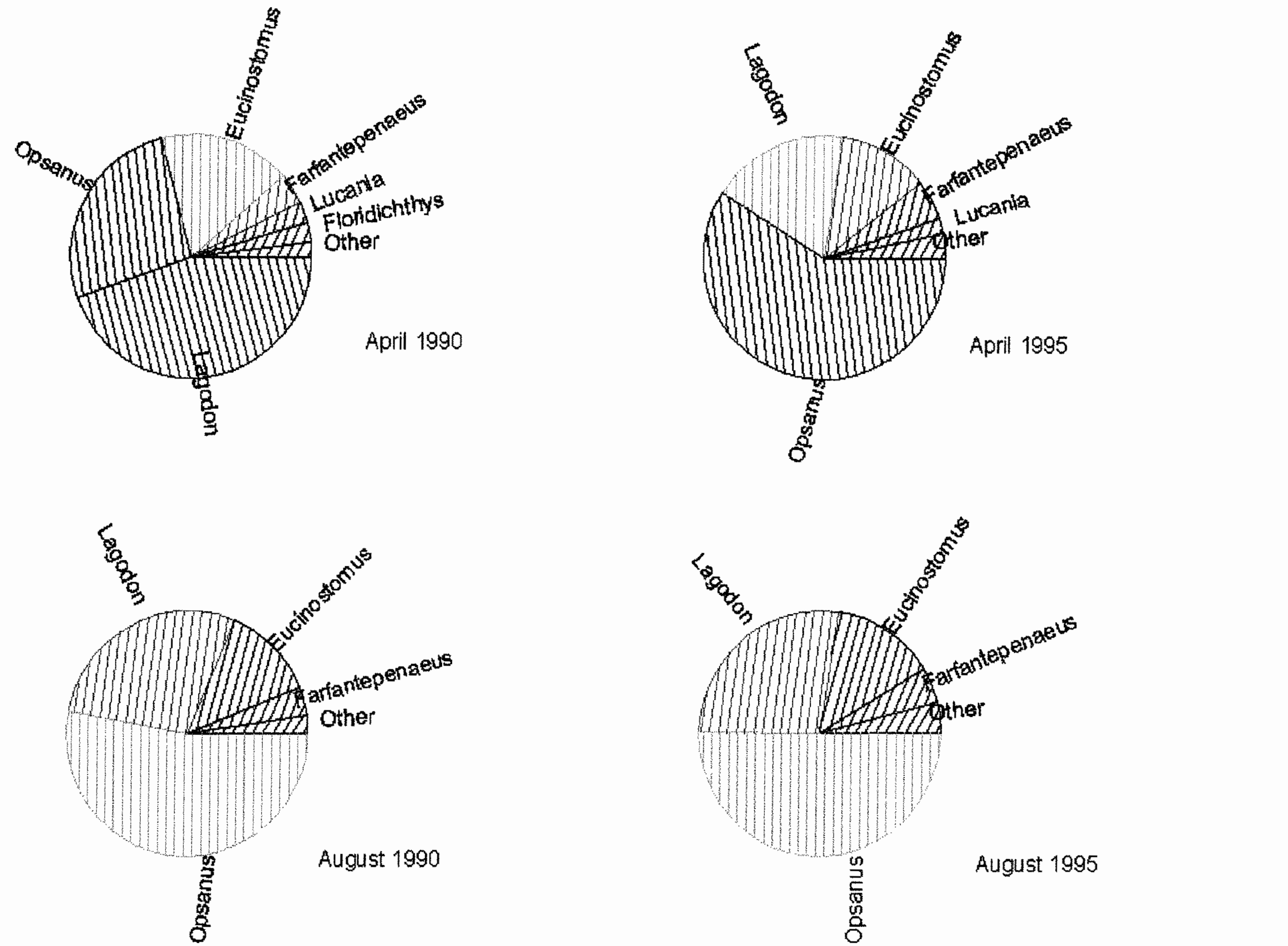


Figure 47. Predicted biomass of individual forage species for the entire Florida Bay for dry (April) and wet (August) seasons of 1990 (extreme dry year) and 1995 (extreme wet year).

Predicted biomass of 11 forage species in Florida Bay for 1990 (dry year) and 1995 (wet year). Numbers above bars are the average bay salinities.

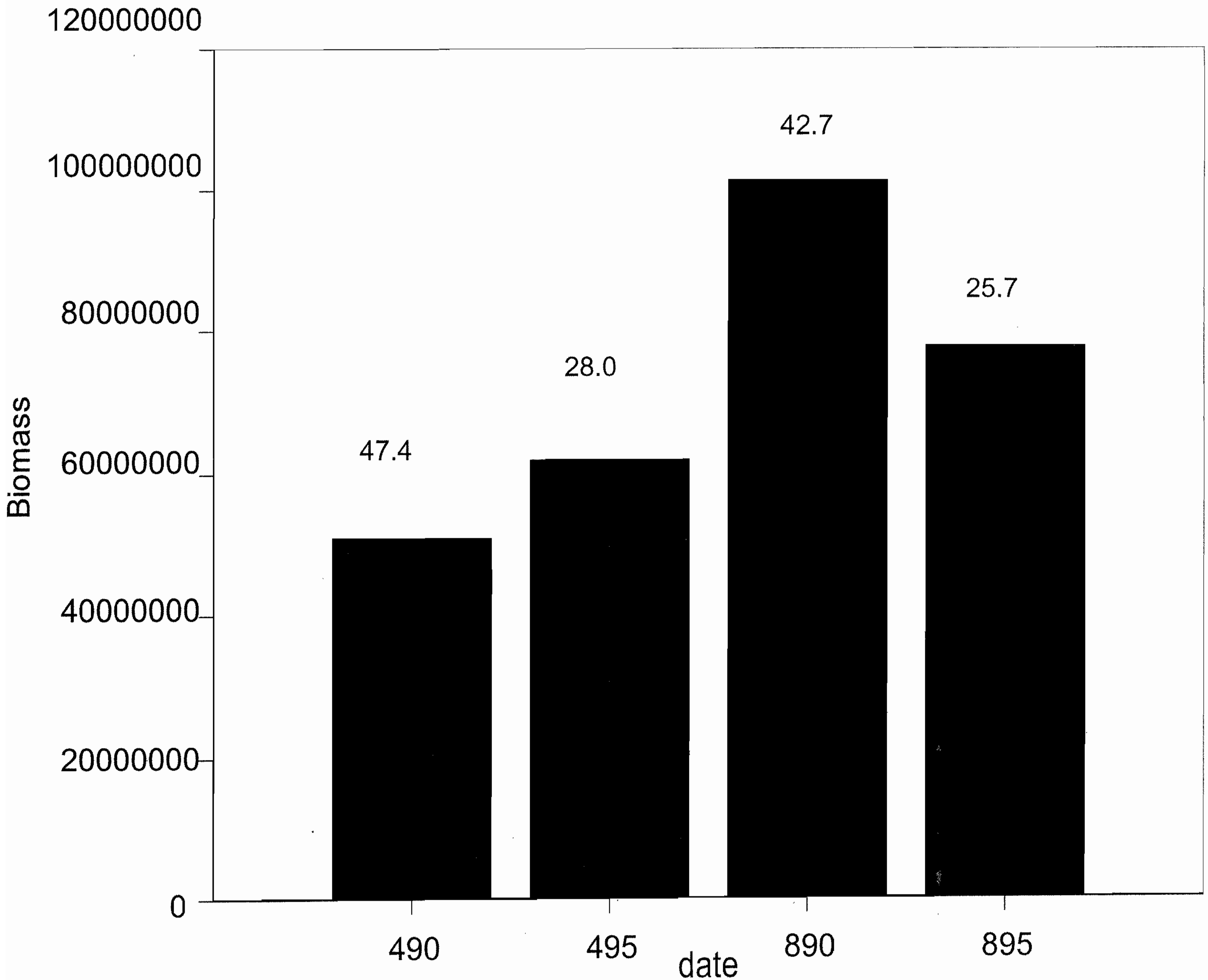
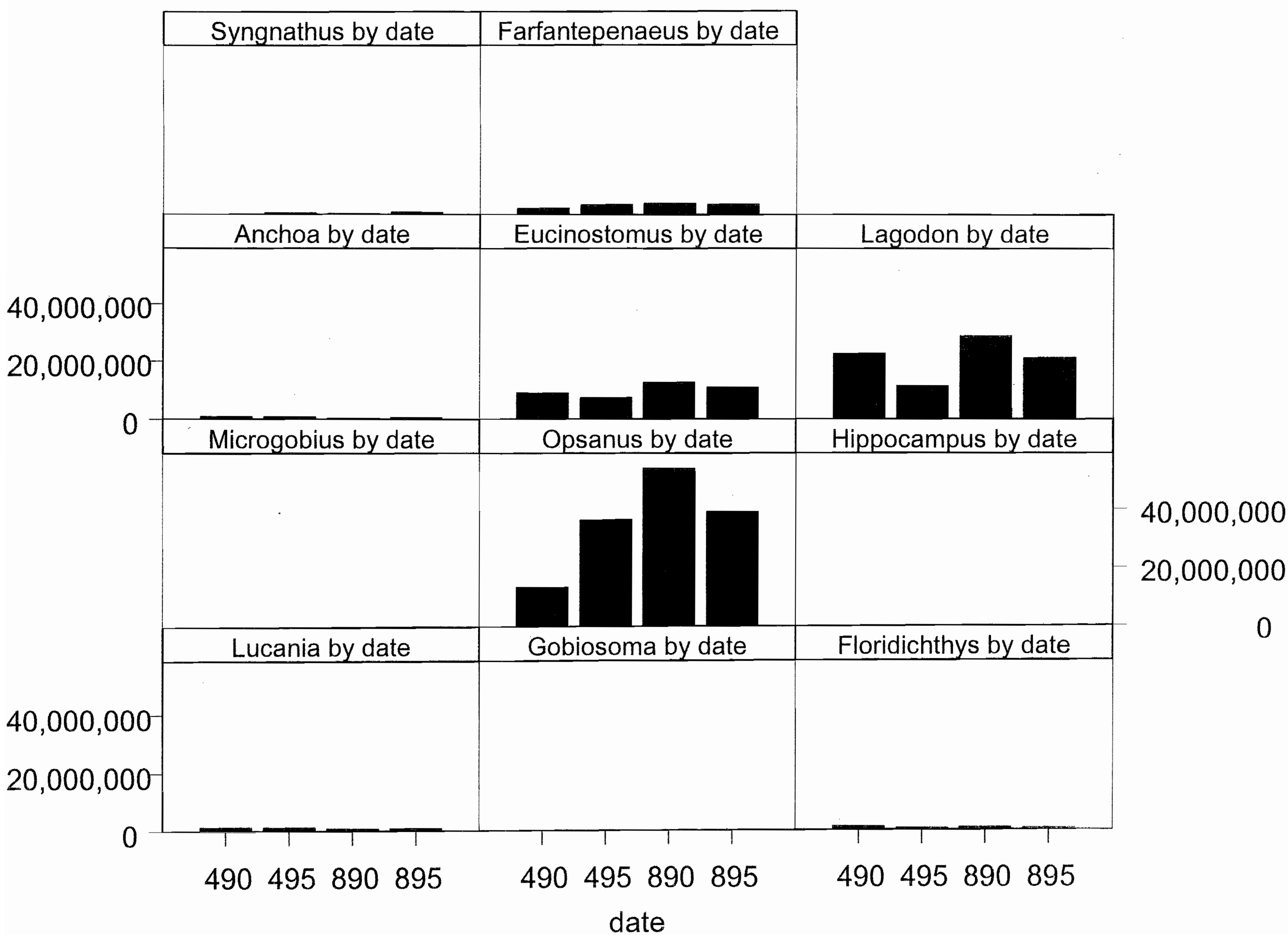


Figure 48. Predicted biomass per hectare of individual species by habitat for dry (April) and wet (August) seasons of 1990 (extreme dry year) and 1995 (extreme wet year).


Syngnathus by date
Farfantepenaeus by date
Anchoa by date
Eucinostomus by date
Lagodon by date
Microgobius by date
Opsanus by date
Hippocampus by date
Lucania by date
Gobiosoma by date
Floridichthys by date
40,000,000
20,000,000
0
490 495 890 895
date

both seasons of the dry year (Fig. 48). The predicted bay-wide percent composition of *Opsanus* was greater during the dry season in the wet year than the dry year. Predicted percent composition was similar between the two years (Fig. 47).

Predicted Densities and Salinity

Figure 49 shows the predicted densities for all species in response to salinity for 1990 (dry year) and 1995 (wet year). Each point represents an estimate for each habitat within each basin for either wet or dry season. The graph suggests that overall forage species densities are related to salinity. Predicted densities are highest in wet years in the basins with the lowest salinities. Salinities ranged from 8 to 35 ppt in the wet year and 28 to 60 ppt in the dry year.

The individual species predicted response to salinity followed four general trends. Three species (*Farfantepenaeus, Gobiosoma,* and *Lagodon*) had a positive relationship to salinity at low salinities and a negative response at high salinities. Plots of their predicted density in relation to saliniy (Figures 50-52) suggest an optimum approaching 30 ppt. The predicted densities of three species (*Anchoa, Hippocampus,* and *Syngnathus*), decreased in relation to salinity in both years (Figures 53-55). Three species (*Floridichthys, Lucania,* and *Microgobius*) show a negative linear relationship in the wet year (at low salinities) and a relatively flat trend in the dry year (high salinities)(Figures 56-58). Two species (*Opsanus* and *Eucinostomus*) showed a negative relationship at high salinities (dry year) and a flat relationship at lower salinities (Figures 59-60). High variability in some predicted responses suggest strong habitat influence.

Distribution Maps

Distribution maps were constructed for each time period for combined species, and for each species. Maps apply only to basin habitat, which comprised 78.5 % of the Bay. Highest predicted densities (numbers/hectare) of the 11 species combined were in August in three Gulf basins (basins 38, 39, 40) and three nearshore areas (basins 8, 12, and 25), and in August 1995 in the northeastern portion of the Bay. Lowest densities of forage species were predicted in the inshore interior areas, which exhibited salinities of 57-60 ppt in April 1990, and basin 31 adjacent to the Florida Keys in April 1995. In general, densities were higher in August than in April and higher in the wet year than in the dry year.

Table 6 summarizes salinity ranges of the highest predicted densities. Reduced densities of forage species in the dry season/dry year were predicted for the central Bay, which experienced hypersaline conditions. Highest dry season/dry year densities were predicted at salinities from 44-45 ppt when average basin salinities ranged from 38-60 ppt. Highest dry season/wet year predicted densities were within a salinity range of 20-26 ppt when average basin salinities ranged from 19-34 ppt. During the wet season/dry year, highest predicted densities were at 29-42 ppt when average basin salinities ranged from 29-52 ppt. Highest predicted densities during the wet season/wet year were at 6-15 ppt when densities average basin salinities ranged from 6-35 ppt.

Figure 49. Predicted number per hectare of total 11-species forage community by salinity for dry and wet years (points represent individual predictions for each basin, month, and habitat types).

Predicted Density of 11-Species Community by Salinity for Dry and Wet Years
(points represent predictions for all basins and habitat types for wet and dry seasons).

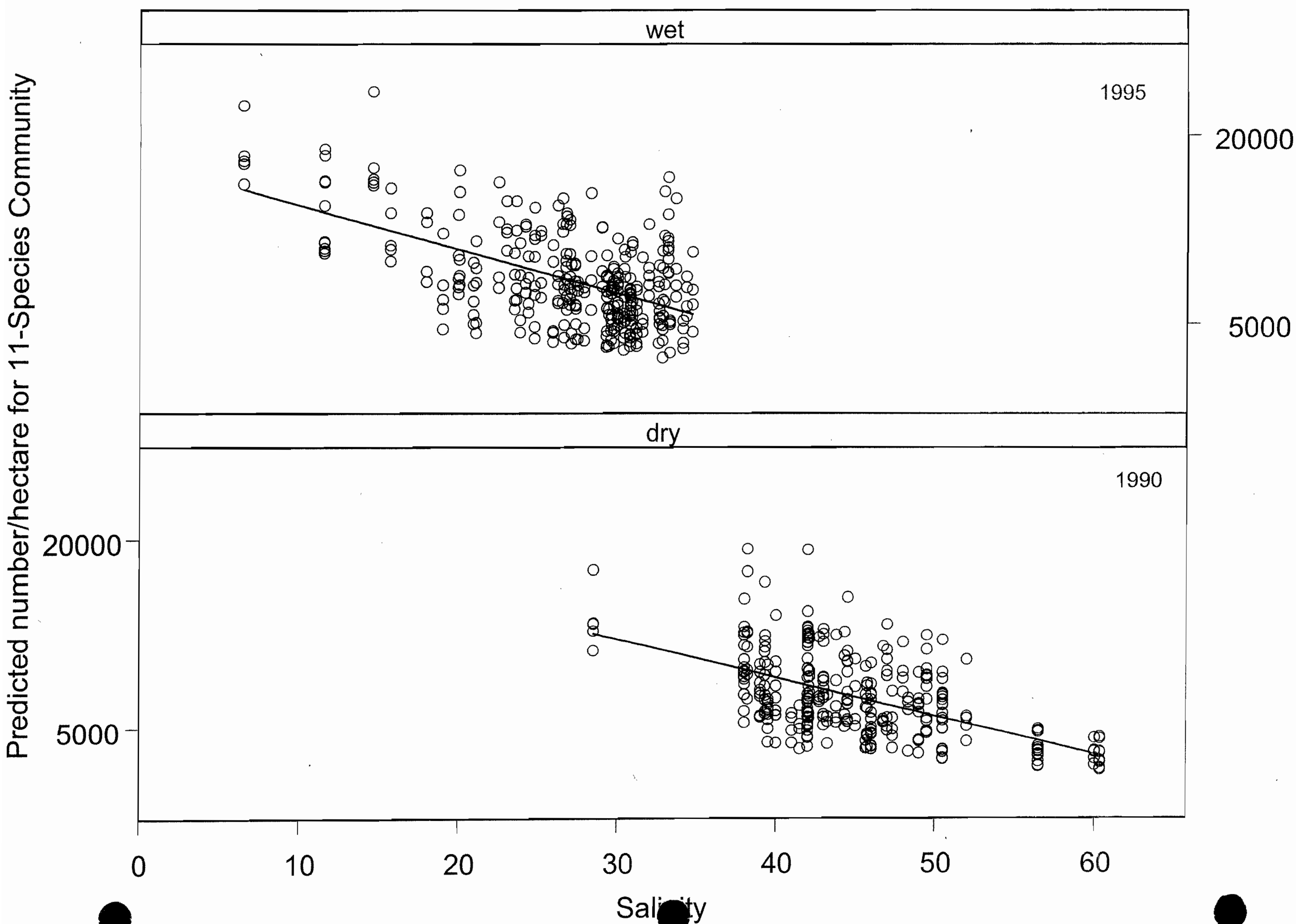


Figure 50. Predicted number per hectare of *Farfantepenaeus duorarum* by salinity for dry and wet years (points represent individual predictions for each basin, month, and habitat types).

Predicted Density of *Farfantepenaeus duorarum* by Salinity for Dry and Wet Years (points represent predictions for all basins and habitat types for wet and dry seasons).

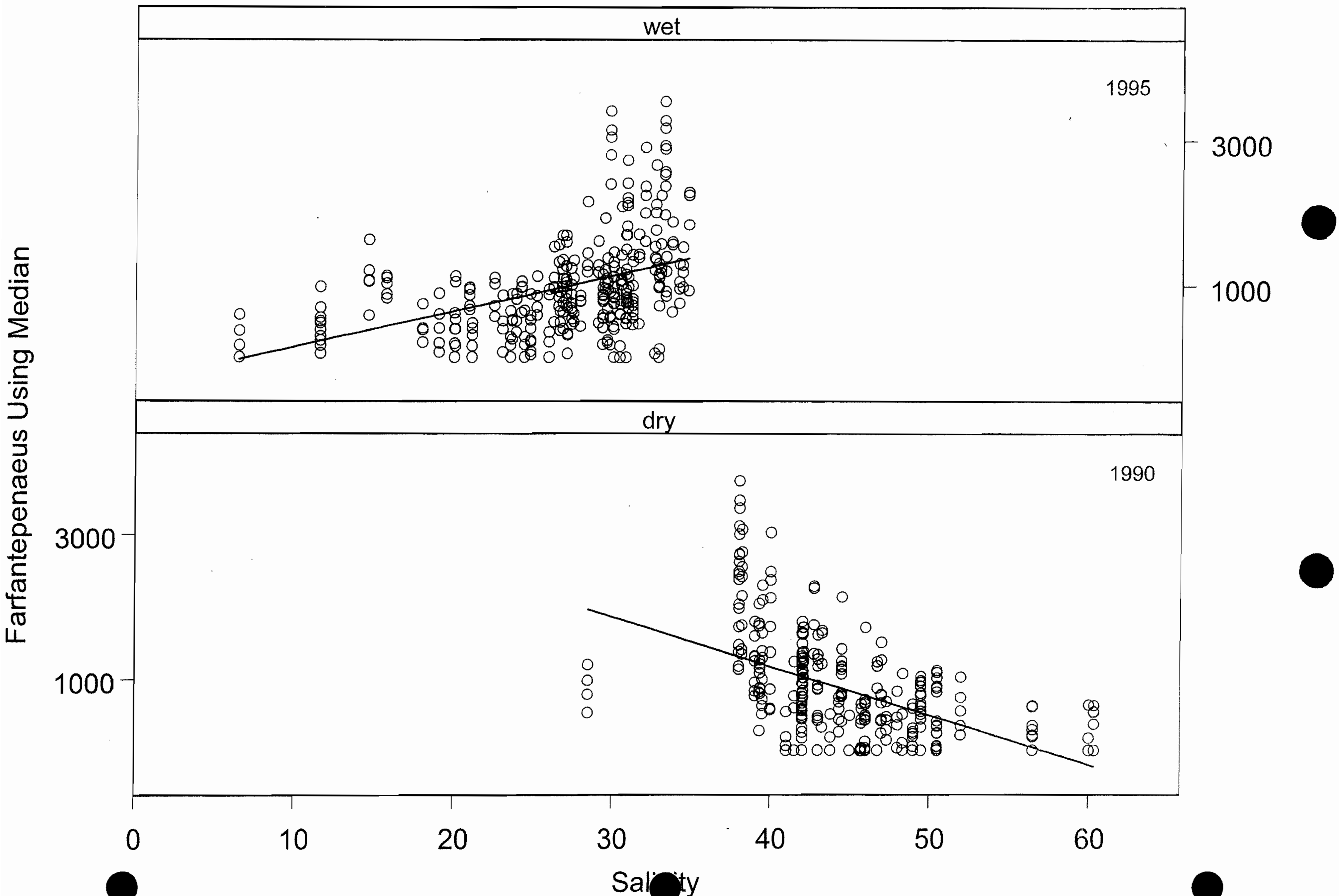


Figure 51. Predicted number per hectare of *Gobiosoma robustum* by salinity for dry and wet years (points represent individual predictions for each basin, month, and habitat types).

Predicted Density of *Lagodon rhomboides* by Salinity for Dry and Wet Years (points represent predictions for all basins and habitat types for wet and dry seasons).

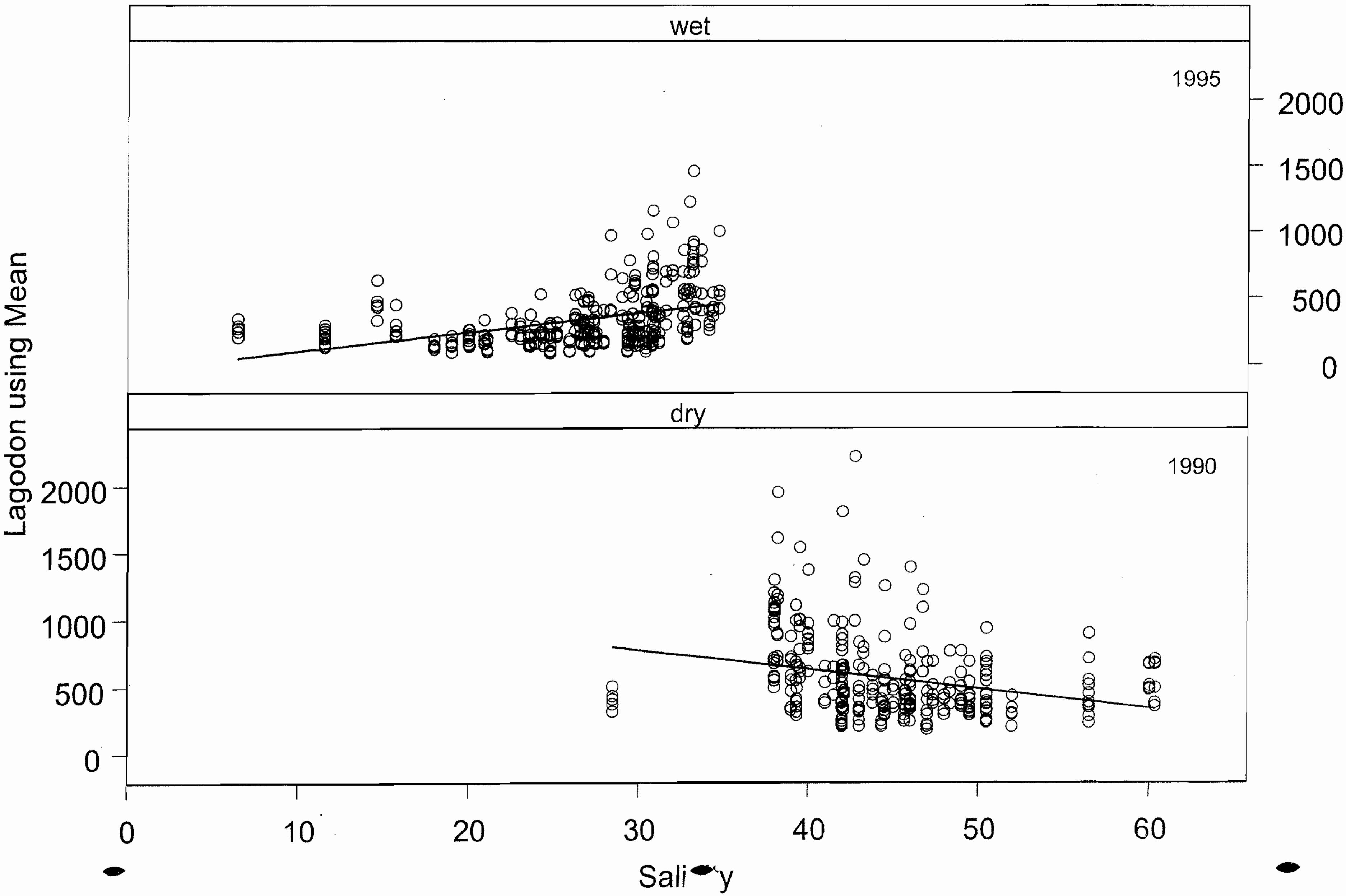


Figure 53. Predicted number per hectare of *Anchoa mitchelli* by salinity for dry and wet years (points represent individual predictions for each basin, month, and habitat types).

Predicted Density of *Anchoa mitchelli* by Salinity for Dry and Wet Years (points represent predictions for all basins and habitat types for wet and dry seasons).

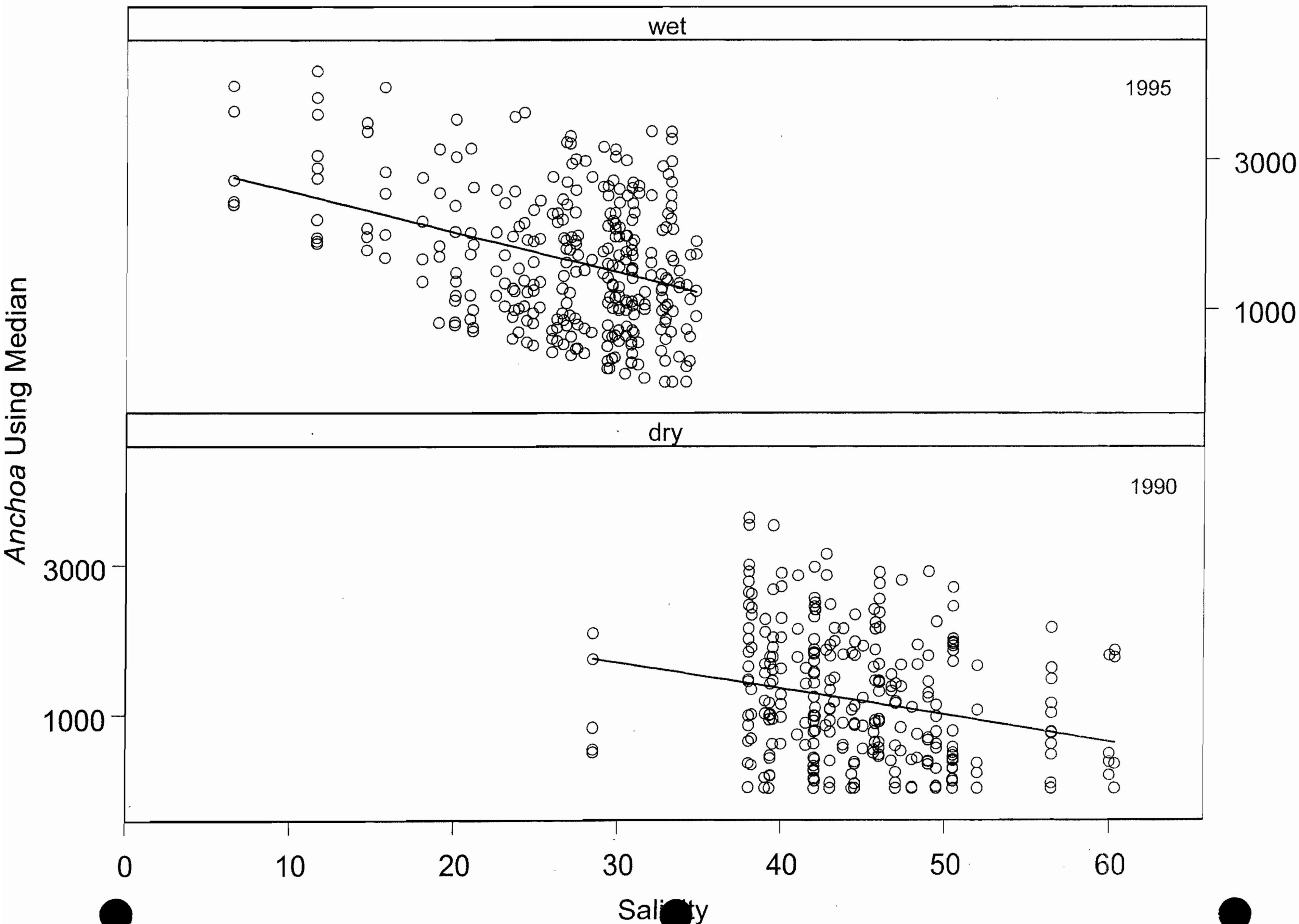


Figure 54. Predicted number per hectare of *Hippocampus zostera* by salinity for dry and wet years (points represent individual predictions for each basin, month, and habitat types).

Predicted Density of *Hippocampus zosterae* by Salinity for Dry and Wet Years (points represent predictions for all basins and habitat types for wet and dry seasons).

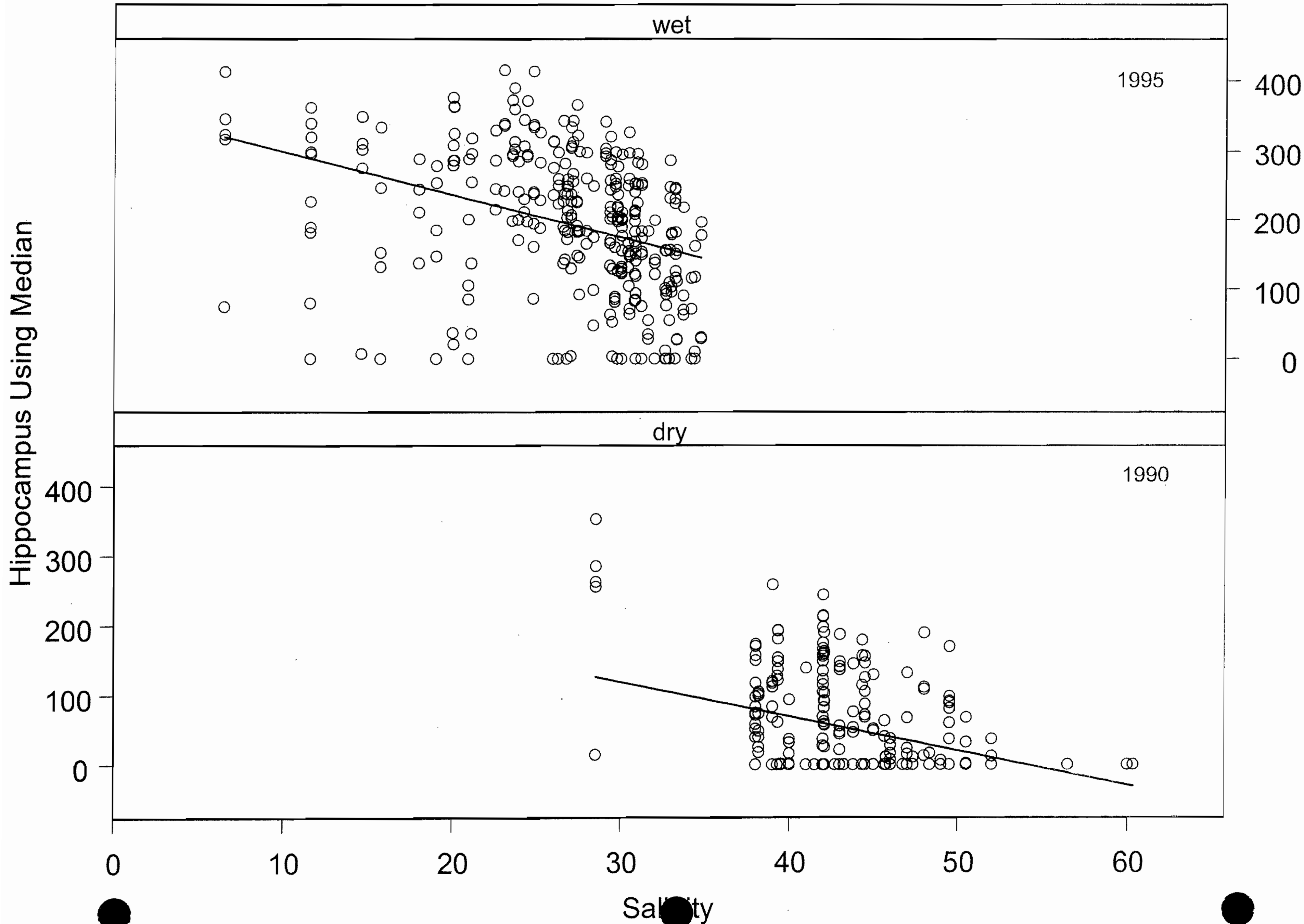


Figure 55. Predicted number per hectare of *Syngnathus scovelli* by salinity for dry and wet years (points represent individual predictions for each basin, month, and habitat types).

Predicted Density of *Syngnathus scovelli* by Salinity for Dry and Wet Years (points represent predictions for all basins and habitat types for wet and dry seasons).

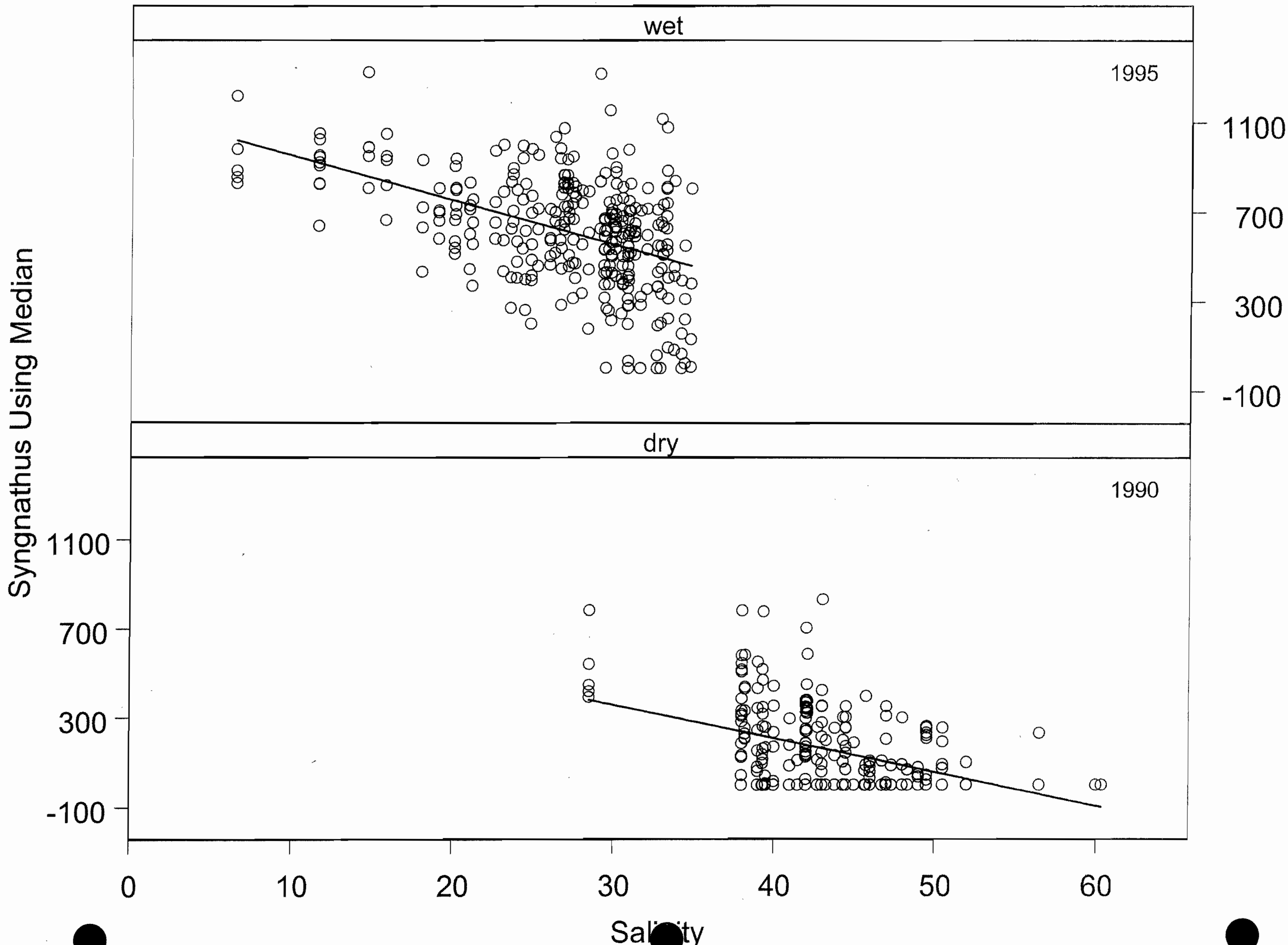


Figure 56. Predicted number per hectare of *Floridichthys carpio* by salinity for dry and wet years (points represent individual predictions for each basin, month, and habitat types).

Predicted Density of *Floridichthys carpio* by Salinity for Dry and Wet Years (points represent predictions for all basins and habitat types for wet and dry seasons).

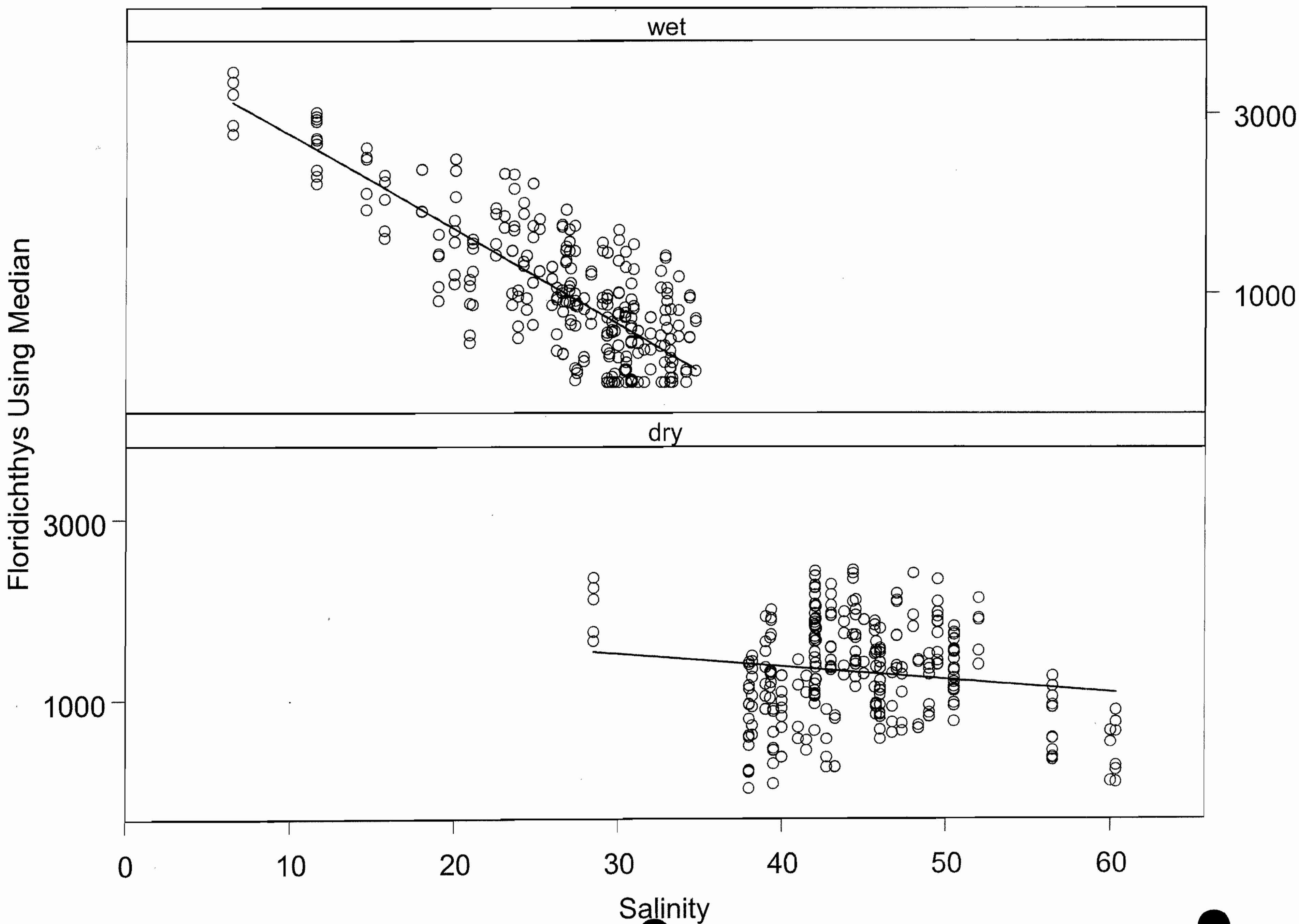


Figure 57. Predicted number per hectare of *Lucania parva* by salinity for dry and wet years (points represent individual predictions for each basin, month, and habitat types).

Predicted Density of *Lucania parva* by Salinity for Dry and Wet Years (points represent predictions for all basins and habitat types for wet and dry seasons).

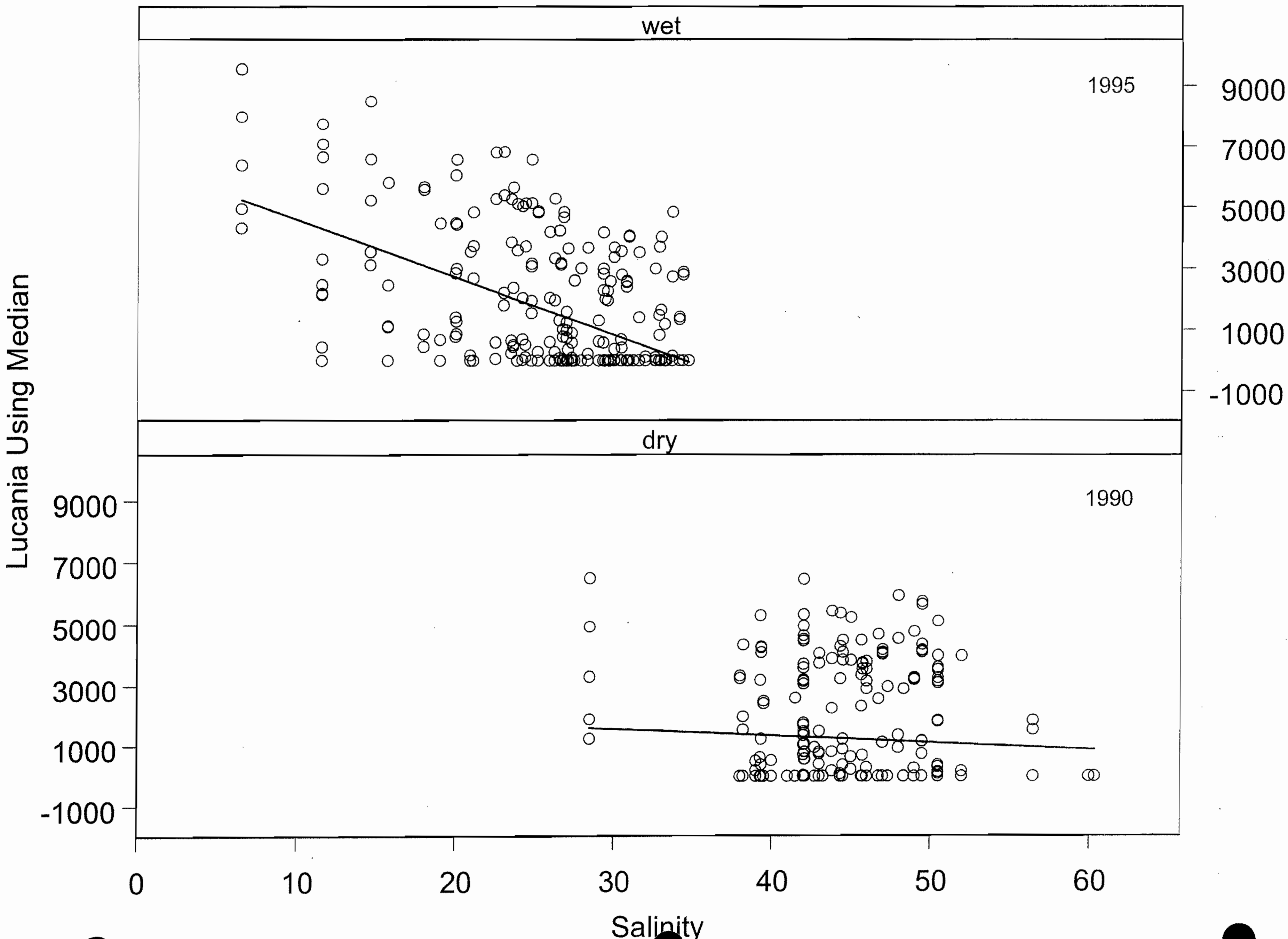


Figure 58. Predicted number per hectare of *Microgobius gulosus* by salinity for dry and wet years (points represent individual predictions for each basin, month, and habitat types).

Predicted Density of *Microgobius gulosus* by Salinity for Dry and Wet Years (points represent predictions for all basins and habitat types for wet and dry seasons)

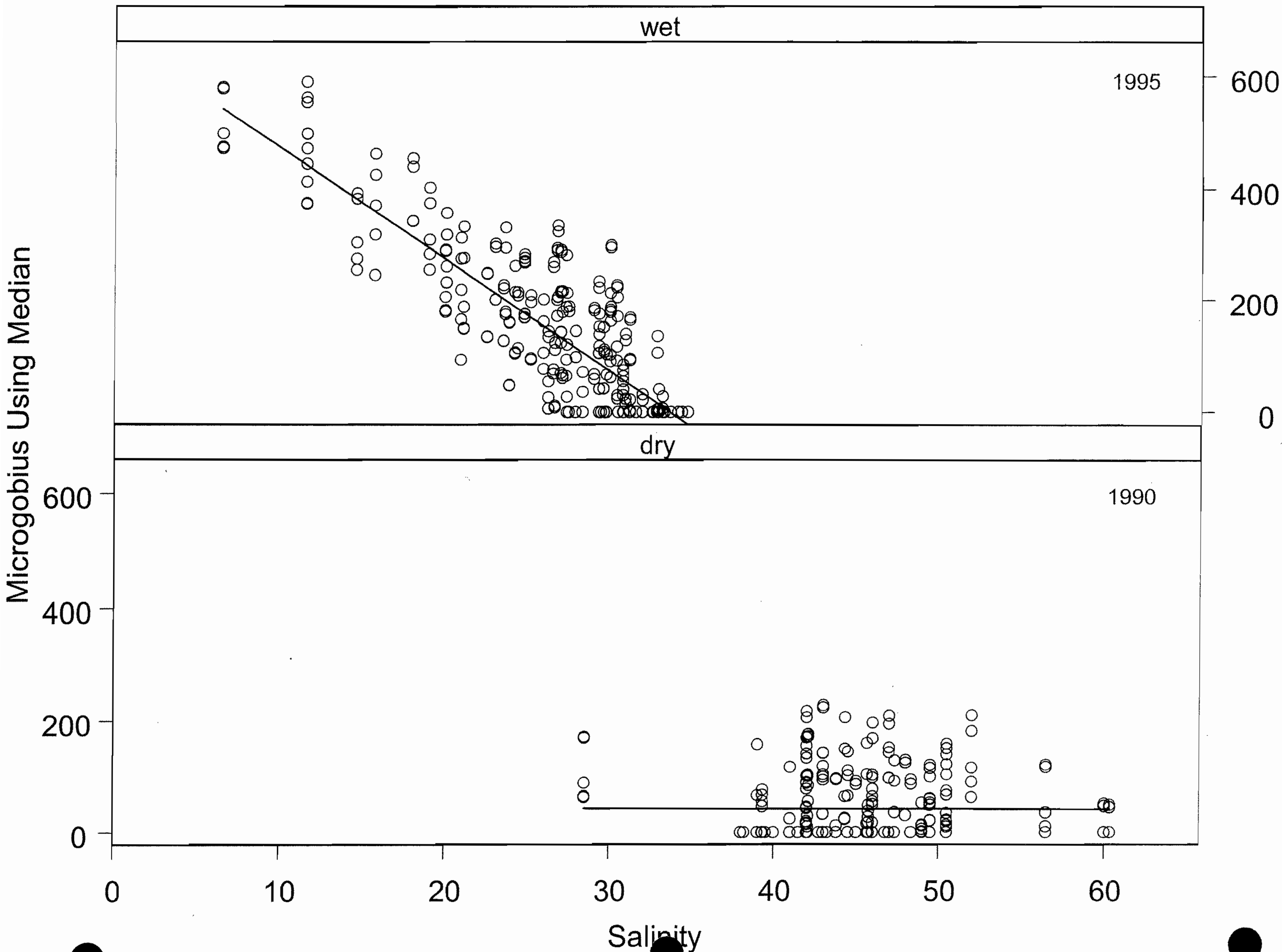


Figure 59. Predicted number per hectare of *Opsanus beta* by salinity for dry and wet years (points represent individual predictions for each basin, month, and habitat types).

Predicted Density of *Opsanus beta* by Salinity for Dry and Wet Years (points represent predictions for all basins and habitat types for wet and dry seasons)

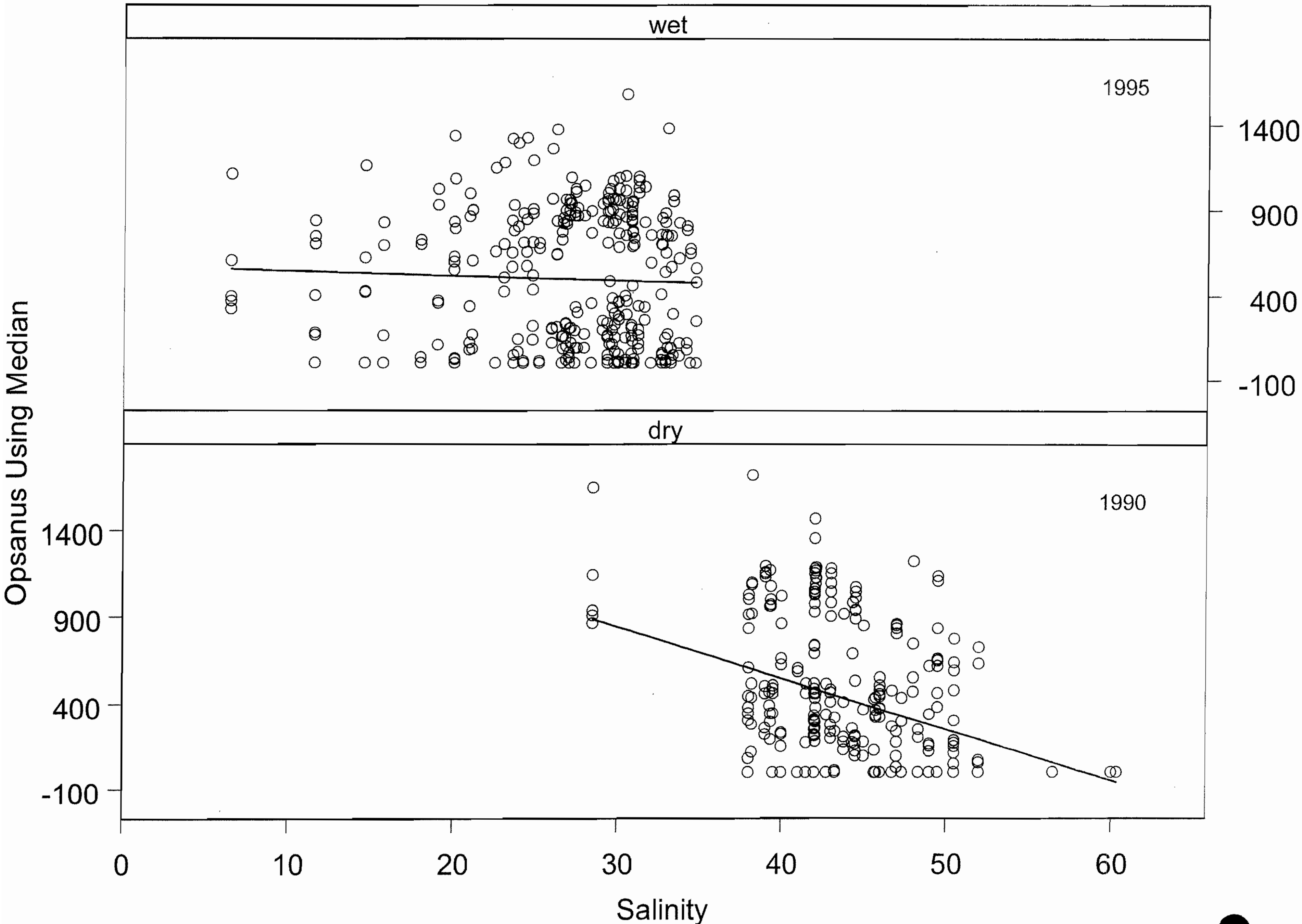


Figure 60. Predicted number per hectare of *Eucinostomus spp.* by salinity for dry and wet years (points represent individual predictions for each basin, month, and habitat types).

Predicted Density of *Eucinostomus spp.* by Salinity for Dry and Wet Years (points represent predictions for all basins and habitat types for wet and dry seasons).

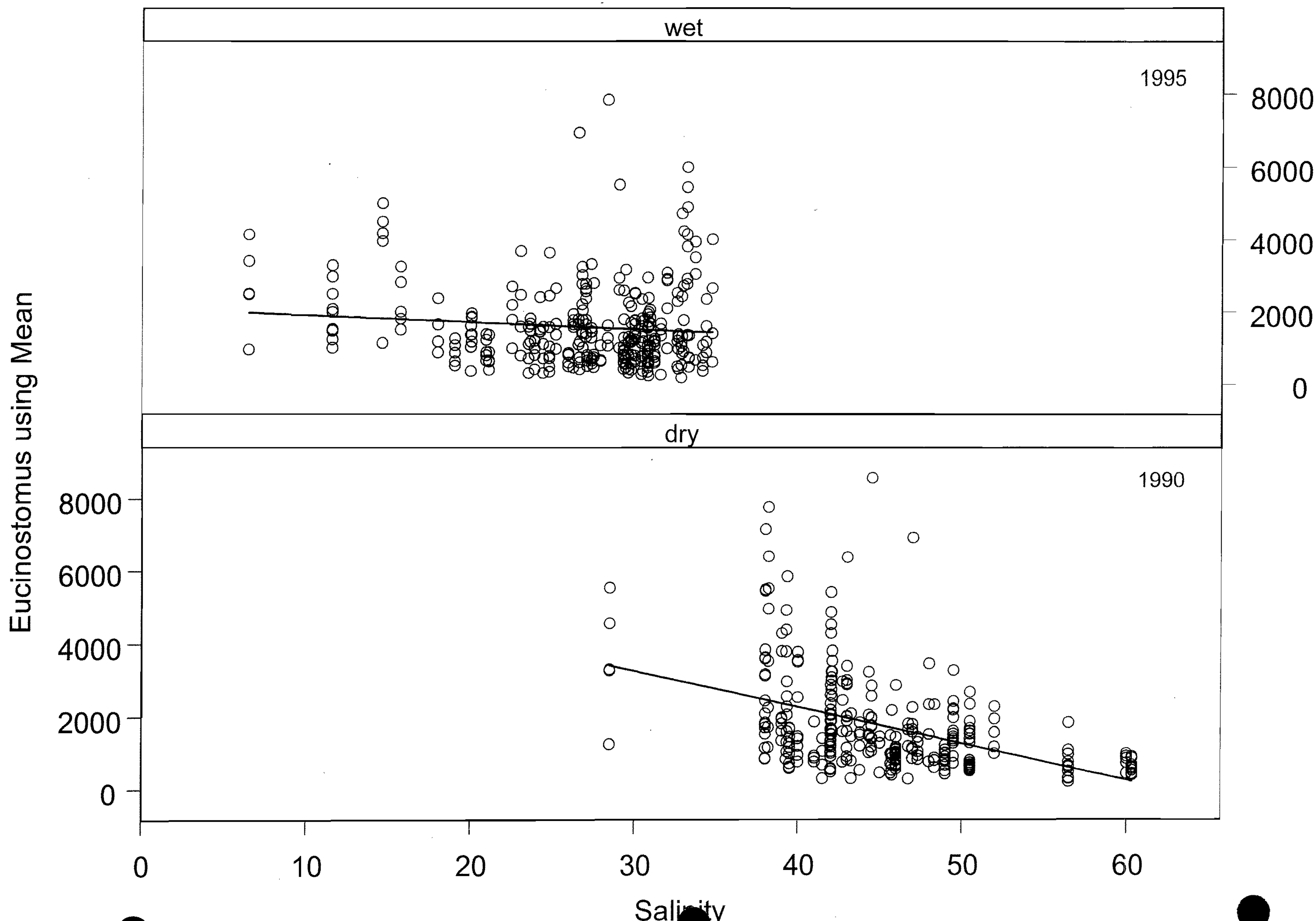


Table 6. Average basin salinity range in Bay and salinity range at highest predicted density of all 11 forage species combined, all species except *Lucania*, and each species.

	Apr-90 dry/dry	Apr-95 dry/wet	Aug-90 wet/dry	Aug-95 wet/wet
Average Basin Salinity	38-60	19-34	29-52	6-35
Total Forage	44-45	20-26	29-42	6-15
Total minus *Lucania*	38-46	19-31	29-42	6-29
Anchoa	40-49	21-30	39-50	12-25
Eucinostomus	38-47	26-32	29-43	27-34
Farfantepenaeus	38-43	30-33	38-40	32-33
Floridichthys	44-45	19-26	42-50	6-20
Gobiosoma	40-43	27-33	38-47	27-33
Hippocampus	38-51	26-31	39-50	15-29
Lagodon	42-43	30-33	38-40	32-34
Lucania	45-49	23-26	39-50	6-25
Microgobius	42-51	21-30	42-47	6-18
Opsanus	44-45	23-26	29-42	22-25
Syngnathus	38-46	26-31	38-40	6-29

Discussion

The purpose of the model application section was to demonstrate how the forage fish models might be used collectively to predict bay-wide change in the forage fish and shrimp community that might result from changes to freshwater inflows and Bay salinity patterns brought about by CERP. The forage species models were based upon the relationships of individual species to their habitat and environmental conditions. We used the models to predict faunal densities and bay-wide abundance based on estimates of the average environmental states of each basin at a particular point in time. The reliability of predictions depended upon both the relationships embodied in the models and the quality of the basin-specific input data used to make the predictions. In order to obtain bay-wide estimates, parameters such as seagrass type and density, water depth, and salinity had to be estimated for all basins, including some having little or no data. For those with no data, we used data from neighboring basins. The information used to estimate seagrass type and density in the northeastern basins of the Bay was especially poor. Seagrass models and salinity models promise to someday provide output data that, used as input to forage community models, might improve the reliability of predictions.

The validation exercise indicated that median-based models were more realistic than mean-based models for all but two of the 11 species. This may be because the models were developed based on median rather than mean values (although it does not explain why the mean-based models were more realistic for the two remaining species). The combination of median-based models for nine species and mean-based models for two species yielded reasonable results, but the r^2's of the fit of predictions to observations was not very high, even when data were combined (across dates and habitats) within basins. One might think that the correlation of predictions to observations might be related to the r^2s of the predictive models, however there was no relationship between these statistics, both of which can be seen in Table 1.

One source of error in our predictions was that the flow data in the prediction data set for the dry season/dry year was outside the range of the flow data in the data set used to develop the models. Conditions were more extreme (on the low side) in the prediction data set than in the data set from which the model was constructed. GAM models will not make predictions based on data that is outside the range of the variables used in the model. The only way we could make predictions for April, 1990 was by artificially adjusting flow to the minimum in the model data set, as follows: Flow 1 from 0 to 929 acre feet, Flow 2 from 2.27 to 960, and Flow 3 from 167 to 500. These particular changes probably had minor effects on predictions, however improvements (i.e., the addition of data beyond the present extremes for flow and salinity) should be made in the database used for model development so that such alterations are unnecessary.

Some unavoidable shortcomings of the validation data set also affected the correlation between predicted and observed values. These included a sparsity of data for some basins, lack of replication, and many zeros in the database.

The models indicated a strong affinity of faunal density with seagrass density and/or type. This was true for many, although not all, of the 11 species. The relationships with seagrass were well defined. The models should be valuable for evaluating the effect of water management policies that affect seagrass density and composition. It would not, however, be possible to evaluate the effect of restoring *Ruppia* in the northeastern Bay since *Ruppia* was not covered by the models.

These models could potentially be used to evaluate alternative water management strategies, however their reliability (as suggested by confidence limits) is weakest near the range extremes of salinity and water flow. This probably is because, although the data set used in model development represented a wide range of conditions in the Bay, the data were sparsest at the extremes. The sparsity of data at range extremes may explain the poor fit of some models in comparisons of 1995 predictions to observations. 1995 was an extreme wet year. In follow-up work, increasing the number of data points near the range extremes is as important as expanding the ranges.

Our working hypothesis throughout the project was that salinity influenced the distribution and abundance of forage fauna but that the influence was masked by the strong influence of habitat, both physical and biological, which has been observed by other authors (Robblee et al. 1991, Sheridan 1992, Thayer et al. 1989, Thayer et al. 1999). We proposed that analyses that accounted for the effects of these other factors would reveal relationships with salinity. This set of analyses has certainly confirmed the importance of seagrass habitat to forage faunal density and species composition. A relationship between faunal density and salinity seems clear for some species and more equivocal for others. For one species, pink shrimp, we know from other work (Browder et al., in press) that the response to salinity is near range extremes, where these results are affected by data scarcity. The rainwater killifish, on the other hand, appeared to have been favorably affected by the range extremes, possibly because of constraints on predators.

We initially suggested that predictions of abundance from the 11 species models could be combined and summed over the entire Bay to provide a measure of performance related to water management and associated changes in freshwater inflow and salinity. Our combined predictions suggest little difference in total faunal density between an extreme wet and extreme dry year, when one would expect extreme conditions of salinity and freshwater inflow. On the other hand, our visual examination of predictions of density in relation to salinity (Figs. 49-60) suggest that the predictions are related to salinity. The relationships differ among species, however overall density decreased with increased salinity.

Total baywide biomass of the 11 species was also proposed as a possible performance measure, however our calculations of biomass based on predictions were strongly biased by one or two large species. Biomass based on predictions was highest in the dry year.

The use of an evenness measure conditional to the 11 species of our model is another possible measure of performance related to water management and associated salinity changes. The analysis of evenness in density predictions from the 11 models suggested that species composition varied substantially among time periods (Fig. 42) and was affected by salinity (Fig. 43).

In general, this work suggests that concept of forage community indices based on statistical models has promise but the approach should be further developed and tested. Two paths are suggested. One is to refine these models by adding more data to the multi-study data base, increasing data throughout the range and especially at range extremes, and the other is to develop another set of models based on one multidecadal study using one consistent method and gear type. These paths are complementary because they would lead to improved models that could be compared and tested against each other. Both opportunities appear available.

A cursory examination of the 1997-1998 and 1999-2000 trawl databases of Powell et al. (Beaufort Laboratory, NOAA Fisheries) suggests that these databases contain data beyond and near the range extremes for salinity and freshwater inflow in the present data set. Therefore, the reliability of predictions might be improved by the incorporation of the Powell et al. data.

The database for development of the present models included trawl, throw trap, and seine data but depended most heavily on trawl data, which sampled primarily the basins, which made up 80% of Bay area. The fauna of the banks that make up 20% of the Bay may not have been well represented. The throw trap data used in the current models, except for that of Robblee, were limited to the banks. The Robblee throw trap data we used in our models included bank, basin, and near-key habitat but was limited to data only for pink shrimp and only from one part of the Bay, Johnson Key Basin.

A complementary set of models could be developed based entirely on throw-trap gear using the extensive data base of Robblee. The efficiency of throw traps is high compared to other gear (Robblee et al. 1991), and its sampling of specific seagrass density and type is more precise. A larger, more geographically extensive and species inclusive throw trap data set is now becoming available that could be used to develop another set of models. Throw-trap-based models would be particularly valuable in supporting and helping to interpret results of monitoring with throw traps, as proposed in the CERP draft monitoring plan.

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Appendix A. Information on Models and Independent Variables used in the Models

Table A-1.	The independent variables used in the model.
Table A-2.	Seagrass type, by basin and estimation method.
Table A-3.	Seagrass density, by basin and estimation method.
Table A-4.	Average trawl depth from forage fish studies by basin number, geographic area (mainland, interior (near Florida Keys, region (northeast, Atlantic, Gulf, and interior), and habitat type (bank, basin, near-key, etc.). These data, which were interpolated from values for plotted station locations on a map, were used to estimate (impute) missing depths.
Table A-5.	Depth model results (impution of missing values). Average trawl depth by basin from forage fish studies and interpolations by basin number, geographic area (mainland, interior, near Florida keys), region (northeast, Atlantic, gulf, and interior), and habitat type. These are the depths used in the prediction models.
Table A-6.	Program and results of depth analysis used to impute missing values.
Table A-7.	Tidal amplitude assigned to each basin based on M_2 tidal amplitude contours from Smith (1997).
Table A-8.	Physical habitat as percent of basin area, by basin.

Table A-1. Model independent variables used in the models (the models where used are indicated with an x).

Species number	Gear	Month	Temp (○C)	Sal. (ppt)	Grass type	Grass density	Depth (m)	Habitat	Tidal amp (cm)	Sea level diff.	Wind vector	Rain (in)	Flow (ac. Ft.)
1	x	x	x	x	x	x	x	x	x	x	x	x	x
2	x		x	x	x	x	x	x	x	x		x	x
3		x	x	x	x	x	x	x	x	x	x	x	x
4	x	x	x	x	x	x	x	x	x	x	x	x	x
5	x	x	x	x	x	x	x	x	x	x	x	x	x
6	x	x	x	x	x	x	x	x	x		x	x	x
7	x	x	x	x	x	x	x	x	x	x	x	x	x
8	x	x	x	x	x	x	x	x	x	x	x	x	x
9	x	x	x	x	x	x	x	x	x	x		x	x
10	x	x	x	x	x	x	x	x	x	x	x	x	x
11		x		x	x	x	x	x	x				x

Species, by number:

1. *Farfantepenaeus duorarum*, pink shrimp
2. *Lagodon rhomboides*, pinfish
3. *Eucinostomus* spp., mojarras
4. *Anchoa mitchelli*, bay anchovy
5. *Opsanus beta*, Gulf toadfish
6. *Gobiosoma robustum*, code goby
7. *Floridichthys carpio*, goldspotted killifish
8. *Syngnathus scovelli*, Gulf pipefish
9. *Microgobius gulosus*, clown goby
10. *Lucania parva,* rainwater killifish
11. *Hippocampus zosterae,* dwarf seahorse

Footnote to Table A-1.
Hypotheses/Justifications for Consideration of the Independent Variables

Gear. Three types of gear were used in the studies providing data to this analysis. Gear type is known to affect catch per unit area covered and so the density estimated with the three gear may differ.

Month. Timing of spawning and other seasonal factors commonly influence the density of fish and macroinvertebrates. Oceanographic factors may have a seasonal influence on the transport of offshore-spawning species that spend a part of their life in Florida Bay.

Temperature. Temperature is a known factor influencing survival and growth of aquatic animals and so may influence animal density. Growth rates affect predation rate because smaller prey have more potential predators. While temperature varies with month and month is also a variable in the model, temperature was included because temperature varies by year in both winter and summer.

Salinity. Salinity is a known factor influencing survival and growth of estuarine animals and so may influence animal density.

Seagrass type. The species composition of seagrass may affect the density of seagrass associated animals.

Seagrass density. The density of seagrass may affect the density of seagrass-associated animals.

Depth. Water depth (from surface to bottom substrate) is known to affect the density of some fish and macroinvertebrates.

Habitat. Robblee et al. (1991) and Thayer et al. (1987) have shown that animal density differs in different types of physical habitat in Florida Bay.

Tidal amplitude. Tidal transport into Florida Bay may affect transport into the Bay of postlarvae spawned offshore. The variation in tidal amplitude from the edge to the interior of the Bay provides a rough index of relative tidal transport into the different parts of the Bay.

Sea level difference. The difference between measured low tide at Key West and measured high tide at Naples was used as an index of transport from offshore spawning grounds to nursery grounds in Florida Bay. This variable might affect the density of offshore-spawning species that live in Florida Bay.

Rain. Rainfall at Flamingo was used as an index of one freshwater input to Florida Bay. This variable was lagged from one to three months, depending upon the model. Rainfall would be expected to have a general effect on salinity across the entire Bay.

Wind vector. This variable integrates wind speed and direction and could influence the transport of larvae into the Bay or across the Bay.

Flow. Flow across the Tamiami Trail between Levee 31-N and Levee 68 was used as an index of the overland flow to Florida Bay and adjacent coastal waters. Freshwater inflow would be expected to have an effect on salinity in the northern and western part of the Bay. Overland flow might also carry macro and micro nutrients and dissolved and particulate organic carbon into the Bay and stimulate food webs.

Footnote to Appendix Table A-1- continued.

The purpose of including gear and month was to account for these known effects so that the effect of other variables could be better seen.

The purpose of including salinity and freshwater inflow was to determine possible impacts of water management.

Temperature was included because it is a strong variable affecting survival and growth of aquatic animals and is known to interact with salinity.

The purpose of including rainfall was to adjust for this variable, which also affects Bay salinity and the import of nutrients and detritus.

The purpose of including seagrass type and density is because these variables may be changed by water management or chronic or catastrophic events, both natural and human induced. Known seagrass canopy species might be expected to be most tightly linked to these variables.

Physical habitat and depth were included because they are other spatially-distinct habitat variables that, if ignored, could confound the effort to understand seagrass and salinity effects.

Tidal amplitude, wind vector, and sea level difference were included because, through their role in transport, they may affect especially the offshore spawning species.

Table A-2 .Seagrass type by basin and habitat, with estimation method. (Bold indicates estimate based on data, regular print indicates that estimate came from another habitat type within basin, and italics indicate that estimate came from adjacent basin). (thal=*Thalassia*, hal=*Halodule*, mix=mixed seagrasses)

	Habitat Type					
Basin number	bank	basin	channel	island	mainland	region
6	**mix**	**mix**	**mix**	**mix**	mix	main
7	**mix**	**mix**	**mix**	**mix**	mix	main
8	thal	thal	thal	**thal**	**thal**	ne
9	**thal**	**thal**	thal	**thal**		ne
12	**thal**	**thal**	mix	**mix**	**mix**	ne
15	thal	**thal**	mix	**thal**	**mix**	ne
16	**thal**	**thal**	thal	thal		ne
17	*thal*	*thal*	*thal*	*thal*		ne
18	thal	**thal**	thal	thal		ne
19	**thal**	**thal**	**mix**	thal		atl
20	**thal**	**mix**	mix	mix		atl
21	thal	**thal**	mix	**mix**		int
22	thal	**thal**	thal	**thal**		int
23	**thal**	**thal**	**mix**	**thal**	thal	int
24	**thal**	**thal**	**hal**	thal	**thal**	int
25	**thal**	**thal**	thal	thal	thal	int
26	thal	**thal**	thal	thal		int
27	thal	**thal**	thal	thal		int
28	**thal**	**thal**	**mix**	thal		atl
29	thal	**thal**	**mix**	thal		atl
30	**thal**	**thal**	**mix**	**thal**		atl
31	**thal**	**thal**	thal	thal		int
32	**thal**	**thal**	**mix**	**thal**		int
33	**thal**	**thal**	thal	**thal**		int
34	**thal**	**mix**	mix	mix	mix	int
35	mix	**mix**	mix	mix	mix	int
36	*thal*	*mix*	*mix*	*thal*		int
37	**thal**	**mix**	mix	thal	mix	int
38	**thal**	**thal**	thal	**mix**		gulf
39	**thal**	**mix**	**mix**	**mix**		gulf
40	**mix**	**mix**	thal	mix		gulf
41	mix	**mix**	mix	mix	mix	gulf
42	**mix**	**mix**	mix	**mix**	**mix**	gulf
43	**mix**	**mix**	**mix**	**thal**		gulf
44	**mix**	**mix**	mix	mix		int
45	**thal**	**mix**	**mix**	mix		ne
46	thal	**thal**	thal	**thal**		ne
47	thal	**thal**	thal	**thal**	**thal**	ne

Table A-3 .Seagrass density by basin and habitat with estimation method indicated (Bold indicates estimate based on data, regular print indicates that estimate came from another habitat type within basin, and italics indicate that estimate came from adjacent basin.

			Habitat				
Basin Number	Geographic position	region	bank	basin	channel	island	main
6	main	ne	*moderate*	*moderate*	*modsparse*	**dense**	*moderate*
7	main	ne	moderate	moderate	modsparse	**moderate**	moderate
8	int	ne	moderate	moderate	modsparse	moderate	**moderate**
9	keys	ne	sparse	**sparse**	sparse	**sparse**	
12	main	ne	sparse	*sparse*	sparse	sparse	sparse
15	main	ne	sparse	**sparse**	sparse	**modsparse**	**sparse**
16	keys	ne	modsparse	**modsparse**	modsparse	modsparse	
17	keys	ne	moderate	**moderate**	modsparse	moderate	
18	keys	ne	moderate	*moderate*	modsparse	moderate	
19	int	ne	modsparse	**modsparse**	**modsparse**	modsparse	
20	keys	atl	modsparse	**modsparse**	modsparse	modsparse	
21	keys	atl	modsparse	**modsparse**	modsparse	**moddense**	
22	int	int	modsparse	**sparse**	sparse	**moddense**	
23	int	int	modsparse	**modsparse**	**modsparse**	modsparse	
24	main	int	modsparse	**modsparse**	**modsparse**	modsparse	modsparse
25	main	int	*moddense*	moderate	modsparse	moderate	moderate
26	main	int	sparse	**sparse**	sparse	sparse	sparse
27	int	int	sparse	**sparse**	sparse	sparse	
28	int	int	modsparse	**sparse**	**modsparse**	modsparse	
29	keys	atl	modsparse	**modsparse**	**modsparse**	modsparse	
30	keys	atl	moderate	**modsparse**	modsparse	modsparse	
31	keys	atl	*sparse*	**modsparse**	modsparse	modsparse	
32	keys	int	*moddense*	**modsparse**	**modsparse**	modsparse	
33	int	int	modsparse	**modsparse**	modsparse	modsparse	
34	int	int	sparse	**sparse**	**sparse**	sparse	
35	main	int	sparse	**sparse**	**sparse**	sparse	sparse
36	main	int	sparse	sparse	sparse	sparse	sparse
37	main	int	**modsparse**	**modsparse**	modsparse	modsparse	modsparse
38	keys	gulf	*moddense*	**moddense**	**modsparse**	**modsparse**	
39	int	gulf	*moddense*	**moddense**	**modsparse**	**sparse**	
40	int	gulf	modsparse	**moderate**	modsparse	modsparse	
41	main	gulf	modsparse	**modsparse**	**modsparse**	modsparse	modsparse
42	main	gulf	modsparse	**modsparse**	**modsparse**	**sparse**	modsparse
43	keys	gulf	*moderate*	**modsparse**	**modsparse**	modsparse	
44	int	int	*moddense*	**modsparse**	modsparse	modsparse	
45	keys	ne	**modsparse**	**modsparse**	**sparse**	modsparse	
46	keys	ne	modsparse	*moderate*	modsparse	**modsparse**	
47	main	ne	modsparse	*sparse*	modsparse	modsparse	**moderate**

Table A-4 Average trawl depth from forage fish studies by basin number, geographic area (mainland, interior (near Florida Keys, region (northeast, Atlantic, Gulf, and interior), and habitat type (these data, which were interpolated from plotted station locations on a map, were used to estimate (impute) missing depths.

FATHOM basin number	Geographic area	region	bank	basin	channel	island	mainland
6	main	ne		1.6*			1
7	main	ne	1.2	1.6*			1
8	int	ne		1.7*		0.8	1.1
9	keys	ne		2.2*			
12	main	ne	0.5	1.2		0.7	0.7
13	main	ne		1.6*			0.8
14	main	ne		1.6			0.6
15	main	ne	0.7	1.8		0.8	0.8
16	keys	ne	0.6	2.1			
17	keys	ne		2.4*			
18	keys	ne		2.4			
19	int	ne	0.4	1.9	1		
20	keys	atl	0.7	2			
21	keys	atl		2		0.9	
22	int	int		1.7	1.4	0.8	
23	int	int	0.8	1.3	0.9	0.5	
24	main	int	0.6	1	1		0.8
25	int	int	0.8	1.2			
26	main	int		1.3	0.9		
27	int	int		1.7	2		
28	int	int	1	1.9			
29	keys	atl		2.2	1.9		
30	keys	atl	0.6	2.2	3	0.7	
31	keys	atl	0.6	2.2			
32	keys	int		2.2	2.2	0.6	
33	int	int	0.9	1.7		0.4	
34	int	int	0.6	1.8	2.2		
35	main	int		1.3			
36	main	int		1.3*			
37	main	int	0.6	1.2			
38	keys	gulf	0.7	1.8	2	1	
39	int	gulf	0.9	1.6		0.8	
40	int	gulf	0.5	1.2	0.5		
41	main	gulf		0.8	1.9		
42	main	gulf	0.6	1.8	1.9	0.9	0.9
43	keys	gulf	1	2.5	2.8	0.8	
44	int	int	0.7	1.2	1.8		
45	keys	ne	0.5	2.4		0.8	
46	keys	ne	0.7	2.2		0.8	
47	main	ne	0.7	1.8			1.1

Table A-5. Average trawl depth by basin from forage fish studies and interpolations by basin number, geographic area (mainland, interior, near Florida keys), region (northeast, Atlantic, gulf, and interior), and habitat type. These are the depths used in the prediction models.

FATHOM Basin number	Geographic area	region	bank	basin	channel	island	mainland
6	main	ne	0.6	1.6	1.3	0.6	1
7	main	ne	1.2	1.6	1.3	0.6	1
8	int	ne	0.6	1.7	1.3	0.8	
9	keys	ne	0.8	2.2	1.5	0.8	
12	main	ne	0.5	1.2	1.3	0.7	0.7
13	main	ne	0.6	1.6	1.3	0.6	0.8
14	main	ne	0.6	1.6	1.3	0.6	0.6
15	main	ne	0.7	1.8	1.3	0.8	0.8
16	keys	ne	0.6	2.1	1.5	0.8	
17	keys	ne	0.8	2.4	1.5	0.8	
18	keys	ne	0.8	2.4	1.5	0.8	
19	int	ne	0.4	1.9	1	0.6	
20	keys	atl	0.7	2	1.5	0.8	
21	keys	atl	0.8	2	1.5	0.9	
22	int	int	0.6	1.7	1.4	0.8	
23	int	int	0.8	1.3	0.9	0.5	
24	main	int	0.6	1	1	0.6	0.8
25	int	int	0.8	1.2	1.3	0.6	
26	main	int	0.6	1.3	0.9	0.6	0.8
27	int	int	0.6	1.7	2	0.6	
28	int	int	1	1.9	1.3	0.6	
29	keys	atl	0.8	2.2	1.9	0.8	
30	keys	atl	0.6	2.2	3	0.7	
31	keys	atl	0.6	2.2	1.5	0.8	
32	keys	int	0.8	2.2	2.2	0.6	
33	int	int	0.9	1.7	1.3	0.4	
34	int	int	0.6	1.8	2.2	0.6	
35	main	int	0.6	1.3	1.3	0.6	0.8
36	main	int	0.6	1.3	1.3	0.6	0.8
37	main	int	0.6	1.2	1.3	0.6	0.8
38	keys	gulf	0.7	1.8	2	1	
39	int	gulf	0.9	1.6	1.3	0.8	
40	int	gulf	0.5	1.2	0.5	0.6	
41	main	gulf	0.6	0.8	1.9	0.6	0.9
42	main	gulf	0.6	1.8	1.9	0.9	0.9
43	keys	gulf	1	2.5	2.8	0.8	
44	int	int	0.7	1.2	1.8	0.6	
45	keys	ne	0.5	2.4	1.5	0.8	
46	keys	ne	0.7	2.2	1.5	0.8	
47	main	ne	0.7	1.8	0.8	0.6	1.1

Appendix Table A-6. Program and results of depth analysis used to imput missing values.

```
> summary(depthbasinhabitatdataset.transcan, long = T)
transcan(x =  ~ geog + region + habitat + depth, imputed = T, imcat = "score")

Iterations: 7

R-squared achieved in predicting each variable:

  geog region habitat depth
 0.422  0.382   0.835 0.744

Adjusted R-squared:

  geog region habitat depth
 0.401  0.358   0.828 0.723

Coefficients of canonical variates for predicting each (row) variable

         geog region habitat depth
   geog        -0.86  -0.69   -0.60
 region -0.97          0.15    0.13
habitat -0.14  0.03           -0.79
  depth -0.20  0.03   -1.27
```

Table A-7. Tidal amplitude assigned to each basin based on M_2 contours from Smith (1997).

Basin	Tidal Amplitude
6	1
7	1
8	1
9	1
12	1
13	1
14	1
15	5
16	5
17	1
18	1
19	5
20	15
21	15
22	5
23	1
24	1
25	5
26	1
27	5
28	5
29	5
30	15
31	15
32	5
33	5
34	1
35	5
36	5
37	5
38	15
39	25

Basin	Tidal Amplitude
40	15
41	25
42	40
43	25
44	5
45	5
46	5
47	1

Table A-8. Physical Habitat as Percent of Basin Area, by FATHOM Basin.

Basin	%Coverage of each basin by habitat type.			
	%bank	%basin	%main	%island
8	0.0	99.1	0.1	0.8
9	0.0	98.8	0.0	1.2
12	0.7	99.0	0.1	0.2
15	3.2	96.6	0.0	0.2
16	8.5	91.5	0.0	0.0
17	1.0	98.2	0.0	0.8
18	0.0	99.1	0.0	0.9
19	9.4	90.5	0.0	0.1
20	9.5	89.8	0.0	0.7
21	14.1	85.7	0.0	0.2
22	10.5	89.2	0.0	0.3
23	17.3	82.1	0.0	0.6
24	4.8	94.5	0.5	0.2
25	9.8	88.2	1.5	0.4
26	18.1	81.6	0.0	0.3
27	16.1	83.7	0.0	0.2
28	21.4	78.2	0.0	0.3
29	15.6	84.3	0.0	0.0
30	14.1	85.7	0.0	0.2
31	6.4	93.3	0.0	0.3
32	17.1	82.8	0.0	0.0
33	27.4	72.3	0.0	0.3
34	17.6	82.1	0.0	0.3
35	8.4	91.4	0.2	0.1
36	82.8	16.5	0.4	0.4
37	97.6	2.0	0.2	0.1
38	58.5	41.5	0.0	0.0
39	46.1	53.9	0.0	0.0
40	58.6	41.3	0.0	0.1
41	93.3	6.6	0.1	0.1
42	30.5	69.4	0.0	0.0
43	17.0	83.0	0.0	0.0
44	40.2	59.7	0.0	0.1
45	5.0	94.0	0.0	1.1
46	2.7	97.1	0.0	0.2
47	0.4	99.3	0.1	0.2
Total	0.2	78.5	0.0	0.2

Appendix B
Model Structure and Relationships of the Dependent Variables to Independent Variables Used in the Models

Table B-1. Structure of the 11 forage species models used to make predictions.

Table B-2. Model intercepts and coefficients (of the transformed variables).

Table B-3. Sample size, coefficients of determination (r^2), bootstrap-corrected r^2, and ratios of r^2/bootstrap r^2 of the GAM models.

Table B-4. R^2s of single-variable GAM models with each of the 13 independent variables of the models.

Table B-5. Results of Anovas of the untransformed variables.

Table B-1. Structure of the 11 forage species GAM models used to make predictions.

```
Shrimp ~ Gear + Month + Temperature + Seagrass.Type + Salinity +
   DensityInt + Depth + Habitat + Tidal.Amplitude + SeaLevel(3) +
   WindVector(3) + Rainfall(3) + Flow(3)

Pinfish ~ Gear + Temperature + Seagrass.Type + Salinity +
   Seagrass.Density + Depth + Habitat + Tidal.Amplitude + SeaLevel(1) +
   WindVector(1) + Rainfall(1) + Flow(1)

Mojarras ~ MonthFactor + Temperature + Habitat + Seagrass.Type +
   Salinity + Seagrass.Density + Depth + Tidal.Amplitude + WindVector(2) +
   SeaLevel(2) + Rainfall2 + Flow(2)

Anchovy ~ Gear + MonthFactor + Temperature + Salinity + SeagrassType +
   SeagrassDensity + Depth + Habitat + TidalAmplitude + SeaLevel (2)+
   Rainfall(2) + WindVector(2) + Flow(2)

Toadfish ~ Gear + MonthFactor + Temperature + Seagrass.Type +
   Salinity + Seagrass.Density + Depth + Habitat + Tidal.Amplitude +
   SeaLevel(3) + WindVector(3) + Rainfall(3) + Flow(3)

Gobiosoma ~ Gear + MonthFactor + Temperature + Seagrass.Type +
   Salinity + DensityBB + Depth + Habitat + Tidal.Amplitude + WindVector(1) +
   Rainfall(1) + Flow(2)

Goldspotted killifish ~ Gear + MonthFactor + Temperature + Seagrass.Type +
   Salinity + DensityBB + Depth + Habitat + Tidal.Amplitude + SeaLevel(2) +
   WindVector(3) + Rainfall(3) + Flow(2)

Pipefish ~ Gear + MonthFactor + Temperature + Seagrass.Type +
   Salinity + Seagrass.Density + Depth + Habitat + Tidal.Amplitude +
   SeaLevel(2) + WindVector(2) + Rainfall(2) + Flow(2)

Clown goby ~ Gear + MonthFactor + Temperature + Seagrass.Type +
   Salinity + Seagrass.Density + Depth + Habitat + Tidal.Amplitude +
   SeaLevel(2) + Rainfall(2) + Flow(2)

Rainwater killifish ~ Gear + MonthFactor + Temperature + Seagrass.Type +
   Salinity + Seagrass.Density + Depth + Habitat + Tidal.Amplitude +
   SeaLevel(2) + WindVector(3) + Rainfall(3) + Flow(3)

Seahorse ~ MonthFactor + Seagrass.Type + Salinity + DensityBB +
   Depth + Habitat + Tidal.Amplitude + Flow(2)
```

Table B-2. GAM model intercepts and coefficients (of the standardized transformed variables)(numbers in parenthesis indicate months of time lag.

Species number code	Intercept	Gear	Month	Temp (○C)	Sal. (ppt)	Grass type	Grass density	Depth (m)	Habitat	Tidal amp (cm)	Sealevel diff.	Wind vector	Rain (in)	Flow (ac. Ft.)
1	0.00000	0.99477	1.03094	1.04511	1.01087	1.07884	1.09317	0.80872	0.90282	0.96496	1.07312 (3)	0.40680 (3)	1.32088 (3)	1.73111 (3)
2	0.00000	-.017611		0.87705	0.42582	1.18797	0.96716	1.00759	0.11615	0.98870	1.03436 (1)	0.92369 (1)	1.04948 (1)	1.12010 (1)
3	0.00000		1.01084	1.09778	1.11118	0.99865	0.99626	1.08046	0.96420	1.10441	1.21814 (2)	0.98639 (2)	1.28768 (2)	1.19274 (2)
4	0.00000	0.29143	1.07397	1.20247	1.19651	0.80686	0.15971	1.05155	0.37365	1.38498	0.95317 (2)	1.35511 (2)	0.70002 (2)	1.25568
5	0.00000	0.93537	0.67339	0.86662	0.86306	1.21858	0.85954	0.21380	0.67518	1.16868	0.87605 (3)	0.96348 (3)	0.49389 (3)	0.80618 (3)
6	0.00000	1.22854	1.11836	1.37091	2.43210	0.81623	1.58411	0.70490	0.78295	0.86924		1.09561 (1)	1.05508 (1)	1.15982 (2)
7	0.00000	0.14619	0.99678	0.99842	1.30400	0.81786	1.01378	1.28077	-0.05163	1.09749	0.78847 (2)	1.61755 (3)	1.57884 (3)	1.46979 (2)
8	0.00000	-0.03659	1.07930	1.08148	1.12507	0.86374	1.24841	0.91127	0.10326	1.67921	1.64533 (2)	1.61615 (2)	1.63326 (2)	1.17635 (2)
9	0.00000	0.15620	1.09496	1.07381	1.46388	1.28505	0.95449	0.85415	0.12549	1.05492	1.01281 (2)		1.47024 (2)	1.03556 (2)
10	0.00000	0.45796	1.00980	0.80918	1.72572	0.98989	0.92718	0.87983	0.37801	1.37128	0.63385 (2)	0.73052 (2)	1.34481 (3)	-1.70171 (3)
11	0.00000		0.97609		1.06044	1.01375	1.07355	0.99365	1.02987	1.14549				0.97564 (2)

Species, by number:

1. *Farfantepenaeus duorarum*, pink shrimp
2. *Lagodon rhomboides*, pinfish
3. *Eucinostomus* spp., mojarras
4. *Anchoa mitchelli*, bay anchovy
5. *Opsanus beta*, Gulf toadfish
6. *Gobiosoma robustum*, code goby
7. *Floridichthys carpio*, goldspotted killifish
8. *Syngnathus scovelli*, Gulf pipefish
9. *Microgobius gulosus*, clown goby
10. *Lucania parva,* rainwater killifish
11. *Hippocampus zosterae,* dwarf seahorse

Table B-3. Sample size, coefficients of determination (r^2), bootstrap-corrected r^2, and ratios of r^2/bootstrap r^2 of the GAM models.

		n	r^2(a)	boot r^2(b)	boot r^2 /r^2 ratio
1	*Farfantepenaeus duorarum*, pink shrimp	6,570	0.424	0.423	0.998
2	*Lagodon rhomboides*, pinfish	5,458	0.226	0.218	0.965
3	*Eucinostomus* spp., mojarras	5,458	0.358	0.347	0.969
4	*Anchoa mitchelli*, bay anchovy	5,458	0.146	0.132	0.904
5	*Opsanus beta*, Gulf toadfish	5,458	0.342	0.332	0.970
6	*Gobiosoma robustum*, code goby	5,458	0.194	0.189	0.879
7	*Floridichthys carpio*, goldspotted killifish	5,458	0.302	0.295	0.977
8	*Syngnathus scovelli*, Gulf pipefish	5,458	0.096	0.083	0.865
9	*Microgobius gulosus*, clown goby	5,458	0.187	0.177	0.947
10	*Lucania parva,* rainwater killifish	5,458	0.247	0.237	0.960
11	*Hippocampus zosterae,* dwarf seahorse	5,458	0.105	0.093	0.886

(a) Apparent r2 on transformed y scale
(b) based on up to 20 bootstraps

Table B-4. Summary of r^2 values of single variable GAM models.

Species	Gear	Month	Temperature	Sea grass Type	Salinity	Sea grass Density	Depth	Habitat	Tidal Amplitude	Sea Level	Wind	Rain	Flow
Offshore Spawners													
Farfantepenaeus duorarum	0.1	0.036	0.022	0.038	0.045	0.106	0.036	0.044	**0.217**	0.022	0.019	0.009	0.027
Lagodon rhomboides	0.005	na	0.002	0.105	na	0.014	0.06	0.078	**0.125**	0.005	0.01	0.003	0.013
Eucinostomus spp.	**0.078**	0.057	0.007	0.044	0.007	0.008	0.056	0.047	0.021	0.068	0.022	0.053	0.01
Pelagic species													
Anchoa mitchelli	**0.100**	0.003	0.004	0.007	0.076	0.001	0.065	0.098	0.052	0.000	0.008	0.001	0.005
Resident species													
Opsanus beta	**0.133**	0.047	0.034	0.008	0.022	0.040	0.043	0.065	0.030	0.026	0.030	0.018	0.037
Gobiosoma robustum	**0.101**	0.038	0.007	0.009	0.027	0.045	0.067	0.075	0.066	0.008	0.042	0.024	0.028
Floridichthys carpio	0.190	0.048	0.042	0.042	0.077	0.044	0.163	**0.264**	0.029	0.020	0.034	0.029	0.037
Syngnathus scovelli	0.050	0.008	0.002	0.010	0.001	0.000	0.056	**0.059**	0.017	0.001	0.000	0.000	0.003
Microgobius gulosus	0.031	0.002	0.010	0.008	0.184	0.016	0.020	0.136	**0.186**	0.000	na	0.004	
Lucania parva	0.110	0.027	0.014	0.025	0.042	0.041	0.112	**0.196**	0.005	0.028	0.045	0.017	0.020
Hippocampus zosterae	na	**0.028**	na	0.005	0.010	0.011	0.009	0.011	0.022	na	na	na	0.012

Table B-5. Results (p-values‡) of analysis of variance with the same variables used in the GAM models, but untransformed.

Species number	Gear	Month	Temp (○C)	Sal. (ppt)	Grass type	Grass density	Depth (m)	Habitat	Tidal amp (cm)	Sea level diff. *	Wind vector *	Rain (in) *	Flow (ac. Ft.) *
1	.0000000	.0000000	.9371011	.0000170	.0000000	.0000000	.0000466	.0000000	.0000000	.0000000	.7911485	.0000662	.7088406
2	.0000000		.0035497	.0155776	.0000194	.0000016	.0233251	.8251931	.0000000	.0261259		.7413351	.0367408
3		.0000000	.3739561	.0013383	.0000000	.0847428	.0000901	.0000000	.0000000	.0000000	.3329092	.0541863	.0053309
4	.0000093	.0787864	.1349297	.1327768	.0033914	.0037315	.7546905	.7068067	.1351471	.1195986	.0491937	.8939206	.0982157
5	.0000000	.0000000	.0000452	.0024780	.0000000	.0057973	.3478525	.9932711	.0000000	.0000078	.0009176	.7543066	.0000000
6	.0000000	.0000000	.0000001	.0000000	.0000000	.9749495	.9711823	.9999925	.0000000	.0000000	.0399139	.0000053	.0004130
7	.0000000	.0000000	.8048786	.0000000	.0000000	.0171183	.5922904	.6169318	.1610445	.1070419	.1481638	.8938210	.0020591
8	.0000000	.0004894	.0000118	.0471860	.0000000	.6744387	.8096605	.9982038	.0000002	.9198861	.7182120	.3598330	.8927299
9	.0000000	.0065727	.0226004	.7556867	.8835660	.0000000	.1937756	.6724484	.0000000	.0560237		.8925985	.2272637
10	.0000000	.0000000	.1282817	.0000000	.0000000	.0092296	.0608470	.9647918	.0009358	.0011895	.1199319	.7257911	.0000004
11		.0000000		.9643461	.0000000	.0000002	.0036856	.0000000	.0010952				.0562014

Species, by numeric code:
1. *Farfantepenaeus duorarum*, pink shrimp
2. *Lagodon rhomboides*, pinfish
3. *Eucinostomus* spp., mojarras
4. *Anchoa mitchelli*, bay anchovy
5. *Opsanus beta*, Gulf toadfish
6. *Gobiosoma robustum*, code goby
7. *Floridichthys carpio*, goldspotted killifish
8. *Syngnathus scovelli*, Gulf pipefish
9. *Microgobius gulosus*, clown goby
10. *Lucania parva,* rainwater killifish
11. *Hippocampus zosterae,* dwarf seahorse

‡The lower the p-value, the greater the significance of thevariable to species density (the lower the probability that the observed relationship could have occurred by chance). The higher the p-value, the higher the probability that the relationship could have occurred by chance. P-values higher than p<.05 suggest that the relationship is insignificant.

* See Table A1 for the time lag (1, 2, or 3 mo) of the variable used in the GAM model and in the analysis of variance.

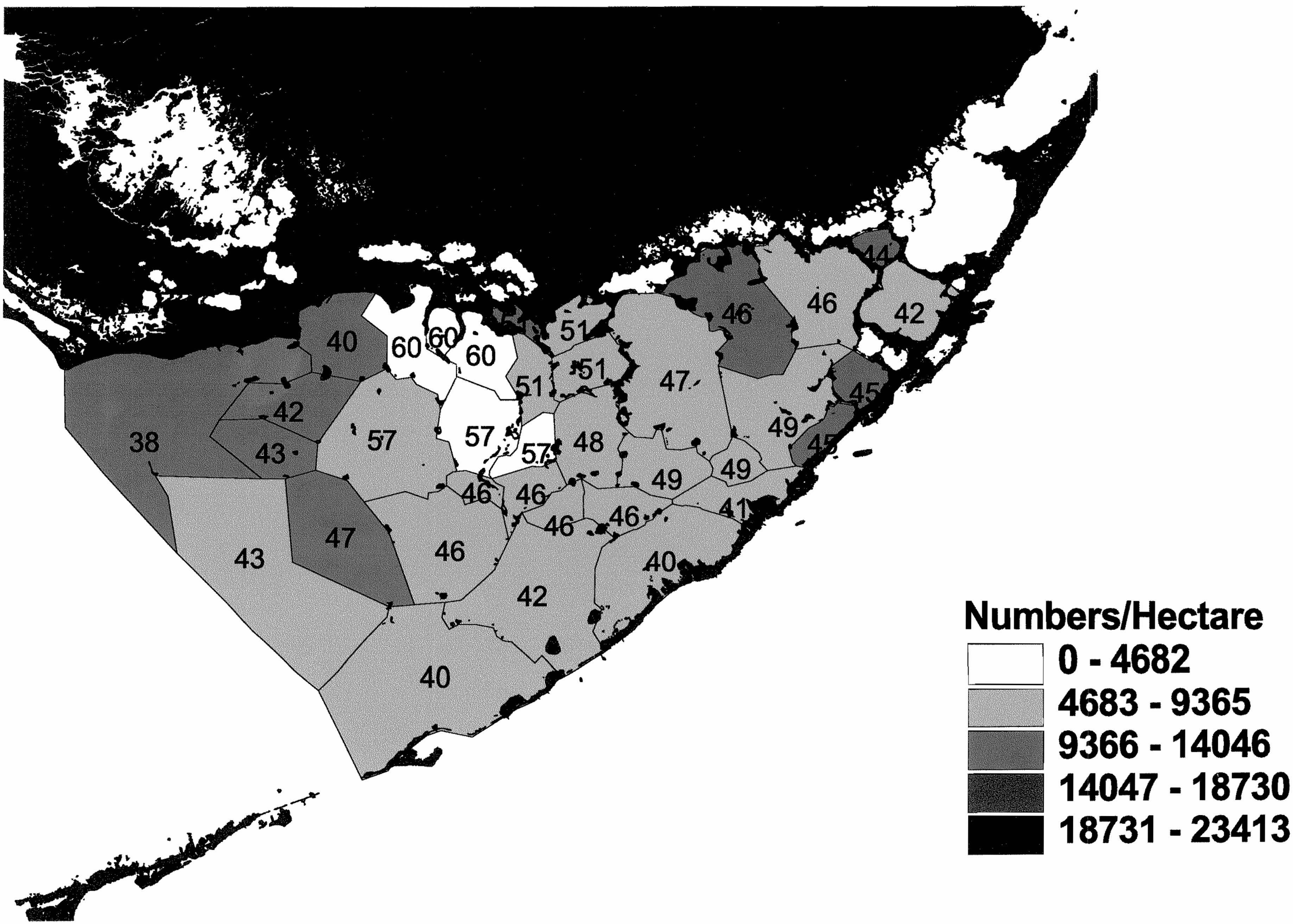
APPENDIX C

Maps of predicted density of the forage community.

APPENDIX C

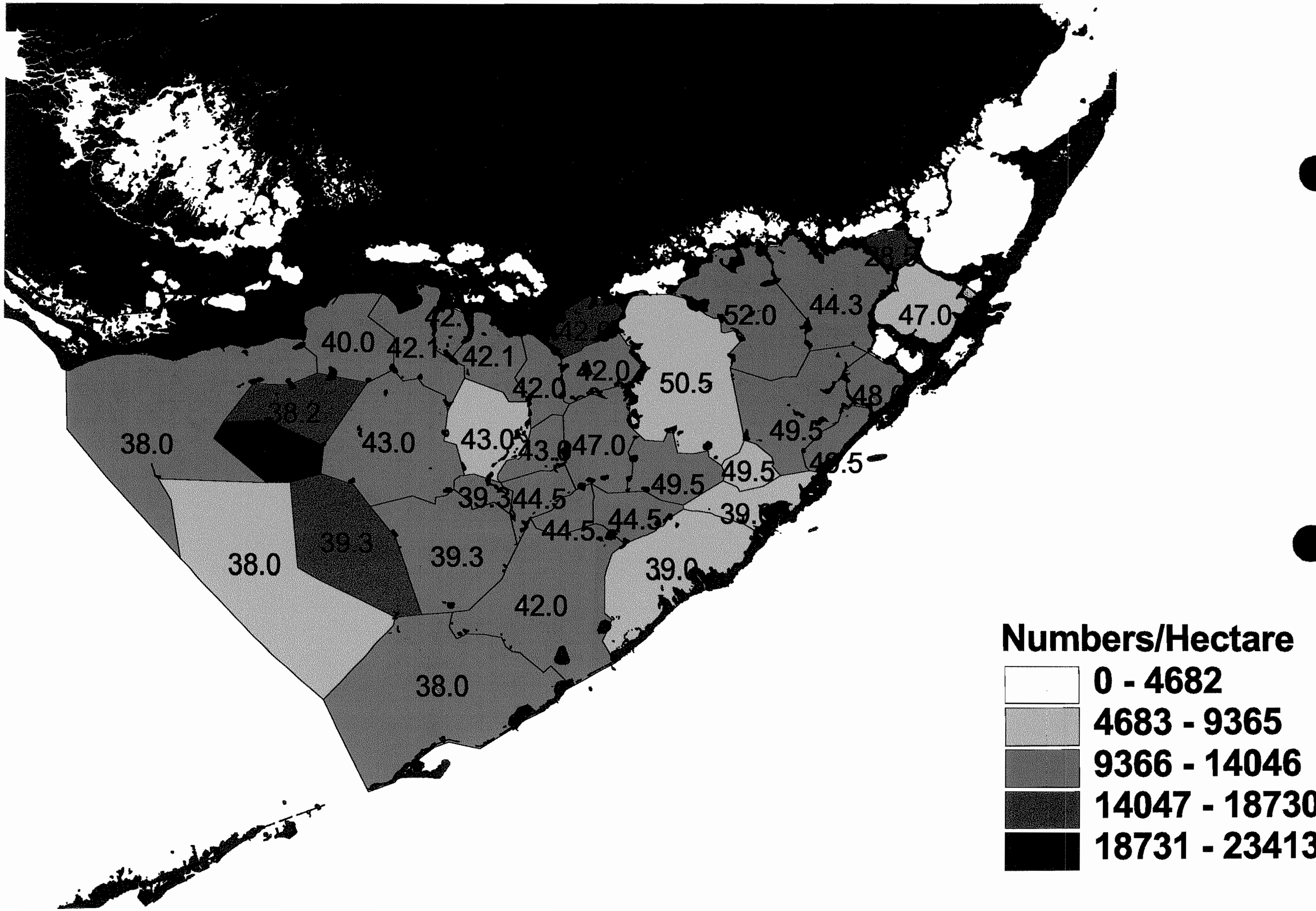
Appendix Figure C-1. Map of predicted densities of 11-species forage community during April 1990 with average salinity for each basin.

Predicted Densities of 11 Forage Fish Species During April 1990 with Average Salinity for each Basin



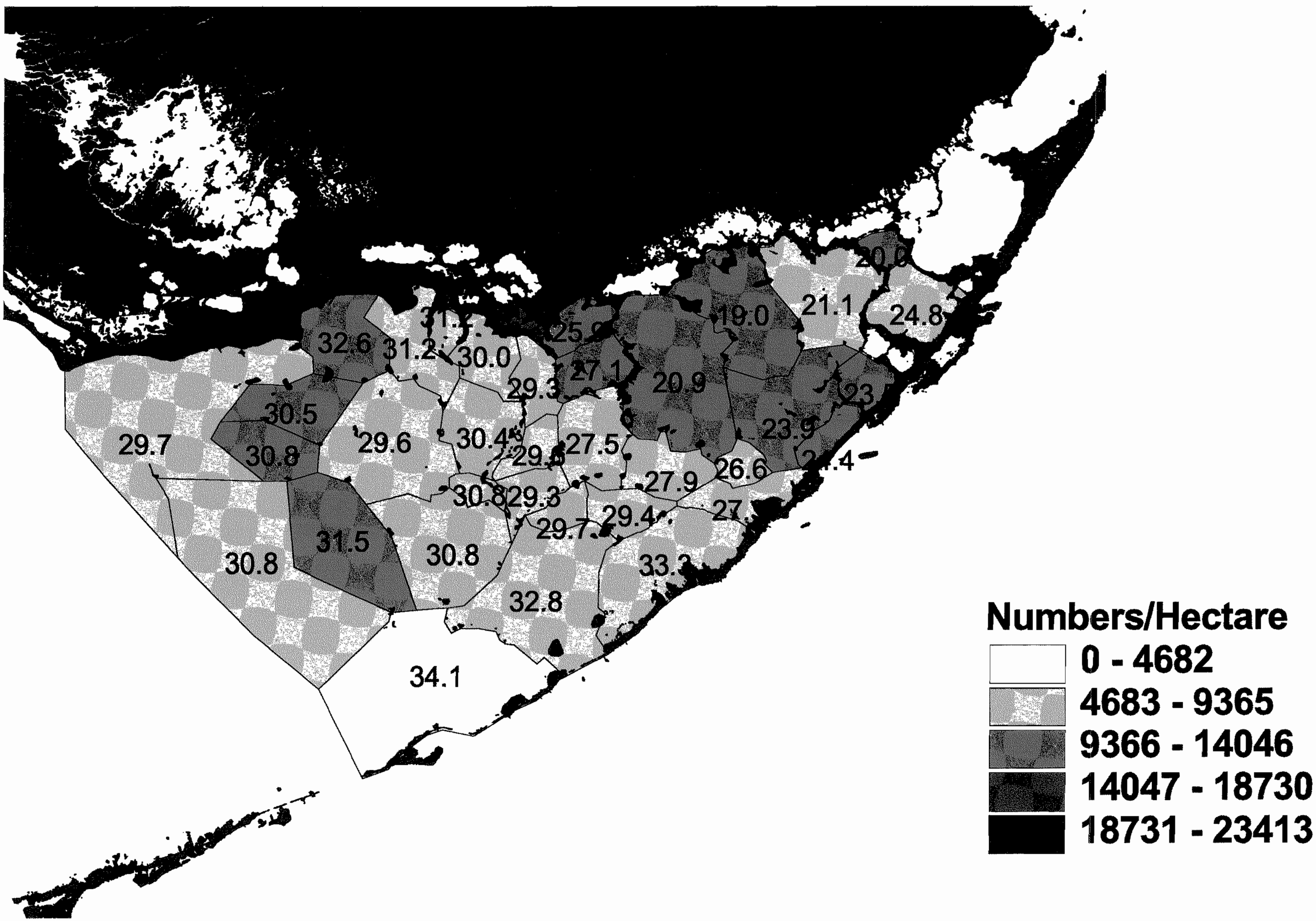
Appendix Figure C-2. Map of predicted densities of 11-species forage community during August 1990 with average salinity for each basin.

Predicted Densities of 11 Forage Fish Species During August 1990 with Average Salinity for each Basin



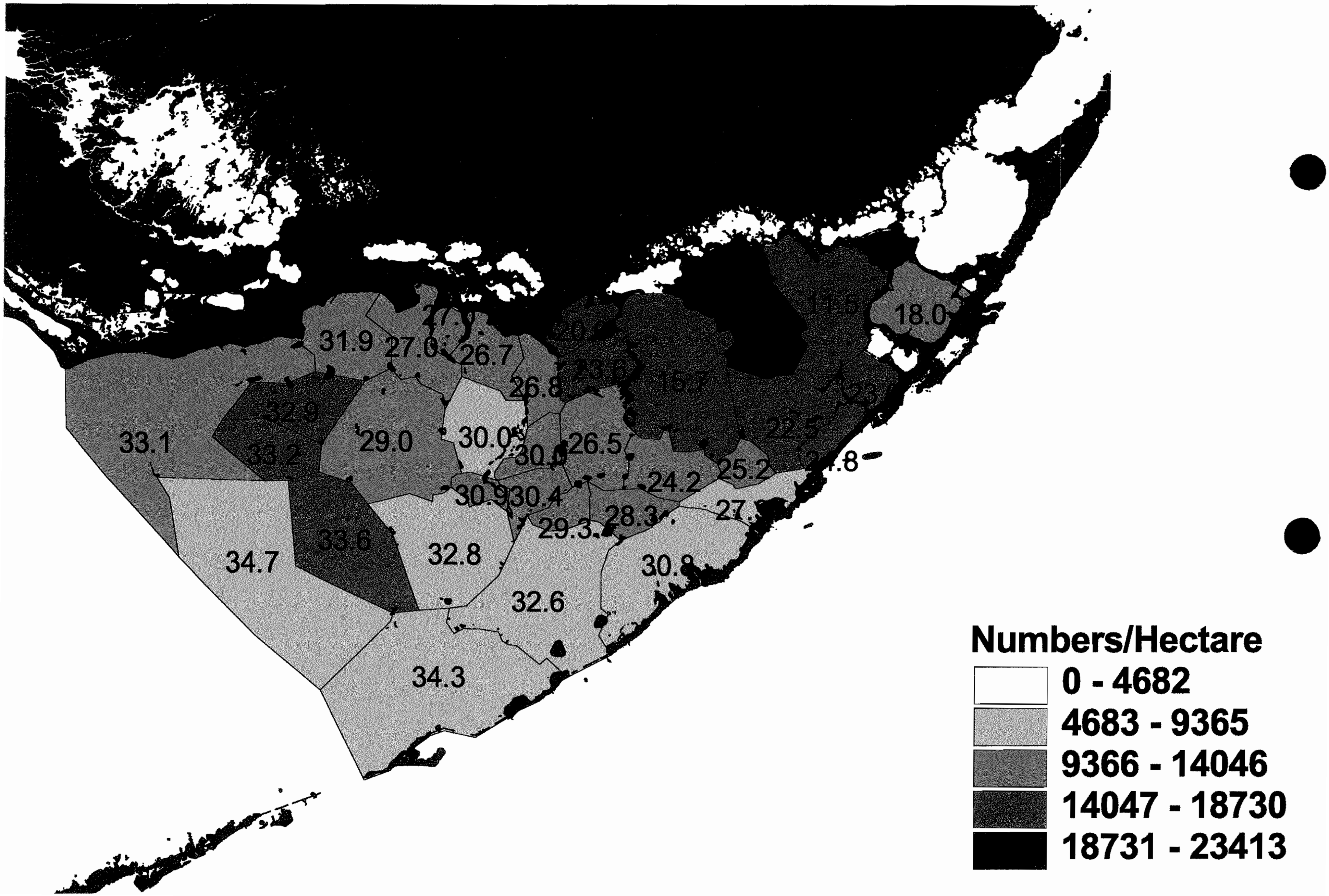
Appendix Figure C-3. Map of predicted densities of 11-species forage community during April 1995 with average salinity for each basin.

Predicted Densities of 11 Forage Species During April 1995 with Average Salinity for each Basin



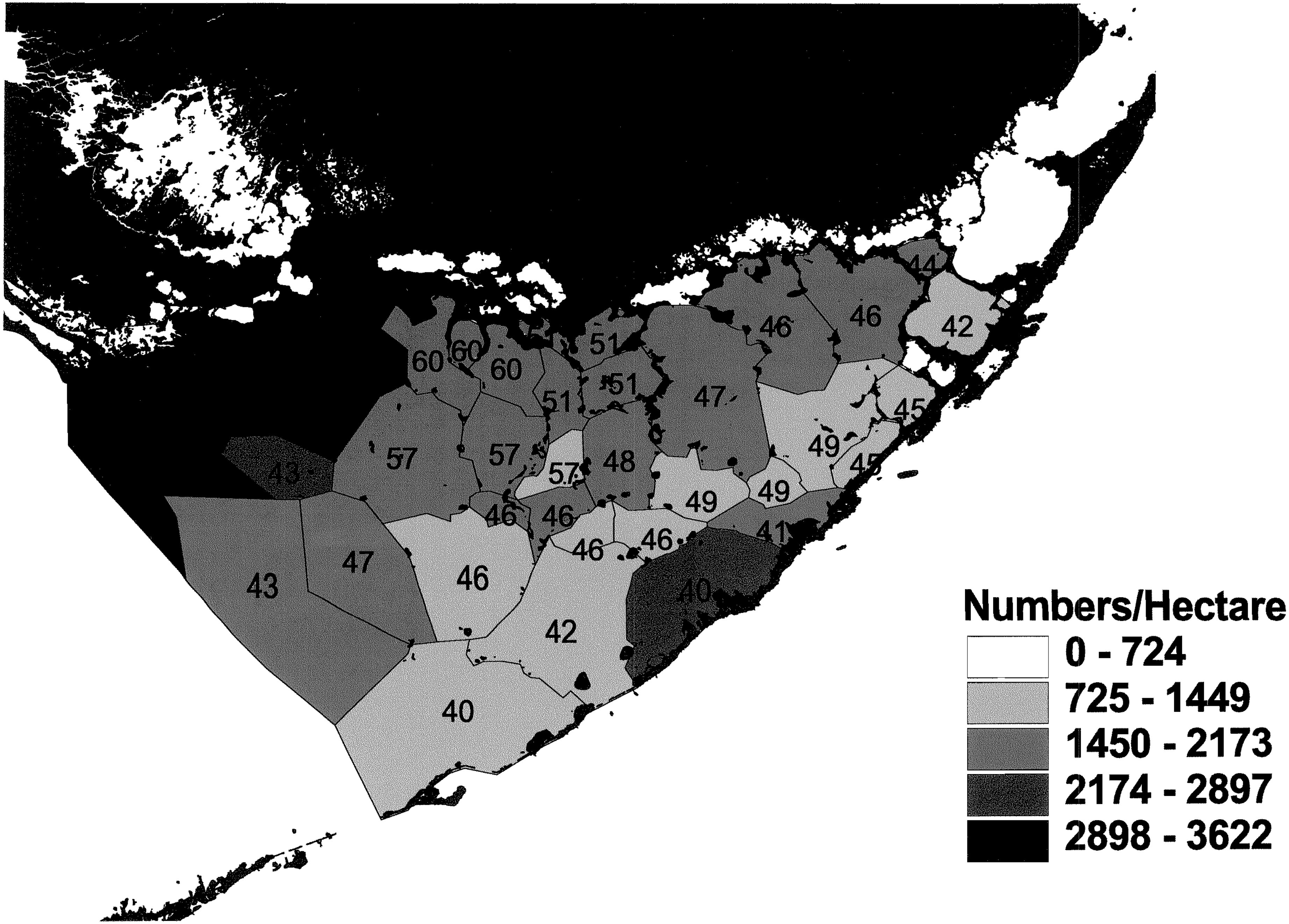
Appendix Figure C-4. Map of predicted densities of 11-species forage community during August 1995 with average salinity for each basin.

Predicted Densities of 11 Forage Species During August 1995 with Average Salinity for Each Basin



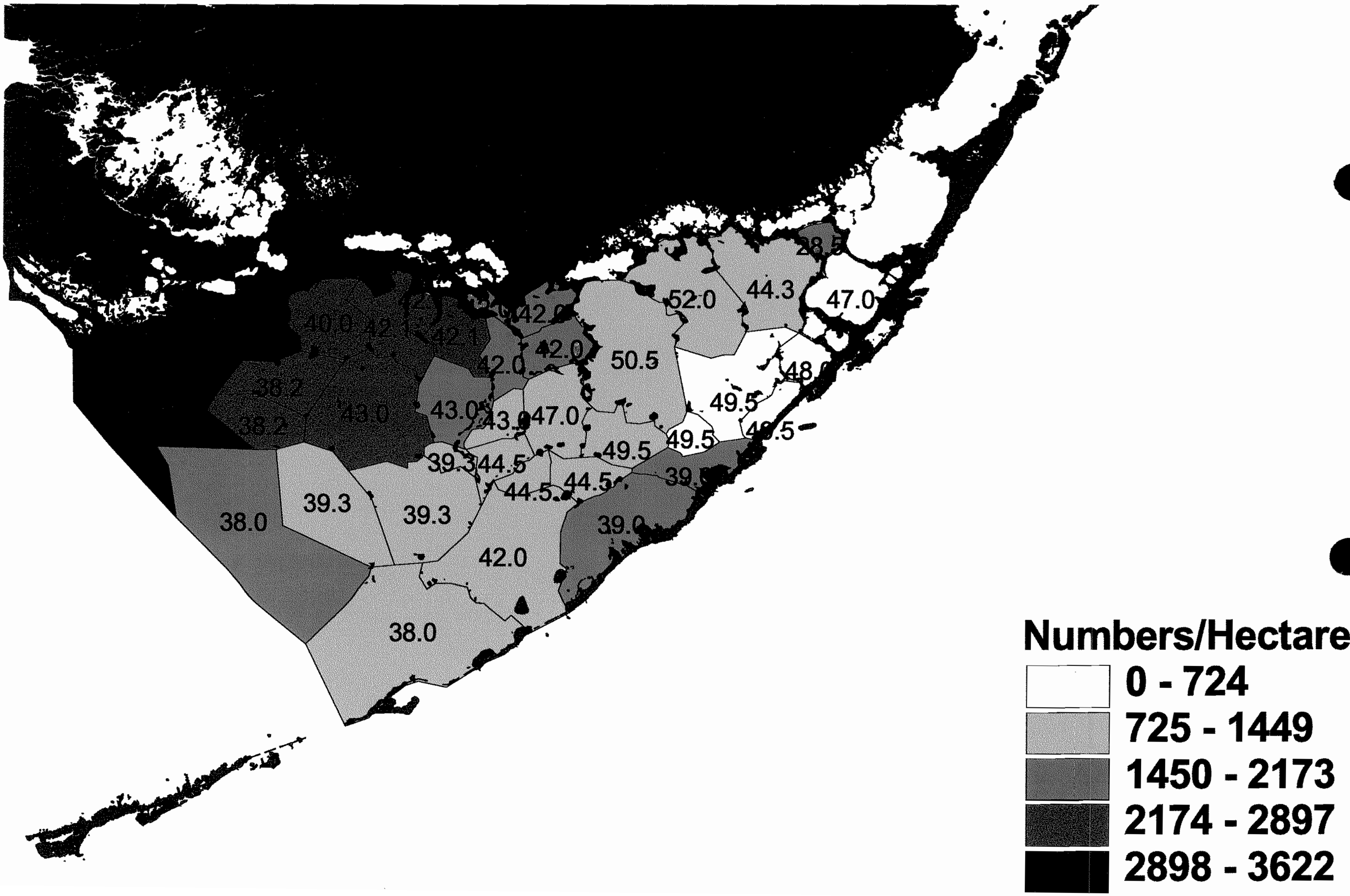
Appendix Figure C-5. Map of predicted densities of *Anchoa mitchelli* during April 1990 with average salinity for each basin.

Predicted Anchoa mitchelli Densities for April 1990 with Average Salinity for Basin



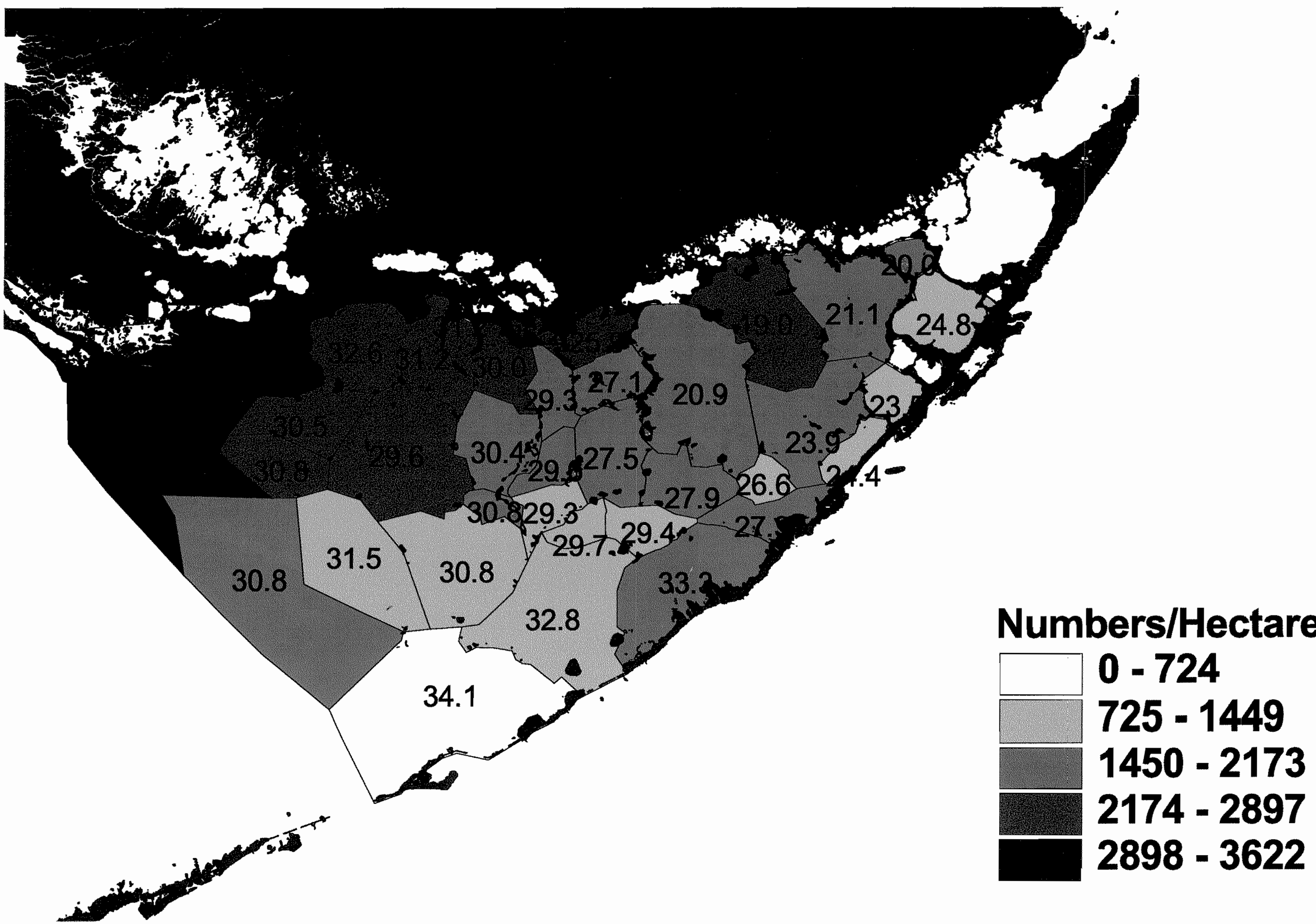
Appendix Figure C-6. Map of predicted densities of *Anchoa mitchelli* during August 1990 with average salinity for each basin.

Predicted Anchoa mitchelli Densities for August 1990 with Average Salinity for Basin



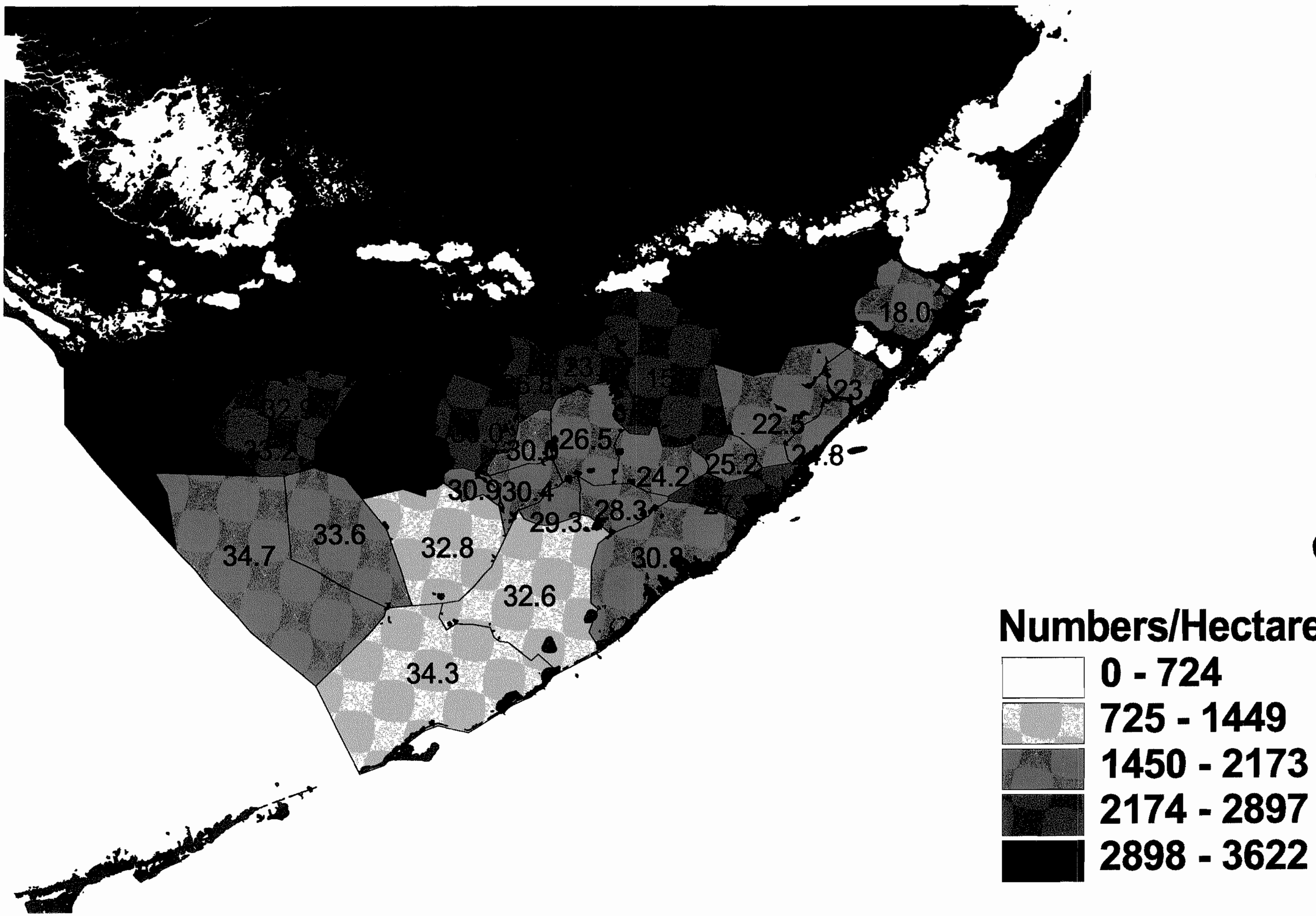
Appendix Figure C-7. Map of predicted densities of *Anchoa mitchelli* during April 1995 with average salinity for each basin.

Predicted Anchoa mitchelli Densities for April 1995 with Average Salinity for Basin



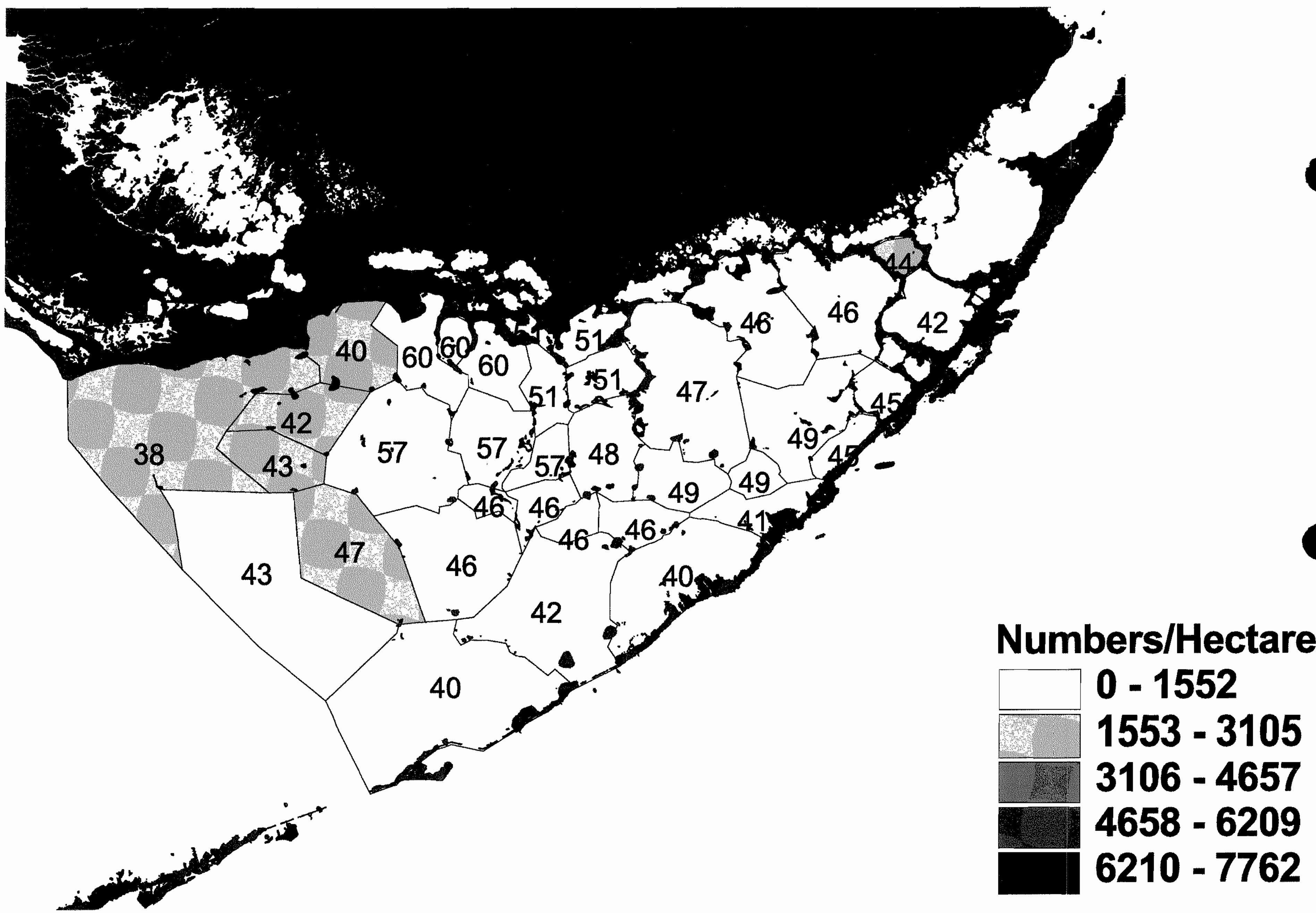
Appendix Figure C-8. Map of predicted densities of *Anchoa mitchelli* during August 1995 with average salinity for each basin.

Predicted Anchoa mitchelli Densities for August 1995 with Average Salinity for Basin



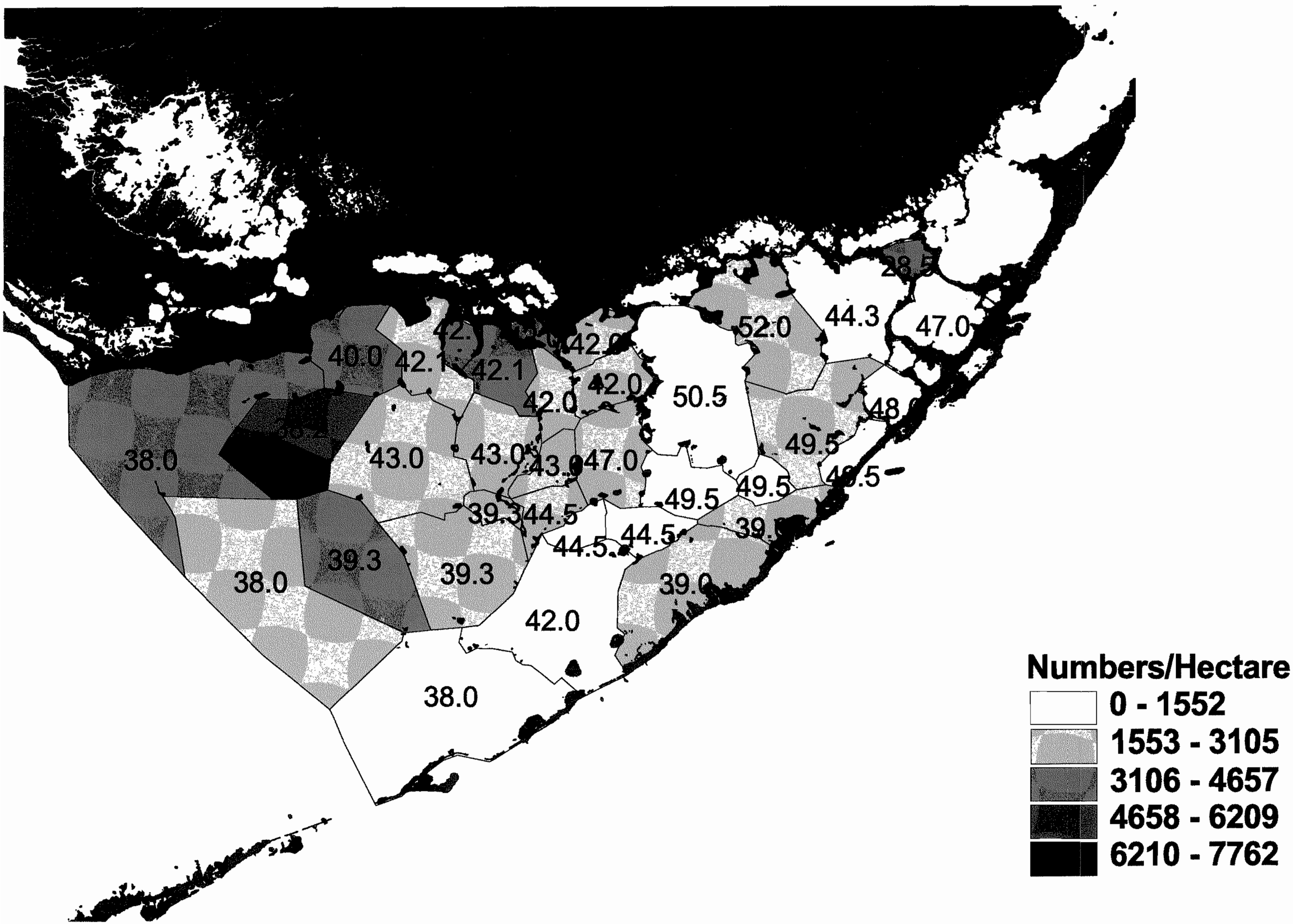
Appendix Figure C-9. Map of predicted densities of *Eucinostomus spp.* during April 1990 with average salinity for each basin.

Predicted Eucinostomus spp. Densities for April 1990 and Average Salinity for Basin



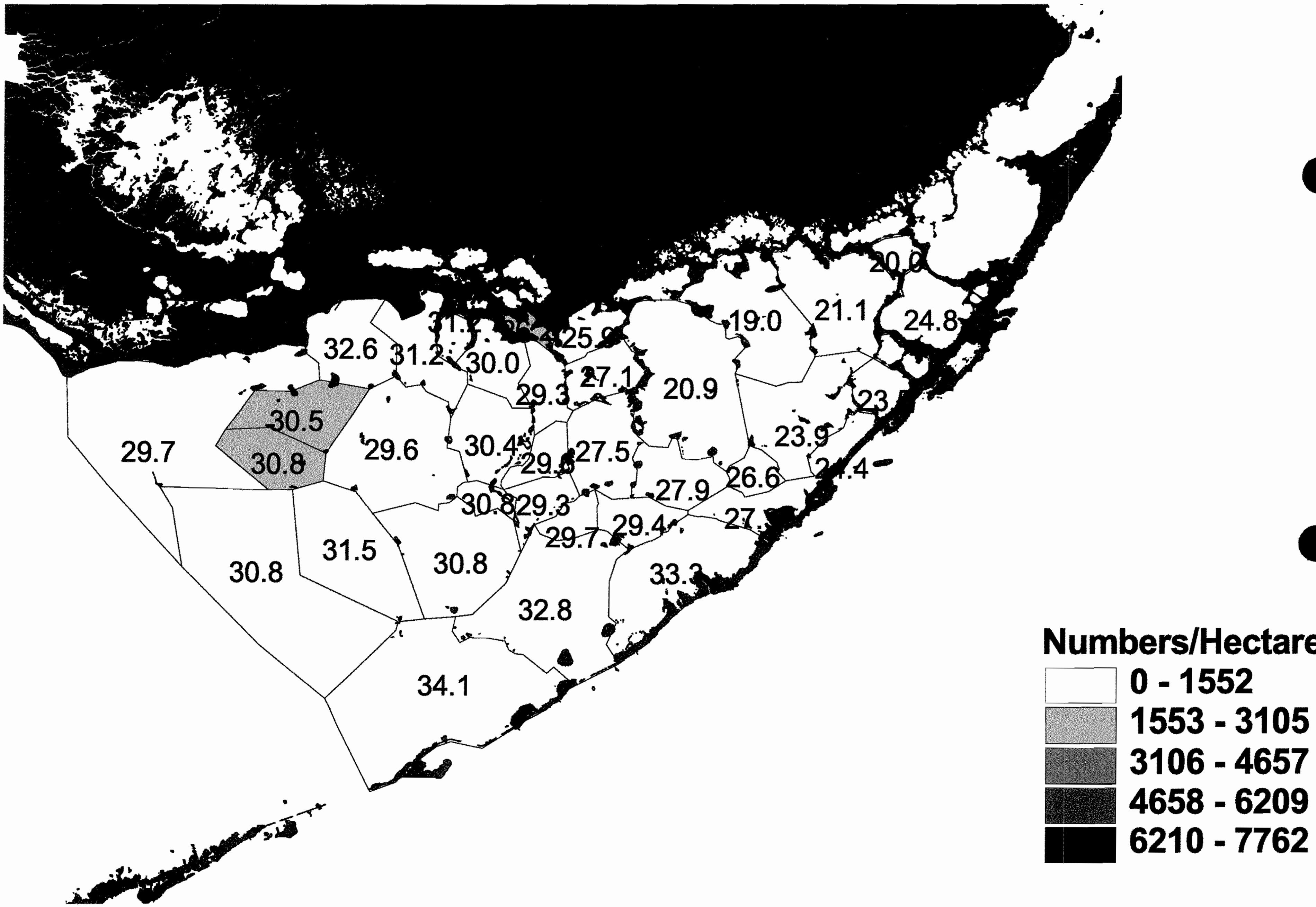
Appendix Figure C-10. Map of predicted densities of *Eucinostomus spp.* during August 1990 with average salinity for each basin.

Predicted Eucinostomus spp. Densities for August 1990 and Average Salinity for Basin



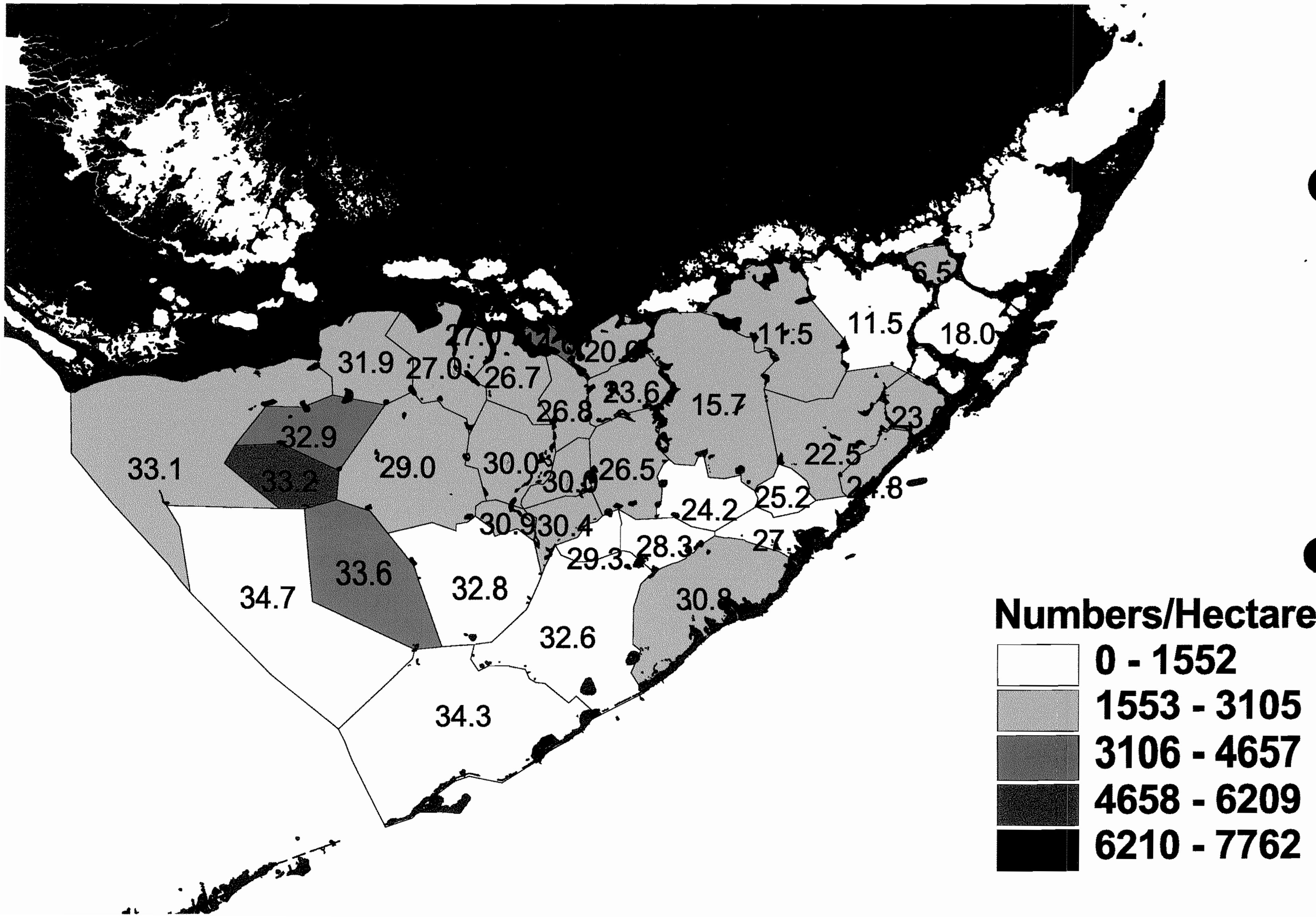
Appendix Figure C-11. Map of predicted densities of *Eucinostomus spp.* during April 1995 with average salinity for each basin.

Predicted Eucinostomus spp. Densities for April 1995 and Average Salinity for Basin



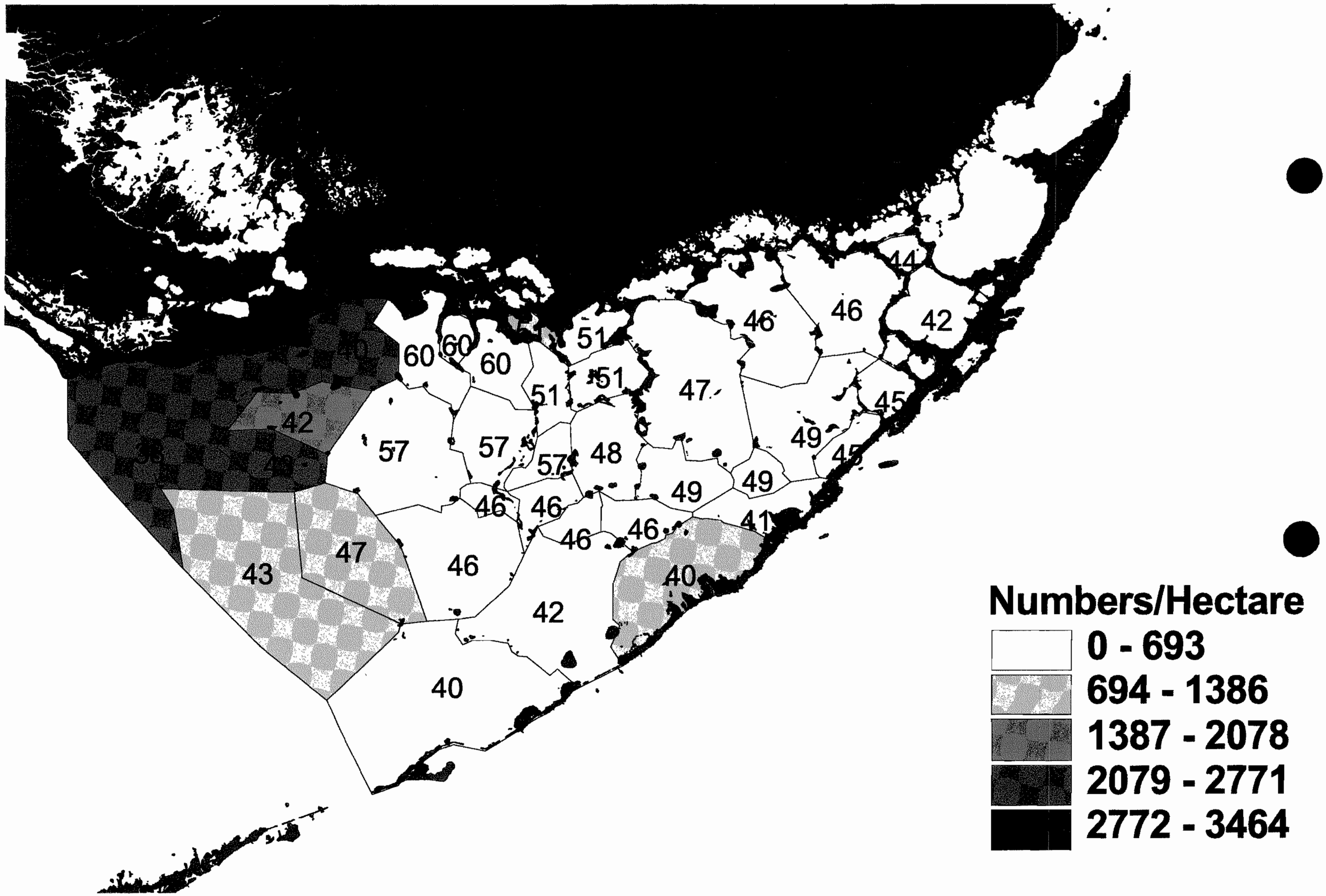
Appendix Figure C-12. Map of predicted densities of *Eucinostomus spp.* during August 1995 with average salinity for each basin.

Predicted Eucinostomus spp. Densities for August 1995 and Average Salinity for Basin



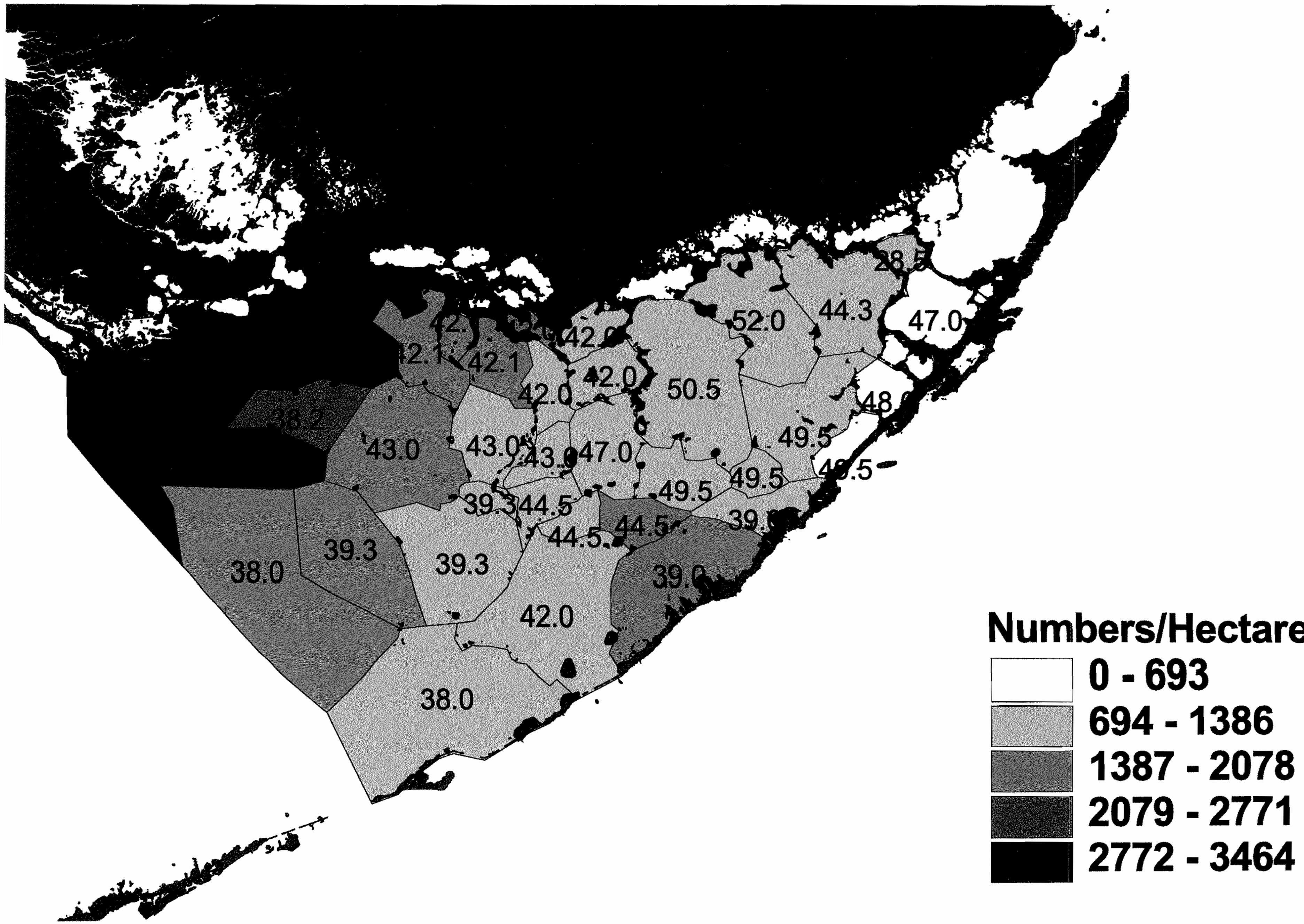
Appendix Figure C-13. Map of predicted densities of *Farfantepenaeus duorarum* during April 1990 with average salinity for each basin.

Predicted Farfantepenaeus duorarum Densities for April 1990 and Average Salinity for Basin



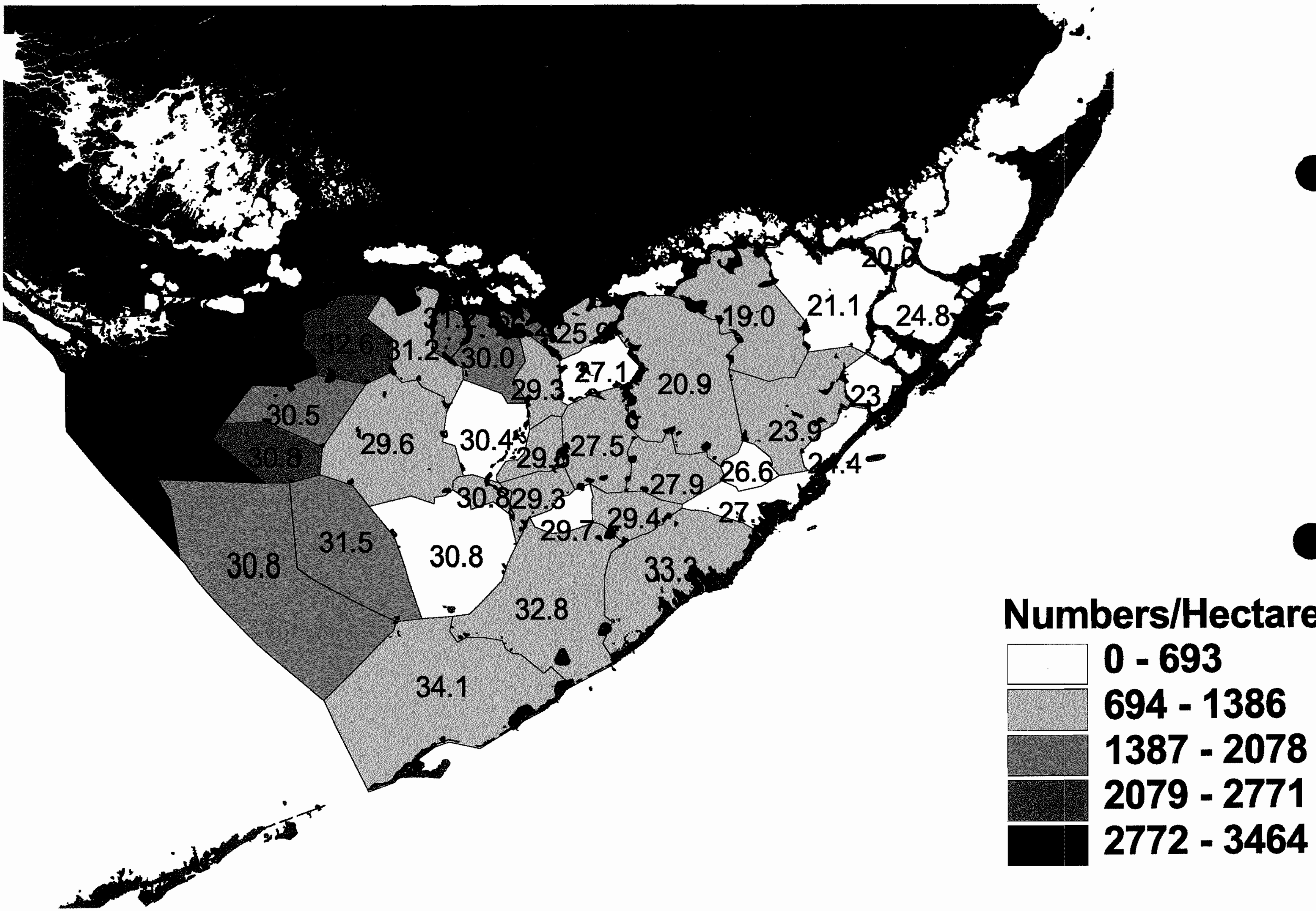
Appendix Figure C-14. Map of predicted densities of *Farfantepenaeus duorarum* during August 1990 with average salinity for each basin.

Predicted Farfantepenaeus duorarum Densities for August 1990 and Average Salinity for Basin



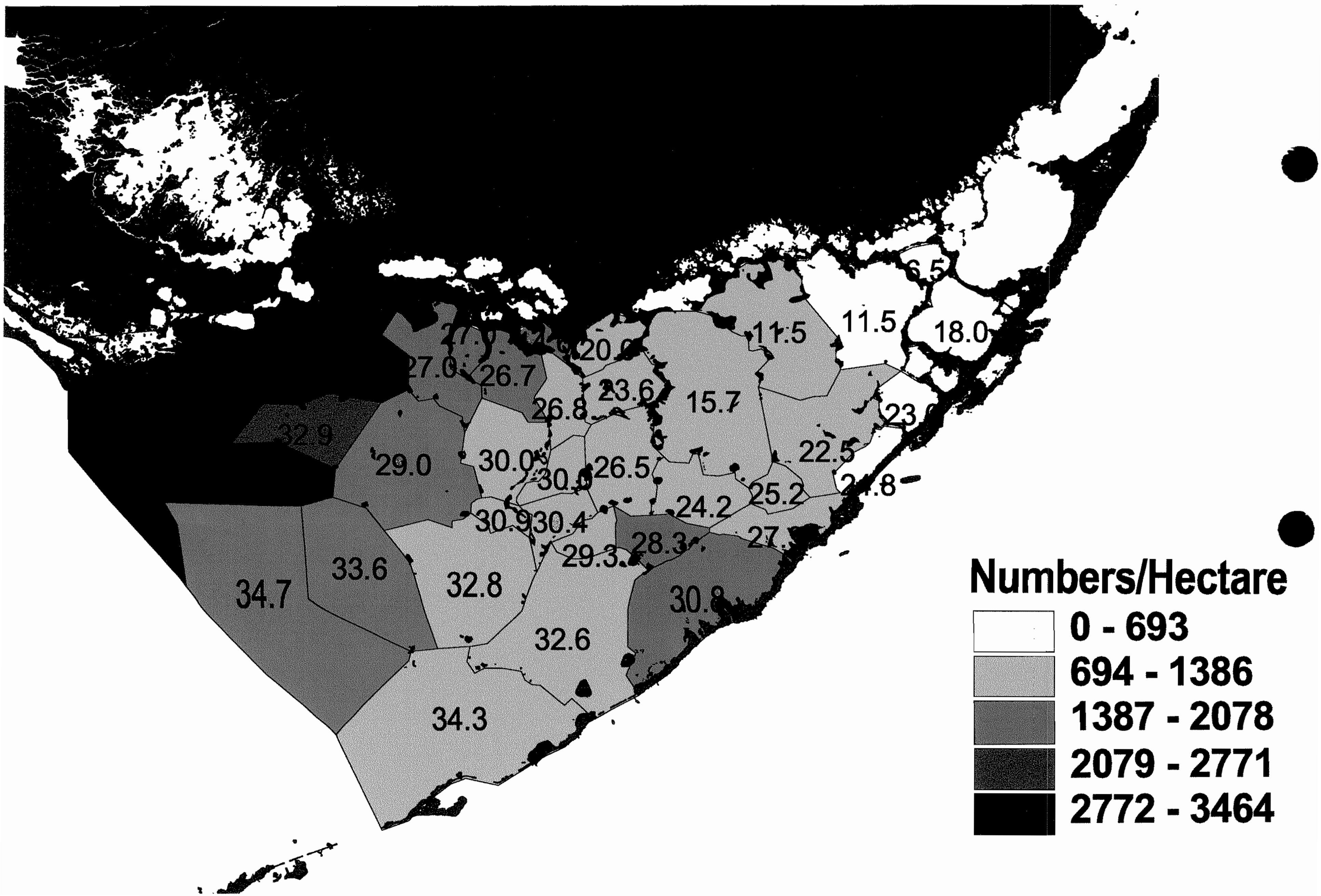
Appendix Figure C-15. Map of predicted densities of *Farfantepenaeus duorarum* during April 1995 with average salinity for each basin.

Predicted Farfantepenaeus duorarum Densities for April 1995 and Average Salinity for Basin



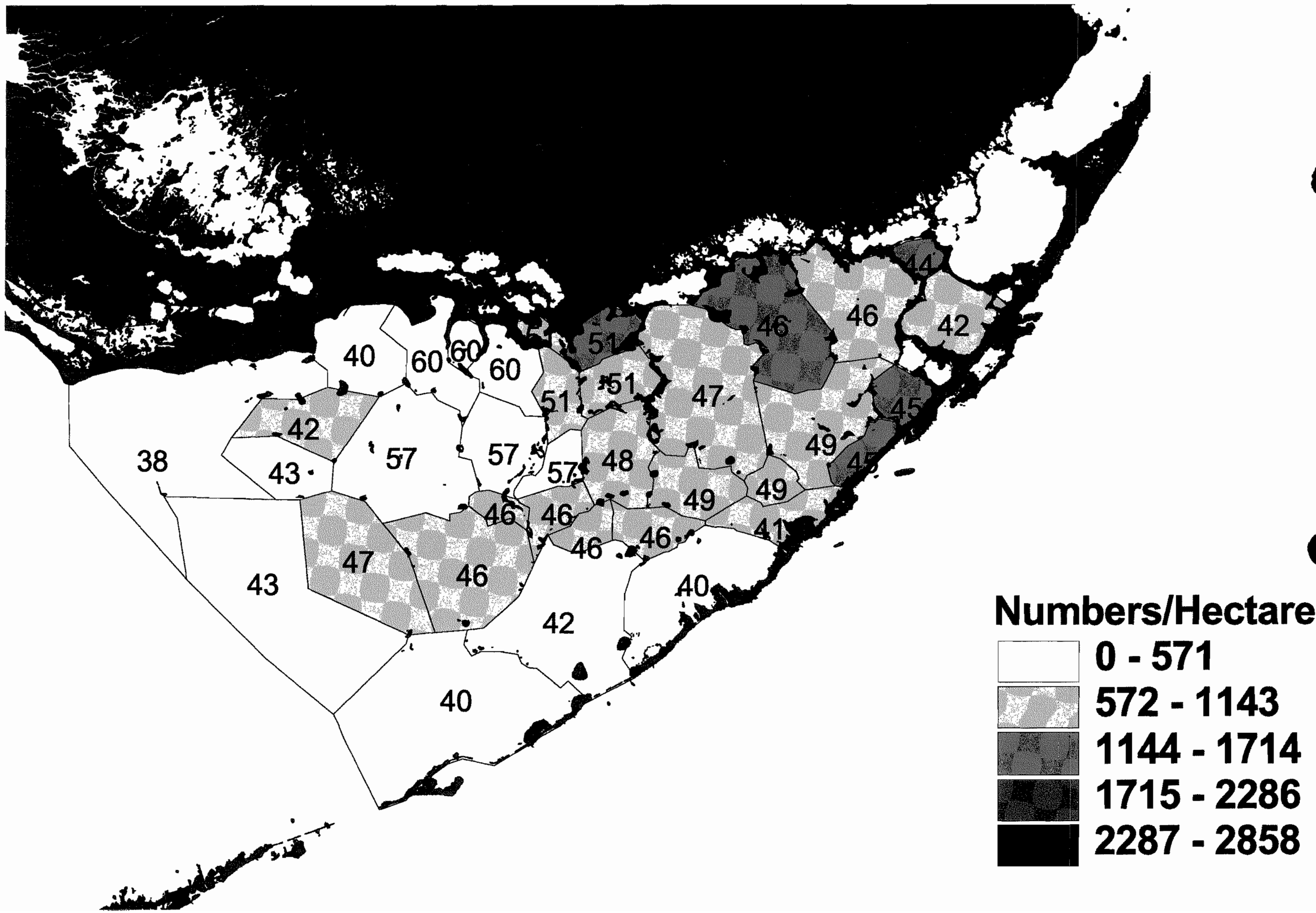
Appendix Figure C-16. Map of predicted densities of *Farfantepenaeus duorarum* during August 1995 with average salinity for each basin.

Predicted Farfantepenaeus duorarum Densities for August 1995 and Average Salinity for Basin



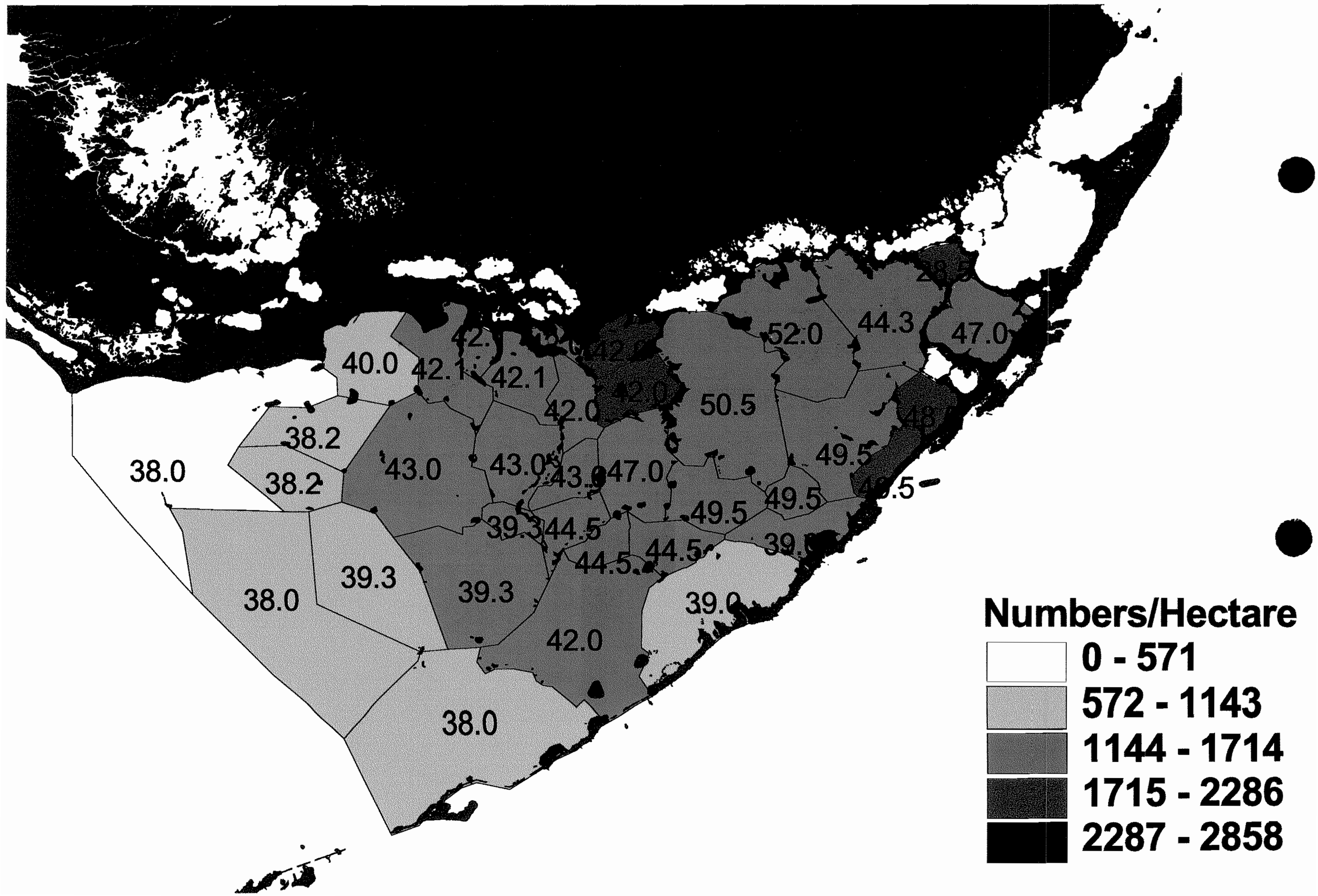
Appendix Figure C-17. Map of predicted densities of *Floridichthys carpio* during April 1990 with average salinity for each basin.

Predicted Floridichthys carpio Densities for April 1990 and Average Salinity for Basin



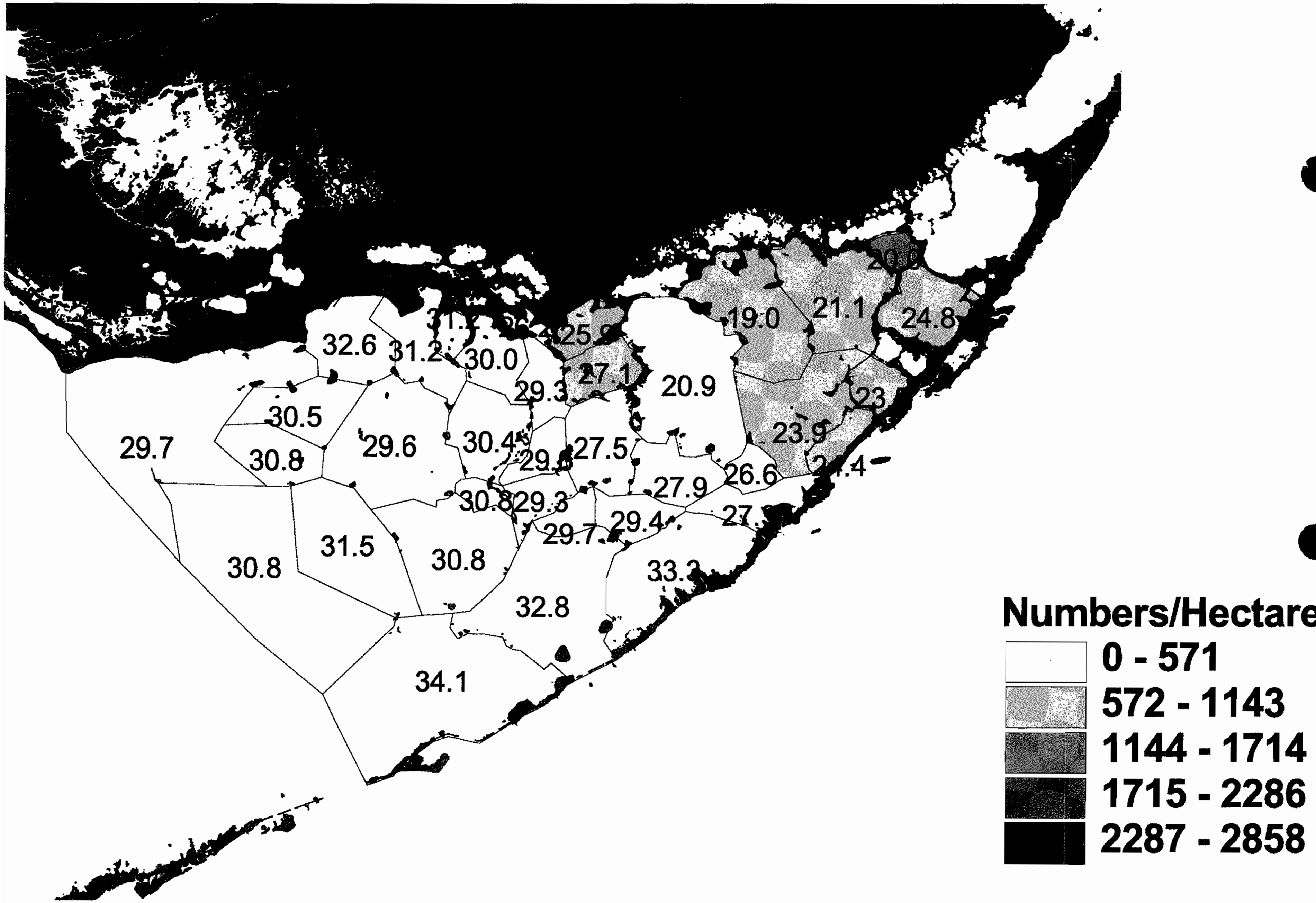
Appendix Figure C-18. Map of predicted densities of *Floridichthys carpio* during August 1990 with average salinity for each basin.

Predicted Floridichthys carpio Densities for August 1990 and Average Salinity for Basin



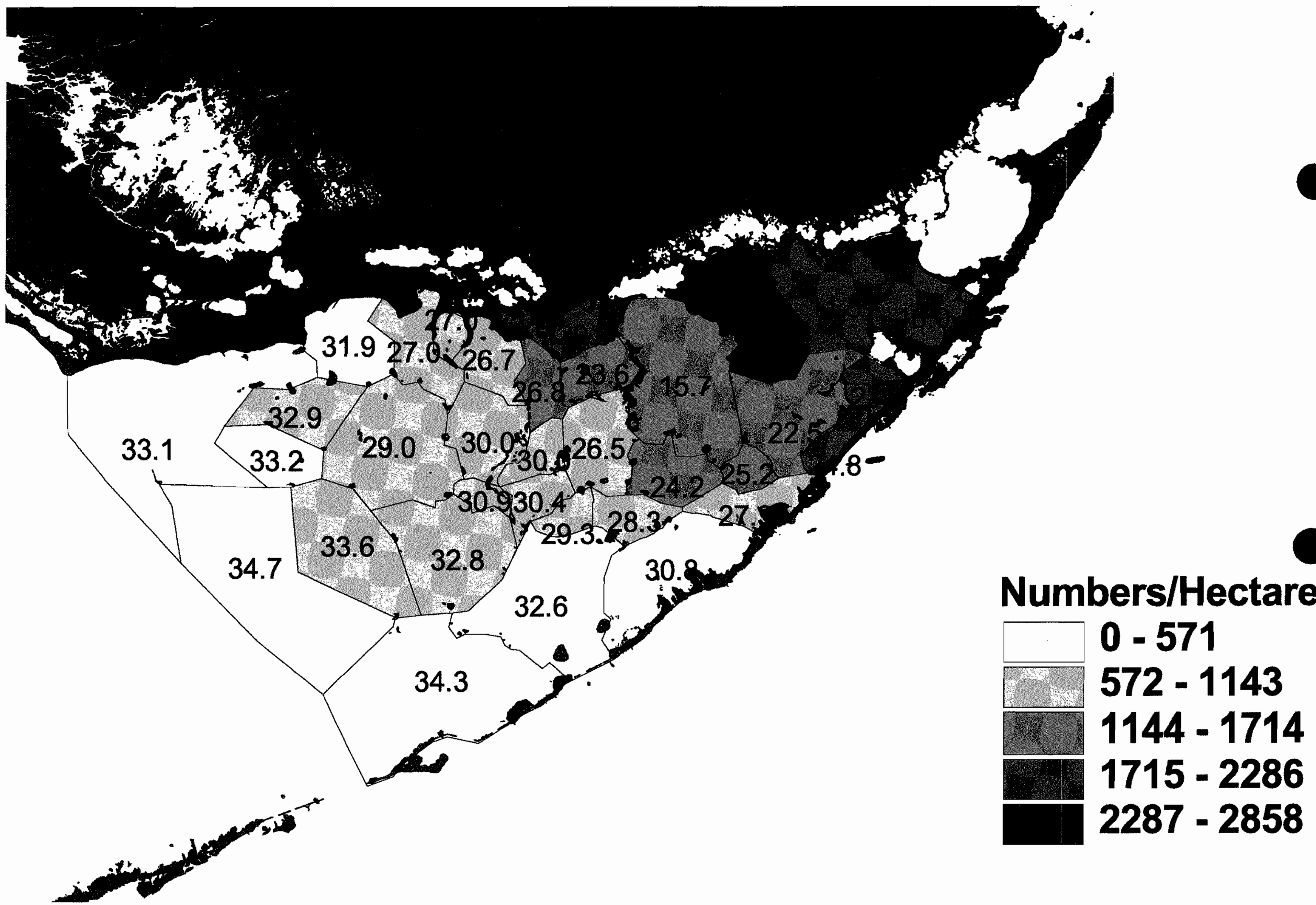
Appendix Figure C-19. Map of predicted densities of *Floridichthys carpio* during April 1995 with average salinity for each basin.

Predicted Floridichthys carpio Densities for April 1995 and Average Salinity for Basin



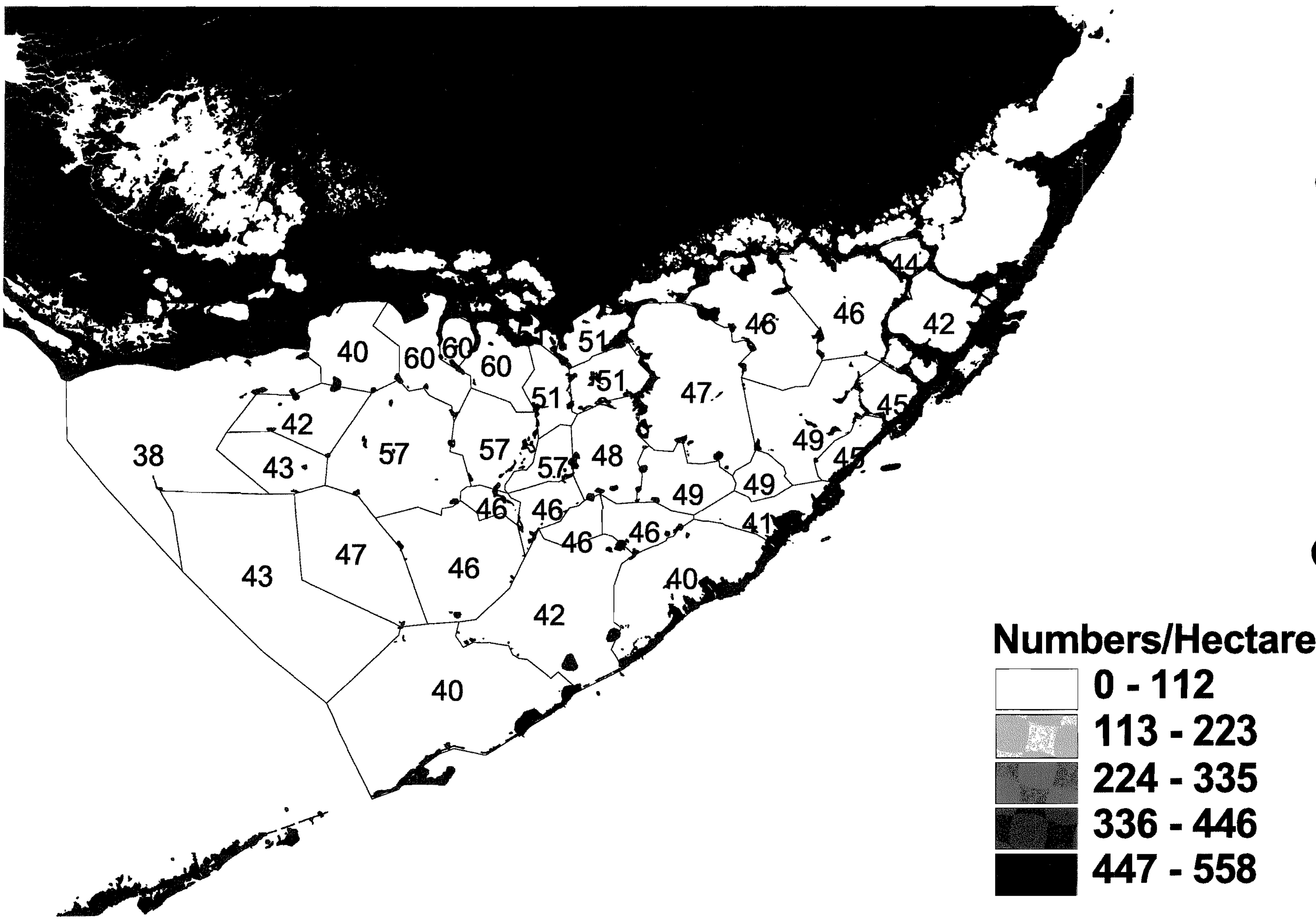
Appendix Figure C-20. Map of predicted densities of *Floridichthys carpio* during August 1995 with average salinity for each basin.

Predicted Floridichthys carpio Densities for August 1995 and Average Salinity for Basin



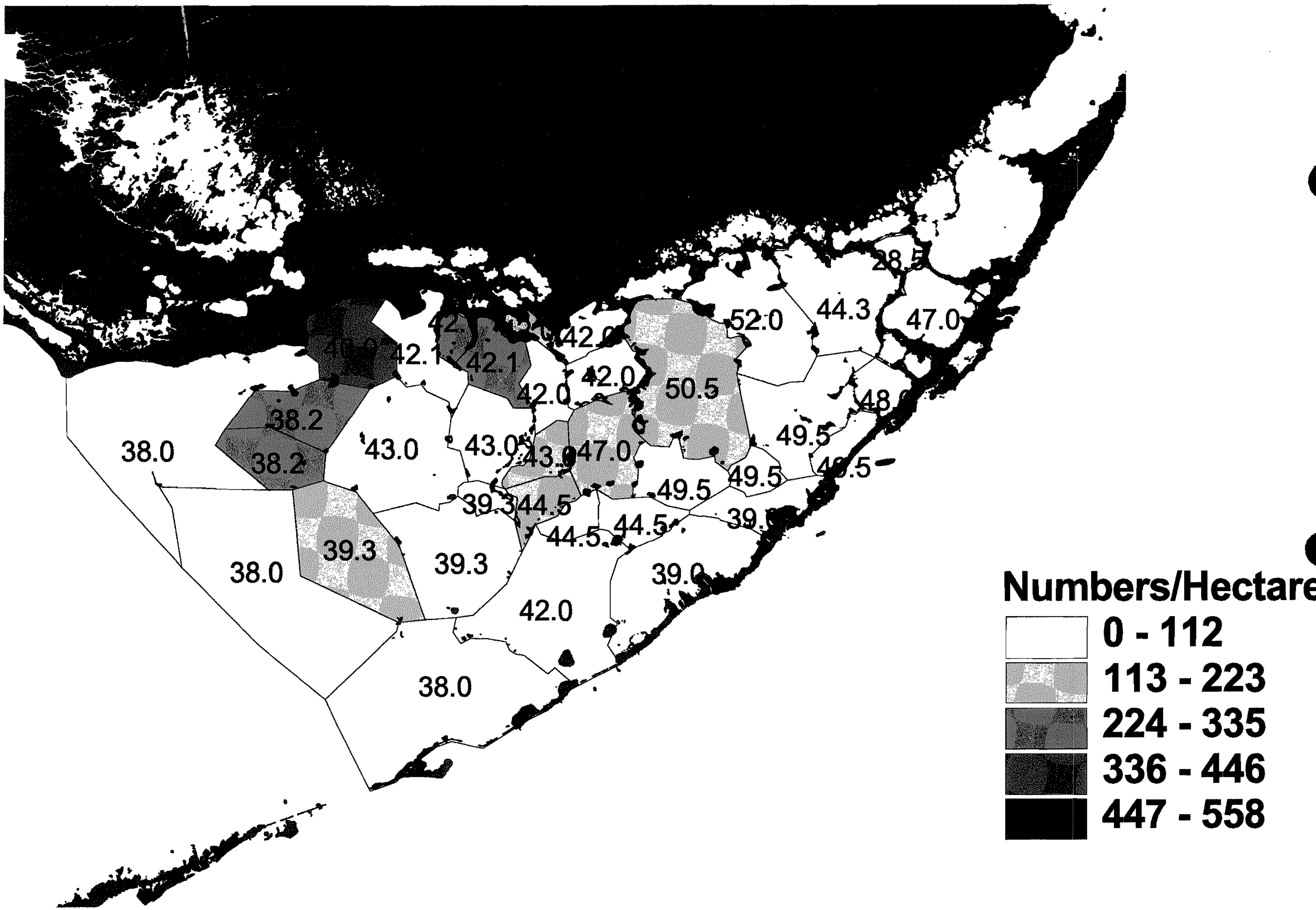
Appendix Figure C-21. Map of predicted densities of *Gobiosoma robustum* during April 1990 with average salinity for each basin.

Predicted Gobiosoma robustum Densities for April 1990 and Average Salinity for Basin



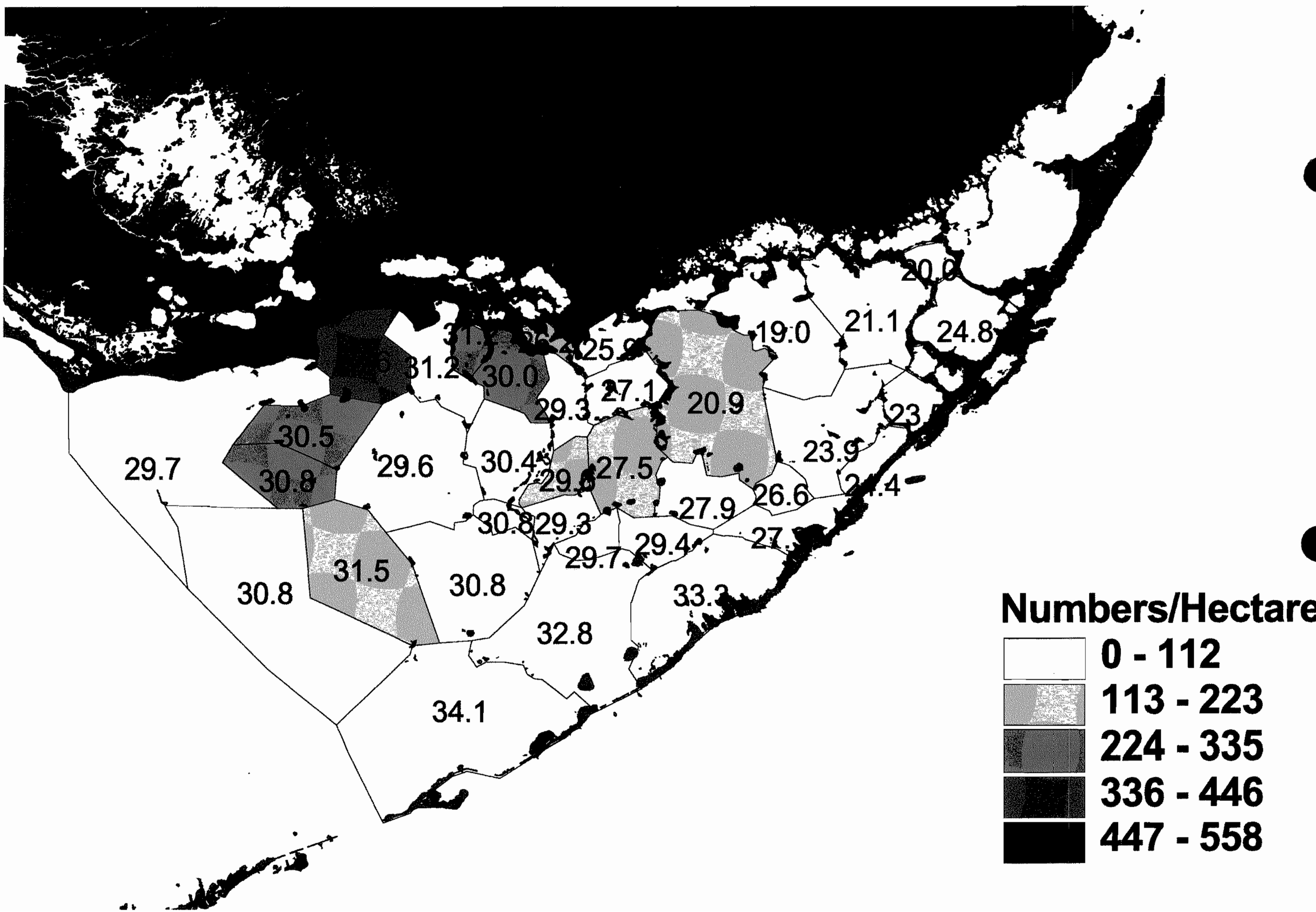
Appendix Figure C-22. Map of predicted densities of *Gobiosoma robustum* during August 1990 with average salinity for each basin.

Predicted Gobiosoma robustum Densities for August 1990 and Average Salinity for Basin



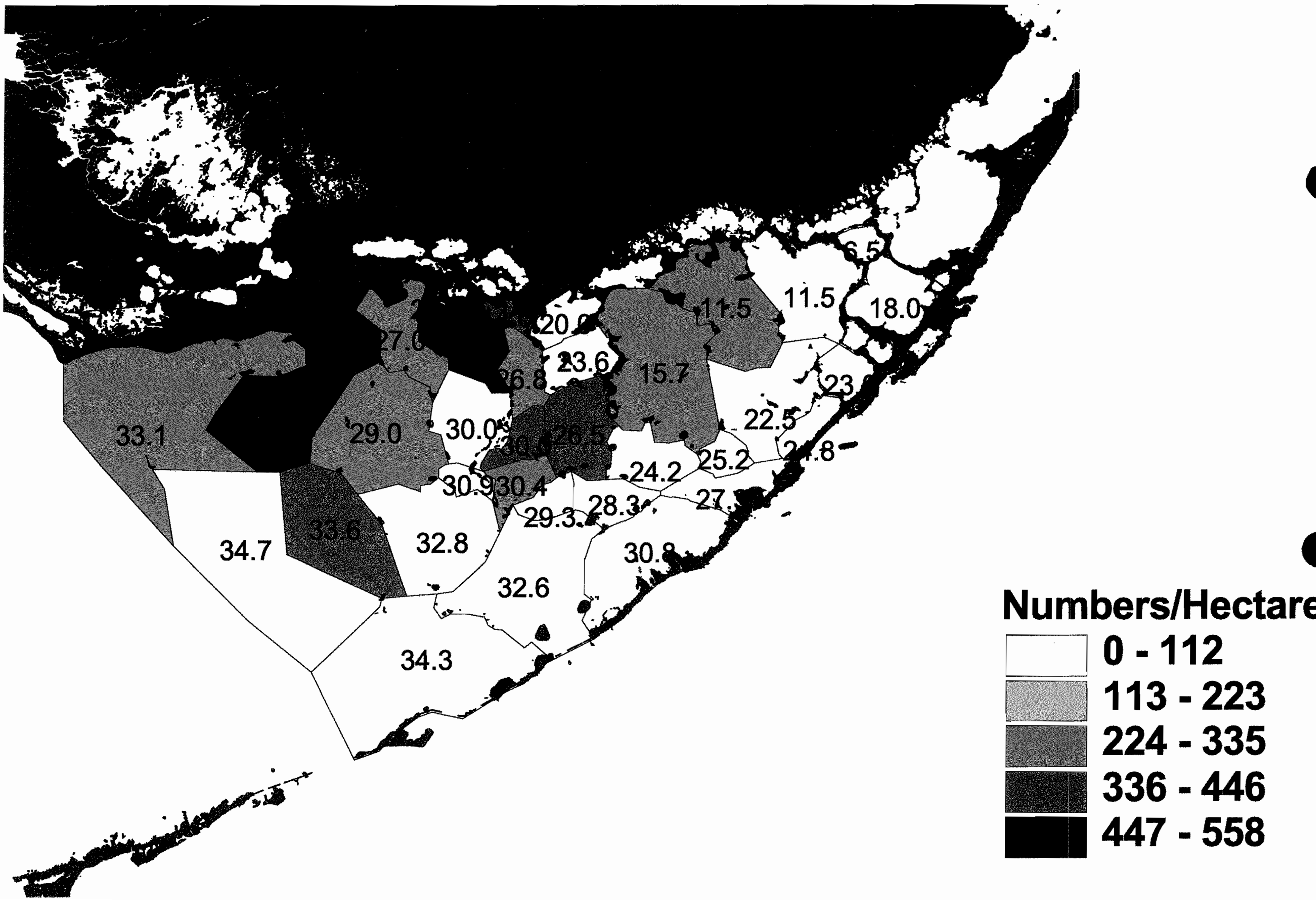
Appendix Figure C-23. Map of predicted densities of *Gobiosoma robustum* during April 1995 with average salinity for each basin.

Predicted Gobiosoma robustum Densities for April 1995 and Average Salinity for Basin



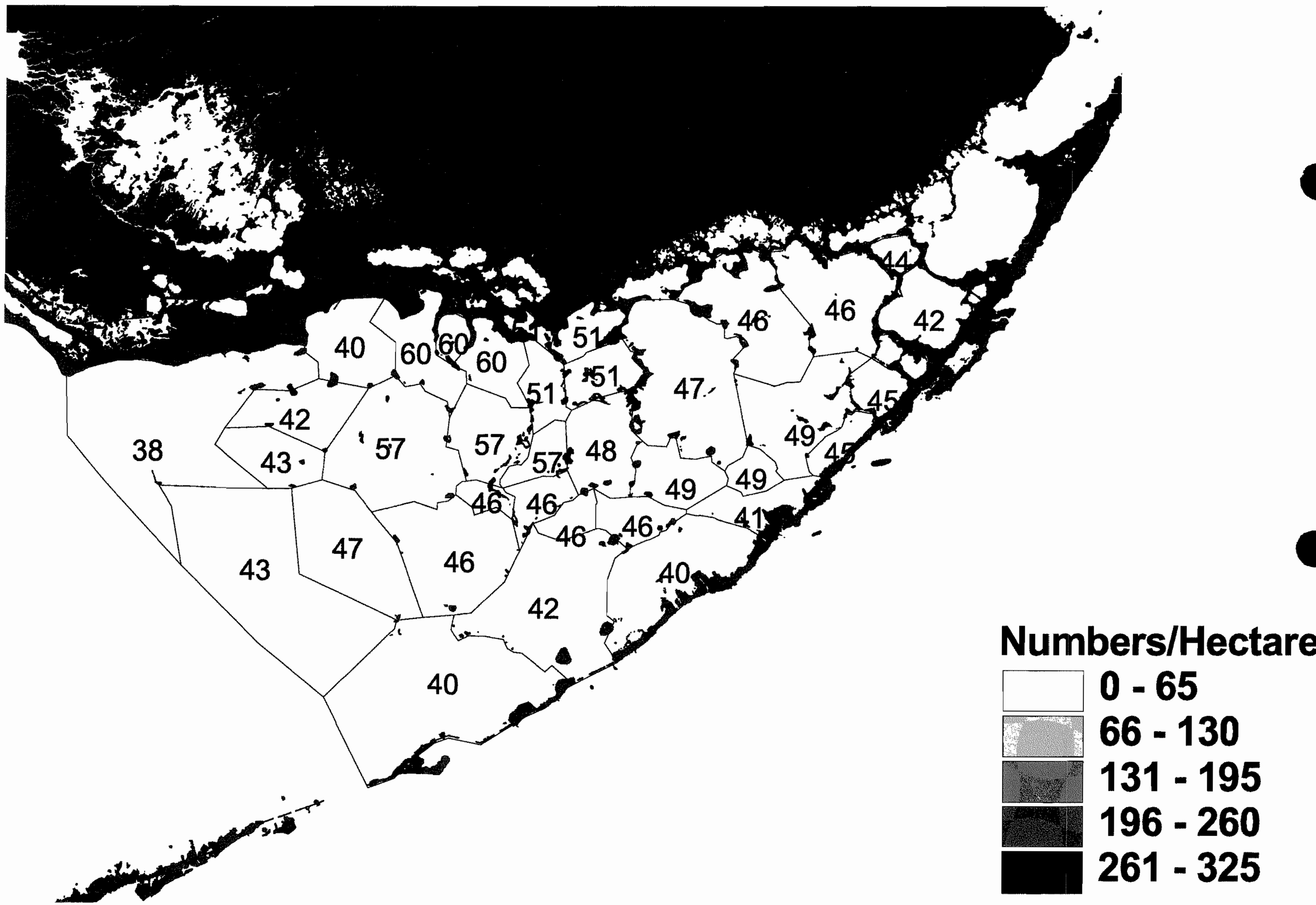
Appendix Figure C-24. Map of predicted densities of *Gobiosoma robustum* during August 1995 with average salinity for each basin.

Predicted Gobiosoma robustum Densities for August 1995 and Average Salinity for Basin



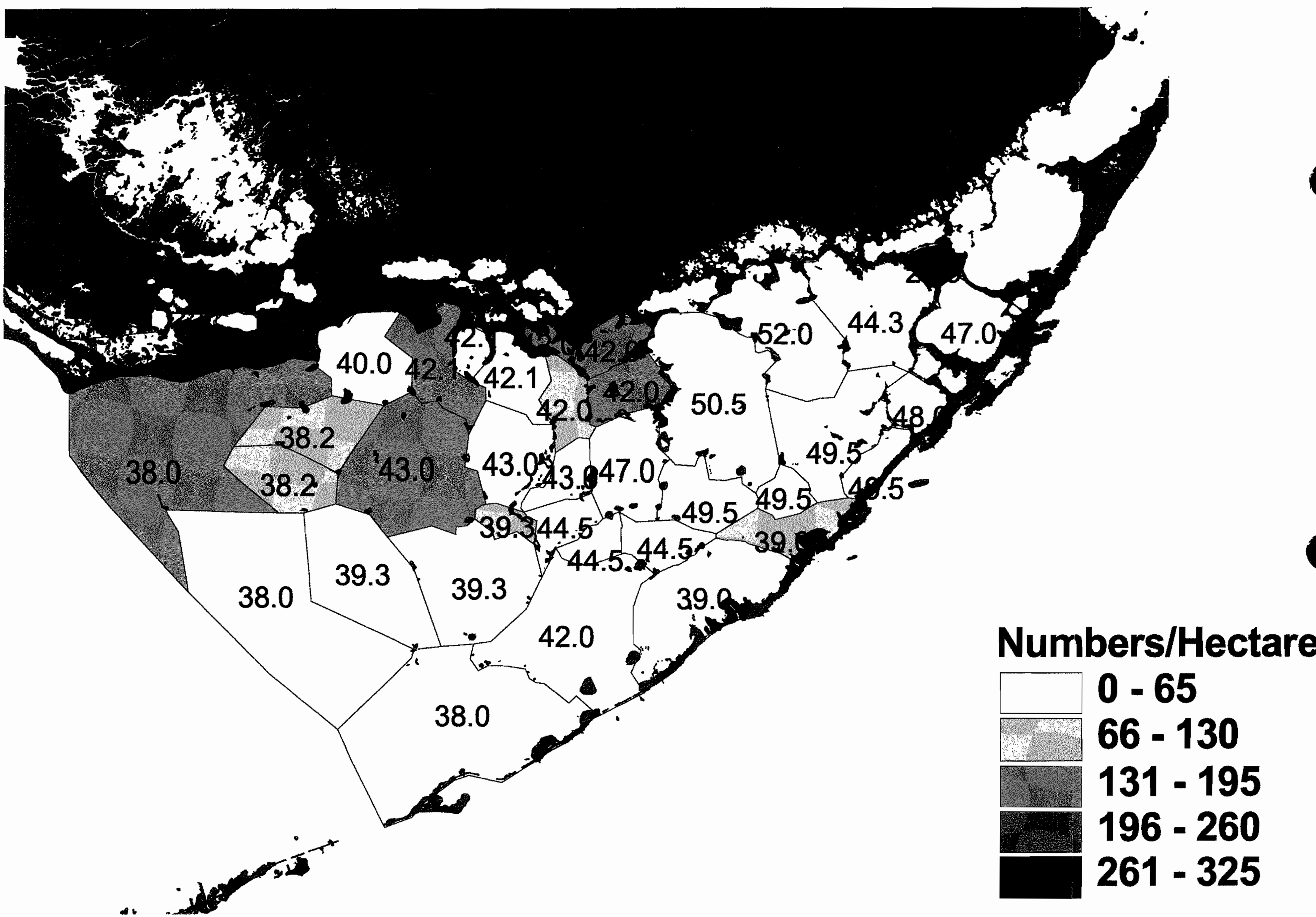
Appendix Figure C-25. Map of predicted densities of *Hippocampus zostera* during April 1990 with average salinity for each basin.

Predicted Hippocampus zosterae Densities for April 1990 and Average Salinity for Basin



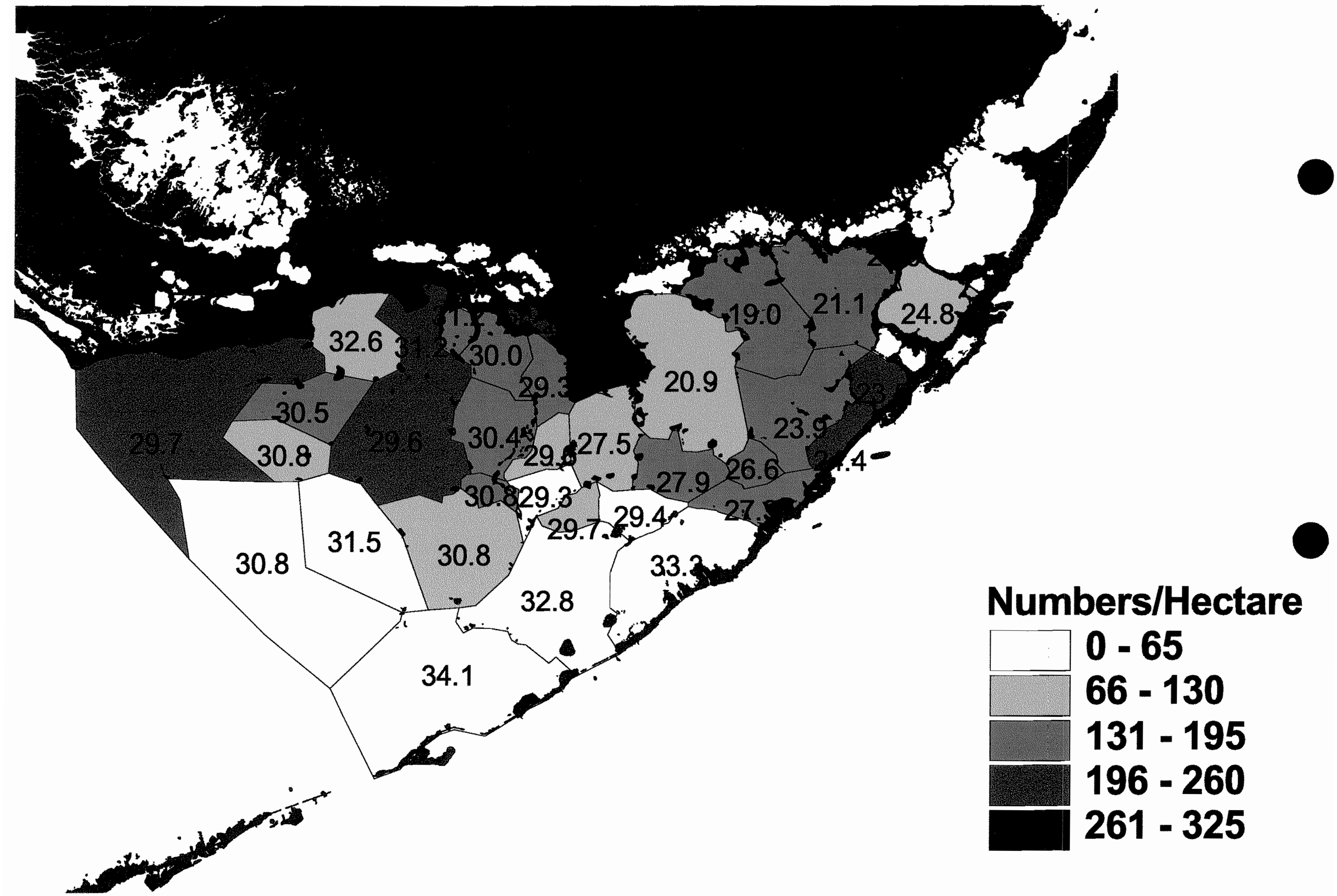
Appendix Figure C-26. Map of predicted densities of *Hippocampus zostera* during August 1990 with average salinity for each basin.

Predicted Hippocampus zosterae Densities for August 1990 with Average Salinity for Basin



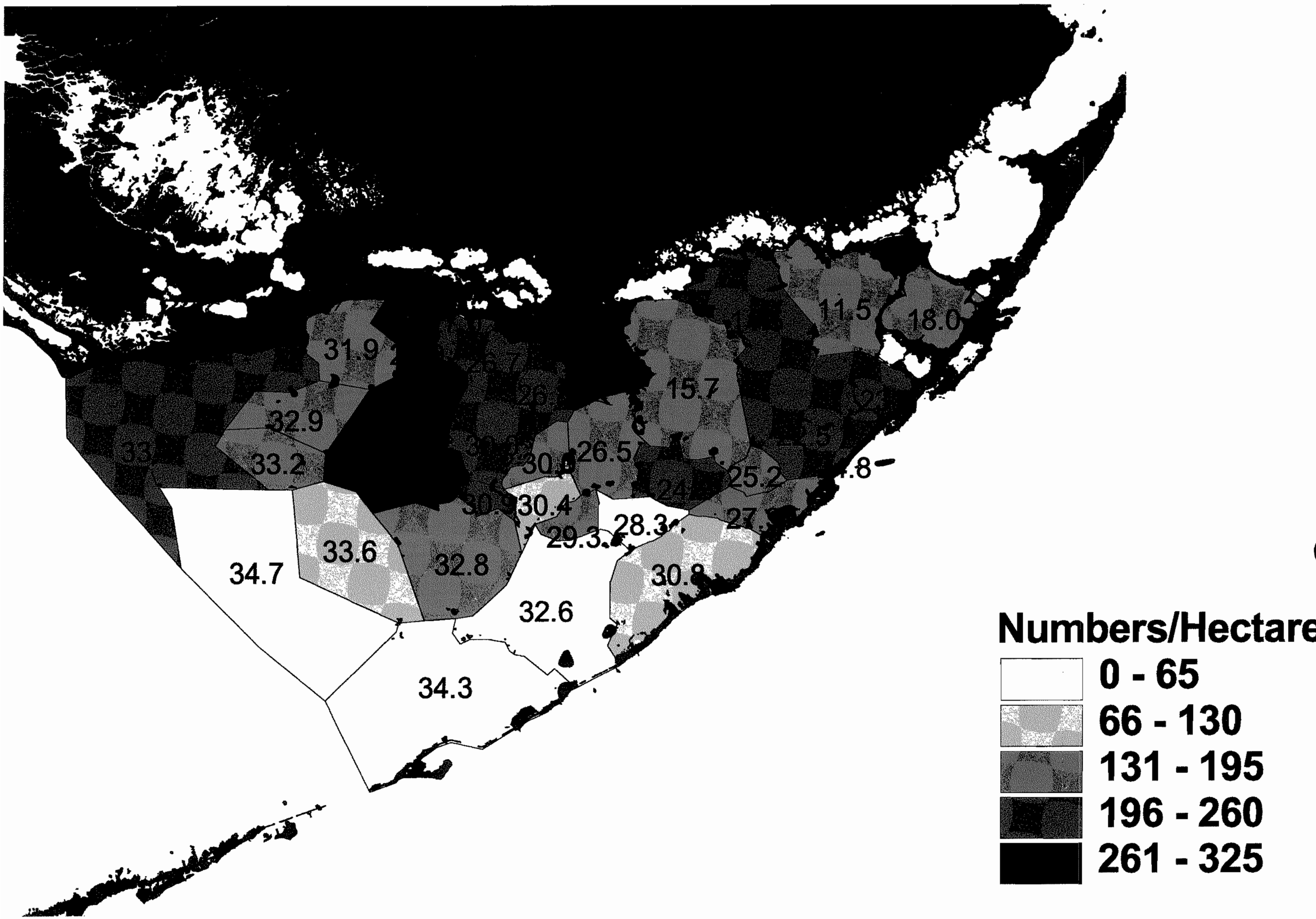
Appendix Figure C-27. Map of predicted densities of *Hippocampus zostera* during April 1995 with average salinity for each basin.

Predicted Hippocampus zosterae Densities for April 1995 and Average Salinity for Basin



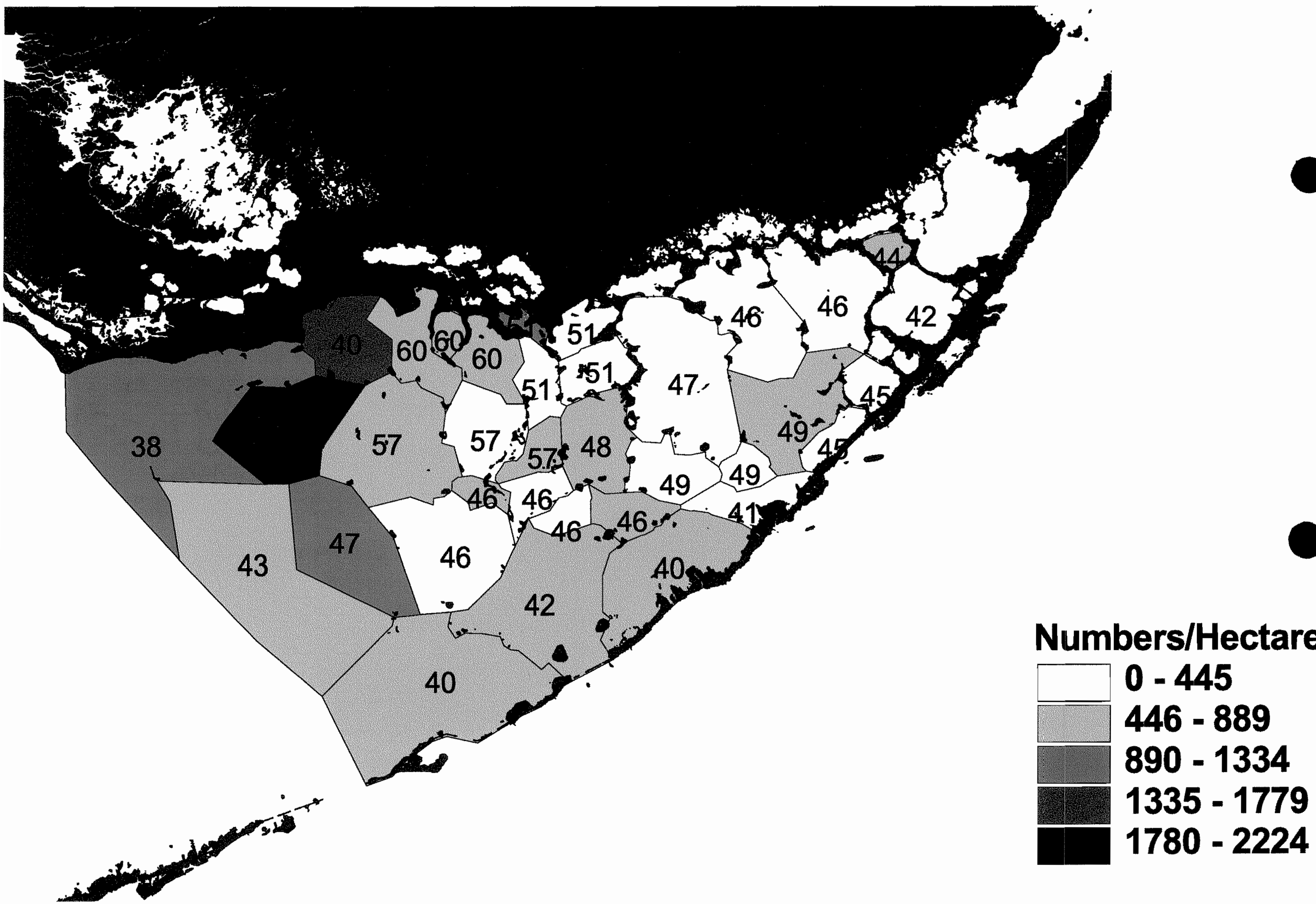
Appendix Figure C-28. Map of predicted densities of *Hippocampus zostera* during August 1995 with average salinity for each basin.

Predicted Hippocampus zosterae Densities for August 1995
with Average Salinity for Basin



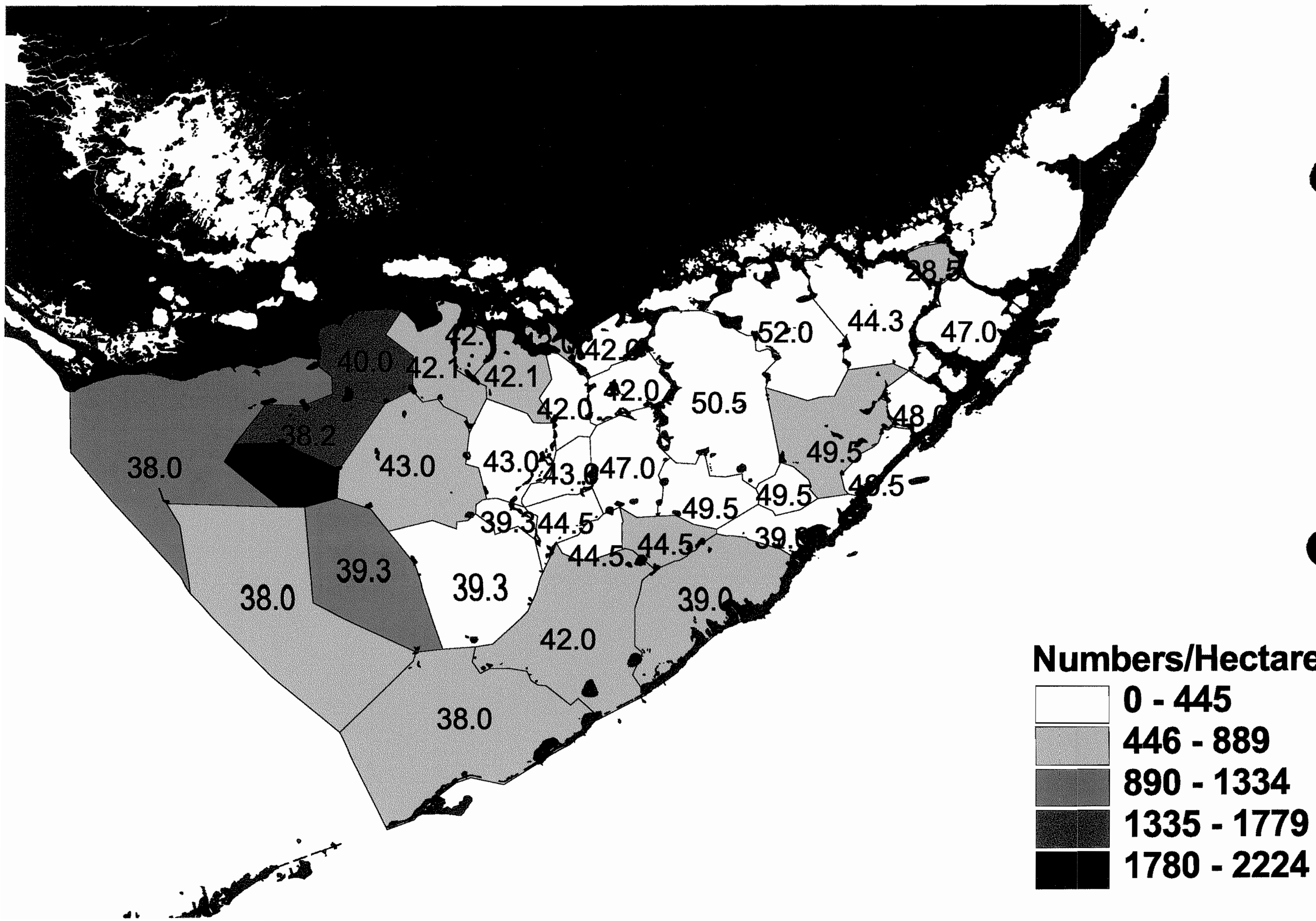
Appendix Figure C-29. Map of predicted densities of *Lagodon rhomboides* during April 1990 with average salinity for each basin.

Predicted Lagodon rhomboides Densities for April 1990 and Average Salinity for Basin



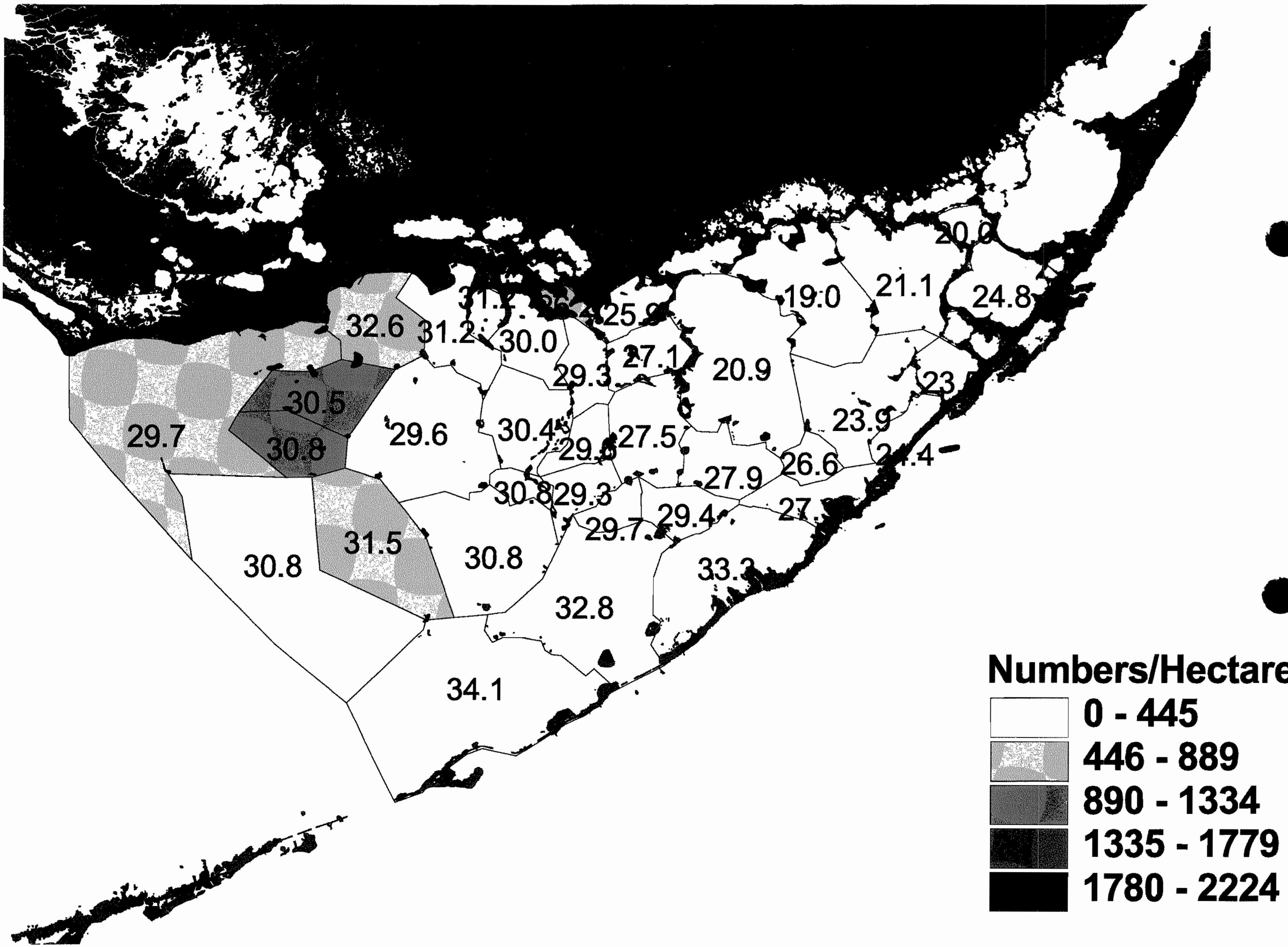
Appendix Figure C-30. Map of predicted densities of *Lagodon rhomboides* during August 1990 with average salinity for each basin.

Predicted Lagodon rhomboides Densities for August 1990 and Average Salinities for Basin



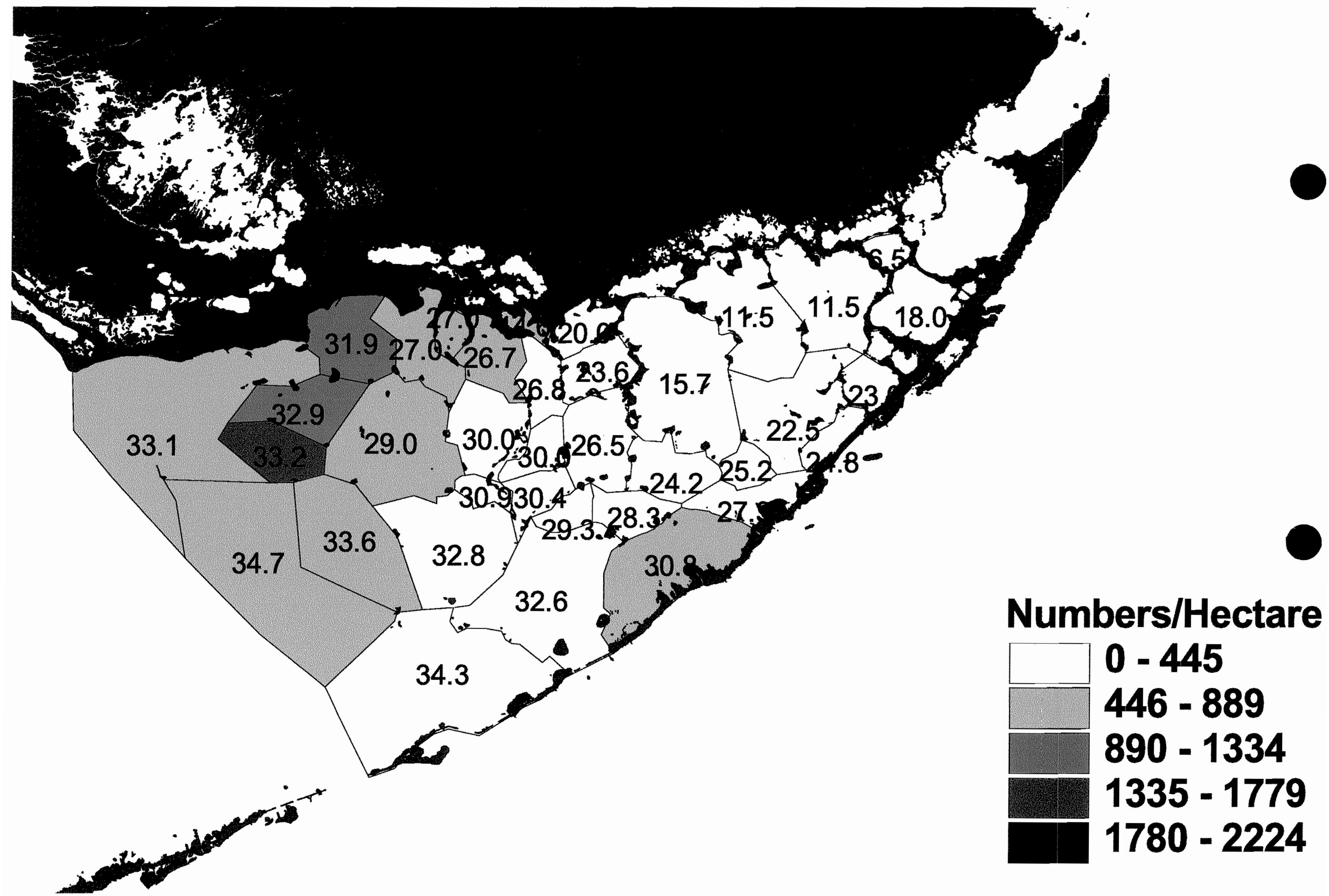
Appendix Figure C-31. Map of predicted densities of *Lagodon rhomboides* during April 1995 with average salinity for each basin.

Predicted Lagodon rhomboides Densities for April 1995 and Average Salinity for Basin



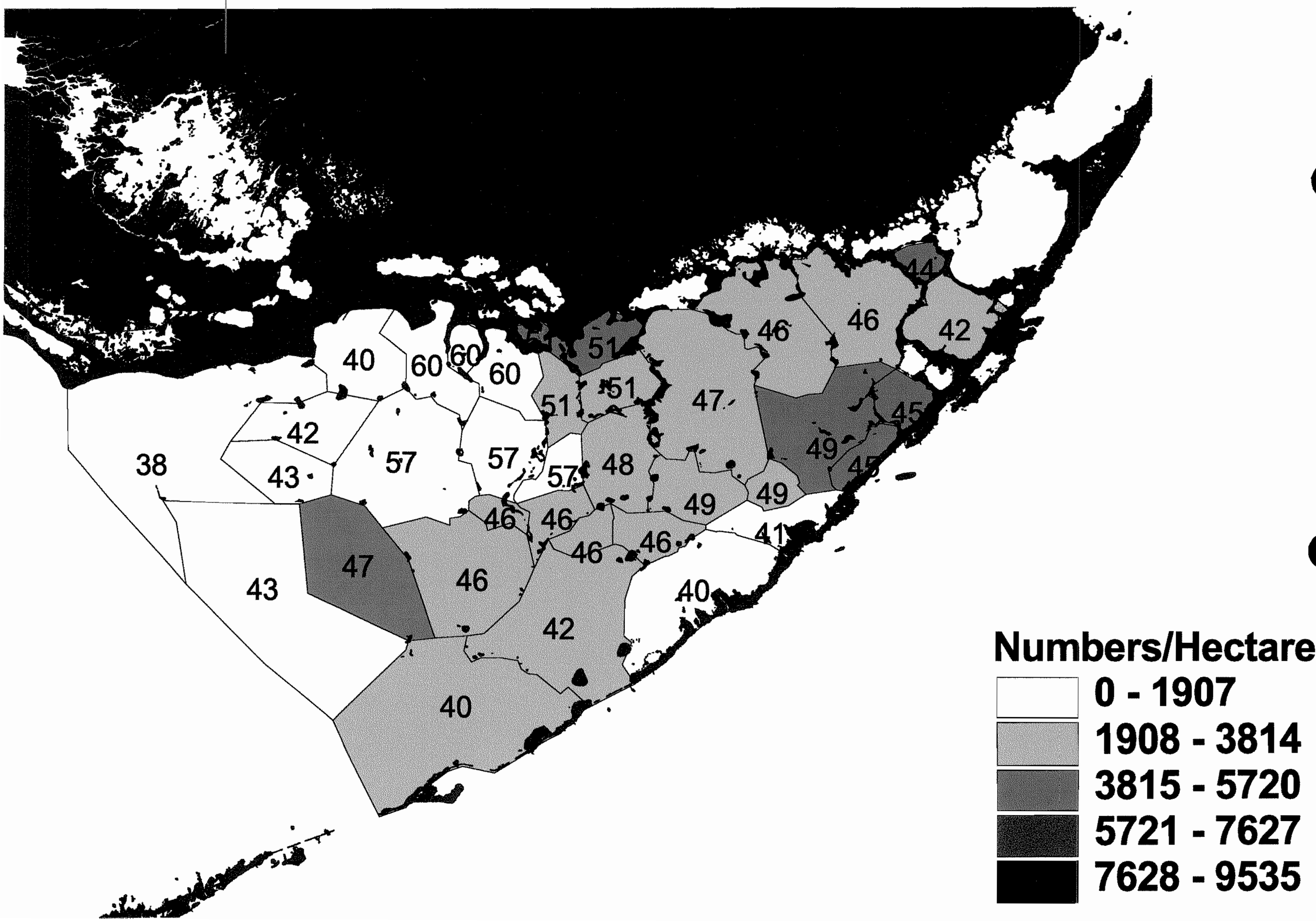
Appendix Figure C-32. Map of predicted densities of *Lagodon rhomboides* during August 1995 with average salinity for each basin.

Predicted Lagodon rhomboides Densities for August 1995 and Average Salinities for Basin



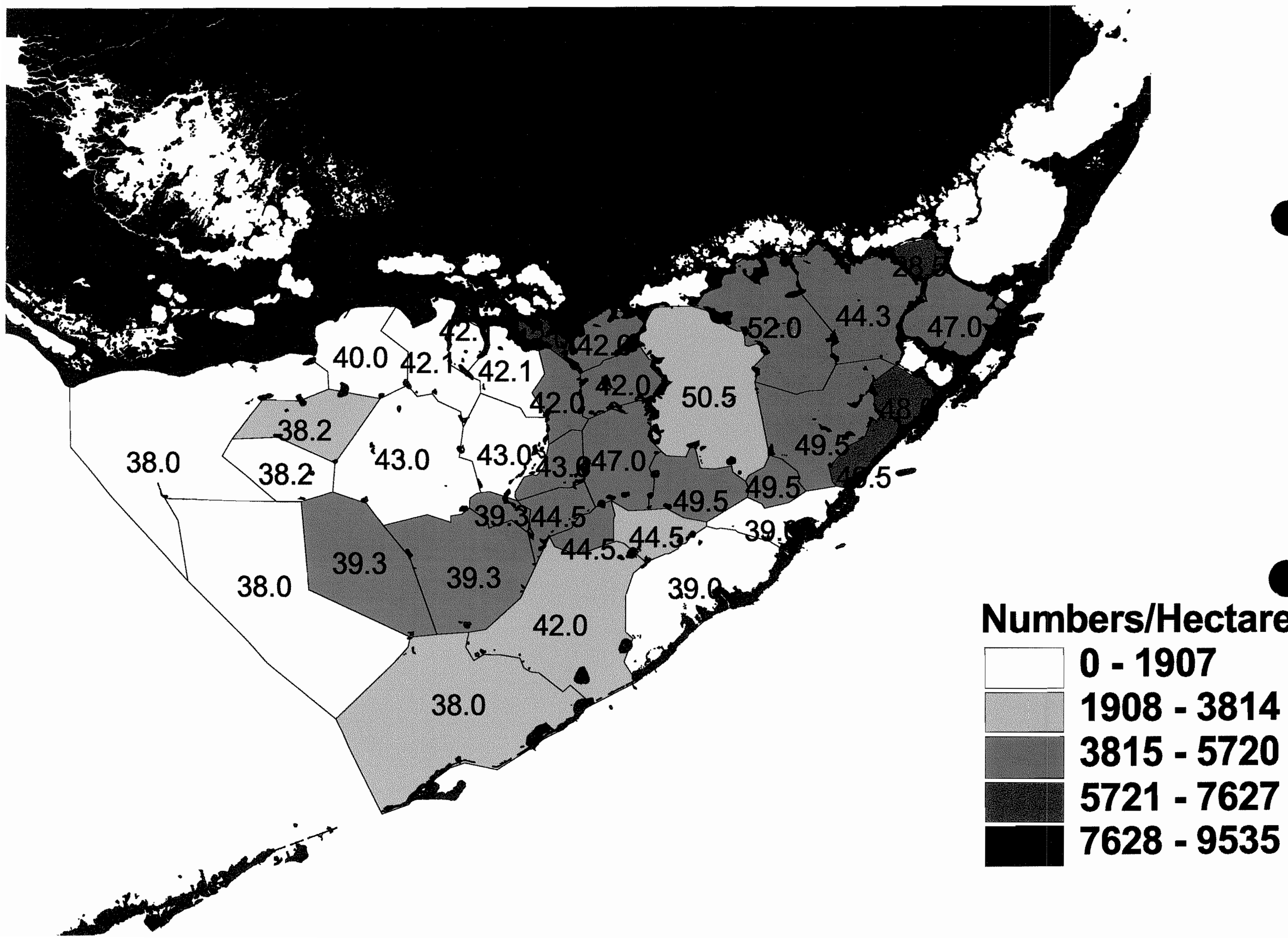
Appendix Figure C-33. Map of predicted densities of *Lucania parva* during April 1990 with average salinity for each basin.

Predicted Lucania parva Densities for April 1990 and Average Salinity for Basin



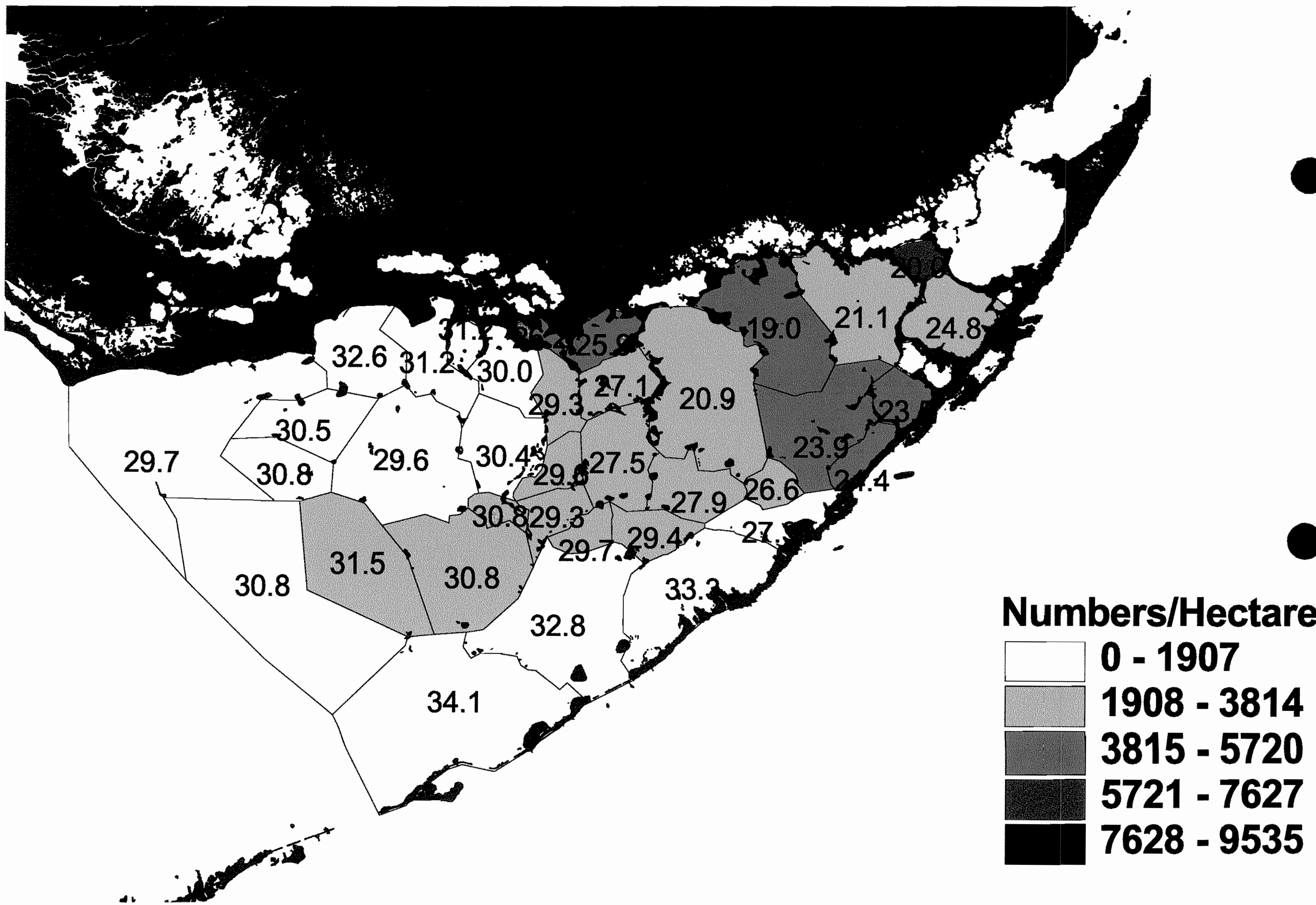
Appendix Figure C-34. Map of predicted densities of *Lucania parva* during August 1990 with average salinity for each basin.

Predicted Lucania parva Densities for August 1990 with Average Salinity for Basin



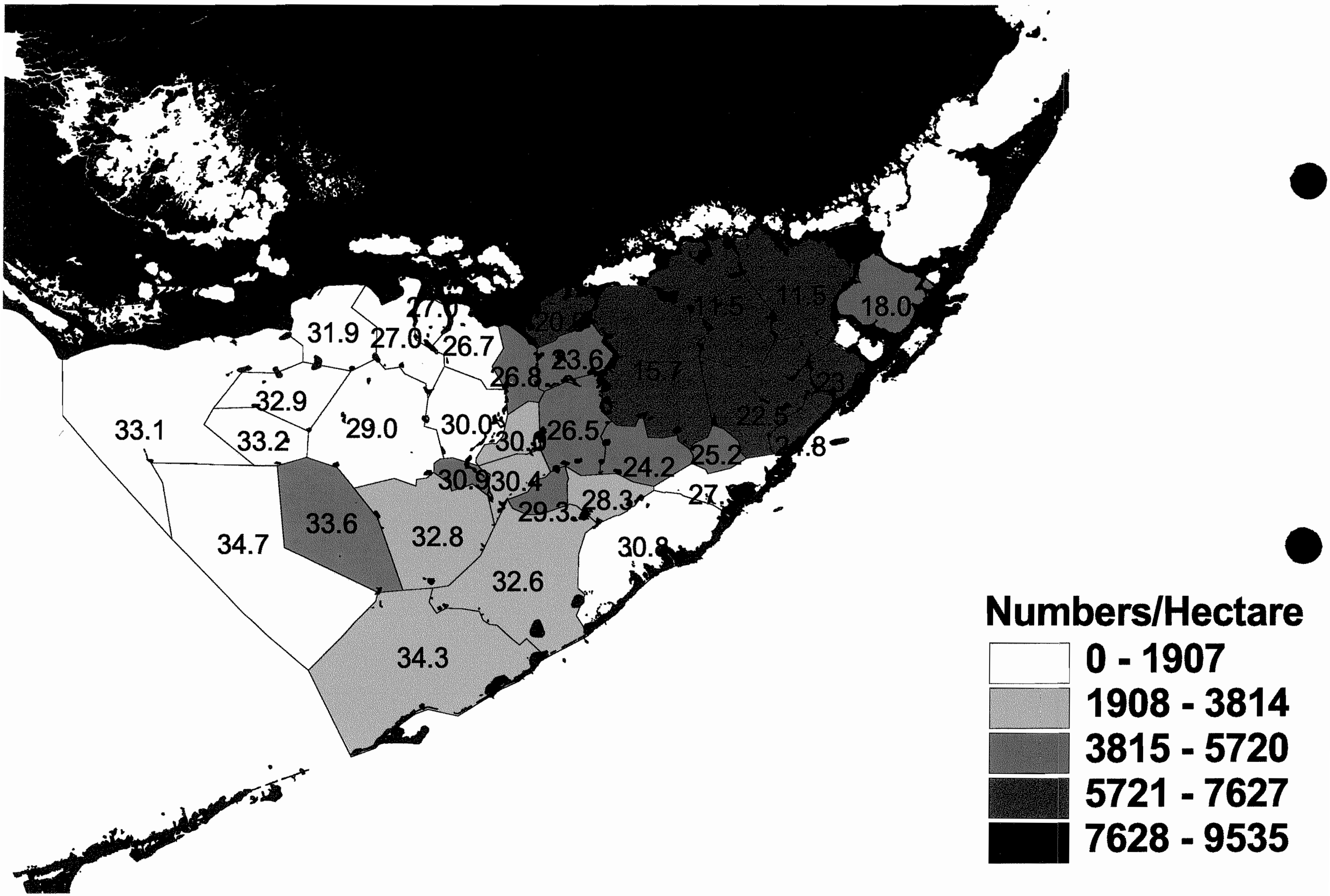
Appendix Figure C-35. Map of predicted densities of *Lucania parva* during April 1995 with average salinity for each basin.

Predicted Lucania parva Densities for April 1995 and Average Salinity for Basin



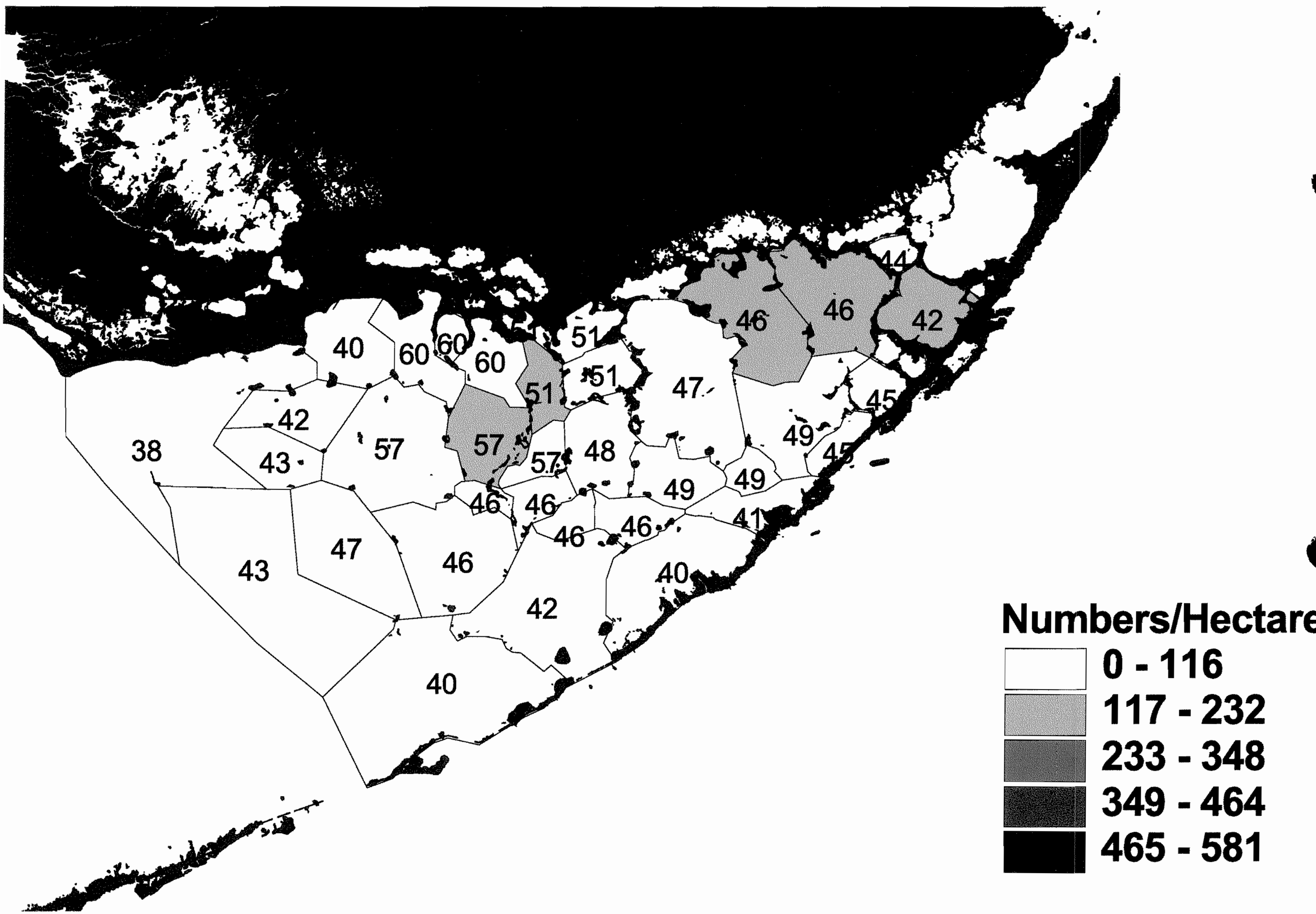
Appendix Figure C-36. Map of predicted densities of *Lucania parva* during August 1995 with average salinity for each basin.

Predicted Lucania parva Densities for August 1995 with Average Salinity for Basin



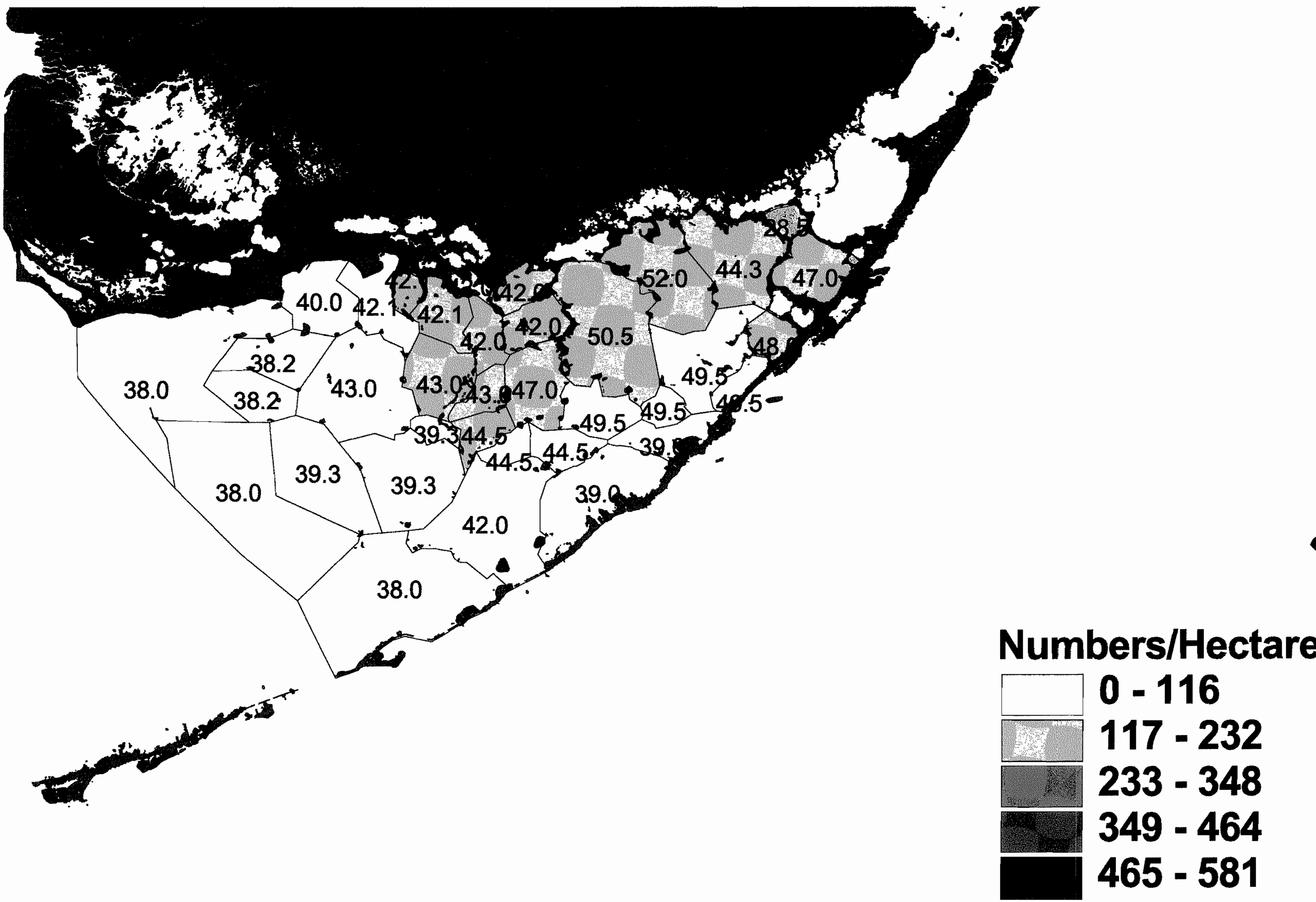
Appendix Figure C-37. Map of predicted densities of *Microgobius gulosus* during April 1990 with average salinity for each basin.

Predicted Microgobius gulosus Densities for April 1990 and Average Salinity for Basin

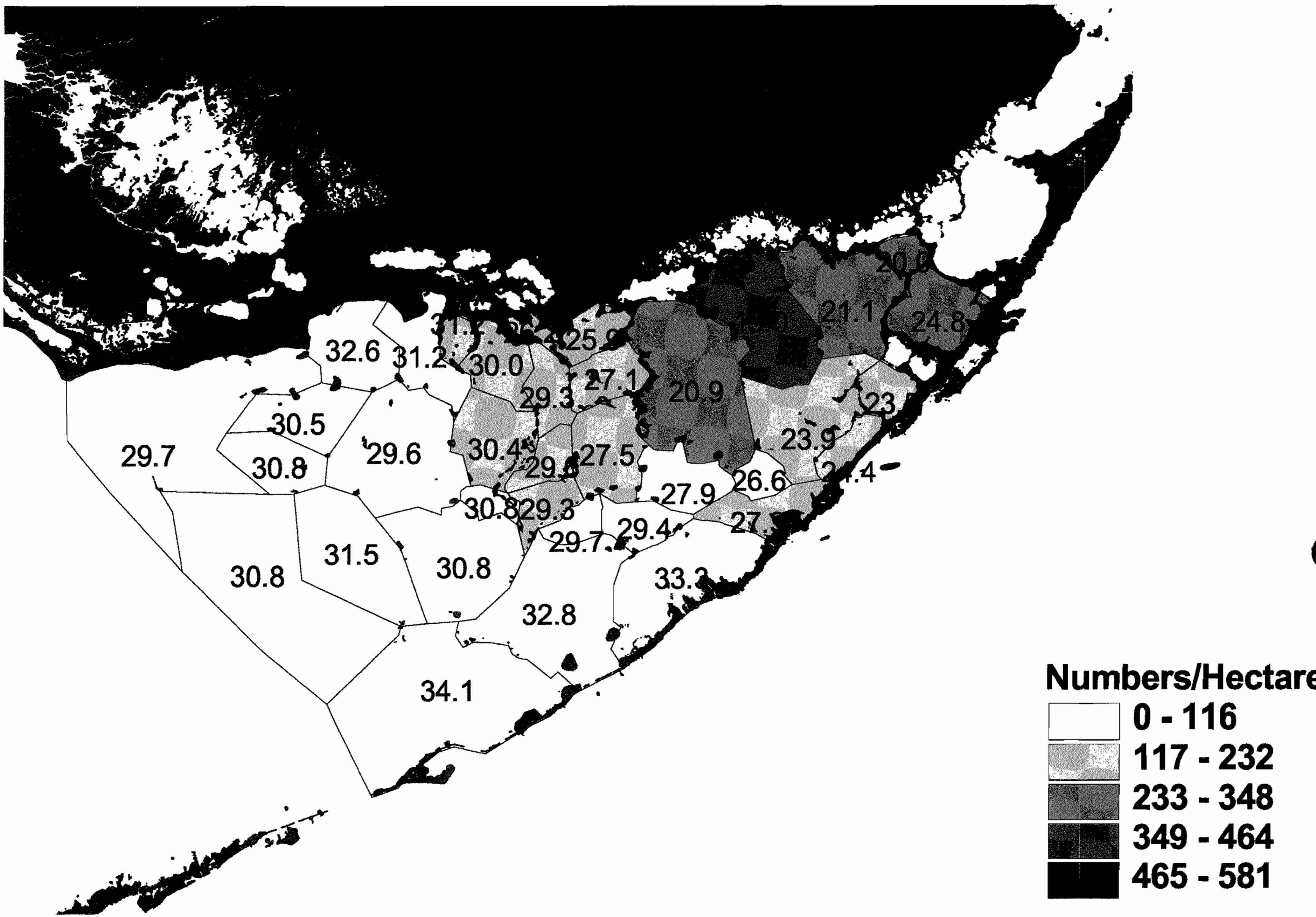


Appendix Figure C-38. Map of predicted densities of *Microgobius gulosus* during August 1990 with average salinity for each basin.

Predicted Microgobius gulosus Densities for August 1990 and Average Salinites for Basin

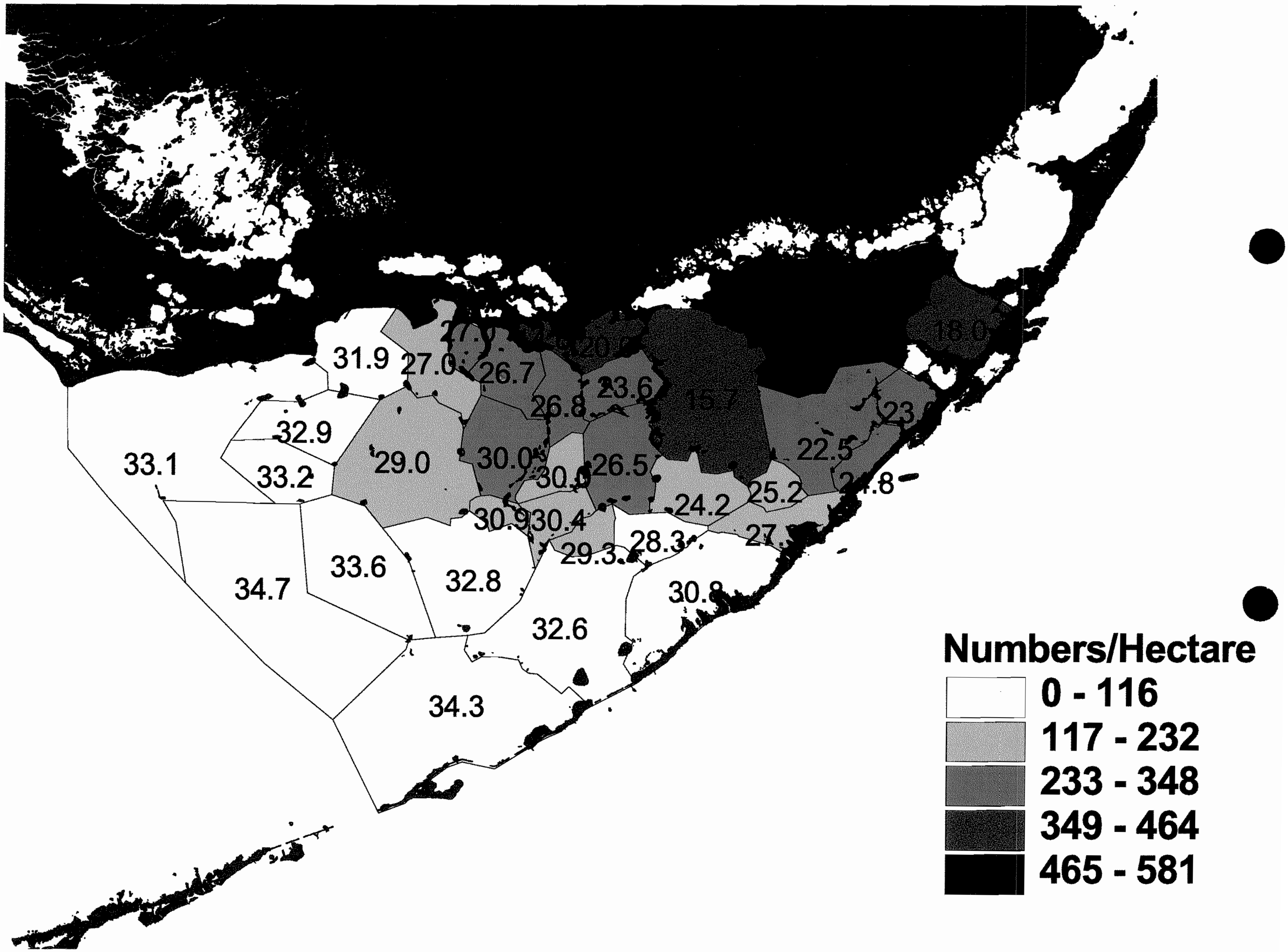


Predicted Microgobius gulosus Densities for April 1995 and Average Salinity for Basin



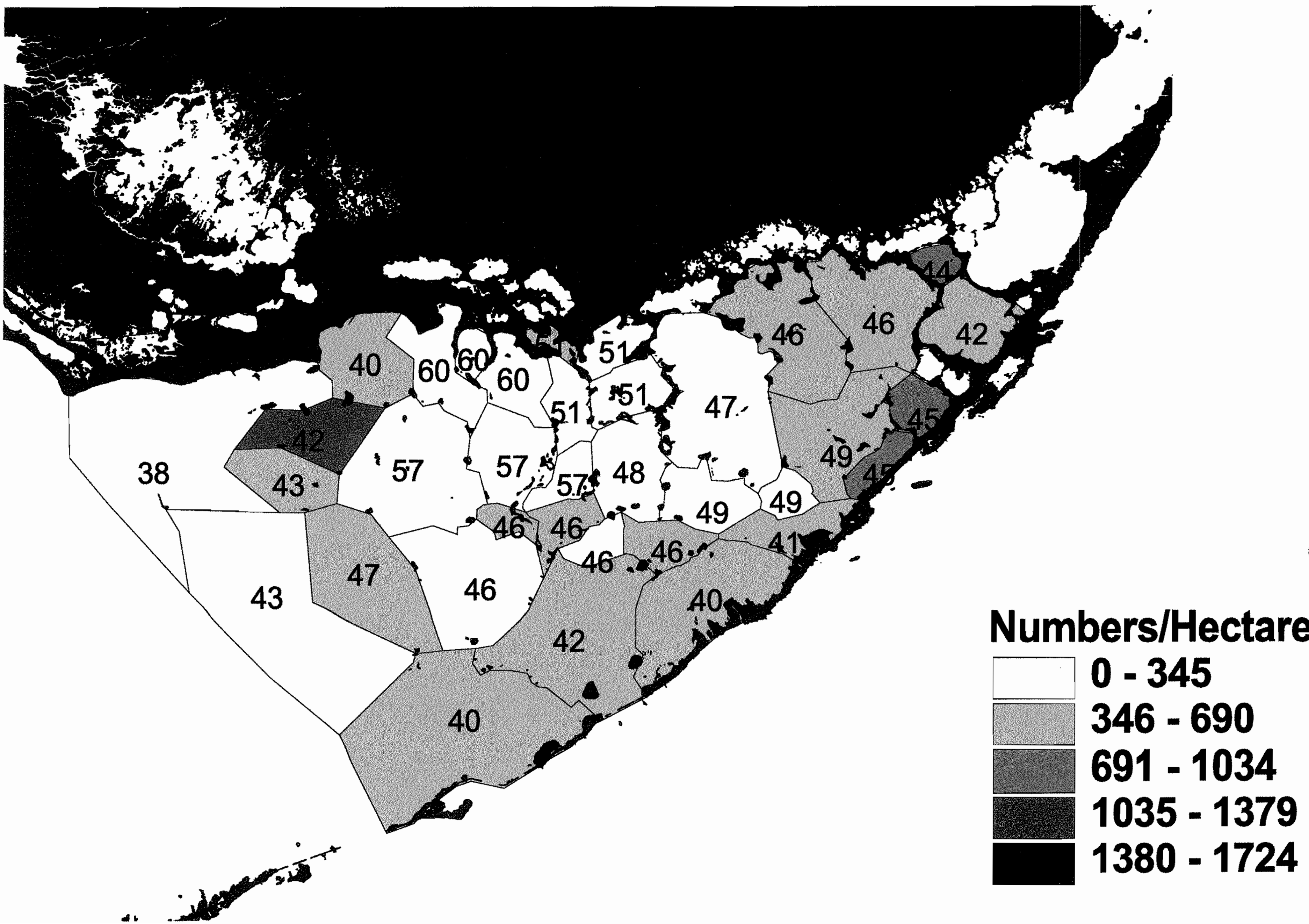
Appendix Figure C-40. Map of predicted densities of *Microgobius gulosus* during August 1995 with average salinity for each basin.

Predicted Microgobius gulosus Densities for August 1995 and Average Salinity for Basin



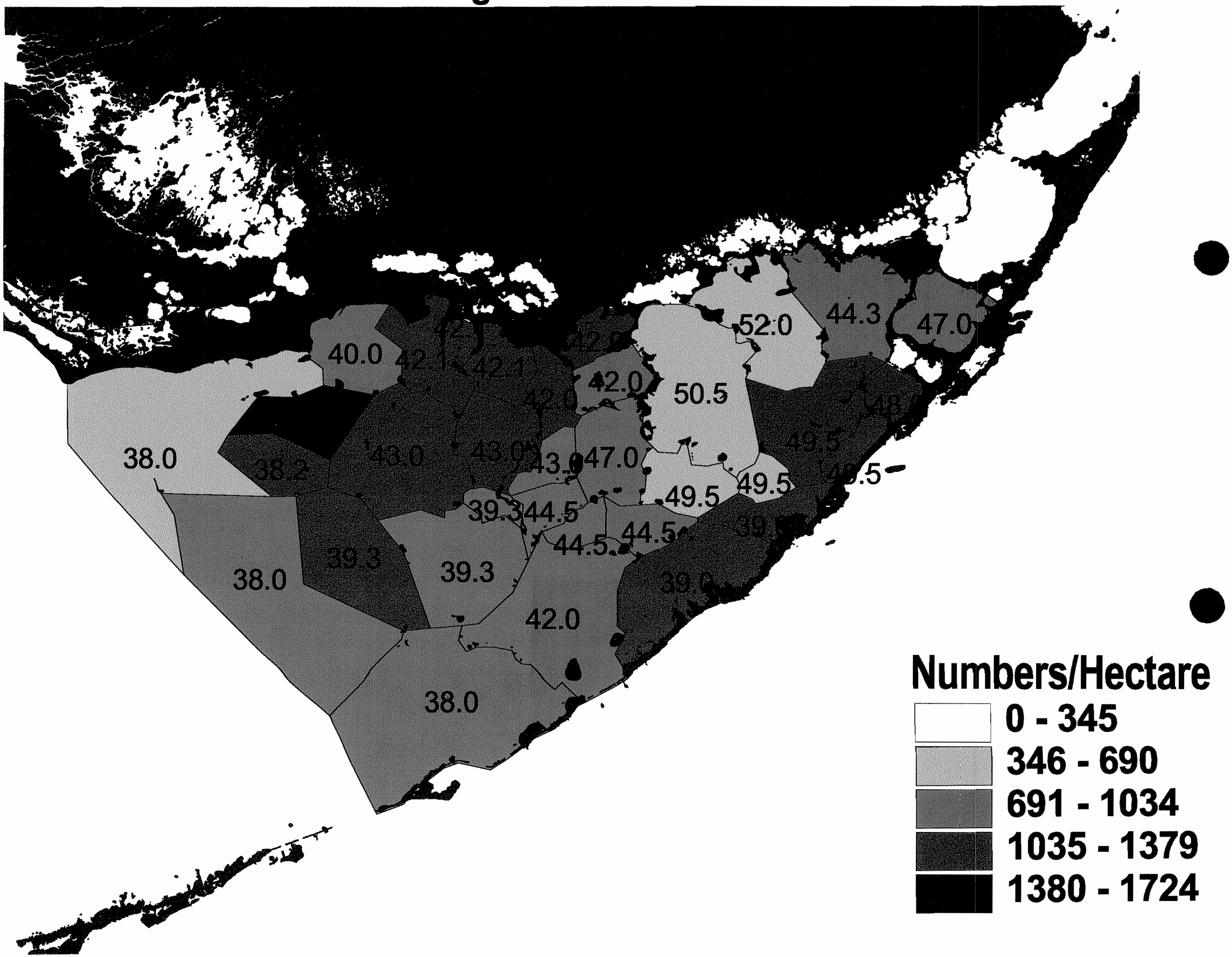
Appendix Figure C-41. Map of predicted densities of *Opsanus beta* during April 1990 with average salinity for each basin.

Predicted Opsanus beta Densities for April 1990 and Average Salinity for Basin



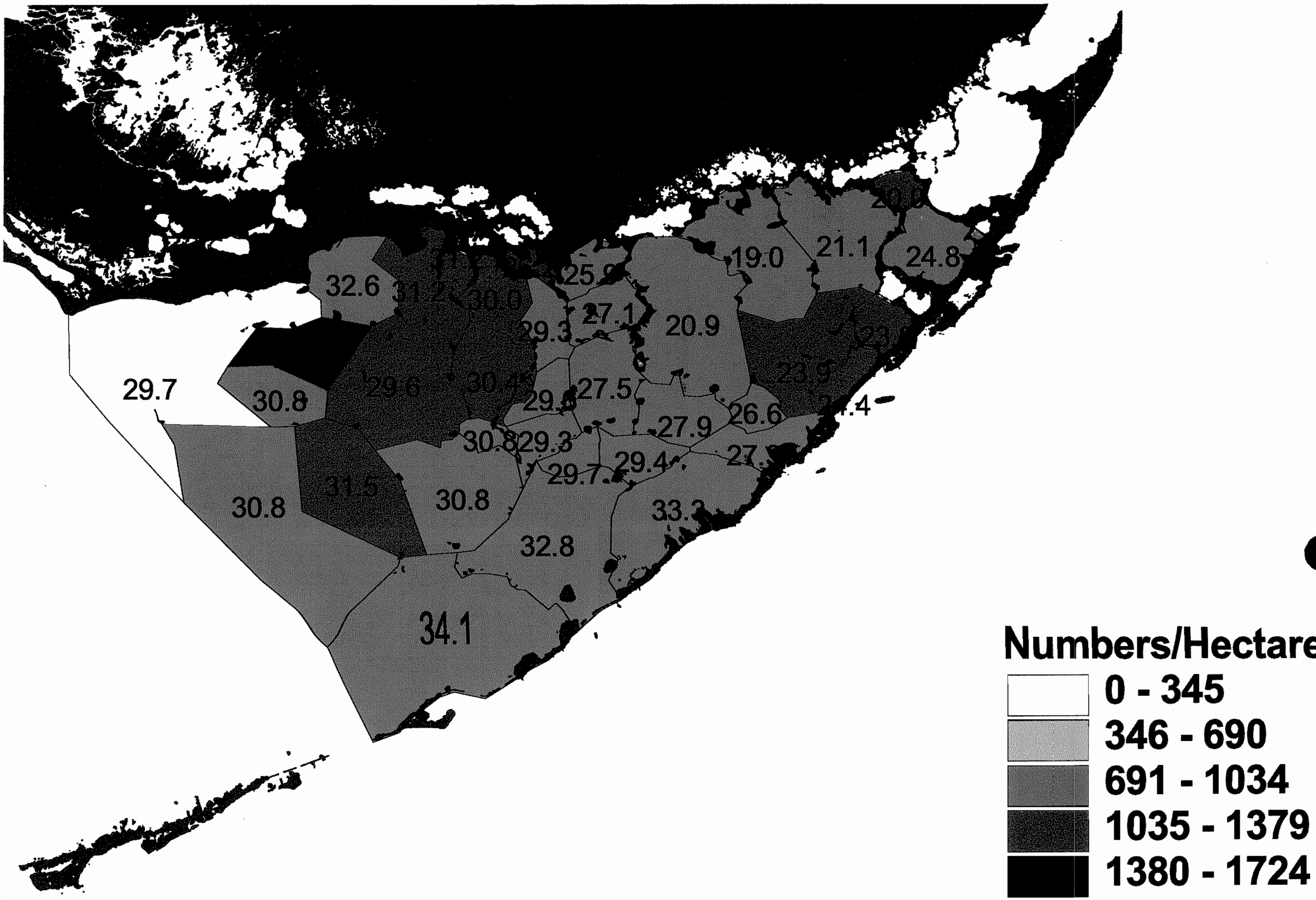
Appendix Figure C-42. Map of predicted densities of *Opsanus beta* during August 1990 with average salinity for each basin.

Predicted Opsanus beta Densities for August 1990 and Average Salinities for Basin



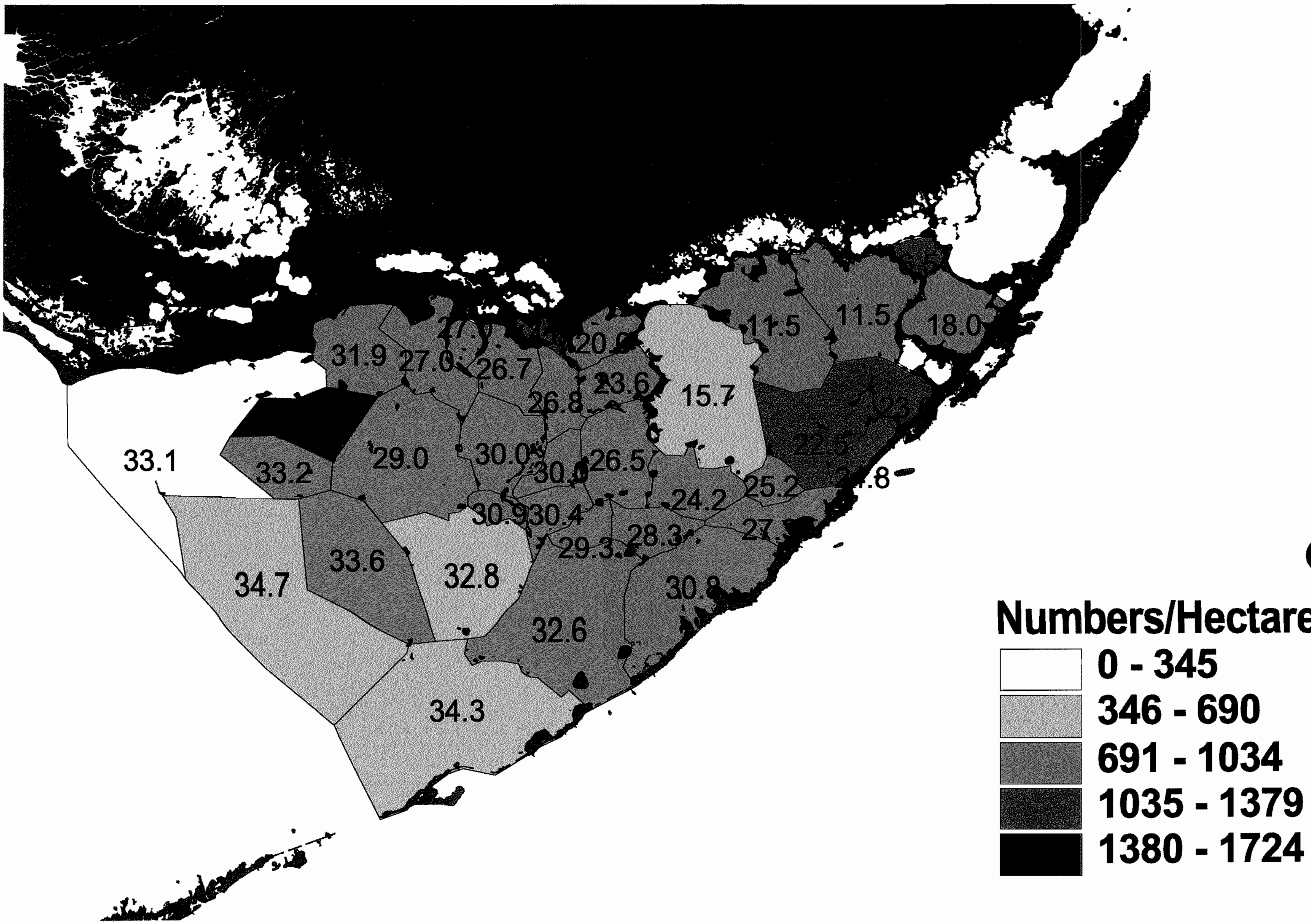
Appendix Figure C-43. Map of predicted densities of *Opsanus beta* during April 1995 with average salinity for each basin.

Predicted Opsanus beta Densities for April 1995 and Average Salinity for Basin



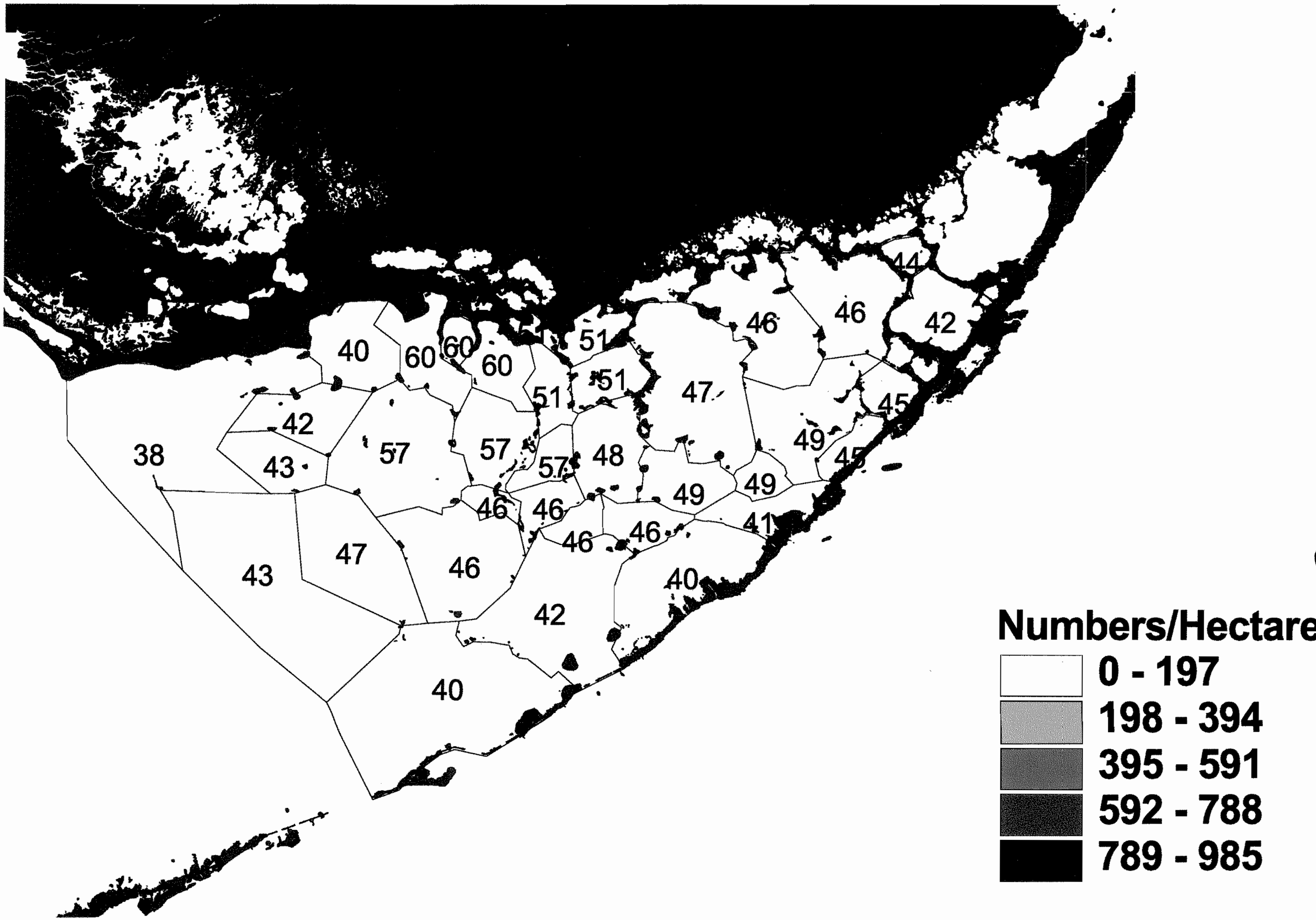
Appendix Figure C-44. Map of predicted densities of *Opsanus beta* during August 1995 with average salinity for each basin.

Predicted Opsanus beta Densities for August 1995 and Average Salinities for Basin



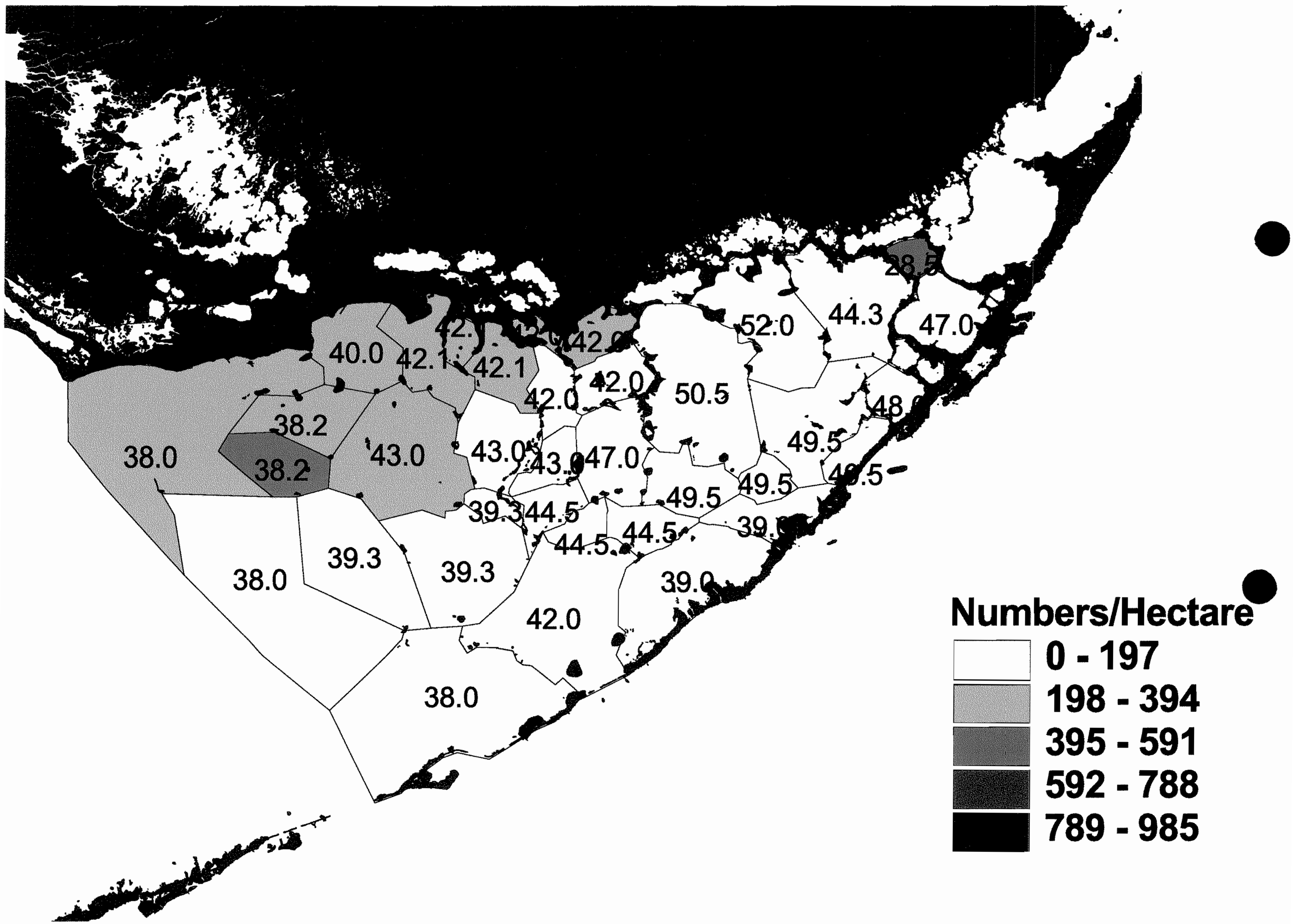
Appendix Figure C-45. Map of predicted densities of *Syngnathus scovelli* during April 1990 with average salinity for each basin.

Predicted Syngnathus scovelli Densities for April 1990 and Average Salinity for Basin



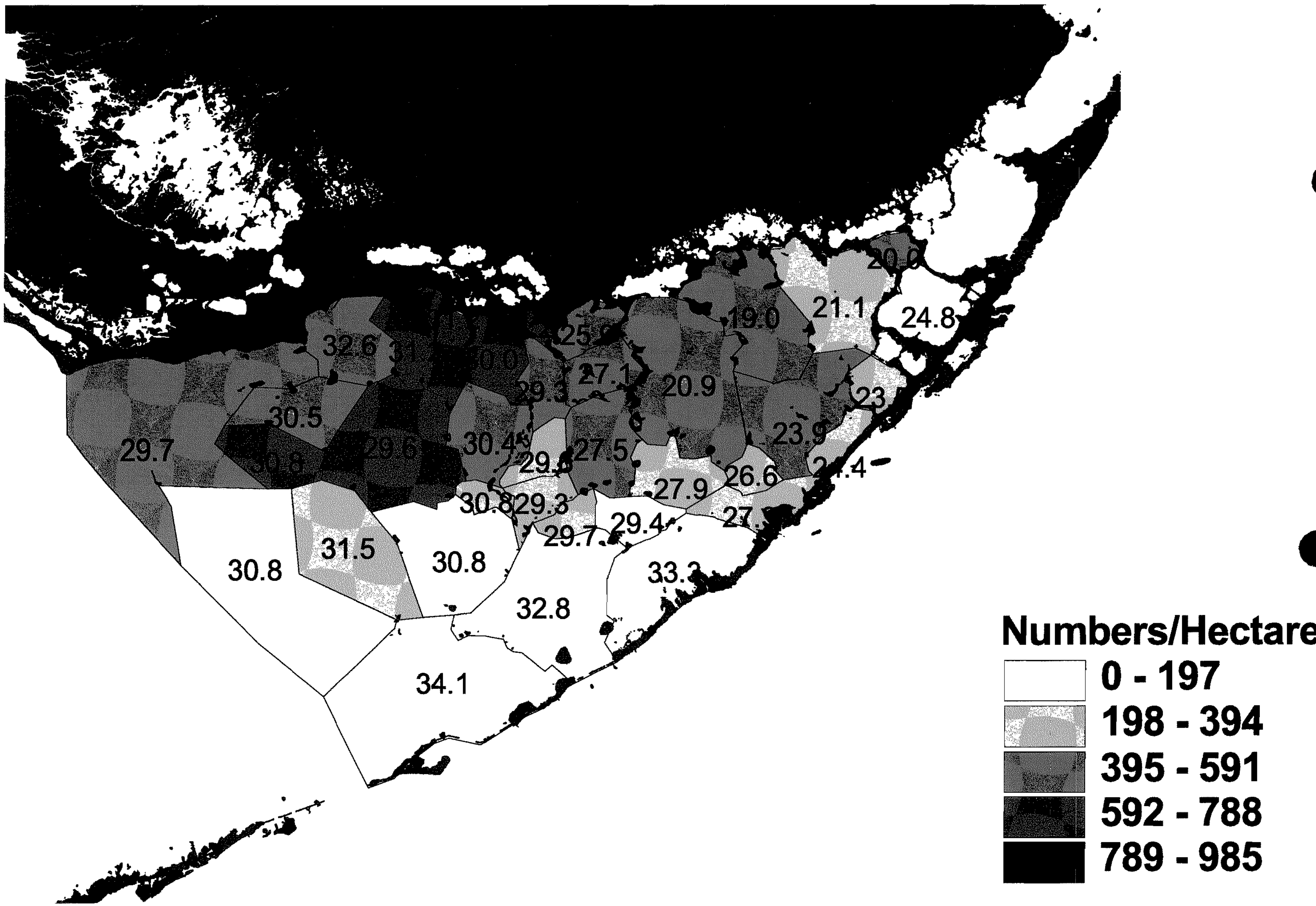
Appendix Figure C-46. Map of predicted densities of *Syngnathus scovelli* during August 1990 with average salinity for each basin.

Predicted Syngnathus scovelli Densities for August 1990 and Average Salinities for Basin



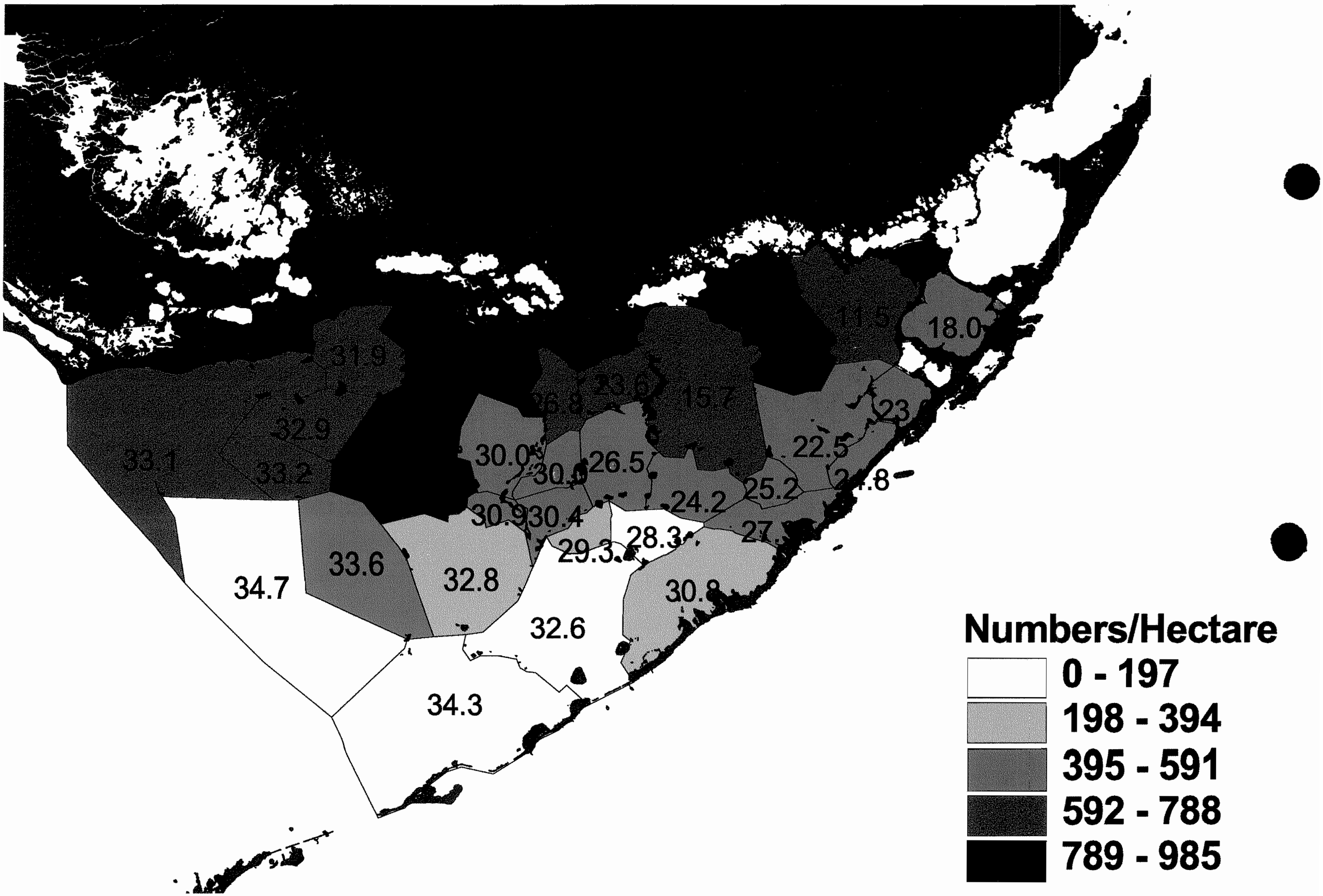
Appendix Figure C-47. Map of predicted densities of *Syngnathus scovelli* during April 1995 with average salinity for each basin.

Predicted Syngnathus scovelli Densities for April 1995 and Average Salinity for Basin



Appendix Figure C-48 Map of predicted densities of *Syngnathus scovelli* during August 1995 with average salinity for each basin.

Predicted Syngnathus scovelli Densities for August 1995 and Average Salinities for Basin



APPENDIX D

Table D-1. Average body wet weight (grams) of forage species in the multi-species data base. Data from Schmidt (ENP, unpublished data) and Powell and Thayer (Beaufort Laboratory, NMFS, unpublished data).

Month	*Farfante-penaeus*	*Lucania*	*Floridichthys*	*Lagodon*	*Anchoa*	*Opsanus*	*Syngnathus*	*Hippo-campus*	*Gobiosoma*	*Microgobius*	*Eucinostomus*
1	0.781	0.369	1.016	23.916	0.509	23.305	0.905	0.246	0.358	0.233	5.598
2	1.302	0.489	1.096	12.552	0.831	68.749	0.835	0.100	0.566	0.811	9.310
3	0.818	0.432	0.948	14.139	0.496	21.279	0.799	0.192	0.285	0.354	4.978
4	1.582	0.528	1.201	19.831	0.326	29.944	0.728	0.177	0.651	0.250	4.861
5	1.426	0.383	1.229	24.314	0.394	26.470	0.752	0.235	0.659	0.146	6.480
6	0.562	0.316	0.893	34.770	1.570	32.223	0.589	0.549	0.448	0.113	3.906
7	0.579	0.265	0.538	23.901	0.724	30.688	0.610	0.214	0.281	0.231	5.338
8	1.483	0.232	0.428	28.007	0.181	40.506	0.800	0.126	0.303	0.203	3.111
9	1.775	0.301	0.494	37.913	0.401	31.762	0.547	0.121	0.326	0.175	3.450
10	0.259	0.380	0.711	49.117	0.834	35.894	0.790	0.185	0.100	0.350	3.064
11	1.169	0.351	0.791	28.974	0.772	28.754	0.691	0.217	0.367	0.181	7.031
12	1.822	0.489	1.092	19.762	0.271	61.589	0.766	0.273	0.429	0.185	2.946
ave	1.156	0.346	0.746	28.524	0.584	31.089	0.713	0.236	0.375	0.254	5.388