

ECOLOGICAL MANUSCRIPTS - NATIONAL PARK SERVICE FRESHWATER FISH PROJECT

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INTRODUCTION

In addition to the freshwater fish inventory undertaken at the northeastern National Parks and Historic Sites, my team has collected substantial data on the patterns and processes exhibited by aquatic communities within the Cape Cod National Seashore kettle ponds in order to understand how these ecosystems function and what role freshwater fish play in them. Below, I review what data we have collected and what hypotheses we are testing with these data. This summary is organized by manuscripts currently in preparation. Because these ponds are unique systems that are ideal for testing a number of questions about community structure, I believe these manuscripts will contribute both to aquatic ecology, in general, and to the management, conservation, and stewardship of the aquatic resources at National Parks and Historic Sites.

WHAT FOLLOWS

What follows are a brief overview of the kinds of data we have and the kinds of ideas we are examining. I look forward to telling you more about this research in person. More complete details of the research, of course, will be included in the manuscript drafts, many of which I hope will be completed by this summer.

GENERAL METHODS

The twenty kettle ponds at the Cape Cod National Seashore (Figure 1) contain 12 naturally reproducing species of freshwater fish that play an array of ecological roles (Figure 2; Table 1). To understand what abiotic and biotic factors structure these communities and to better manage these systems, we extensively sampled water quality, system morphometry, vegetation, invertebrates, and fish communities in the summer of 1999 and the summer and fall of 2000 (Figure 3, Table 2, 3). During this two-year field season, hundreds of fish community, water quality, vegetation, and invertebrate samples were collected and analyzed. Most fish sampling was non-lethal, i.e., we caught, measured, and weighed fish under standard conditions then returned them to the pond.

MANUSCRIPT #1

TITLE: Evaluating patterns and processes along a gradient of variables: the changing role of yellow perch

SYNOPSIS: Yellow perch is the only species consistently found in all of the kettle ponds. Because physical and biological conditions vary dramatically across the kettle ponds, focusing on this species provides a unique opportunity to examine how fish abundance and size structure responds to a gradient of conditions.

In the 20 kettle pond systems, yellow perch span a range of sizes (Figure 4). Because different factors influence different ages of yellow perch, in this manuscript, we individually examine relative abundance of all perch, numbers of four specific size classes of perch, and perch biomass (Table 4). We took a reductionist approach that incorporated six specific steps (Figure 5) culminating in a series of multiple regressions for which a number of criteria were used for model selection (Table 5). Specifically, we examined multiple ways to measure water quality (Figure 6a-b), system morphometry (Figure 6 c-d), vegetation (Figure 6 e-g), food (Figure 6 h-j), predators (Figure 6 k-n) and competitors (Figure 6 o-t) across all 20-kettle ponds and tried to relate them statistically

to patterns of yellow perch (Figure 7). Because many of the factors of interest related to trophic effects, i.e., competition and predation, we first examined a select sample of diets of yellow perch across a range of sizes to identify what perch were eating and with which fish they might be sharing resources (Figure 8).

We sought to understand which of the abiotic and biotic factors examined affected numbers of yellow perch in a number of ways. First, where relevant, we created new variables using principal components (Table 6). Second, we used standard univariate approaches such as correlation (Table 7) and univariate regression (Figure 9). Because many of the abiotic and biotic variables of interest are related, ultimately, we used multiple regression as our primary tool to identify the most important variables that influence numbers and sizes of yellow perch across a gradient of systems (Figure 10). We predicted relationships based on ecological theory (Figure 11, Table 8) and then further tested an array of a posteriori combinations of variables (Table 9-14; Figures 12-17).

Although complex interactions occur, several important, consistent trends were observed. First, abiotic factors in the form of pH or conductivity set the bounds for species interactions (Table 15). Second, within those abiotic limits, interspecific and intraspecific competition play an important role across all sizes. In addition, for young-of-year perch, predators play a facilitating role, actually increasing perch abundance, perhaps by preying on the competitors of yellow perch. Finally, for the larger fish, food quantity via invertebrate abundance was also important.

Based on these analyses, we can start to put together a functional model of how water quality, lake morphometry, food, competition and predation interact to determine numbers, sizes, and biomass of freshwater fish communities. Now that key variables have been identified, we can pursue more focused analyses of finer spatial and temporal scales.

COMPLETED: This manuscript is the basis for Mike Carey's MS thesis. He plans to defend and submit this research for friendly review (by NPS and others) before July 1, 2002.

MANUSCRIPT #2

TITLE: **Patterns and mechanisms for fish community structure: a test of patterns, processes, and multivariate methods**

SYNOPSIS: In this component of the study, we looked beyond yellow perch and asked: (1) Do distinct fish assemblages exist across the kettle ponds? (2) What is the relationship between environmental and biotic variables and these fish community patterns? and (3) Do these patterns change (a) with the response variable measured? (b) with the season? (c) with the year? and (d) with the analysis tool used? To answer these questions we used the same types of data discussed above (20 ponds sampled 3 times in 1999, Summer 2000, Fall 2000) broadened to include all species of fish (12 naturally reproducing species and stocked trout).

We sought to identify patterns using principal component analysis and multidimensional scaling on the fish data, discriminant function analysis on environmental pond variables, and stepwise discriminant analysis to understand why certain environmental variables were correlated with specific fish communities (Figure 18).

Fish communities in the 20 ponds could be classified on the basis of the numbers of banded killifish, pumpkinseed, and yellow perch (Figure 19). Based on physical variables such as depth, surface area, shoreline development, temperature, dissolved oxygen, pH, and conductivity, a discriminant function was constructed for each group of fish clusters

(Table 16). These relationships separated the fish communities in each cluster accurately (Table 17) primarily based on depth, number of dwellings, and pH (Table 18). The mechanism for dwelling effect is unknown. Relative to the other two variables, high numbers of killifish are found in deeper systems (Figure 20) and high numbers of pumpkinseed are found in systems with moderate pH (Figure 21). We think these patterns reflect the type of habitat, vegetation, food, competition, and predation found in the different systems relative to the types of habitats in which different guilds of fish thrive.

Presently, we are rerunning these analyses based on the more complex data set obtained in 2000. With these data, we should be able to better understand why certain fish species occur where they do. Consequently, we should be able to better conserve and manage both fish and their habitats.

COMPLETED: Summer 2002

MANUSCRIPT #3

TITLE: Squeezing the ecological meaning from non-experimental data: insights provided from different data sets using classical and modern multiple regression approaches.

SYSTEM: Cape Cod National Seashore, Wellfleet, MA; Massachusetts Coast; Connecticut River

AUTHORS: Martha Mather, Mike Carey, Kristen Ferry, Mike Sutherland

SYNOPSIS: At present, we have three multi-system data sets that seek to understand what abiotic and biotic factors affect numbers and sizes of fish. These data sets include yellow perch in the 20 kettle ponds, numbers of striped bass across 13 Massachusetts estuaries, and numbers and sizes of Atlantic salmon across 18 tributaries of the Connecticut River. All analyses use classical and modern multiple regression techniques with Akaike Information Criteria as an important criteria for model selections. Although all three data sets ask similar questions with similar methods, the ecological insights provided by each vary dramatically based on characteristics of the fish and the aquatic system. Herein, we compare the kinds of ecological meaning obtained from these three data sets. This should provide useful insights for future comparative studies.

WHEN: Summer 2002

MANUSCRIPT #4

TITLE: Role of temporal scale: a comparison of temporal heterogeneity in fish communities and structuring mechanisms within season, across season, and across year.

SYNOPSIS: Temporal scale is an important consideration in all ecological patterns. We have yellow perch and fish community data for four different scales (Figure 22). In this manuscript we examine similarities and differences in patterns and processes that emerge at each scale. This study should have important consequences for inventory and monitoring by identifying what is lost and gained by different sampling frequencies.

WHEN: Summer 2002

MANUSCRIPT #5**TITLE:** **Within and across cohort interactions among yellow perch.**

SYNOPSIS: Both numbers (Figure 23), spatial patterns (Figure 24), and sizes of yellow perch (Figure 7) vary across systems. These patterns may be related to size-structured interactions among perch as well as to abiotic and biotic variables. In this component of the study, we examine these intra-specific interactions among year classes.

MANUSCRIPT # 6**TITLE:** **Impact of food web variations on yellow perch**

SYNOPSIS: Yellow perch play an array of trophic roles in the Cape Cod kettle ponds (Figures 25, 26). Specifically, they can feed on prey from three different sources of production, i.e., phytoplankton, detritus, and periphyton (Figure 25a; Figure 26). In addition, they occur with pumpkinseed (competitors for benthic invertebrates), killifish (competitors for zooplankton; Figure 25 b-c), or both. Finally, in different ponds they can co-occur with (a) no predators, (b) cannibalistic, piscivorous yellow perch, (c) stocked trout, (d) native pickerel (Figure 25 d), or (e) non-native (largemouth and smallmouth bass) predators (Figure 25 e).

Herein, we ask: (1) What trophic roles do yellow perch play in the food webs of all 20 ponds? (2) Does the presence, type, size, and numbers of competitors change the trophic role of perch via changes in yellow perch abundance, size, and diet? (3) What is the impact of predators on numbers, sizes, and diets of perch and their competitors? (4) Do different species of competitor and predator function differently? (5) How do these patterns relate to production and spatial heterogeneity of the systems? These questions will be addressed using numbers, sizes, and diets of predators, perch, killifish, and pumpkinseed. It would also be interesting to know what food web patterns are elucidated through stable isotope analysis and how these patterns relate to those based on diet, size, and relative abundance.

In future studies, it would be interesting to ask if ponds function differently when the predators are (a) introduced and non-reproducing (stocked trout), (b) non-native but naturally reproducing (largemouth bass) or (c) native and naturally reproducing (pickerels). It would also be interesting to couple this biological study of ecological effects of native and non-native fish species with a sociological study of whether human residents and visitors differentially value systems with native and non-native fish.

MANUSCRIPT #7**TITLE:** **Vegetation as a structuring mechanism for freshwater fish communities**

SYNOPSIS: Vegetation plays an important ecological role for freshwater fish via concentrating food and providing refugia from predation. In the kettle ponds, density and patterns of vegetation vary radically including patterns of dense vegetation throughout the pond (Figure 27a), no rooted vegetation (Figure 27b), the traditional inshore littoral ring of vegetation (Figure 27c), and various configurations and densities of vegetation (Figure 27d-f). We have data on all of these and it would be interesting to see if the pattern of vegetation is related to invertebrate production, fish production, and species interactions, i.e., to evaluate if vegetation is a keystone factor in determining fish community structure.

MANUSCRIPT #8**TITLE:** **How yellow perch responses differ across systems**

SYNOPSIS: Spatial patterns across ponds based on presence-absence, relative abundance, and biomass are very different (Inventory report figures 3-5; this report Figure 24). It would be interesting to correlate these different outcomes with each other to evaluate if there is a single best response variable to use in research and monitoring.

MISCELLANEOUS OTHER MANUSCRIPTS

A random colonization model

Heterogeneity in across pond patterns of environmental and biotic variables

Selectivity of an array of sampling gear for quantifying patterns in freshwater fish communities

Kettle Ponds on the Cape Cod National Seashore

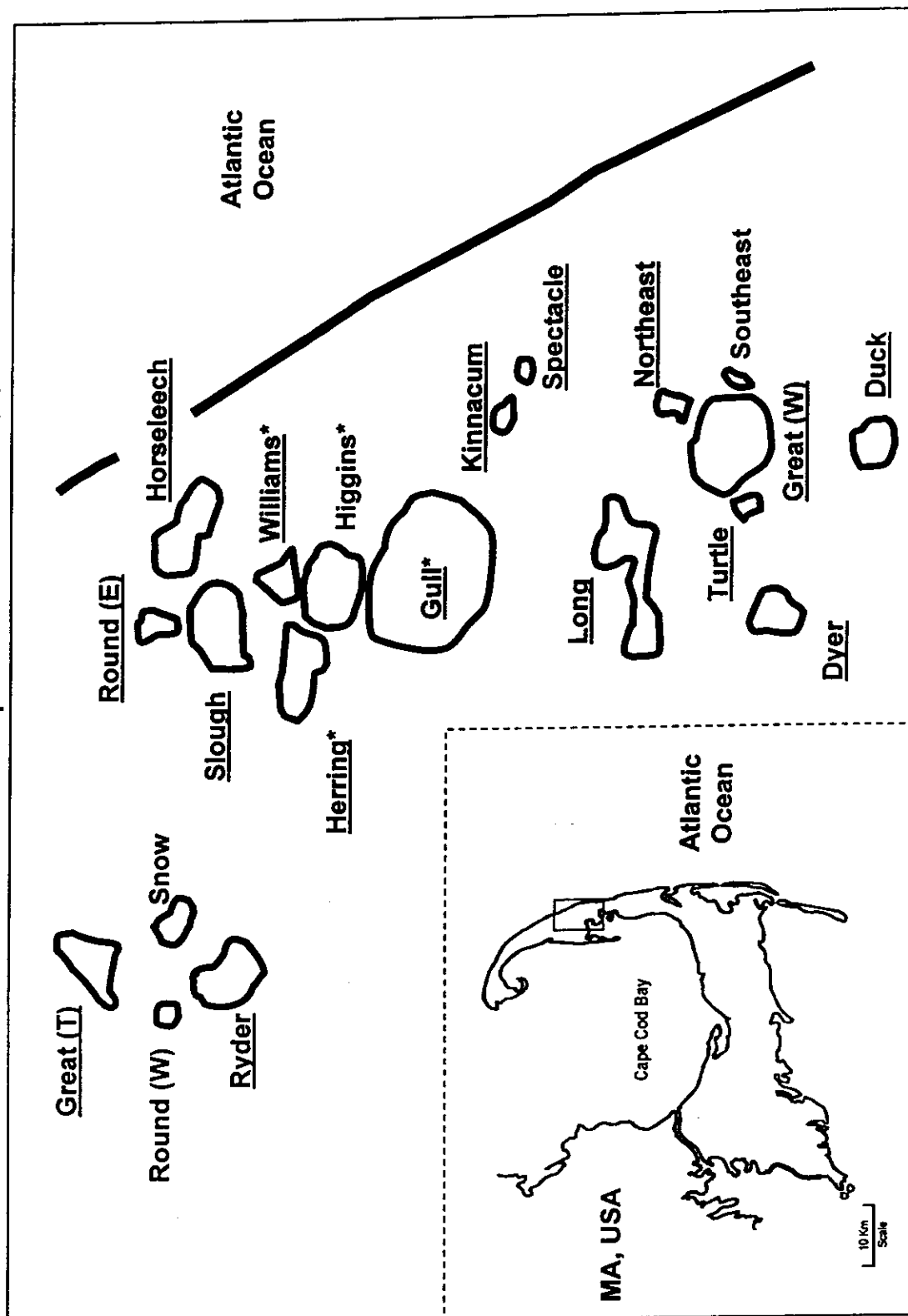


Figure 1

A simplified food web of the kettle ponds

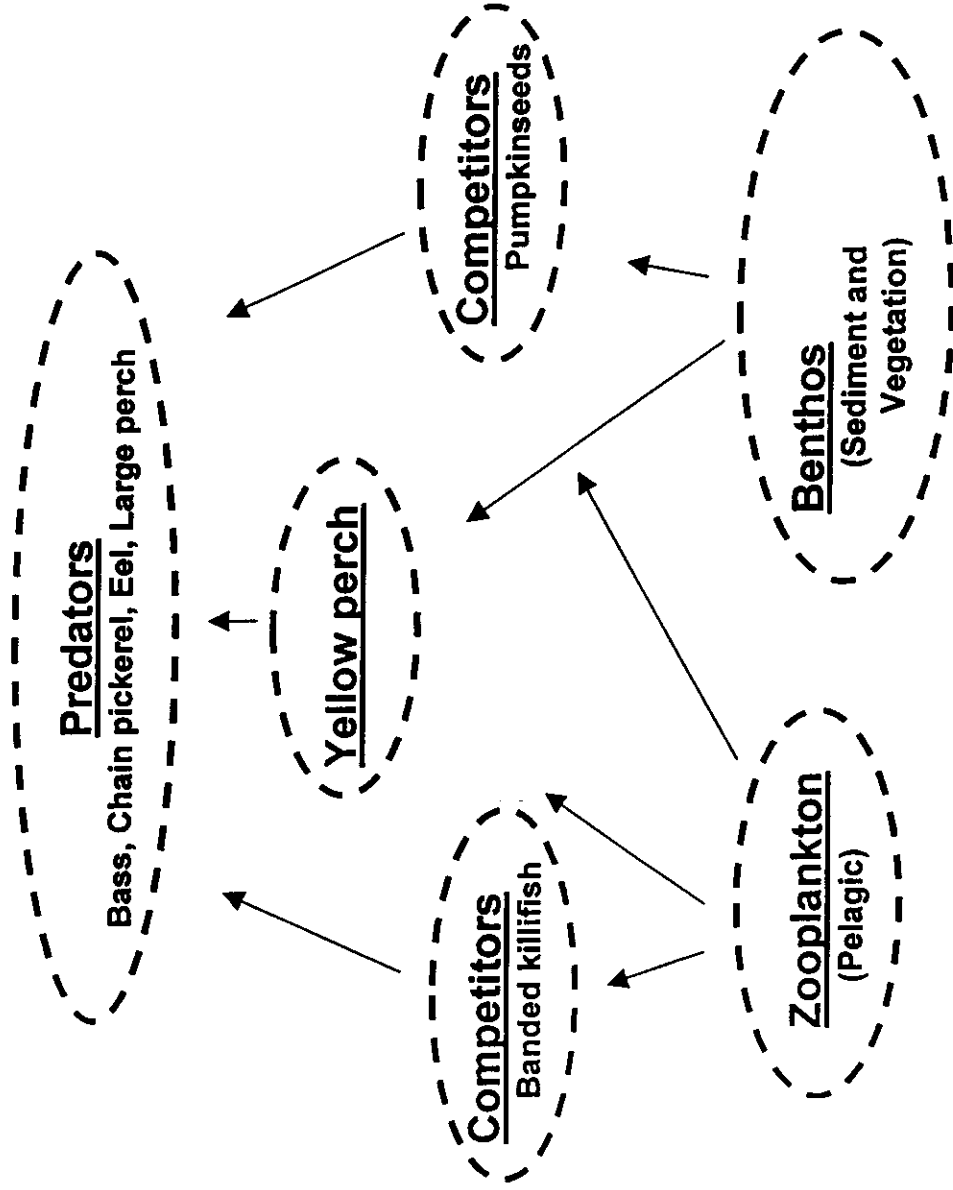


Figure 2

Table 1 The potential fish community members of the kettle ponds on the Cape Cod National Seashore. The common name, Genus species, size specific diet contents, and potential perch interaction is listed for each species.

Common name	Genus Species	Size	Diets		Perch interaction
			Invertebrates Pelagic	Fish Benthic	
Target species Yellow perch	<i>Perca flavescens</i>	YOY Small adult Large adult	X X X	 X X	
Primary species Banded killifish	<i>Fundulus diaphanous</i>		X		Competitor
Pumpkinseeds	<i>Lepomis gibbosus</i>	Small Adult	X X	X	Competitor
Chain pickerel	<i>Esox niger</i>	YOY Adult	X		Predator
Largemouth bass	<i>Micropterus salmoides</i>	YOY Adult	X	X	Predator
Smallmouth bass	<i>Micropterus dolomieu</i>	YOY Adult	X	X	Predator
Other species American eels Brown bullheads Golden shiners River herring White perch White suckers	<i>Anguilla rostrata</i> <i>Ameiurus nebulosus</i> <i>Notemigonus crysoleucas</i> <i>Alosa aestivalis, pseudoharengus</i> <i>Morone Americana</i> <i>Catostomus commersoni</i>		Piscivore Omnivore Zooplanktivore Zooplanktivore Omnivore Benthivore		Predator Competitor Competitor Competitor Competitor Competitor

Example of sampling locations for experimental unit design

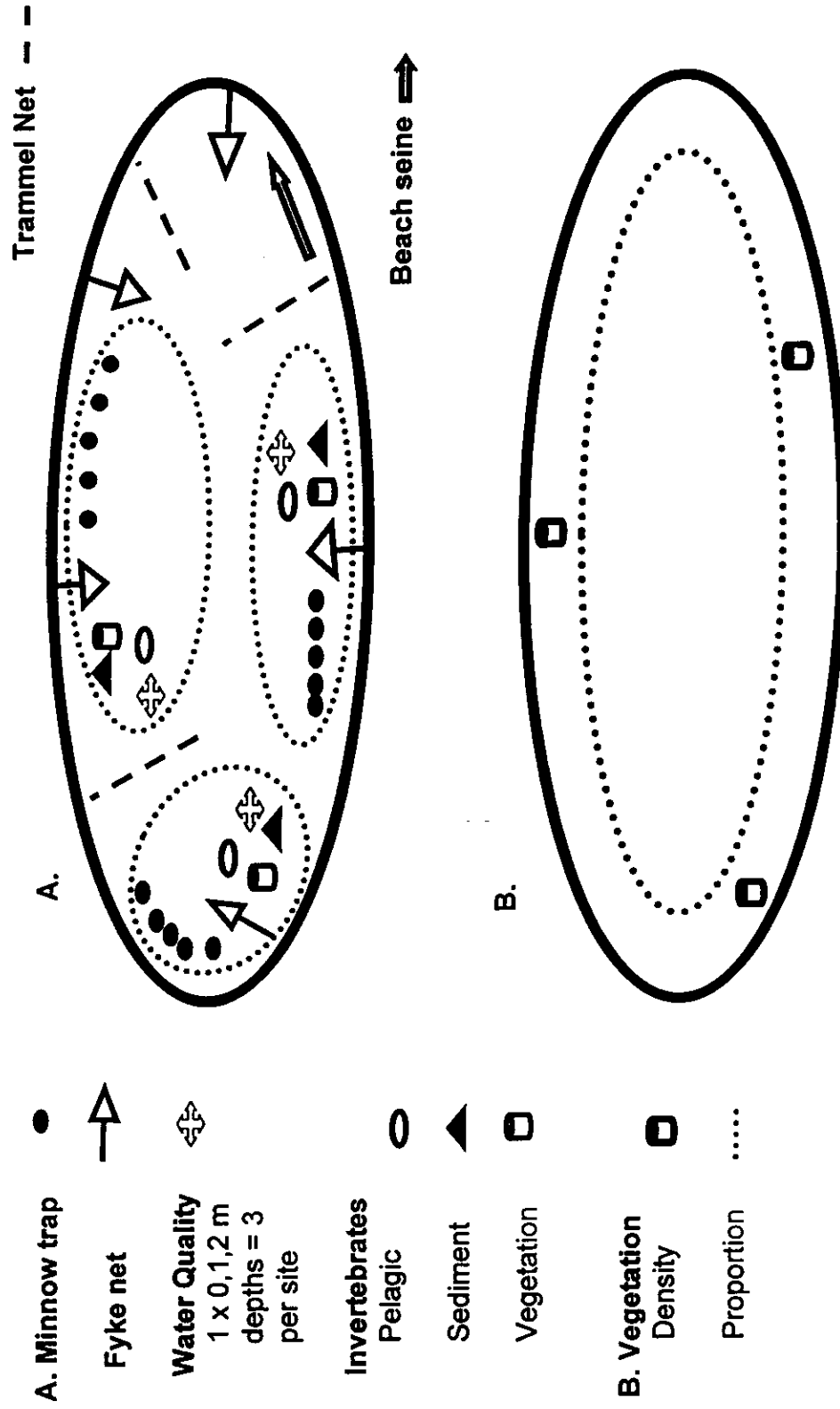


Figure 3

Table 2 For five variable groups (invertebrates, water quality, pond morphometry, and fish community) and the target organism yellow perch, the gear type, size, number, duration, and depth used to sample 16 kettle ponds at the Cape Cod National Seashore. All sampling gears were set simultaneously in one system per day from July 25 – August 16, 2000.

Variable groups	Gear type	Size (m)	Mesh (mm)	No. (#)	Duration	Depth (m)
Water quality (pH, Cond, DO, °C)	Horiba U -10 water quality			9		0,1,2
(pH minimum)	NPS database			4		
Morphometry (Area, depth)	NPS database					
Vegetation Density	Stovepipe sampler	0.25 x 0.91		3		0.5
Proportion	Snorkel observation			1	Circumference	1
Number	Stovepipe X snorkel			1		1
Invertebrates Pelagic (Zooplankton)	Vertical tow net	0.5	53 µm	3		2
Sediment	Sediment corer	20.8 mm	125 µm	3		1
Vegetation	Stovepipe sampler	0.25 x 0.91		3		0.5
Fish community	Fyke net	6.1 lead, 0.91	9.53	5	8 h	
Fish community	Minnow trap	0.23 x 0.45	3.18	15	8 h	
Fish community	Trammel net	1.22 x 33.18	25.4, 38.1, 50.8	3	4 h	
Fish community	Beach seine	7.2	3.18	1	33 m transect	

Table 3 The key abiotic and biotic factors important to the perch populations in the kettle ponds during the summer 2000, including the specific variable measurement used in the analysis, the variable abbreviations, units, sample size (N), and data source.

Variable groups	Specific Variable	Measurement	Abbreviation	Units	N	Data source
<u>Water Quality</u>						
	pH	Minimum 2000	pH (min)	pH	4	NPS data
	pH	x sample date	pH ($\bar{x}$)	pH	9	This study
	Conductivity	x sample date	Cond ($\bar{x}$)	ms/cm	9	This study
<u>Morphometry</u>						
	Surface area	Total	Area	ha	1	NPS data
	Depth	Maximum	Depth	m	1	NPS data
<u>Vegetation</u>						
	Density	Number/m ²	Stem (#)	#/m ²	3	This study
	Proportion	Shoreline	Stem (%)	%	1	This study
	Total stems	Total number	Stem (all)	#	1	This study
<u>Invertebrates</u>						
	Abundance	#/CPUE	Inv (ab)	#	9	This study
	Richness	# of Families	Inv (rich)	#	9	This study
	Benthic	Sediment and vegetation	Inv (ben)	#	6	This study
<u>Fish community</u>						
<i>Predator</i>						
	Species	Total species	Pred (sp)	#	16	This study
	Abundance	# predator species	Pred (ab)	#	16	This study
	Major species	Bass and pickerel	Pred (major)	#	16	This study
	Large	Predators > ??? mm	Pred l(g)	#	16	This study
<i>Competitor</i>						
	Proportion	Comp # / total #	Comp (%)	%	16	This study
	Species	Total species	Comp (sp)	#	16	This study
	Pumpkinseed	Number	PS (ab)	#/CPUE	16	This study
	Banded killifish	Number	BK (ab)	#/CPUE	16	This study
<i>Integrated Fish</i>						
	Fish richness	Total species	Fish (sp)	#/CPUE	16	This study
	PC 1	1 st principal component	PC1		16	This study

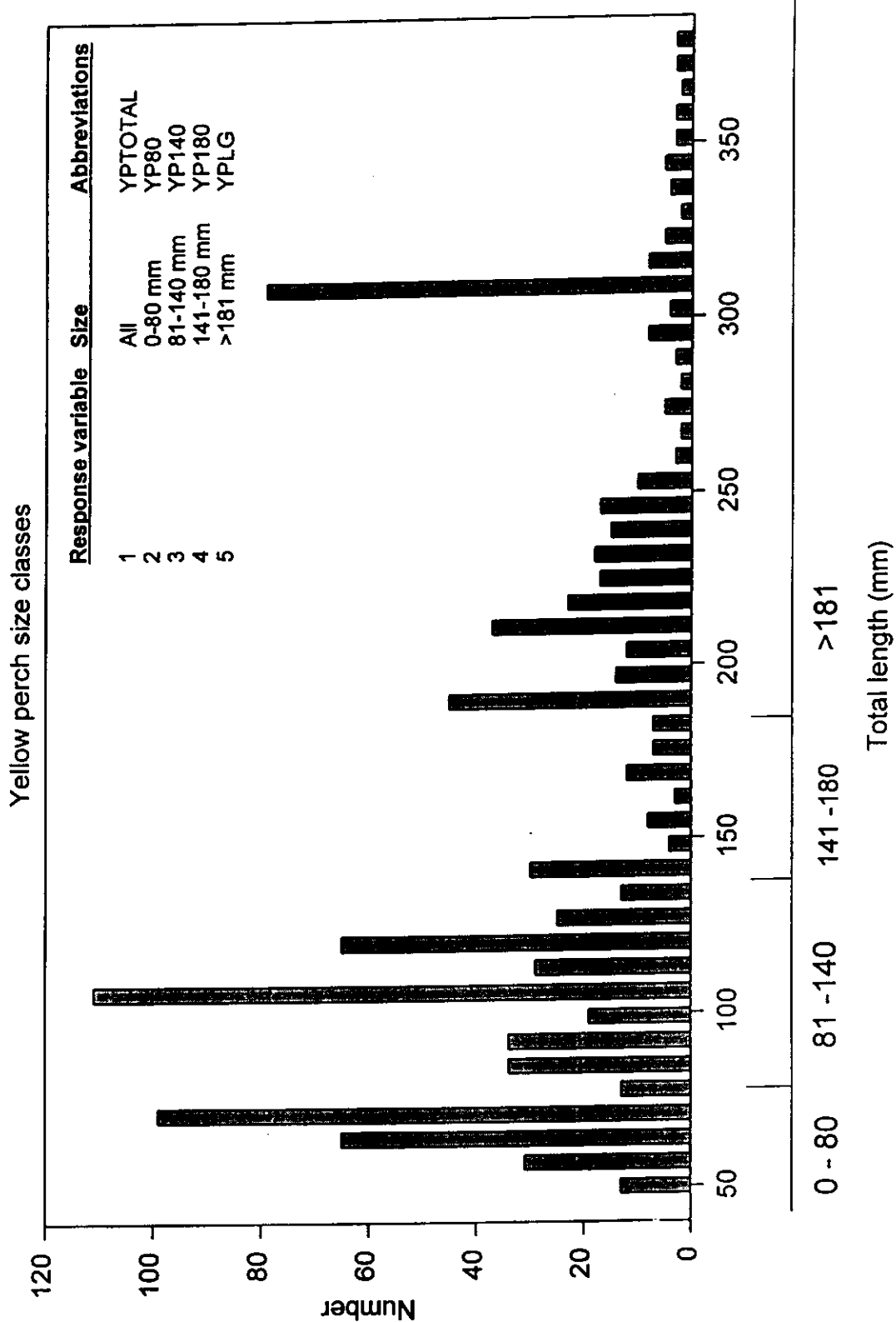


Figure 4

Table 4 The six response variables used in each analysis to characterize the perch populations in the kettle ponds during the summer 2000, including the responses, sizes, abbreviations, and tables and figure of corresponding results.

Analysis	Species	Response	Size	Abbreviation	Tables	Figure
1	Perch	Abundance	All	YPTOTAL	R.4	R.5
2	Perch	Abundance	0 – 80 mm	YP80	R.5	R.6
3	Perch	Abundance	81 – 140 mm	YP140	R.6	R.7
4	Perch	Abundance	141 – 180 mm	YP180	R.7	R.8
5	Perch	Abundance	> 181 mm	YPLG	R.8	R.9
6	Perch	Biomass	All	YPMASS	R.9	R.10

Data analysis steps

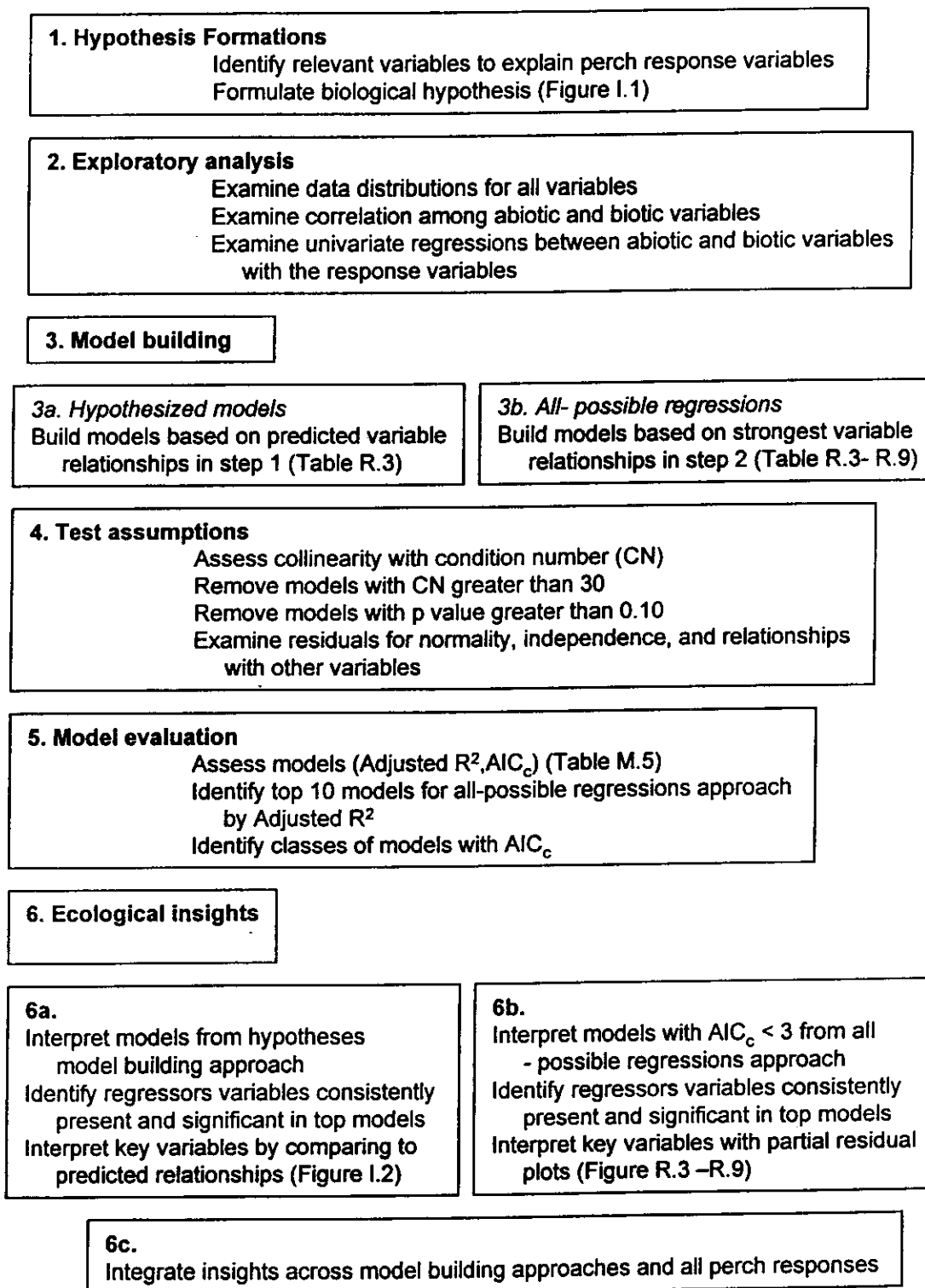


Figure. 5

Table 5 The six criteria, definitions, and objectives used to evaluate and interpret the multiple regression models for the perch response variables of the 16 kettle ponds in the summer 2000.

Number	Criteria	Definition	Objective	References
1	R^2	$R^2 = \frac{SS_{\text{model}}}{SS_{\text{total}}}$	Maximize	Myers (1990)
2	Adjusted R^2	Adjusted $R^2 = 1 - \frac{SS_{\text{error}}/n - p}{SS_{\text{total}}/n - p}$	Maximize	Kachigan (1991)
3	AIC_c	$AIC_c = -2\log(L(\theta) + 2K + \frac{2k(k+1)}{n - k - 1})$	Minimize	Burnham and Anderson (1998)
4	Significant β	$t = \beta / se$ (Partial F test)	Maximize t Minimize P	Philippi (1993)
5	Coefficient β sign	+ or -		
6	Biological Sense		Maximize	

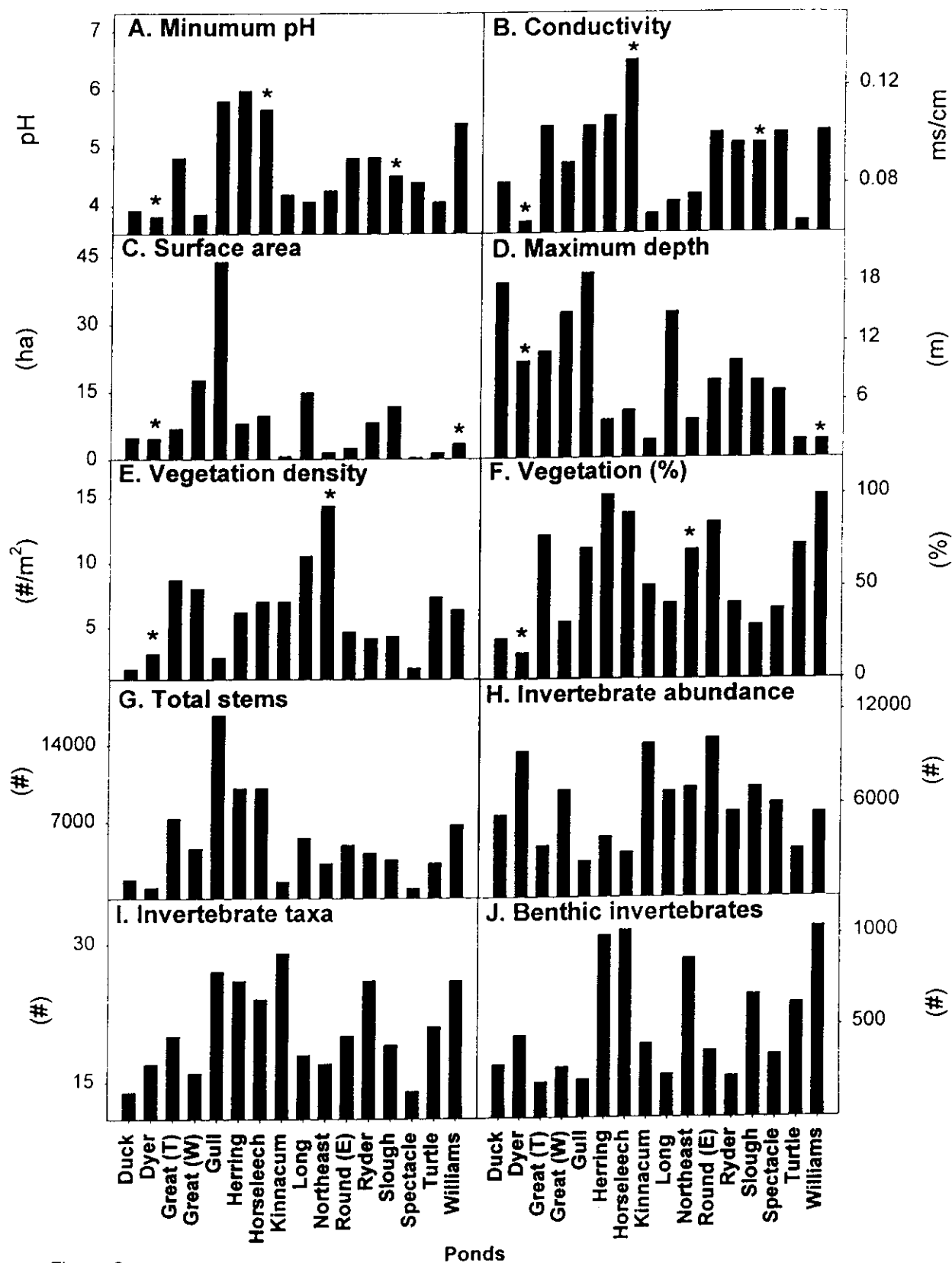


Figure 6

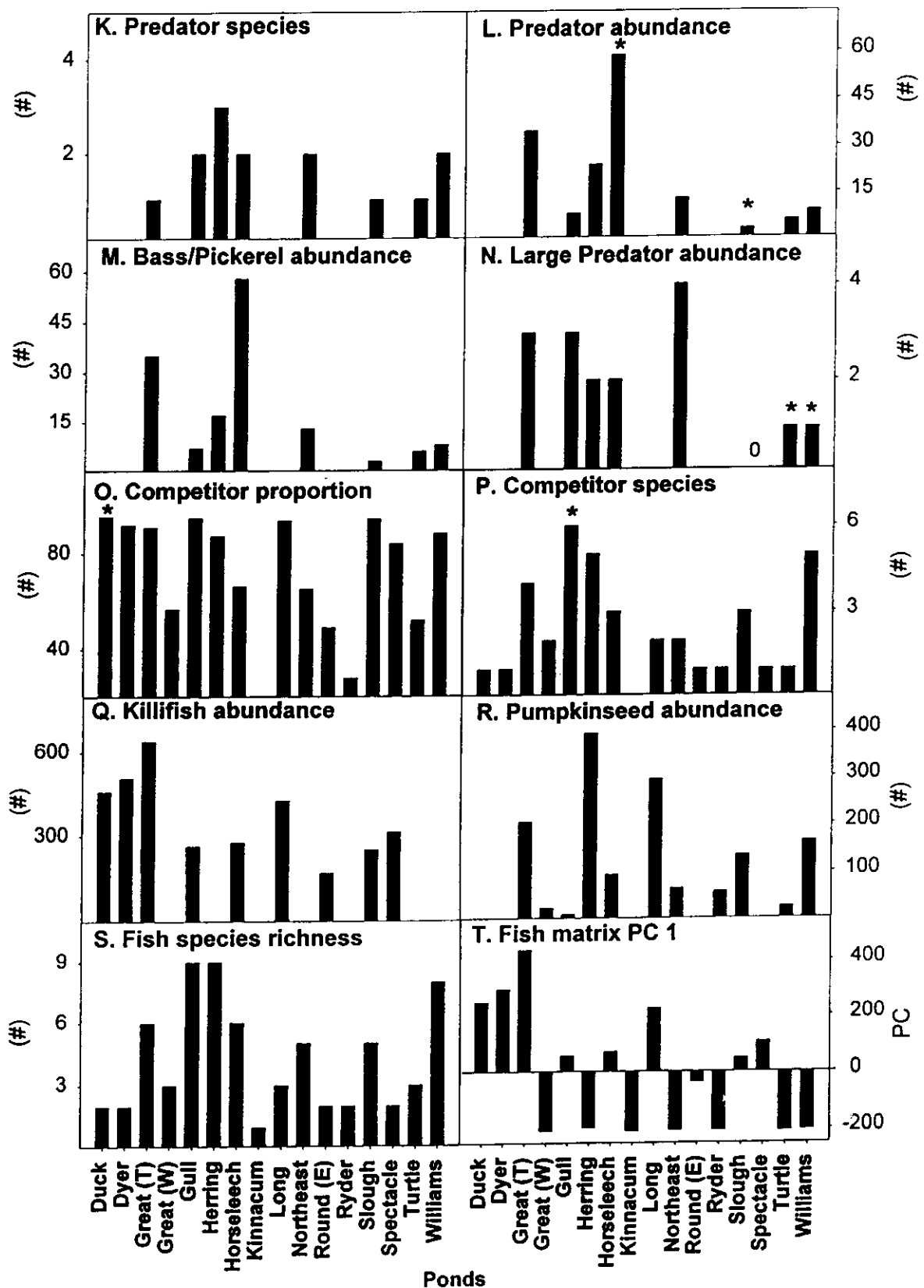


Figure 6 cont.

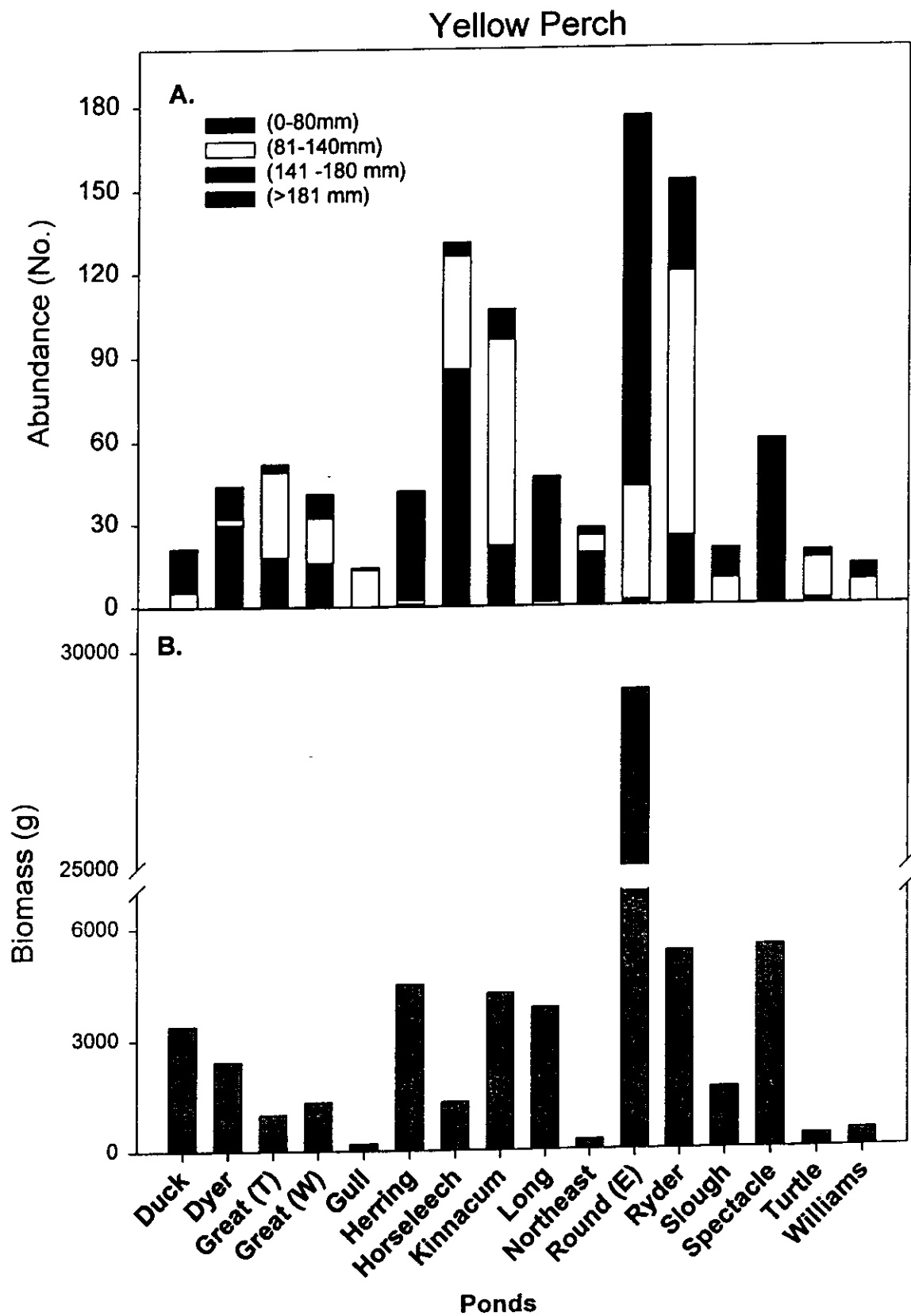
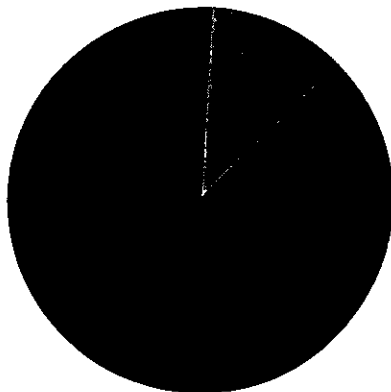


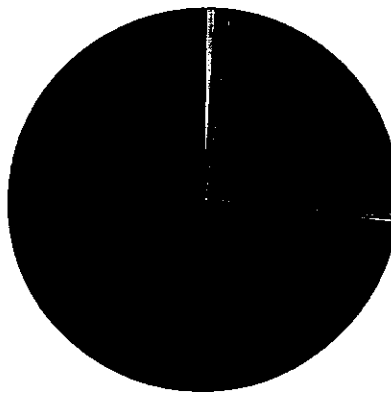
Figure 7

Perch 0 - 80 mm



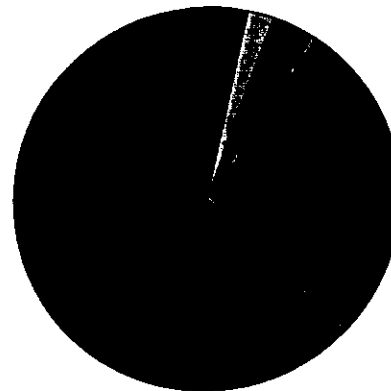
Zooplankton
Benthos
Unknown

Perch 81 - 140 mm



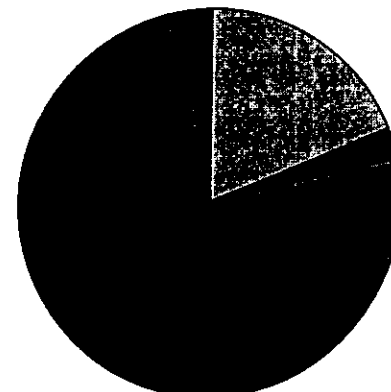
Zooplankton
Benthos
Unknown

Perch 141 - 180 mm



Zooplankton
Benthos
Unknown

Perch > 181 mm



Zooplankton
Benthos
Fish

Figure 8

Table 6 Results of principal components analysis of the fish community relative abundance matrix for the kettle ponds summer 2000 sampling. The proportion of variation accounted for by the first three principal components including the cumulative amounts (A). The variables accounting for the majority of each component is listed for the first three principal components, which are banded killifish (*Fundulus diaphanus*), pumpkinseeds (*Lepomis gibbosus*) and yellow perch (*Perca flavescens*) for principal components 1, 2, and 3 respectively.

A

<u>Eigenvalue</u>	<u>Proportion</u>	<u>Cumulative</u>
1	0.7287	0.7287
2	0.2178	0.9465
3	0.04	0.9869

B

	<u>Principal Component 1</u>	<u>Principal Component 2</u>	<u>Principal Component 3</u>
Banded Killifish	0.9986		
Pumpkinseed		0.9915	
Yellow Perch			0.9734

Table 7 The correlation of key variables related to the across pond patterns of perch response variables during the summer 2000. The Pearson's correlation coefficient and p value are listed. The variables include sample date pH, conductivity (ms/cm), invertebrates abundance (#), predator species (#), competitor proportion, and fish richness (#).

	Sample date pH	Conductivity	Stem density	Invertebrates abundance	Predators species	Competitor proportions	Fish Richness
Sample Date pH	1	0.756 0.0007	-0.091 0.738	-0.611 0.012	0.581 0.018	0.272 0.307	0.881 0.001
Conductivity		1	-0.209 0.437	-0.474 0.064	0.474 0.064	0.216 0.422	0.568 0.021
Stem Density			1	0.016 0.954	0.271 0.311	-0.173 0.523	0.129 0.635
Invertebrates abundance				1	-0.594 0.015	-0.365 0.164	-0.642 0.007
Predator species					1	0.308 0.246	0.914 0.0001
Competitor proportions						1	0.487 0.056
Fish richness							1

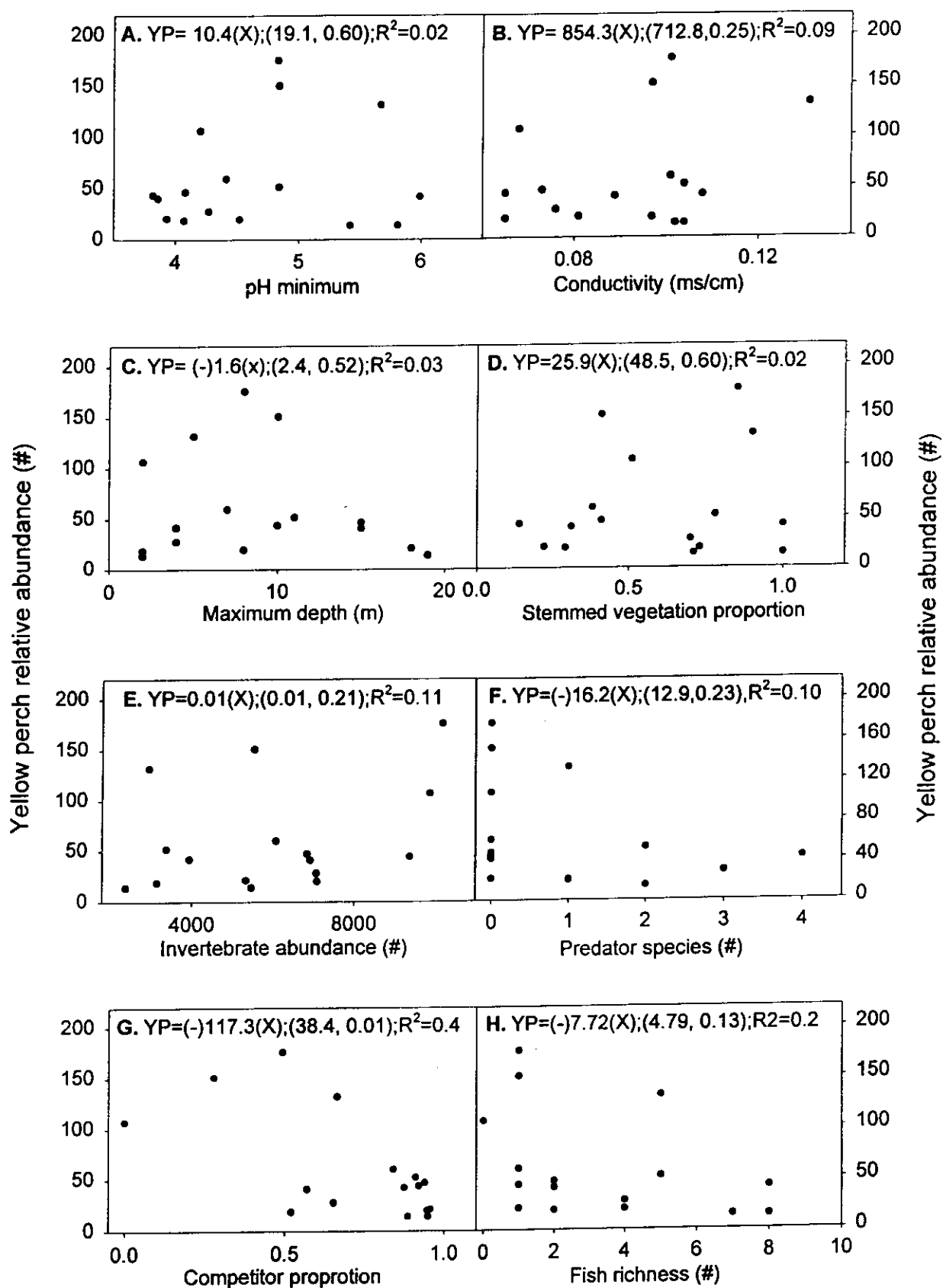


Figure 9

All possible regressions interpretation steps

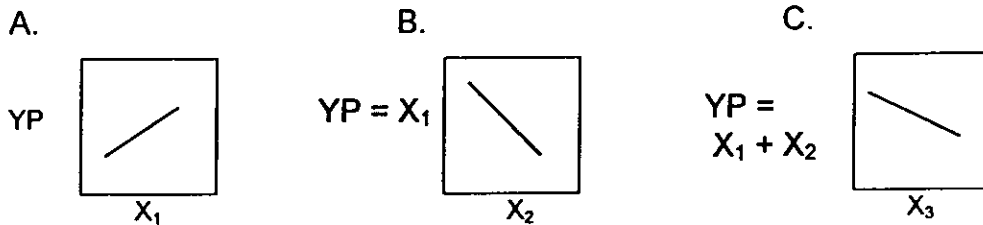
Model	Evaluation criteria	Variables	Interpreted
1	# # # # #	(X ₁) (X ₂) (X ₃)	Figure
2	# # # # #	(X ₁) (X ₂) (X ₃)	Figure
Step 3			
9	# # # # #	X ₁ X ₂ X ₃ X ₄	
10	# # # # #	X ₁ X ₂ X ₅	

Step 1 Identify top models by adjusted R^2 that satisfy assumptions for each response variable listed by ascending AICc values. (Models 1 ... 10)

Step 2 Identify top class of models based on AICc (<3) and group them for interpretation (Model 1 and 2)

Step 3 Identify consistently important and significant (indicated by parentheses) regressors in the top class of models (X₁, X₂, and X₃)

Step 4 Examine nature of interaction between response (YP) and regressor variables of top models with partial residual plots (A – C).



Step 5. If a relationship exists between the residuals of the response variable (YP) equal to the first regressor (X₁) and the second regressors variable (X₂) then X₂ is contributing to the explanation of the response variable patterns. These relationships were explored sequentially through the regressor variables, i.e., YP = X₁ + X₂ plotted against X₃.

Figure 10

Predicted relationships of regressors and the response variables of yellow perch for the kettle ponds on the Cape Cod National Seashore.

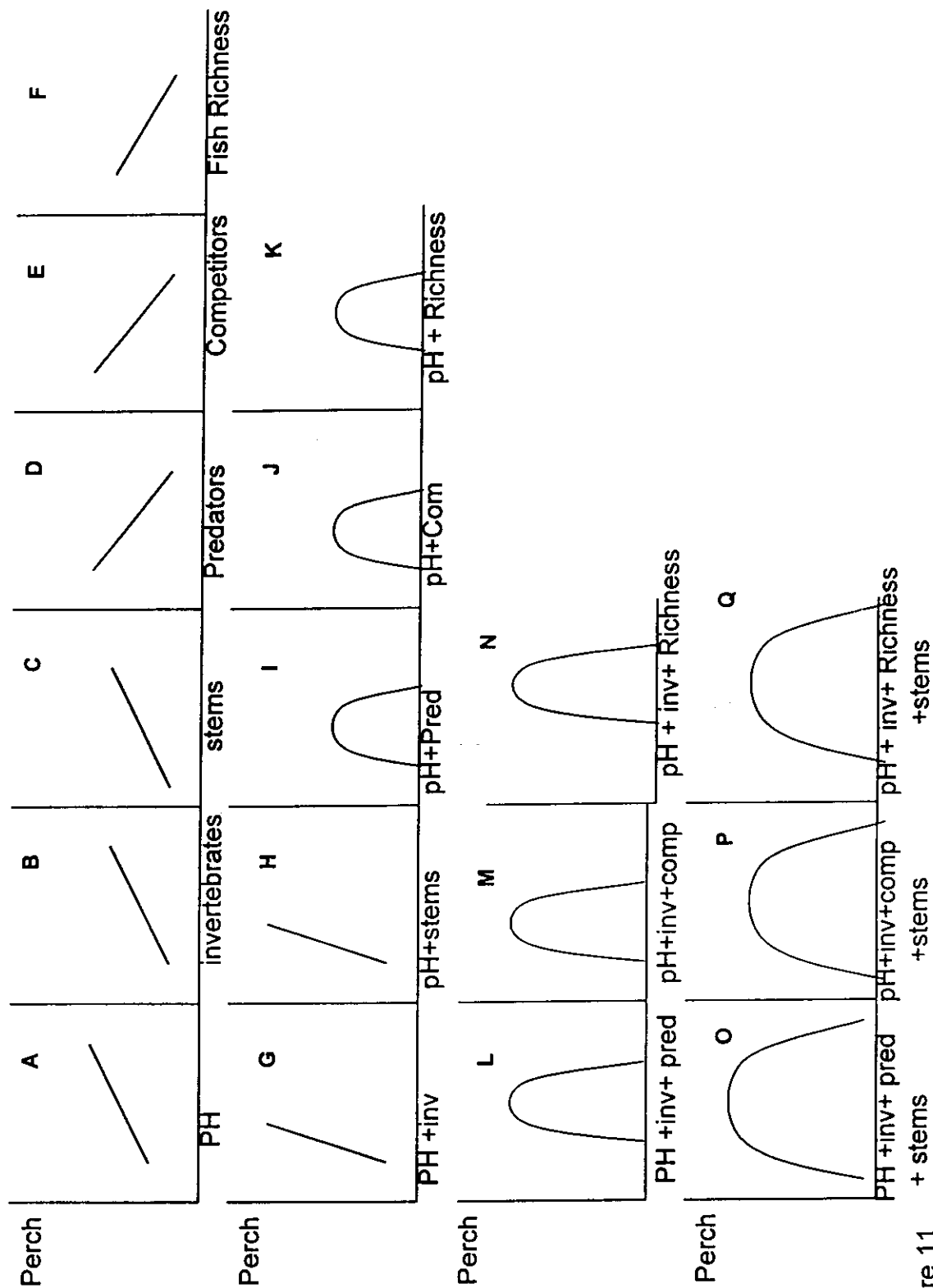


Figure 11

Table 8 Hypothesized models

Evaluation Criteria					Variables								
Model	AIC _c	Adj.R ²	R ²	CN	P	pH min	Inv ab	Pred sp	Comp (%)	Fish sp	Stem (#)	Interpreted	Prediction panels
1-1	21.87	0.15	0.26	21.9	0.14	+	(+)					No	
1-2	16.62	0.39	0.47	22.9	0.02	(+)		(-)				Yes	A, D, I
1-3	13.28	0.38	0.47	16.2	0.02	+			(-)			Yes	A, E, J
1-4	0.00	0.78	0.81	25.6	0.00	(+)				(-)		Yes	A, F, K
1-5	26.36	-0.13	0.02	22.8	0.86	+					+	No	
1-6	16.96	0.44	0.55	27.7	0.02	(+)	+	(-)				Yes	A, B, D, L
1-7	17.11	0.44	0.55	26.0	0.02	(+)	+		(-)			Yes	A, B, E, M
1-8	1.22	0.79	0.83	29.8	0.00	(+)	+			(-)		Yes	A, B, F, N
1-9	17.09	0.51	0.64	33.9	0.02	(+)	+	(-)			+	No	
1-10	20.35	0.40	0.56	33.7	0.04	+	+		(-)		-	No	
1-11	2.54	0.80	0.85	37.4	0.00	(+)	+			(-)	+	No	

Table 9 Total abundance

Evaluation Criteria						Variables								Interpreted
Model	AIC _c	Adj.R ²	R ²	CN	P	pH min	Fish sp	Cond x	Inv ab	Pred sp	Area	Stem #	Comp (%)	
2-1	0.00	0.78	0.81	25.6	<0.01	(+)	(-)							Fig. R.5 A,B
2-2	1.22	0.79	0.83	29.8	<0.01	(+)	(-)		+					Fig. R.5 A,B, C
2-3	3.01	0.77	0.81	28.9	<0.01	(+)	(-)			+				Fig. R.5 A,B,D
2-4	3.04	0.77	0.81	28.4	<0.01	(+)	(-)				-			Fig. R.5 A,B,E
2-5	7.26	0.74	0.81	19.01	<0.01		(-)	(+)				+	(-)	No
2-6	7.58	0.73	0.80	21.46	<0.01		(-)	(+)	+				(-)	No
2-7	8.80	0.76	0.84	23.86	<0.01		(-)	(+)	+			+	(-)	No
2-8	9.93	0.74	0.83	21.63	<0.01		(-)	(+)	+		+	(+)		No
2-9	10.40	0.73	0.82	20.84	<0.01		(-)	(+)			+	+	-	No
2-10	11.29	0.71	0.81	21.49	<0.01		-	(+)		-		+	(-)	No

Total perch abundance (#)

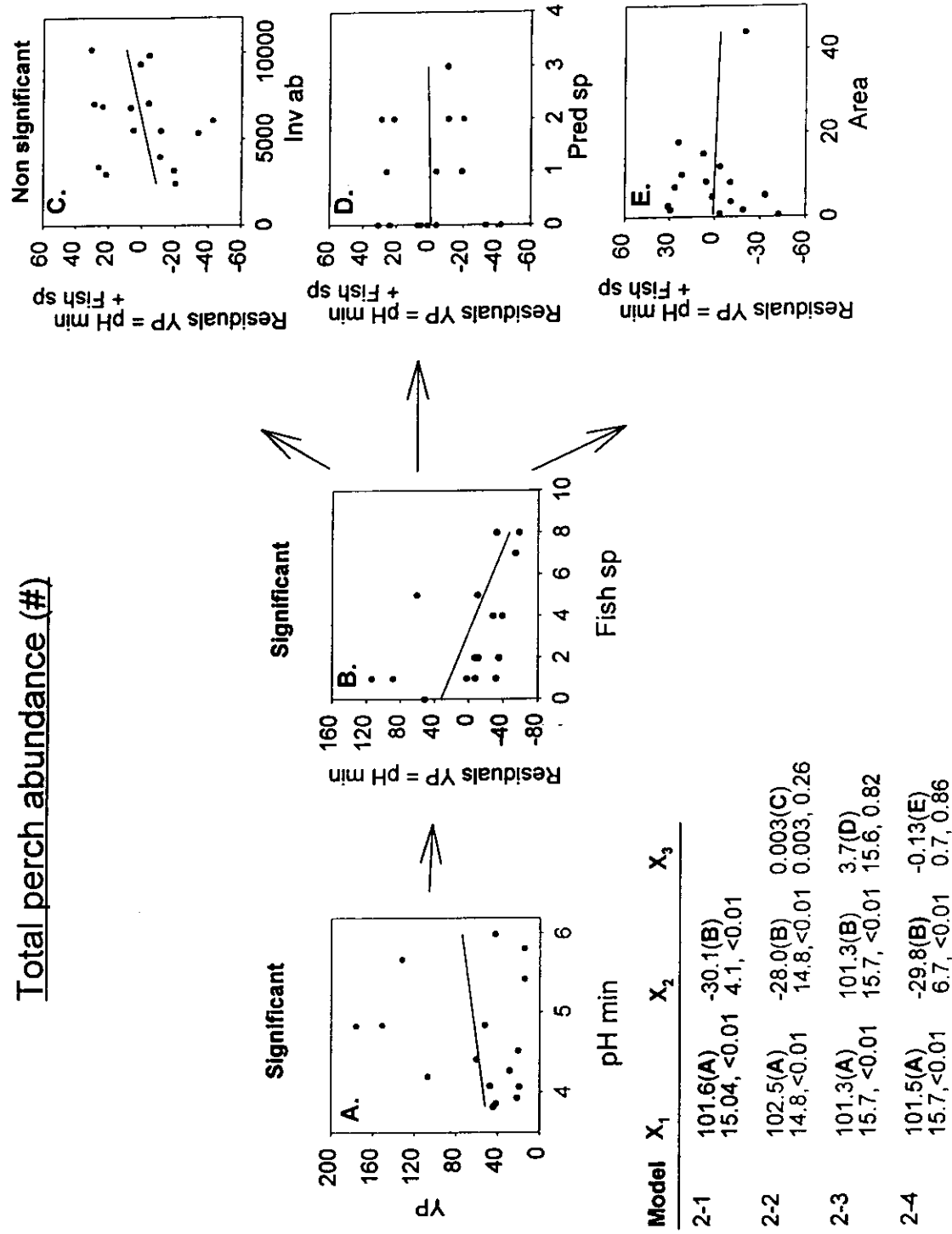


Figure 12

Table 10 0-80mm

Evaluation Criteria						Variables								Interpreted	
Model	AIC _c	Adj.R ²	R ²	CN	P	Comp (%)	Pred ab	pH min	Cond	Depth	Stem (#)	Inv rich	Fish sp		YP140
3-1	0.00	0.59	0.68	20.0	<0.01	(-)	(+)	(-)							Fig. R.6 A,B,C
3-2	2.15	0.54	0.63	16.5	<0.01	(-)	(+)		-						Fig. R.6 A,B,D
3-3	2.96	0.59	0.68	22.4	<0.01	(-)	(+)	(-)		+					Fig. R.6 A,B,D,E
3-4	3.58	0.56	0.68	22.7	<0.01	(-)	(+)	(-)					+		No
3-5	3.58	0.56	0.68	29.1	<0.01	(-)	(+)	-	-						No
3-6	3.61	0.56	0.68	25.0	<0.01	(-)	(+)	(-)			-				No
3-7	4.16	0.54	0.67	18.3	0.01	(-)	(+)		(-)	+					No
3-8	4.31	0.54	0.66	19.7	0.01	(-)	(+)		-			-			No
3-9	4.44	0.54	0.66	19.7	0.01	(-)	(+)		-				-		No
3-10	7.30	0.53	0.69	24.7	0.02	(-)	(+)	(-)		+				-	No

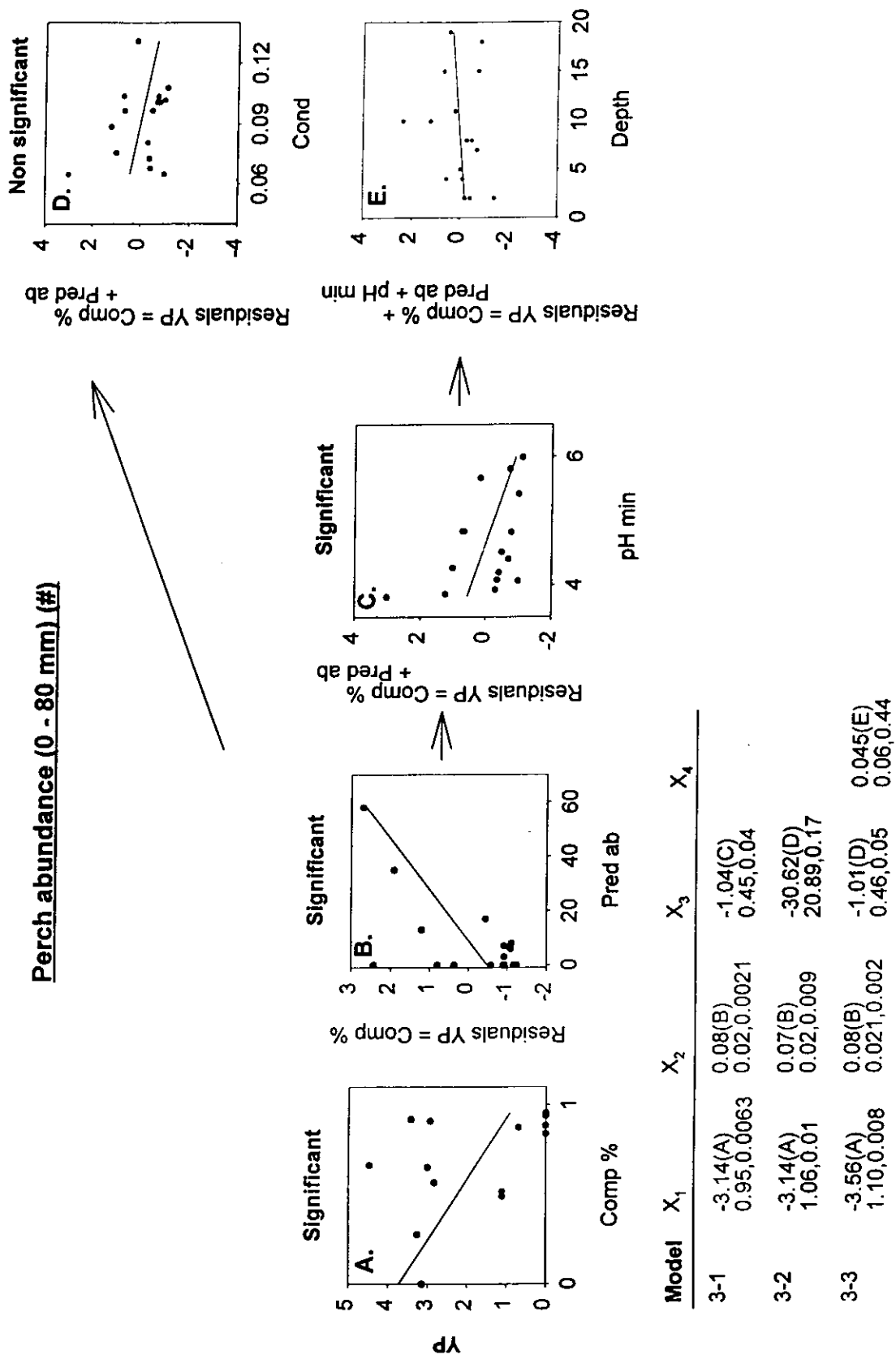


Figure 13

Table 11 81 -140 mm

Evaluation Criteria						Variables							Interpreted	
Model	AIC _c	Adj.R ²	R ²	CN	P	Comp (%)	YP180	Cond	Pred (major)	Depth	Stem (#)	Inv rich		Fish sp
4-1	0.00	0.75	0.80	18.8	<0.01	(-)	(-)	+						Fig. R.7 A,B,C
4-2	1.02	0.74	0.79	6.8	<0.01	(-)	(-)		(+)					Fig. R.7 A,B,D
4-3	1.82	0.76	0.82	18.0	<0.01	(-)	(-)	+	+					Fig. R.7 A,B,D,E
4-4	3.24	0.74	0.81	17.9	<0.01	(-)	(-)	(+)				+		No
4-5	3.50	0.73	0.81	15.4	<0.01	(-)	(-)	(+)		+				No
4-6	3.53	0.73	0.80	8.0	<0.01	(-)	(-)		(+)	+				No
4-7	5.33	0.75	0.83	19.6	<0.01	(-)	(-)	+	+	+				No
4-8	5.86	0.74	0.83	21.1	<0.01	(-)	(-)	+	+			+		No
4-9	6.16	0.74	0.83	20.1	<0.01	(-)	(-)	+	+					No
4-10	6.18	0.74	0.82	21.2	<0.01	(-)	(-)	+	+					No

Perch abundance (81 -140 mm) (#)

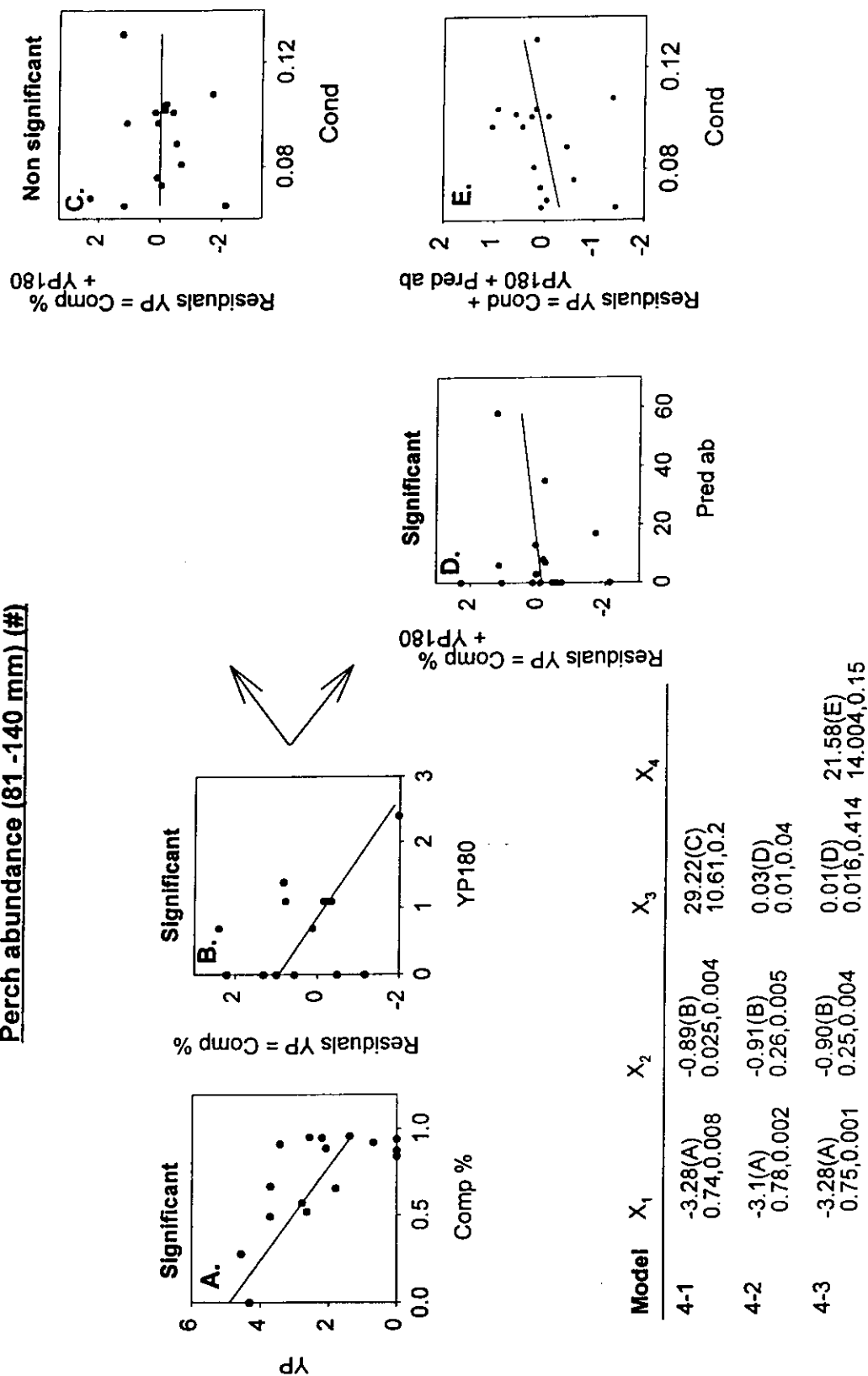


Figure 14

Table 12 141 -180 mm

Evaluation Criteria						Variables								Interpreted	
Model	AIC _c	Adj.R ²	R ²	CN	P	Yp140	Depth	Inv ben	Cond	pH min	Ps ab	Stem (all)	Pred sp		PC 1
5-1	0.00	0.42	0.50	5.1	0.01	(-)	-								Fig. R.8 A,B
5-2	1.00	0.38	0.47	5.3	0.02	(-)		+							Fig. R.8 A,C
5-3	1.48	0.43	0.55	13.8	0.02	(-)	-		+						Fig. R.8 A,B,D
5-4	2.29	0.40	0.52	18.6	0.03	(-)	-			+					Fig. R.8 A,B,E
5-5	2.77	0.39	0.51	6.7	0.03	(-)	-				+				Fig. R.8 A,B, F
5-6	4.63	0.40	0.56	17.1	0.05	(-)	-		+			+			No
5-7	4.67	0.40	0.56	15.1	0.05	(-)	-	-	+						No
5-8	4.86	0.39	0.55	16.1	0.05	(-)	-		+				-		No
5-9	5.02	0.38	0.55	14.1	0.05	(-)	-		+					-	No
5-10	5.10	0.38	0.55	14.9	0.05	(-)			+			+		-	No

Perch abundance (141 -180 mm) (#)

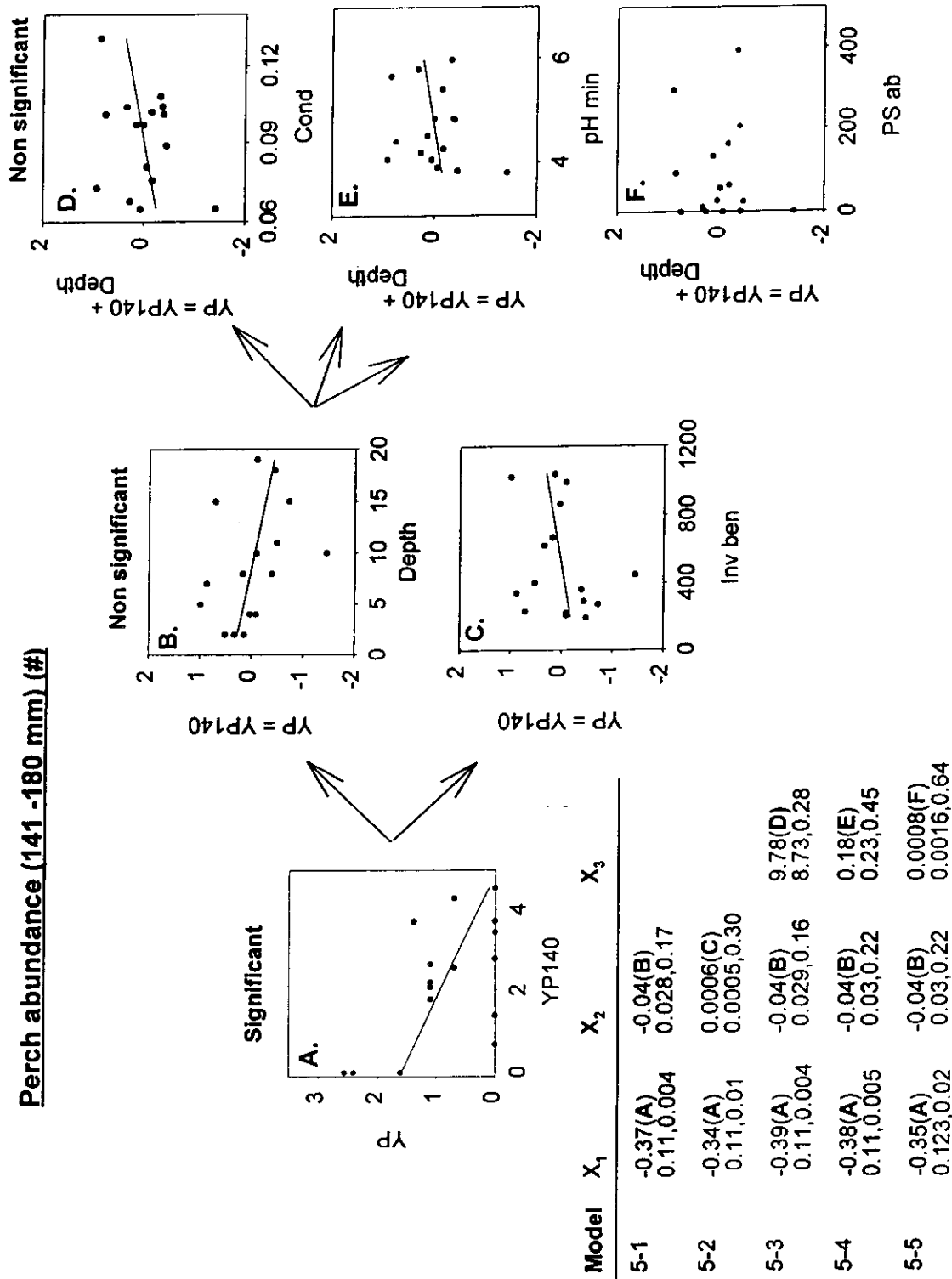


Figure 15

Table 13 >180 mm

Evaluation Criteria						Variables								Interpreted	
Model	AIC _c	Adj.R ²	R ²	CN	P	Inv ab	Cond	YP140	Pred (lg)	Fish sp	Comp sp	Area	Stem (all)		pH x
6-1	0.00	0.56	0.68	20.0	<0.01	(+)	(+)	-	(-)						Fig R.9 A,B,C,D
6-2	0.87	0.54	0.66	20.1	0.01	(+)	(+)	(-)		(-)					Fig R.9 A,B,C,E
6-3	2.45	0.57	0.72	22.3	0.01	(+)	(+)	(-)	-	-					Fig R.9 A,B,C,D,F
6-4	2.66	0.57	0.71	22.2	0.02	(+)	(+)	(-)	(-)		-				Fig R.9 A,B,C,D,G
6-5	2.99	0.56	0.71	21.3	0.02	(+)	(+)	-	(-)			-			Fig R.9 A,B,C,D,H
6-6	4.22	0.52	0.68	22.1	0.02	(+)	(+)	-	(-)				-		No
6-7	4.50	0.52	0.68	13.4	0.03	+		-	(-)			(-)	(+)		No
6-8	4.81	0.51	0.67	23.1	0.03	(+)	(+)	(-)		-	+				No
6-9	4.84	0.51	0.67	21.8	0.03	(+)	(+)	(-)		(-)			+		No
6-10	4.86	0.50	0.70	27.7	0.03	+		-	(-)			-		(+)	No

Perch abundance (>180 mm) (#)

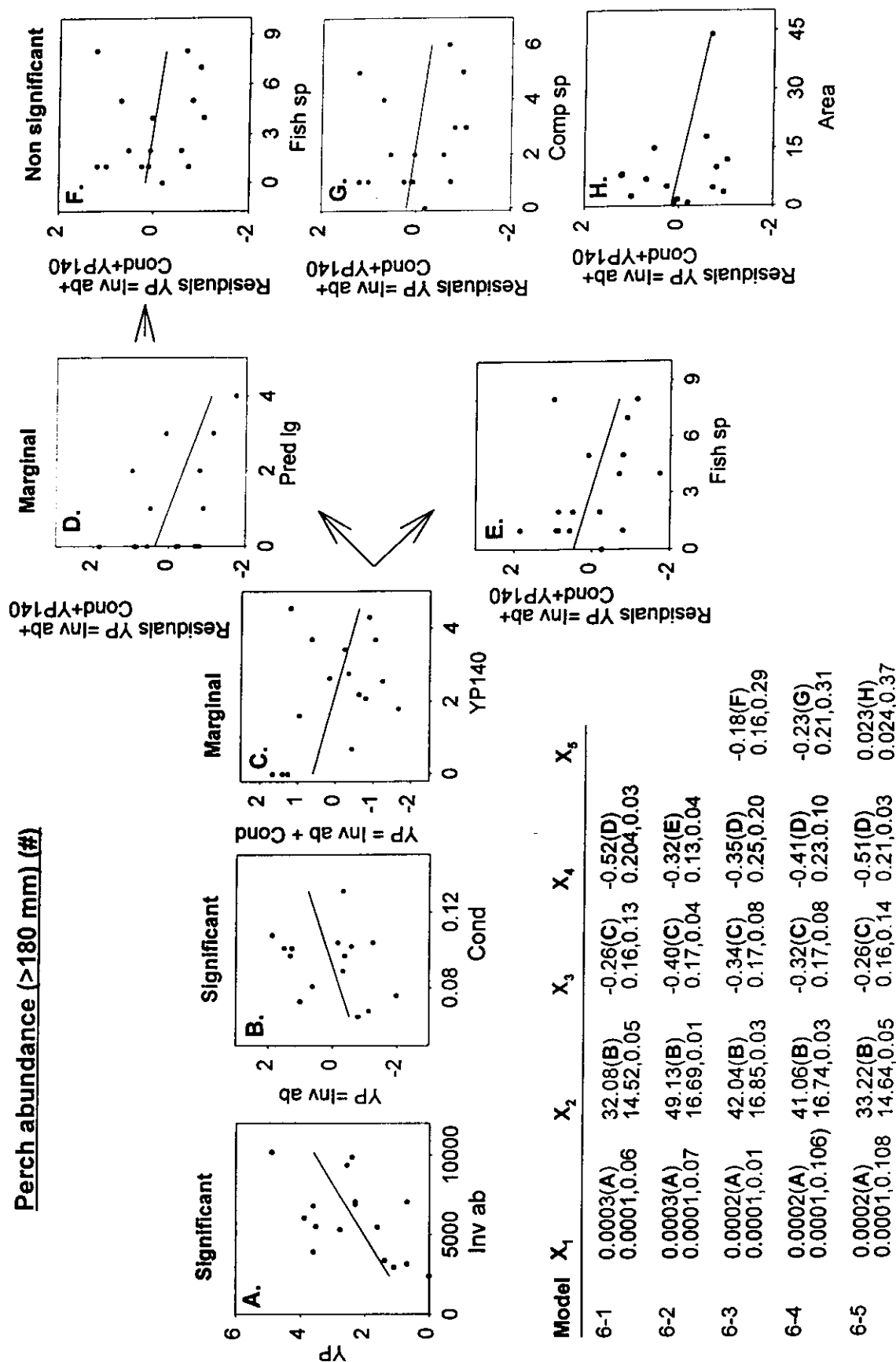


Figure 16

Table 14 Biomass

Evaluation Criteria						Variables						Interpreted	
Model	AIC _c	Adj.R ²	R ²	CN	P	Cond	Inv ab	Pred (lg)	Comp (sp)	Fish (sp)	Area		Stem (#)
7-1	0.00	0.55	0.64	17.9	0.01	(+)	(+)	(-)					Fig. R.10 A,B,C
7-2	1.37	0.58	0.69	20.1	0.01	(+)	+	(-)	-				Fig. R.10 A,B,C,D
7-3	1.56	0.57	0.69	20.1	0.01	(+)	+	-	-				Fig. R.10 A,B,C,E
7-4	2.09	0.56	0.67	19.4	0.01	(+)	(+)	(-)			-		Fig. R.10 A,B,C,F
7-5	4.47	0.58	0.72	13.6	0.01		+	(-)		-	(-)	(+)	No
7-6	5.19	0.55	0.70	24.1	0.02	(+)	(+)	(-)			-	+	No
7-7	5.19	0.55	0.70	21.8	0.02	(+)	+	-		-	-		No
7-8	5.21	0.55	0.70	22.2	0.02	(+)	(+)	(-)	-			+	No
7-9	5.25	0.55	0.70	13.7	0.02		+	(-)	-		(-)	(+)	No
7-10	5.37	0.54	0.70	21.8	0.02	(+)	+	(-)	-		-		No

Total Perch biomass (g)

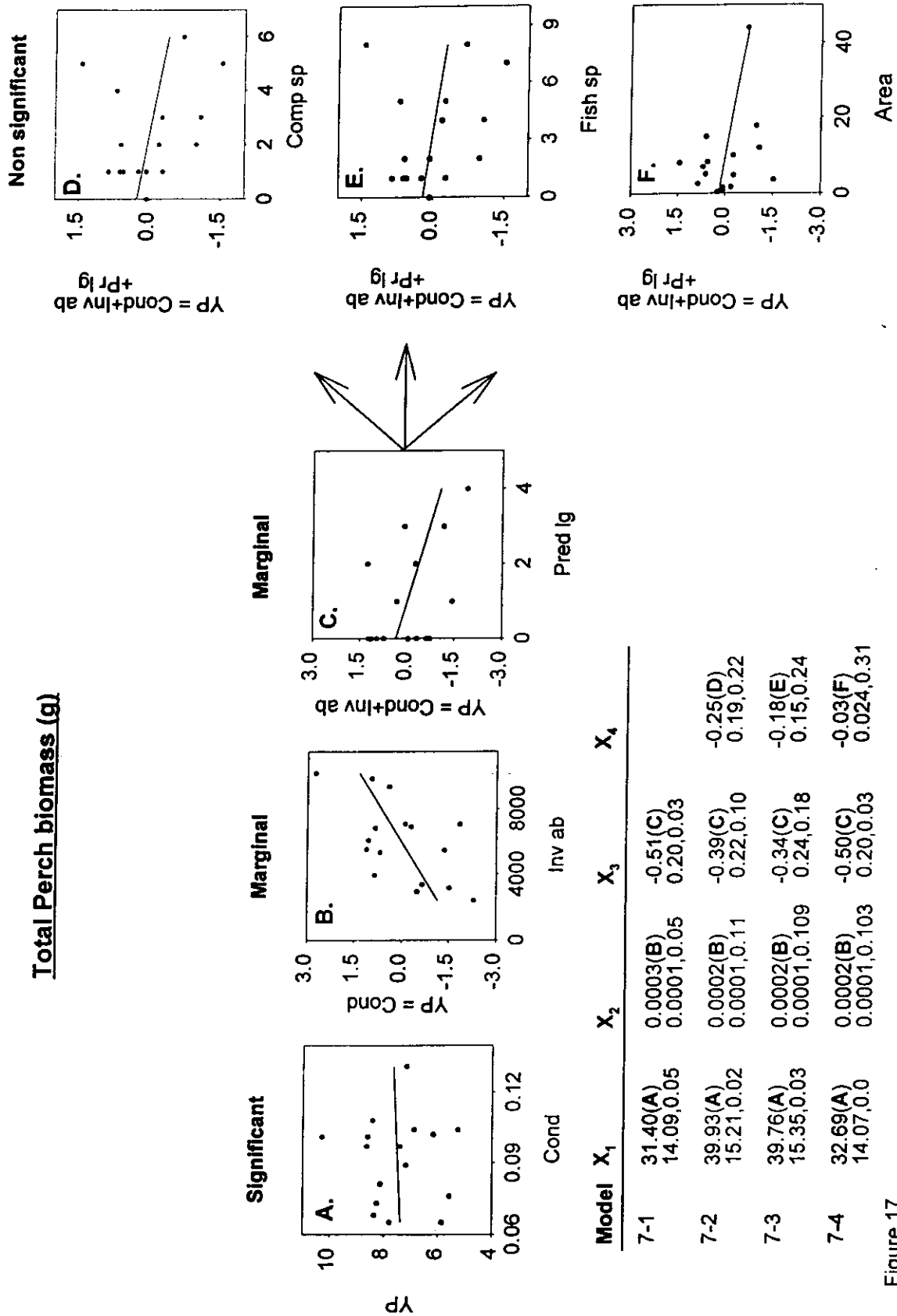


Figure 17

Table 15 summary

Model	Adj.R ²	Variables								
		pH min	Cond x	Comp %	Fish sp	YP140	YP180	Pred ab	Pred lg	Depth Inv ab
Total (#)	0.78	101.6			-30.12					
2-1		(-15.04)			-4.1					
		(<0.01)			(<0.01)					
<80 mm	0.68	-1.04		-3.15				0.08		
3-1		-0.45		(0.95)				-0.02		
		(<0.04)		(<0.01)				(<0.01)		
81 -140 mm	0.75		29.2	-3.28			-0.89			
4-1			(10.6)	-0.74			-0.25			
			(0.02)	(<0.01)			(<0.01)			
141 - 180mm	0.42									
5-1					-0.37					-0.04
					(0.11)					(0.03)
					(<0.01)					(0.17)
>181 mm	0.56		31.4		-0.26			-0.52		0.0003
6-1			(14.09)		(0.16)			(0.2)		(.0001)
			(0.05)		(0.13)			(0.03)		(0.06)
Biomass	0.55		31.40					-0.51		0.0003
7-1			(14.09)					(0.2)		(.0001)
			(0.05)					(0.03)		(0.05)

Flow chart of the fish community analysis

(1) Classify fish

PCA on fish community



(2) Test classifications

Discriminant function
analysis on physical
and biological variables



(3) Understand why

Stepwise discriminant
analysis

Figure 18

Relative Abundance - Fish Groupings

Tier 2

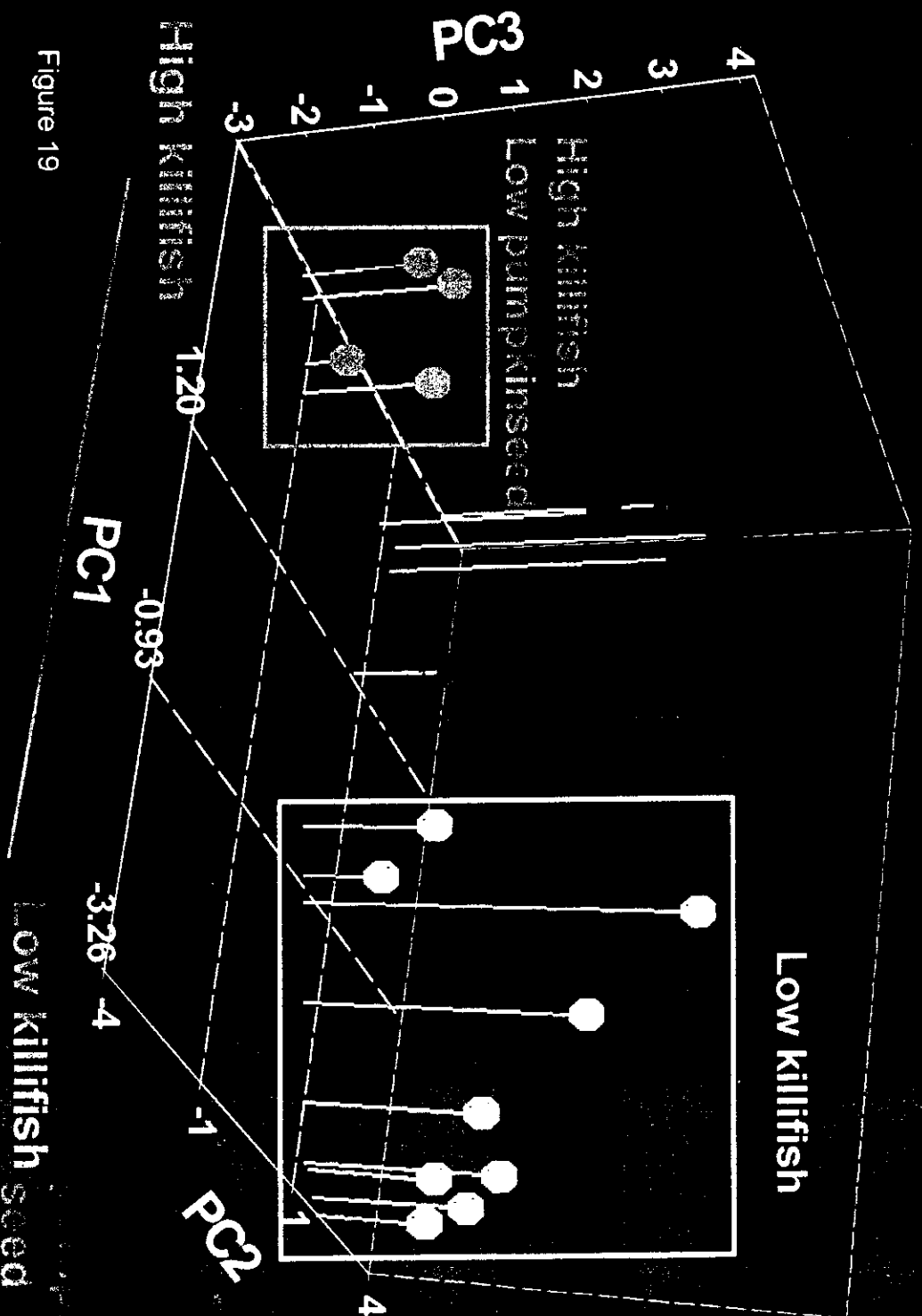


Figure 19

Discriminant Function Analysis Results

Relative Abundance (*Intensive/Extensive*) - Tier 2 Fish clusters

Discriminant Function			
		2a	2b
<u>Killifish</u>		High	High
<u>Pumpkinseed</u>		High	Low
<u>Perch</u>			
MAXDPTH	0.481164	0.498473	-0.488088
LOGAREA	1.272331	-0.626936	-0.512624
LOGDWELL	1.433722	-1.000372	-0.460084
SURFTEMP	-0.373459	0.446755	0.045373
SURFDO	0.243910	-0.205328	-0.064214
SURFPH	0.935688	-0.667529	-0.294401
SURFCOND	0.492641	-0.130955	-0.243202

Discriminant Function Analysis Results

Relative Abundance (*Intensive/Extensive*) - Tier 2 Fish clusters

Number of correct classifications				
	<u>Killifish</u> <u>Pumpkinseed</u>	2a High High	2b High Low	2c Low
2a	High Killifish High Pumpkinseed	6	0	0
2b	High Killifish Low Pumpkinseed	0	4	0
2c	Low killifish	0	0	10
Total Correct		100%	100%	100%

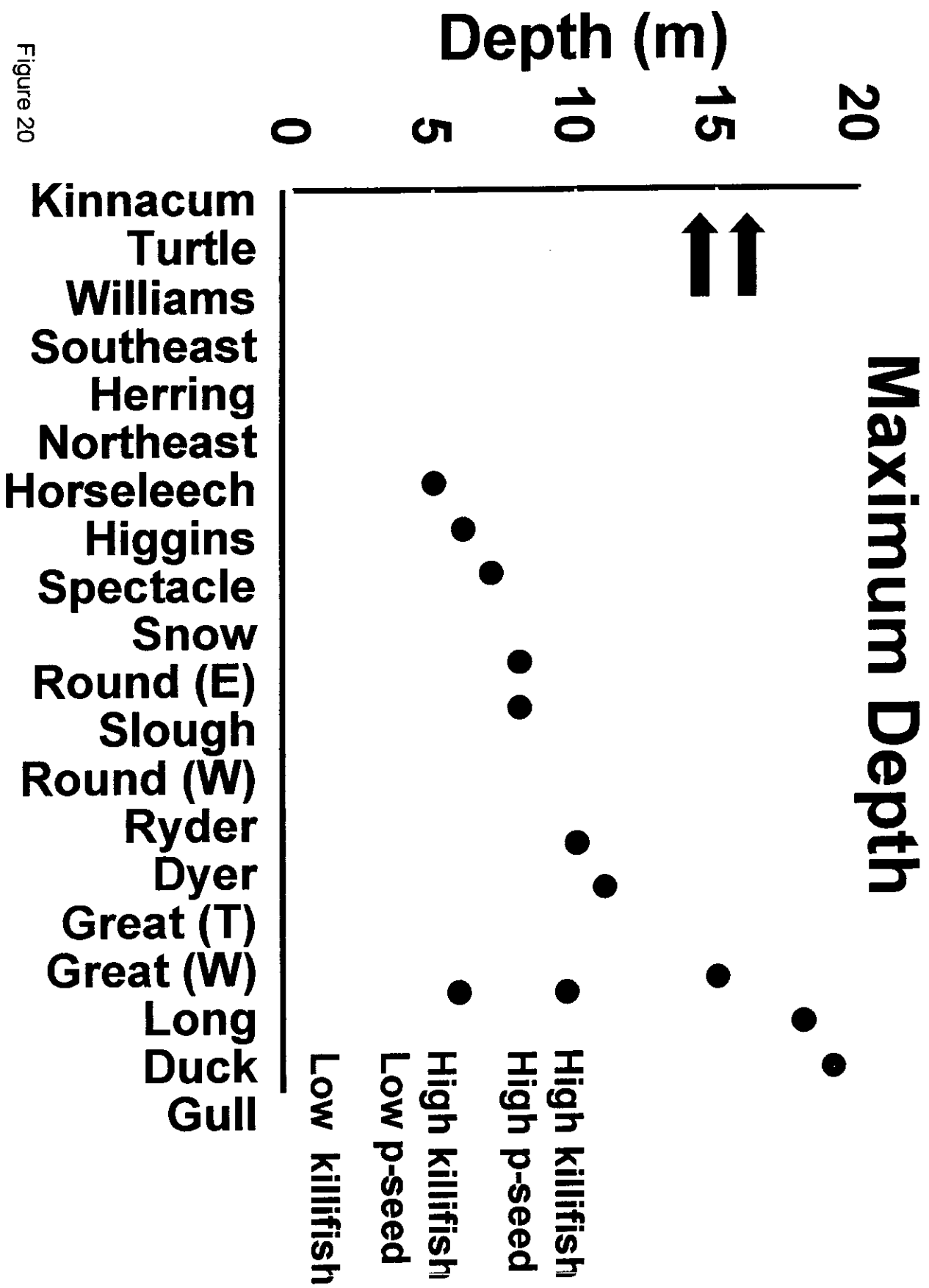
Table 17

Stepwise Discriminant

Relative Abundance (*Intensive/Extensive*) - Tier 2 Fish clusters

	R ²	F Statistic	Prob F
Variables retained			
Maximum depth	23	2.195	0.1458
Number of dwellings	52	9.227	0.0019
pH	32	3.73	0.0468

Table 18



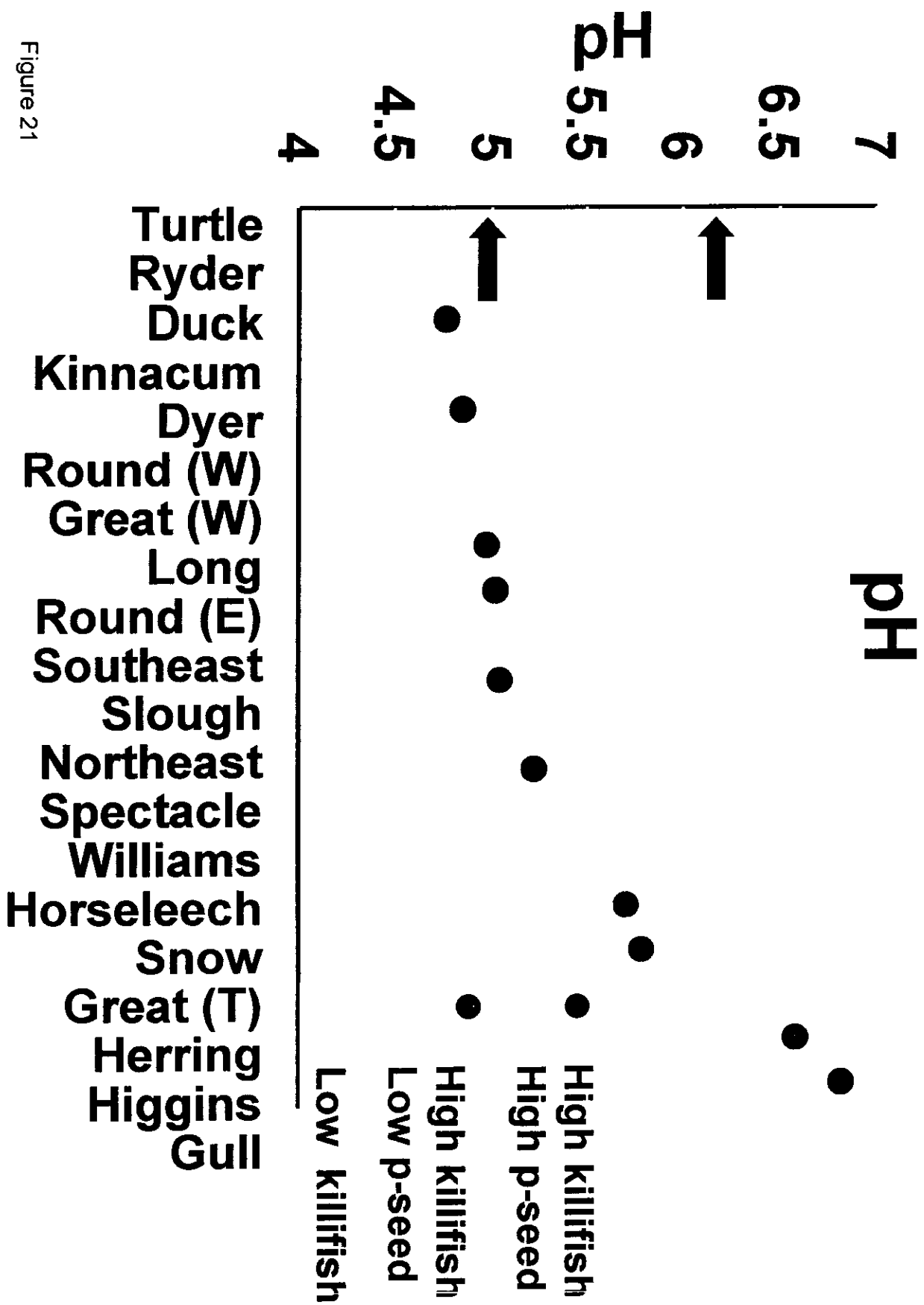


Figure 21

Influence of Temporal Scale on Fish Community Patterns

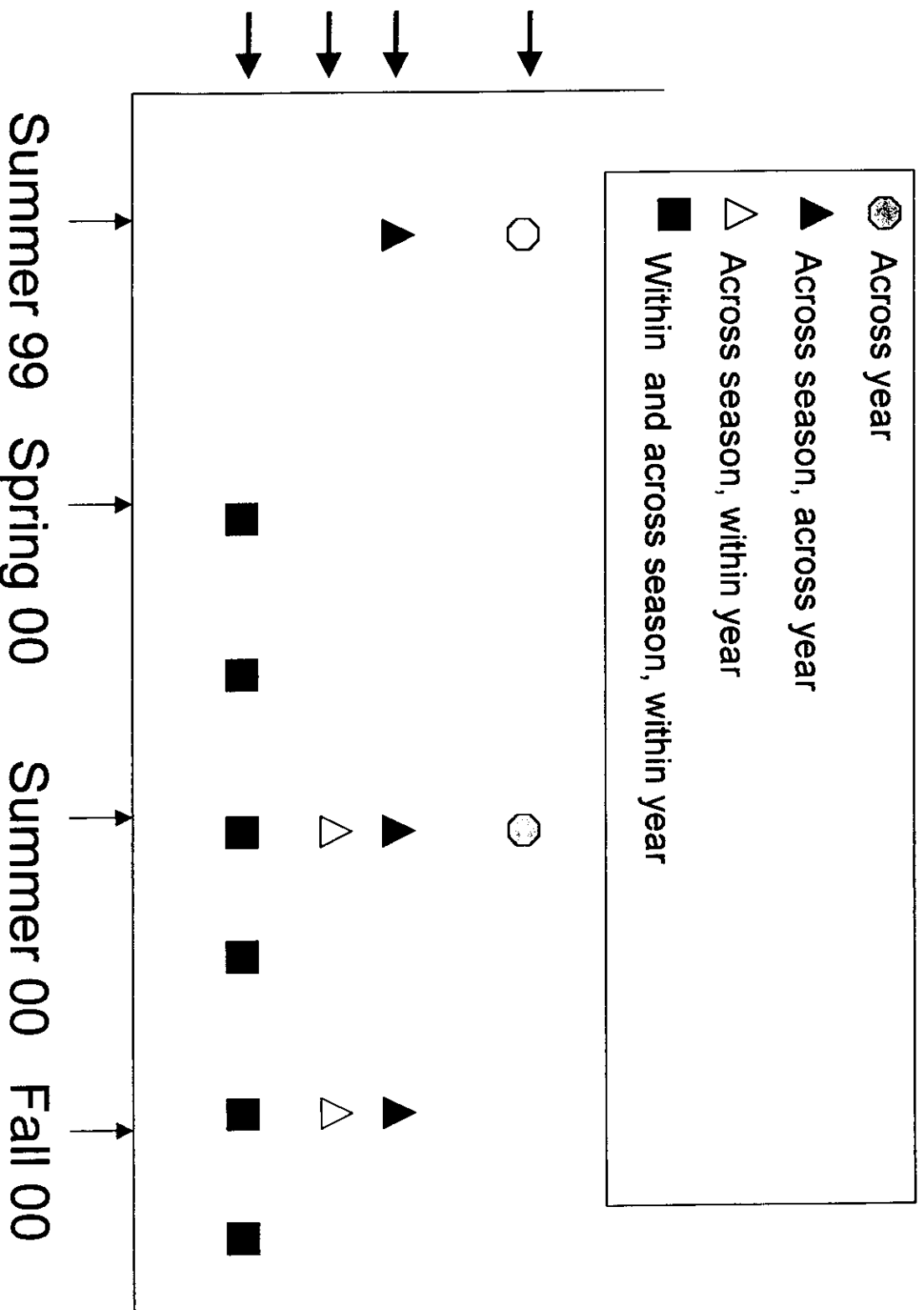


Figure 22

Yellow Perch Relative Abundance

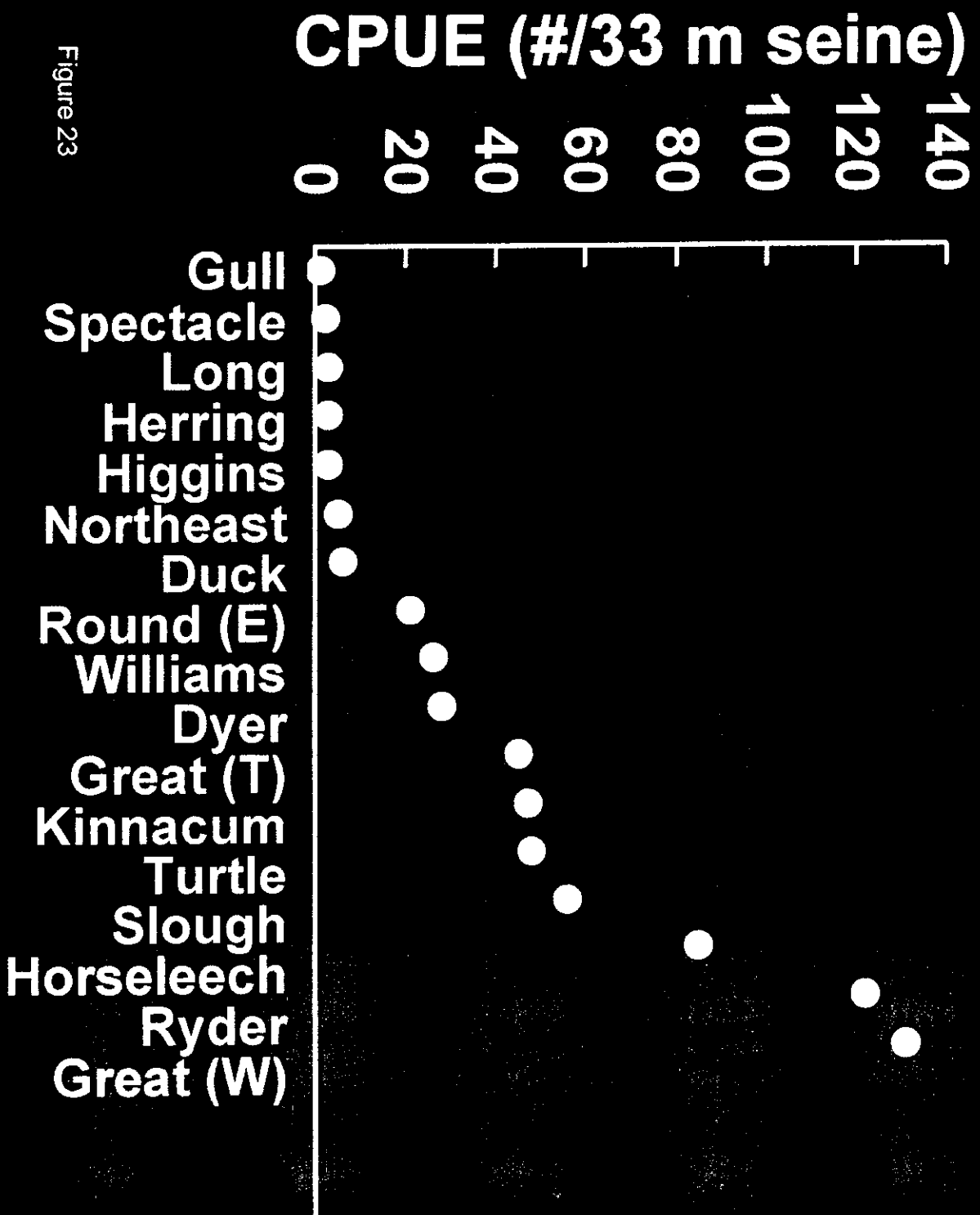


Figure 23

Cape Cod Ponds Fish Relative Abundance

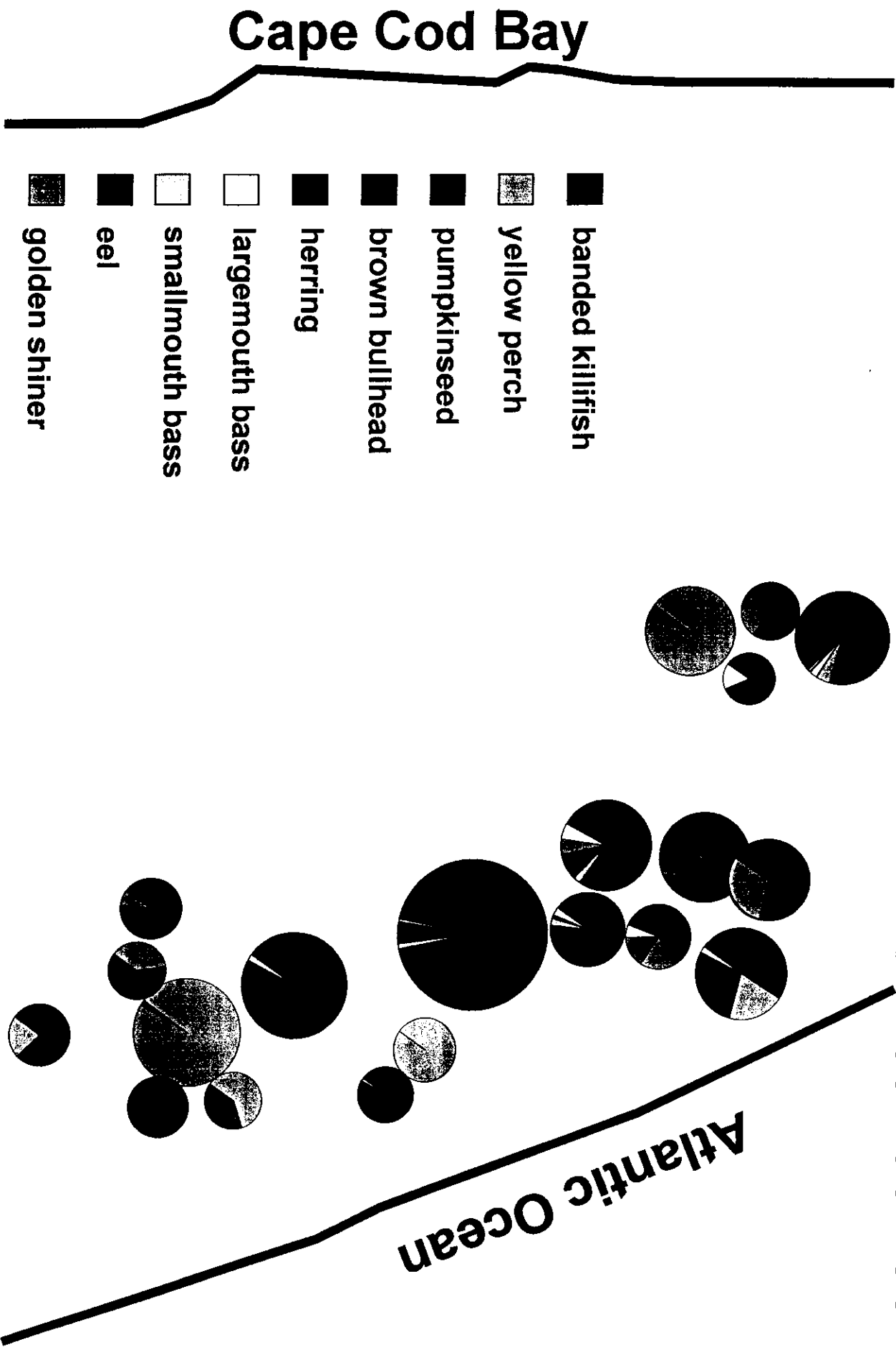


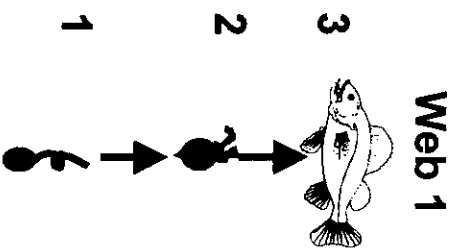
Figure 24

Examples of the different trophic configurations in which yellow perch are found in Kettle Ponds

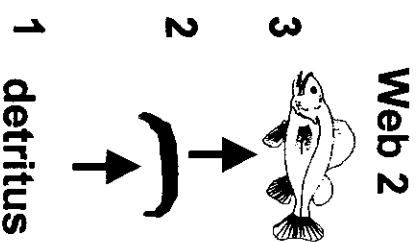


Figure 25

Location: Water column
Production: Phytoplankton



Sediment
Detritus



Vegetation
Periphyton

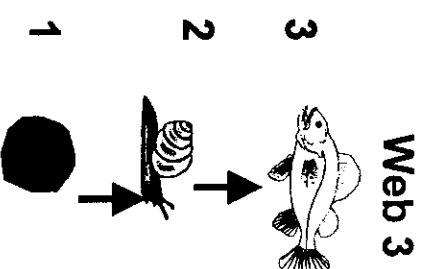
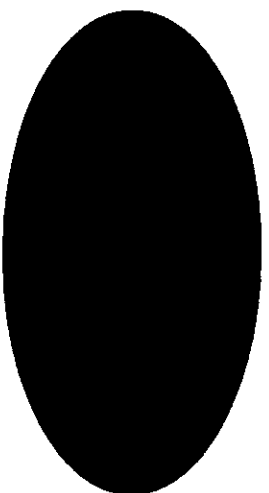


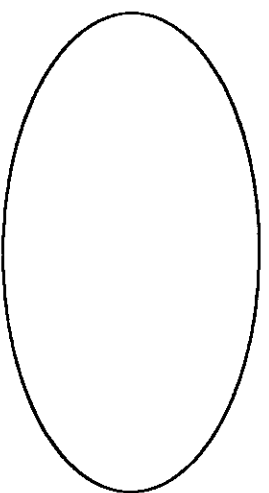
Figure 26

Some Examples of Possible Configurations of Vegetation

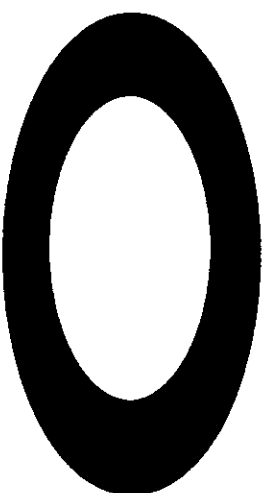
A



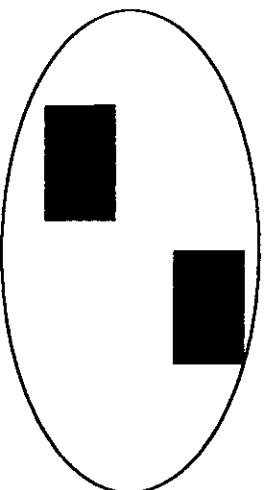
B



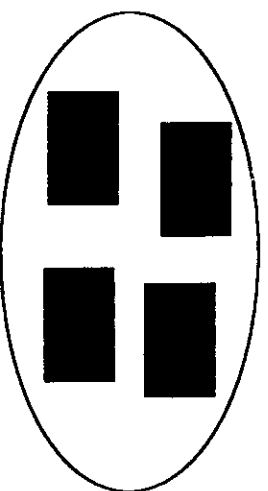
C



D



E



F

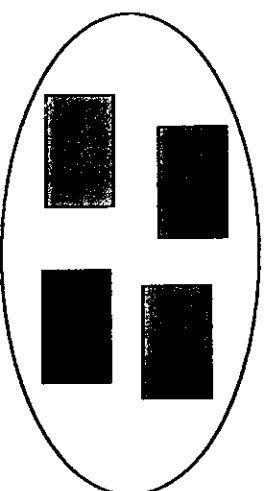


Figure 27