FOOD CONVERSION EFFICIENCY
AND GROWTH IN THE AMERICAN EEL
(*Anguilla rostrata* (Lesueur))

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Gary Wayne Reynolds

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AND GROWTH IN THE AMERICAN EEL
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ABSTRACT

Gary Wayne Reynolds. 1979. Food conversion efficiency and growth in the American eel (Anguilla rostrata (Lesueur)). (Under the direction of Charles W. O'Rear, Jr., Ph.D) Department of Biology, East Carolina University.

Increasing foreign market demand for pond cultured American eels has sparked an interest in eel aquaculture in this country. Biological information on growth in aquaculture is scarce for this species. To assess the efficiency of food conversion, growth and protein absorption were determined for eels from a North Carolina eel farm.

Growth as protein accumulation over a given time was determined from monthly collections of pond raised eels. Estimation of growth in wild eels was based on collections obtained in November 1976 and in March and April 1977. Analyses of length, wet weight, dry weight, ash weight, protein, fat, girth, liver wet weight, liver dry weight, and liver protein were made for pond and wild eels. Correlation and regression analyses showed that wet weight was determined to be the best single independent variable for predicting growth or protein accumulation in both eel populations.

Tissue comparisons between pond and wild eels of similar size indicated a greater amount of protein and fat in pond eels. This is attributed to dietary as well

as other environmental differences.

Protein absorption was estimated from a sample of 8 laboratory maintained eels. The eels, obtained from the North Carolina eel farm, were fed a measured amount of protein. Feces from the lower third of the gut were collected and analyzed for protein content after 4 hours of digestion. Average protein absorption was 99.6%.

A conversion factor of 3.5, determined by dividing growth (protein change) by the average protein consumed per gram of eel during the study, established that much of the protein consumed was not being utilized for growth. An assessment of the exact protein requirements of the American eel would allow fat or carbohydrate to be used to replace the more expensive protein, which is not being utilized for growth.

ACKNOWLEDGMENT

I wish to express my deepest gratitude to several unselfish individuals involved in this study. Foremost in appreciation is Dr. Charles W. O'Rear, the thesis chairman, who guided and patiently aided me in overcoming seemingly unsurmountable problems. Thanks also are given to my committee members, Dr. Davis, Dr. Heckrotte, and Dr. Pennington.

I sincerely thank Dr. Rickards and the staff at the Neuse River eel farm for aid in any material needs as well as advice in completing this research. Thanks is also acknowledged for the supply of research funds by the University of North Carolina Sea Grant Program.

I cannot fail to mention my sincerest respect and indebtedness to Mrs. Martha Jones for all the tests she performed as well as much welcomed advice as to method technique for many tests. I also thank Mike White, Jr., who performed long hours perfecting protein determinations on fish tissue by Lowry technique during the summer of 1976. I also extend a warm handshake and thanks to John Glenn and Roger Black for time-saving aid and advice in completing computer work.

This thesis is a result of the aid of these and other individuals, including a special student nurse who

lifted my spirits when times were "getting tight." I cannot express enough gratitude for my parents' encouragement and support--financial as well as moral--which saved me from being a North River addict, at least for a while.

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INTRODUCTION

A foreign market for pond-cultured American eels (*Anguilla rostrata* (Lesueur)) is being developed in such countries as Japan, Germany and Denmark. The success of eel aquaculture in this country requires that a reasonable profit margin be provided. In terms of production costs, naturally occurring wild eels have several advantages over pond-raised eels. While wild eels eat at no cost to the fisherman, the pond cultured eels are fed an artificial diet. Problems not encountered in wild eels can arise in a pond where population density may retard growth and enhance disease (Cooper et al, 1962; Kawamoto, 1961). Aquaculture, however, is valuable in assuring marketability of the fish by controlling the quality of the product (Otwell et al, unpublished data). Important environmental factors such as oxygen and temperature (Polyakov, 1970) can be more easily controlled in a pond thus assuring that the fish reach acceptable market size faster than the wild eels (University of North Carolina Sea Grant College Newsletter, 1977). The goal of this research was to assess the efficiency of food conversion in American eels. To accomplish this, growth and food absorption efficiency were determined on eels from an experimental eel farm at Vanceboro, North Carolina.

Growth efficiencies have been determined for pond and wild eels in the European and Japanese Anguillid species (Anguilla anguilla and Anguilla japonica, respectively) (Frost, 1945; Usui, 1974; Forrest, 1976). Such basic information is scarce for the pond-cultured American eel, although there have been several studies of growth in wild populations of American eels (Hurley, 1972, 1973; Wenner, 1973; Wenner and Musick, 1974).

Efficiency estimations are based on growth, or change in protoplasm as indicated by protein change over a given time period (Gerking, 1954), as well as food absorption. To assess growth in pond eels, an indicator needs to be selected and studied for at least a year. A year's observation of pond eel samples can provide information on the seasonal effects on growth, which are known to influence growth patterns in most fish species (Kachina, 1969, Markevich and Shatunovskiy, 1969; Gritsenko, 1970; Khasem, 1970; Khalturin and Ryzhov, 1972). Other factors, such as fish size and sexual maturity, must also be considered since these factors are correlated with growth (Gerking, 1955; Andrews and Stickney, 1972; Khashem, 1970; Weatherly, 1976). A good indicator is protein accumulation (Gerking, 1954, 1955; Halver and Shanks, 1960; Deyoe et al, 1966; Byerly, 1967; Ringrose, 1971; Halver, 1972; Shcherbina, 1975; Weatherly, 1976; Zeitoun et al, 1976) since protein has the advantage over other growth indices (such as wet weight, dry weight, or fat) of being less variable (Gerking, 1954).

While protein is easily measured by colorimetric techniques such as the Lowry procedure (Lowry et al, 1951) and the biuret test (Gornall et al, 1949), the aquaculturist desires rough estimates of growth without the effort required for laboratory analyses. By use of simple live measurements such as length and wet weight, the fish protein composition can be predicted. Estimators can be established by regression models from measurements and growth estimated without individual fish analysis (McComish et al, 1974).

In addition to growth, food absorption efficiency should also be determined to assess pond production efficiency. An essential consideration in assessing any production process is an animal's food absorption efficiency (Byerly, 1967). Food is useless to an animal if it is not assimilated (Ricker, 1971).

Protein absorption efficiency:

$$\frac{\text{protein consumed} - \text{protein in feces}}{\text{protein consumed}} \times 100$$

is of primary interest since protein accumulation is one of the best single indicators of growth. Protein absorption efficiency is of interest to the aquaculturist from an economic viewpoint since the efficiency of protein absorption indicates whether the protein component of the diet is being maximally absorbed.

The North Carolina experimental eel farm started by the University of North Carolina Sea Grant Program over 3 years ago provided an opportunity to study these problems. Elvers were captured from the nearby Neuse and Tar Rivers in North Carolina as well as shipped from Maine. The elvers, fed formulated artificial diets, have provided growth estimates in American pond eels raised on Japanese methodology.

MATERIALS AND METHODS

Collection and Handling

Pond Eels

American eels (*Anguilla rostrata* (Lesueur)) were collected from the experimental eel farm near Vanceboro, North Carolina. Eels used in protein absorption studies were maintained at East Carolina University, Department of Biology in dechlorinated tap water, and fed the same menhaden-based diet (Table 1) as fed at the farm.

Eels were collected from 1 of 4 outdoor ponds (pond 4) for growth assessment and estimation of fish condition. Pond 4 contained eels considered to be stunted in size as compared to eels of the same age in the 3 other ponds (Foster, 1977). These stunted eels were selected for study to establish baseline information. The first collection was made May 26, 1976, and monthly collections continued through October 27, 1976. During the winter, collections were stopped since the eels were not fed, and became inactive as is characteristic of pond cultured Anguillidae (Usui, 1974). Two additional collections were obtained from the pond on March 24 and April 21, 1977, after feeding was resumed in the spring.

The eels were dipped from the pond randomly about 10:00 A. M. during the morning feeding. The eels were packed on ice, and immediately transported to ECU where they were weighed, measured and frozen.

Wild Eels

American eels were collected from the Neuse River in North Carolina by both eel pots and elver traps on November 25, 1976, and on March 24, 1977. A third collection was taken on April 13, 1977, from the Tar River in North Carolina by hook-and-line.

Growth Assessments

Length, wet weight, dry weight, ash weight, and protein were determined for each month's collection. Girth measurements were made on samples from the April collection. Liver wet weight, dry weight, and protein as well as whole body fat analyses were made on March and April collections.

Dry weights were taken from 72 pond eels. With smaller eels, the entire frozen fish was cut into fine pieces, placed in tared aluminum pans or crucibles (samples which were later ashed), and oven-dried for 24 h at approximately 100 - 101 C. Larger fish were ground with a meat grinder to prepare a homogenous mixture. Approximately 0.5 g samples in duplicate or triplicate were used for each fish, and analyzed like the smaller eels. Dry weights were recorded after cooling in a desiccator for 10 minutes.

Table 1. Composition of artificial diet fed to pond eels[a]

FISH MEAL (menhaden):	112.5 g/ 150 g mix
STARCH (alfa corn):	37.5 g/ 150 g mix
SALT:	9.0 mg/ 150 g mix
VIATMINS	3.0 mg/ 150 g mix

Approximate composition of food mix

MOISTURE:	7:12%
FAT:	5.60%
PROTEIN:	49.3%
ASH:	15.2%

[a] Foster, 1977.

Ash composition was determined for 67 of the 72 fish used for dry weight analysis. The oven dried samples were ashed for 6 h at approximately 550 C, cooled in a desiccator for 10 min and weighed.

Body protein of 126 eels was measured by the biuret technique (Gornall et al, 1949) utilizing the modifications of Robinson and Hogden (1940), and Weichselbaum (1946). Smaller fish were thawed, and the entire fish was used to determine the amount of protein per fish while larger fish were ground, and duplicate or triplicate samples of the homogenate were analyzed. Protein estimation is based on wet weight.

Fat content of 10 of the pond eels was analyzed by the Babcock method (Association of Official Agricultural Chemists, 1965). Dry weight was also determined in 2 of these fish.

Liver wet weights were recorded for 11 pond eels. These fish were then frozen for later chemical analyses. Liver dry weights were determined for 6 pond eels while liver protein was determined for 7 eels. The analytical methods were those described for fish tissue analyses.

Wild Eels

All measurements were made in each of the 3 collections except fat, girth and liver analyses. Fat and girth were measured in the April collection while liver protein and liver wet weight were determined for the

November and April samples. Measurements of tissue composition of wild American eels were as for pond eels.

Prediction of Fish Composition

Tissue variables were utilized to establish regression models from which fish composition could be predicted in pond eels. Simple regression models of single independent variables of wet weight, length, dry weight, girth, and liver wet weight with each of the dependent variables of dry weight, ash weight, and protein were established. Length and wet weight were used as a multiple regression model to predict these dependent variables.

Protein Absorption Efficiency

The diet fed pond eels were used to estimate protein absorption in 8 eels. Protein content of the diet was determined by the biuret technique to be 49.8%.

Protein absorption was calculated following the methods of Gerking (1955):

protein fed - (protein in water
after feeding + feces' protein) -
protein absorbed

The experimental eels were fed 4.3 g of diet (dry powder mix), or 12.9% of the total wet weight on each of 3 days. The food contained 1,935 mg protein, or 0.129 mg protein/ml water in the tanks. The total wet weight of the eels was used to estimate the amount of protein consumed per gram of eel based on the protein remaining in water after the fish had eaten.

The average protein (mg protein/ml water) was determined by Lowry technique (Lowry et al, 1951) in before and after feeding water samples to establish the protein remaining in water after feeding. In both before and after water samples, the experimental eels were removed and placed in a holding tank. The water was vigorously stirred, and 150 ml was collected in plastic bottles and immediately frozen. To obtain after feeding water samples, the eels were replaced in the tank, fed, and after allowing them to feed for 30 minutes were again removed. The water was stirred, and again 150 ml samples were collected and frozen.

Feces' protein was estimated from the 8 eels. On the last day of the experiment, the eels were anesthesized by M.S. 222 (tricaine methanesulfonate) 4 h after the feeding. Each eel was dissected, and the lower third of the intestine was sectioned with monofilament fishing line. This material was collected by a dropper and placed into tared aluminum boats and oven-dried for 24 h at 85 C. The dried feces were cooled in a desiccator for 10 minutes, and the weights recorded. The feces were then analyzed for total nitrogen by a Coleman Model 29 nitrogen analyzer, thus allowing an estimate of the protein in the feces by multiplying by the conversion factor 6.25.

Data Analyses

Data was analyzed by the Statistical Packages for the Social Sciences (Nil et al, 1976). Student-Newman-Keul's test (SNK) was employed in determining the effect of seasons on growth. Student's t distribution between 2 means was used in determining significance for protein content in the eel water. Significant differences are at the 95% level of probability. Zar (1974) served as the statistical guide.

RESULTS

Fish Composition Analysis

Average composition of wild and pond eels is shown in Table 2. Correlations of all combinations of length, wet weight, dry weight, ash weight, protein, fat, girth and liver wet weight were tested to compare body composition in pond and wild eels and to establish descriptive as well as predictive models of growth in pond eels. The best independent variable for use in descriptive and predictive models was wet weight. Summaries of individual log-log repressions of wet weight versus dry weight, ash weight and protein are presented in Tables 3 and 4. Pond eels had greater concentration of protein and dry weight and less ash than wild eels. The individual regression equations are shown in Figures 1 through 6. Since wild eels were consistently larger than pond eels (Table 2), size classes were established to eliminate size as a variable. Pond eels still exhibited greater dry weights than wild eels of the same size class (Table 4). The relationship between fat and wet weight is different in pond and wild eels, being significantly correlated in pond eels (Figure 7) and nonsignificant in wild eels (Figure 8) at the 95% level of probability.

Independent variables of length, dry weight, girth and liver wet weight versus the dependent variables

Table 2. Average fish composition analysis in pond 4 and wild American eels[a]

	BODY LENGTH $\overline{X}$ ±SE (cm)	WET WEIGHT $\overline{X}$ ±SE (g)	DRY WEIGHT $\overline{X}$ ±SE (g)	ASH WEIGHT $\overline{X}$ ±SE (g)	PROTEIN $\overline{X}$ ±SE (g)	FAT $\overline{X}$ ±SE (g)
POND 4	8.53	2.48	1.04	0.057	0.233	1.62
	±0.334	±0.471	±0.341	±0.020	±0.080	±0.500
	n=203	n=203	n=72	7-67	n-126	n-10
WILD	16.0	53.3	14.2	2.22	13.3	20.4
	±2.96	±23.5	±6.46	±0.941	±5.7	±6.1
	n=31	n=31	n=29	n=17	n=17	n=4

[a] Fish variables determined from several different eels

Table 3. Comparison of regressons of wet weight versus dependent variables in all pond 4 and wild eels

Dependent Variable	Eel Type	Slope (b)	y-interest (a)	n	Conclusion*
DRY	Pond	1.07	-0.676	72	$b_{pond} = b_{wile}$
	Wild	1.04	-0.717	29	$a_{pond} \neq a_{wild}$
ASH	Pond	0.952	-1.80	67	$b_{pond} = b_{wild}$
	Wild	1.07	-1.77	17	$a_{pond} \neq a_{wild}$
PROTEIN	Pond	1.04	-0.889	126	$b_{pond} = b_{wild}$
	Wild	1.02	-0.911	17	$a_{pond} \neq a_{wild}$

*b = b: No significance at the 95% level of probability

a ≠ a: Significant difference at the 95% level of probability

Table 4. Wet weight common class comparisons in pond and wild American eels[A]

Dependent Variable	Eel Type	Slope (b)	y-intercept (a)	n	Conclusion *
DRY	POND	0.205	0.002	27	$b_{pond}=b_{wild}$
	WILD	0.189	-0.003	20	$a_{pond}=b_{wild}$
ASH	POND	0.018	0.00	26	$b_{pond}=b_{wild}$
	WILD	0.020	-0.001	09	$a_{pond}=a_{wild}$
PROTEIN	POND	0.101	0.007	60	$b_{pond}=b_{wild}$
	WILD	0.094	0.007	10	$a_{pond}=a_{wild}$

A
I = 0.124 = 0.240 (g) (CLASS I)

II = 0.468 = 0.912 (g) (CLASS II)

*b = b: No significant correlation at the 95% level of probability

a - a: Significant difference at the 95% level of probability

Figure 1. Log dry weight versus log wet weight scatter diagram and regression for pond 4 American eels

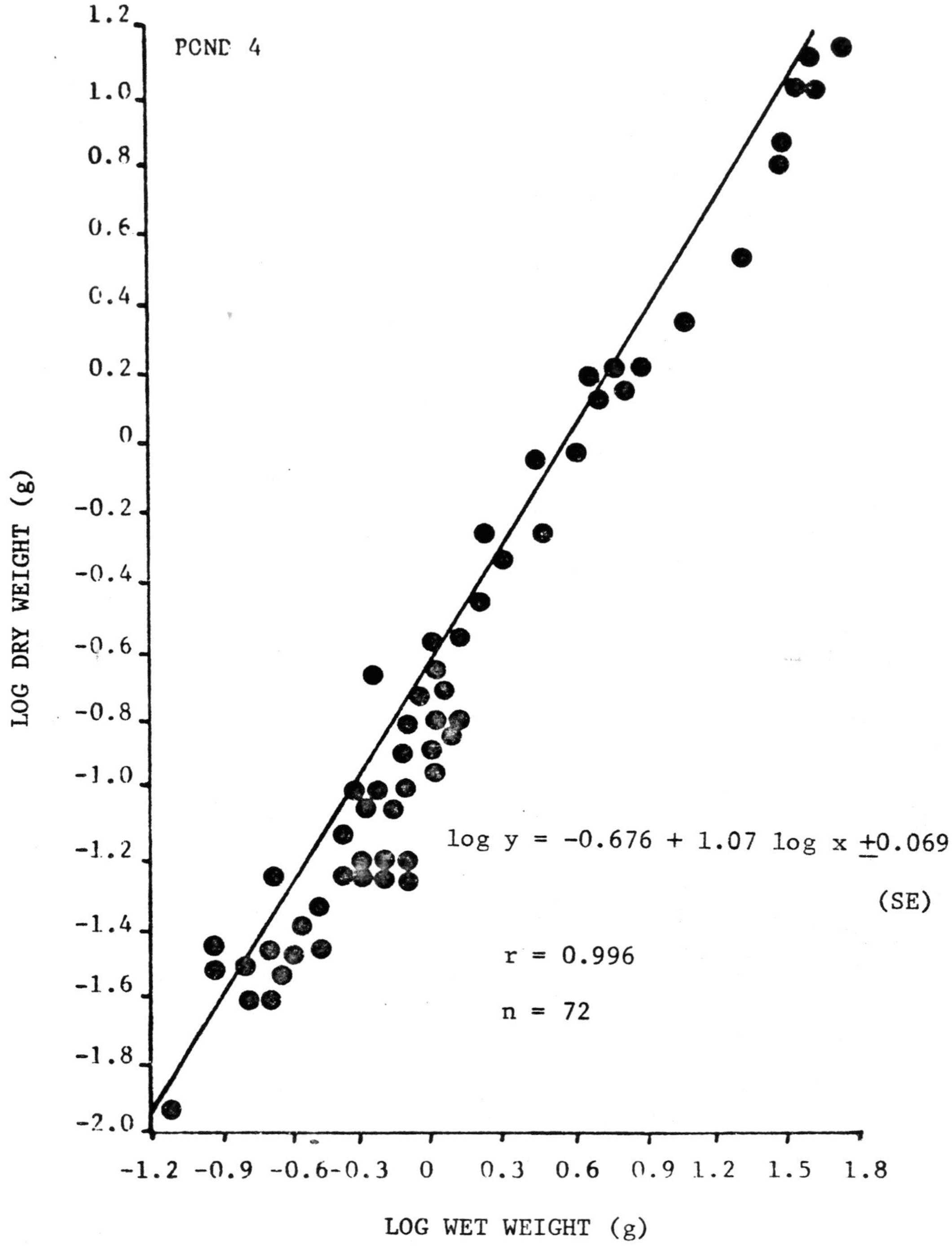

POND 4
LOG DRY WEIGHT (g)
1.2
1.0
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
-1.4
-1.6
-1.8
-2.0
-1.2 -0.9 -0.6 -0.3 0 0.3 0.6 0.9 1.2 1.5 1.8
LOG WET WEIGHT (g)
log y = -0.676 + 1.07 log x ±0.069
(SE)
r = 0.996
n = 72

Figure 2. Log dry weight versus log wet weight scatter diagram and regression for wild American eels

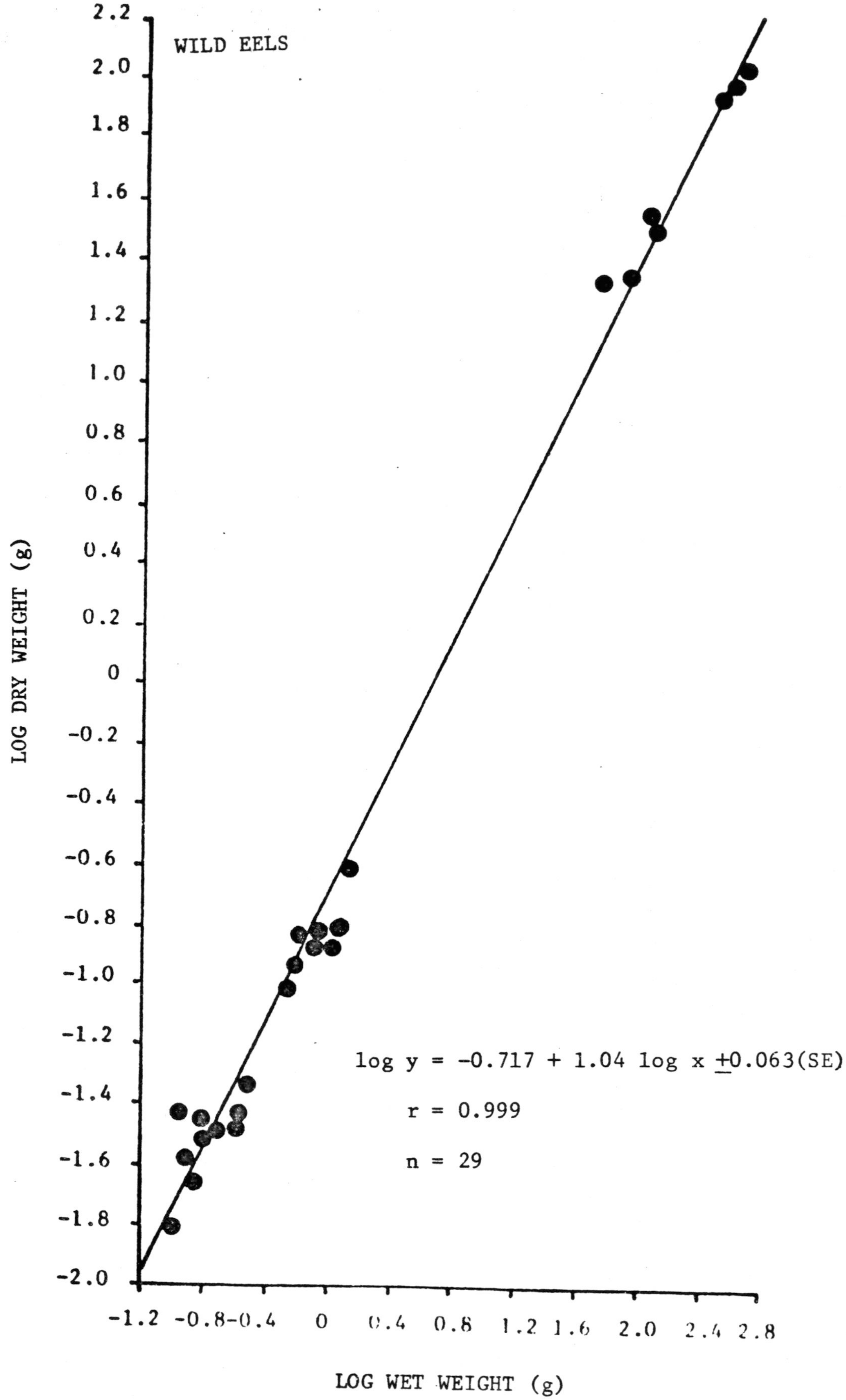
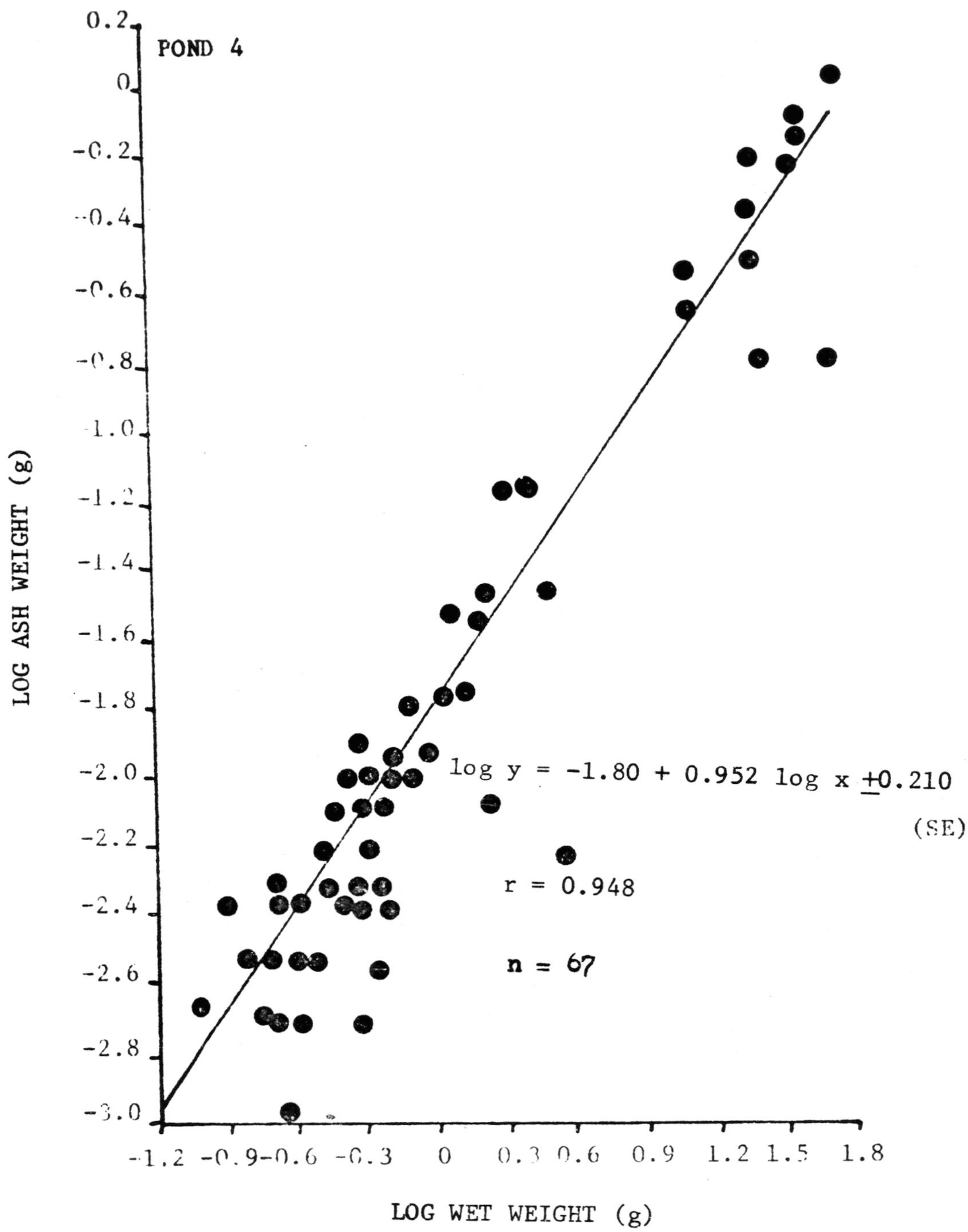

WILD EELS
LOG DRY WEIGHT (g)
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
-1.4
-1.6
-1.8
-2.0
-1.2 -0.8-0.4 0 0.4 0.8 1.2 1.6 2.0 2.4 2.8
LOG WET WEIGHT (g)
log y = -0.717 + 1.04 log x ±0.063(SE)
r = 0.999
n = 29

Figure 3. Log ash weight versus log wet weight scatter diagram and regression for pond 4 American eels



POND 4
LOG ASH WEIGHT (g)
0.2
0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
-1.4
-1.6
-1.8
-2.0
-2.2
-2.4
-2.6
-2.8
-3.0
-1.2 -0.9 -0.6 -0.3 0 0.3 0.6 0.9 1.2 1.5 1.8
LOG WET WEIGHT (g)
log y = -1.80 + 0.952 log x ±0.210
(SE)
r = 0.948
n = 67

Figure 4. Log ash weight versus log wet weight scatter diagram and regression for wild American eels

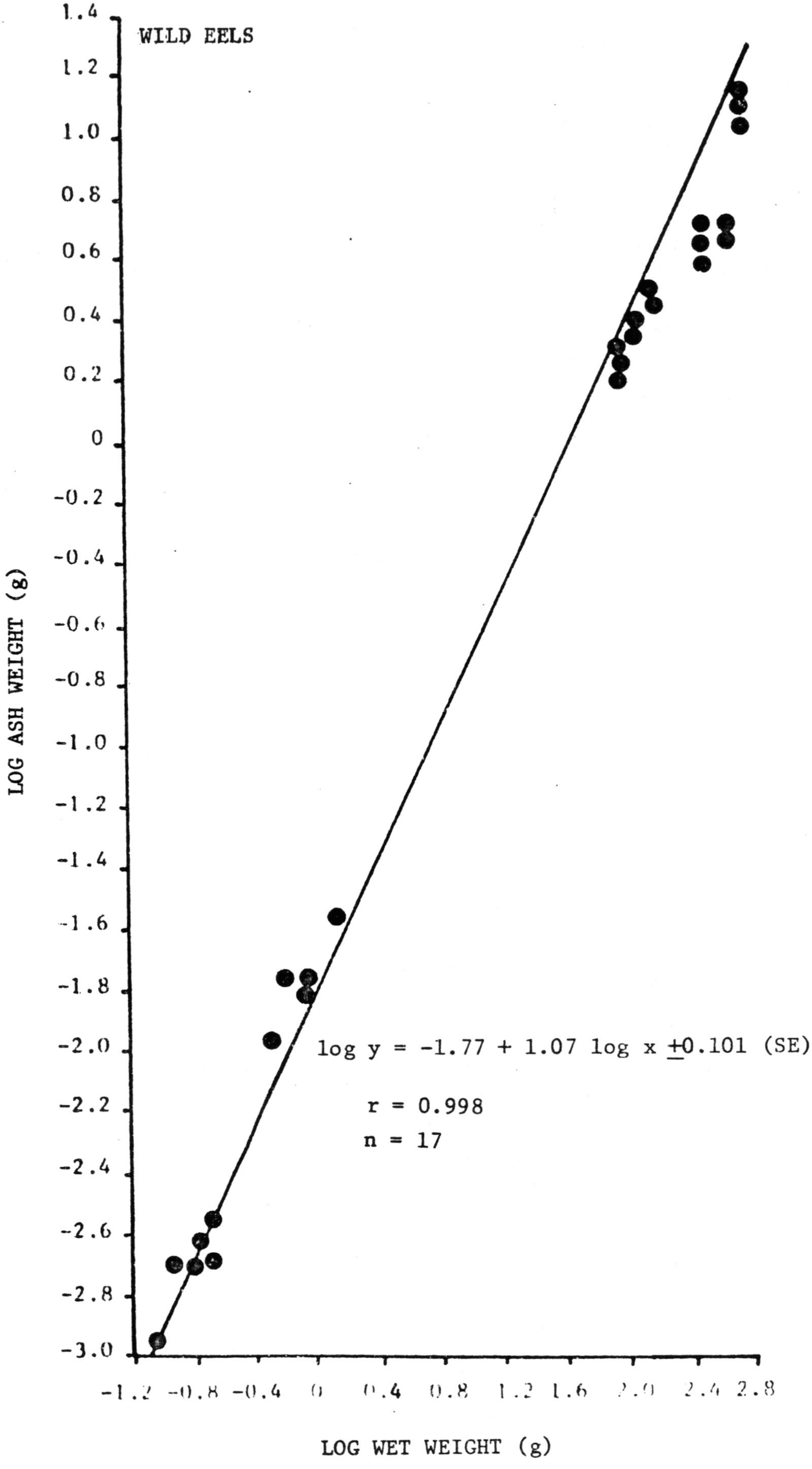

WILD EELS
LOG ASH WEIGHT (g)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
-1.4
-1.6
-1.8
-2.0
-2.2
-2.4
-2.6
-2.8
-3.0
log y = -1.77 + 1.07 log x ±0.101 (SE)
r = 0.998
n = 17
-1.2
-0.8
-0.4
0
0.4
0.8
1.2
1.6
2.0
2.4
2.8
LOG WET WEIGHT (g)

Figure 5. Log protein versus log wet weight scatter diagram and regression for pond 4 American eels

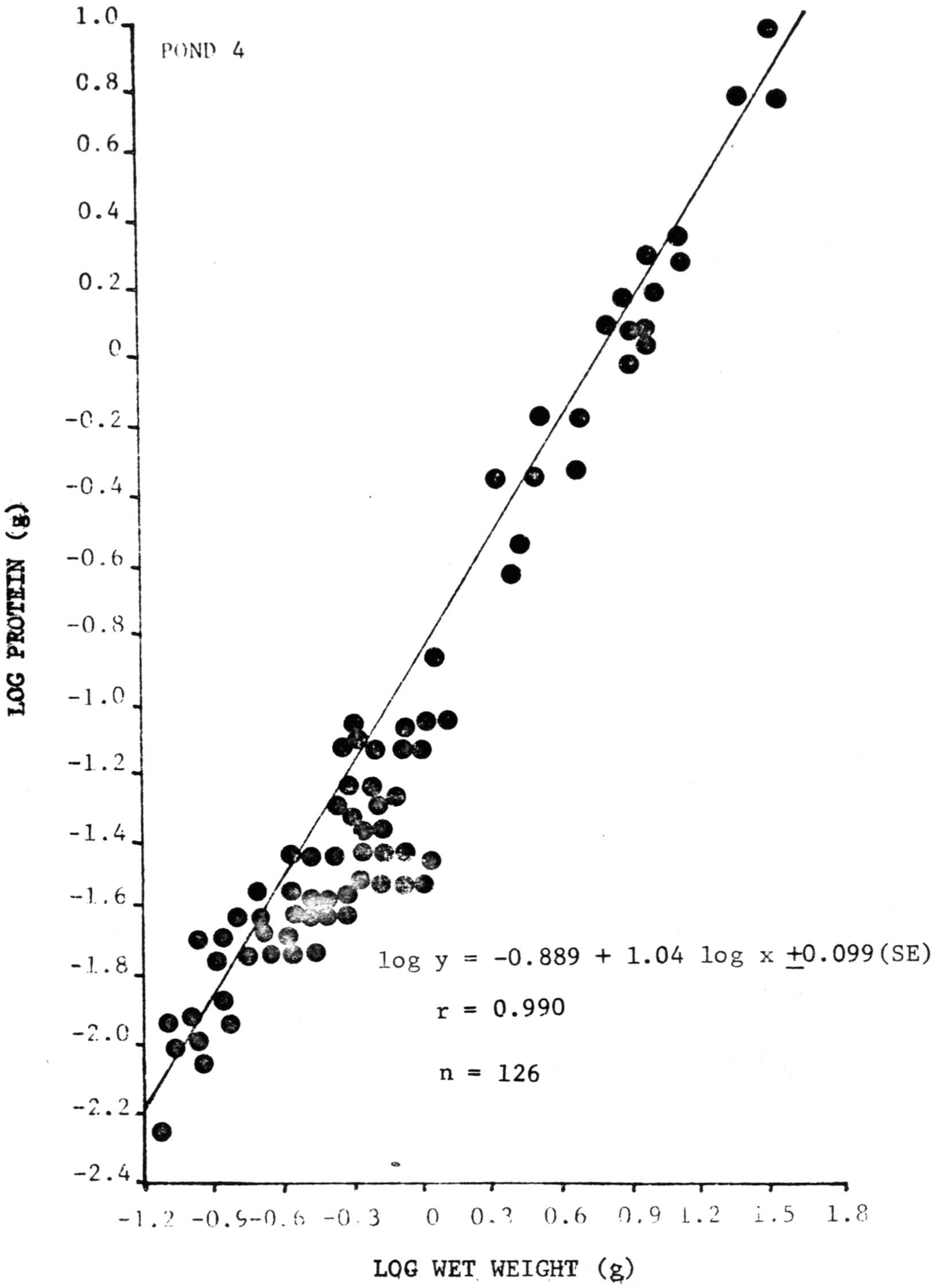

POND 4
LOG PROTEIN (g)
1.0
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
-1.4
-1.6
-1.8
-2.0
-2.2
-2.4
log y = -0.889 + 1.04 log x ±0.099(SE)
r = 0.990
n = 126
-1.2 -0.9 -0.6 -0.3 0 0.3 0.6 0.9 1.2 1.5 1.8
LOG WET WEIGHT (g)

Figure 6. Log protein versus log wet weight scatter diagram and regression for wild American eels

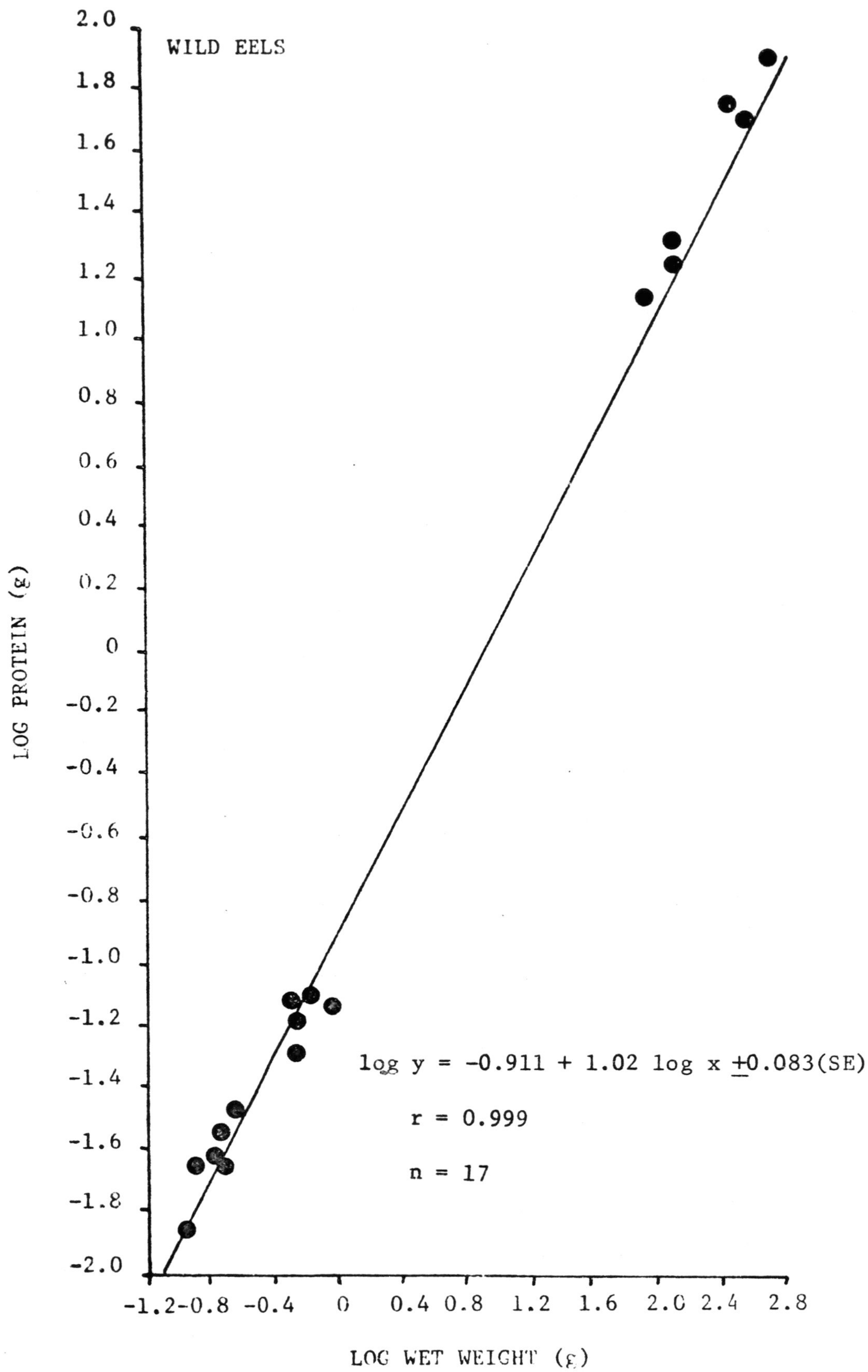

WILD EELS
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
-1.4
-1.6
-1.8
-2.0
LOG PROTEIN (g)
log y = -0.911 + 1.02 log x ±0.083(SE)
r = 0.999
n = 17
-1.2 -0.8 -0.4 0 0.4 0.8 1.2 1.6 2.0 2.4 2.8
LOG WET WEIGHT (g)

Figure 7. Log fat versus log wet weight scatter diagram and regression for pond 4 American eels

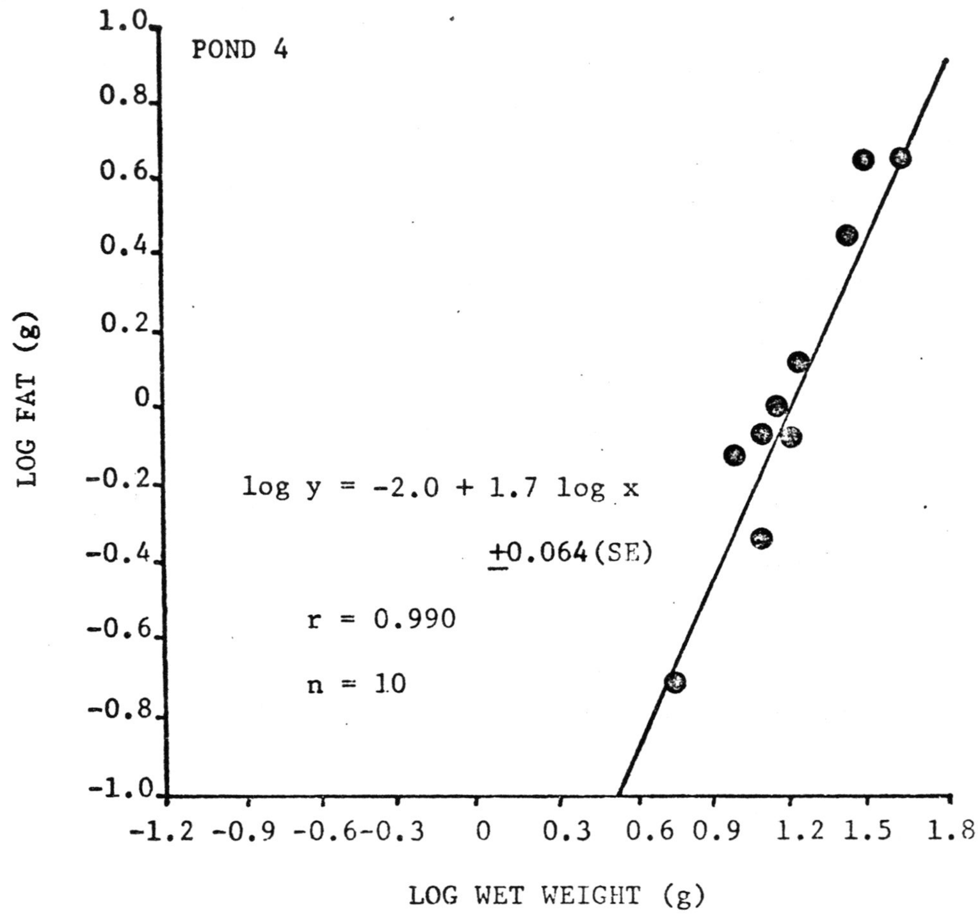
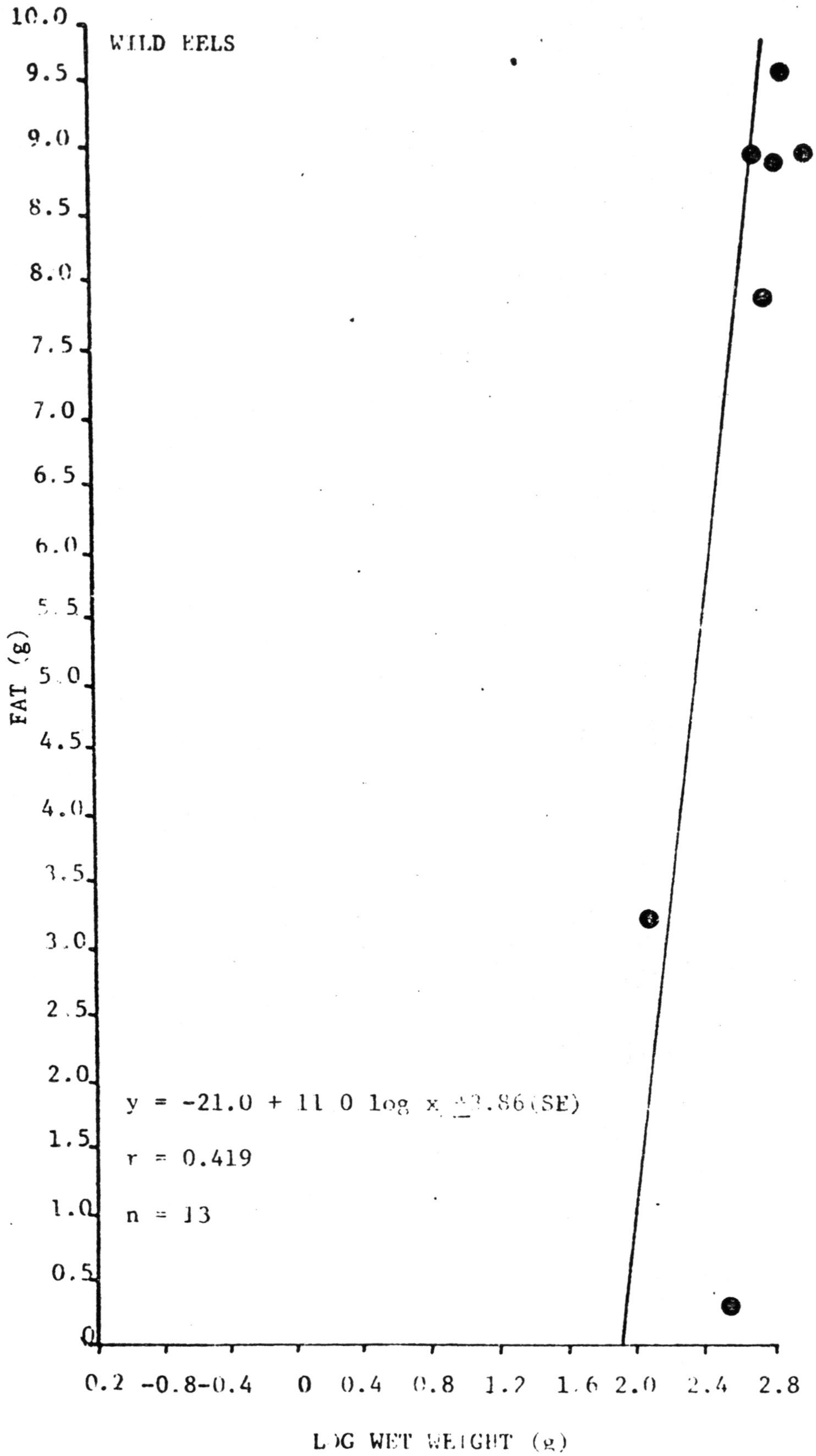

POND 4
1.0
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1.0
LOG FAT (g)
log y = -2.0 + 1.7 log x
±0.064 (SE)
r = 0.990
n = 10
-1.2 -0.9 -0.6 -0.3 0 0.3 0.6 0.9 1.2 1.5 1.8
LOG WET WEIGHT (g)

Figure 8. Fat versus log wet weight scatter diagram and regression for wild American eels


WILD EELS
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
FAT (g)
y = -21.0 + 11 0 log x
r = 0.419
n = 13
0.2 -0.8-0.4 0 0.4 0.8 1.2 1.6 2.0 2.4 2.8
LOG WET WEIGHT (g)

of dry weight, ash weight, protein and fat were treated by single regression analyses (Table 5). Dry weight, girth (Figures 9 through 12) and liver wet weight (Figure 13) exhibited highly significant correlations with those dependent variables in which there were sufficient data points to establish a correlation; however, these dependent variables were limited as descriptive models due to small sample numbers and few intermediate points in establishing a regression (Zar, 1974).

Growth of pond eels (Table 6) was 0.258 g protein/g of eel/month. Food conversion (total protein consumed/growth) was 3.52. Growth determinations were impossible in wild eels since they were not collected on a monthly basis.

Protein Absorption Efficiency

Laboratory eels consumed 1,170 mg protein based on the results of water analysis. The eel tank water contained 765 mg protein after the eels were fed 1,935 mg protein. This indicated that 45.0 mg protein was consumed per gram of wet weight of eel. Average protein absorption was 99.6% ±0.1 (CI). Experimental results are presented in Table 7.

Table 5. Summary of regressions of length, girth, dry weight and liver wet weight to predict dry weight, ash weight, protein and fat in pond 4 American eels

Independent Variable	Dependent Variable (n)	Correlation Coefficient *
LENGTH	DRY WEIGHT (72)	0.987
	ASH WEIGHT (67)	0.950
	PROTEIN (126)	0.971
	FAT (10)	0.884
GIRTH	DRY WEIGHT (23)	0.969
	ASH WEIGHT (13)	0.840
	PROTEIN (10)	0.986
DRY WEIGHT	ASH WEIGHT (67)	0.949
LIVER WET WEIGHT	FAT (8)	0.979

*correlation coefficient at the 95% level of probability

Figure 9. Log fish dry weight versus log fish girth scatter diagram and regression for pond 4 American eels

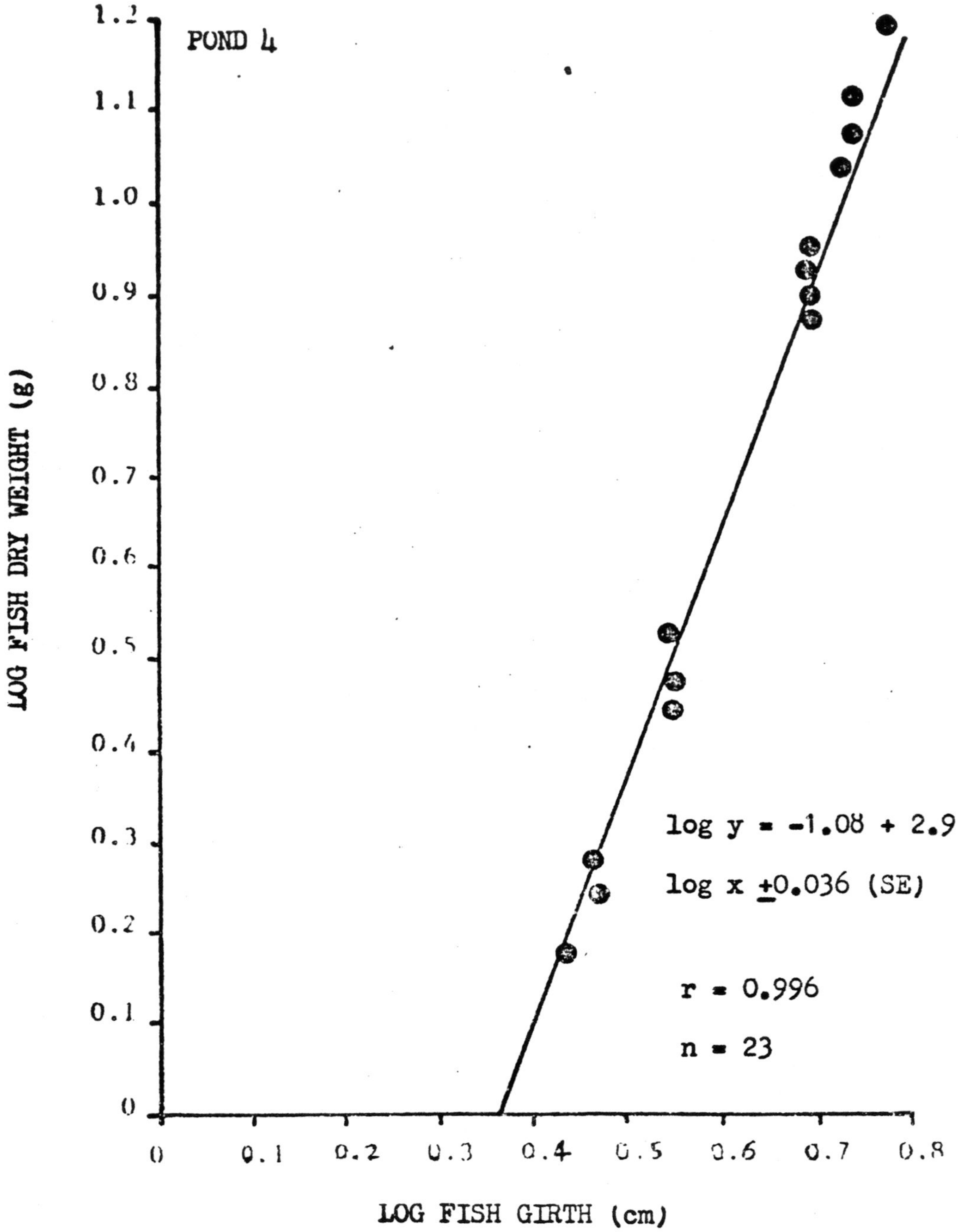

POND 4
LOG FISH DRY WEIGHT (g)
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
LOG FISH GIRTH (cm)
log y = -1.08 + 2.9
log x ±0.036 (SE)
r = 0.996
n = 23

Figure 10. Log fish ash weight versus log fish girth scatter diagram and regression for pond 4 American eels

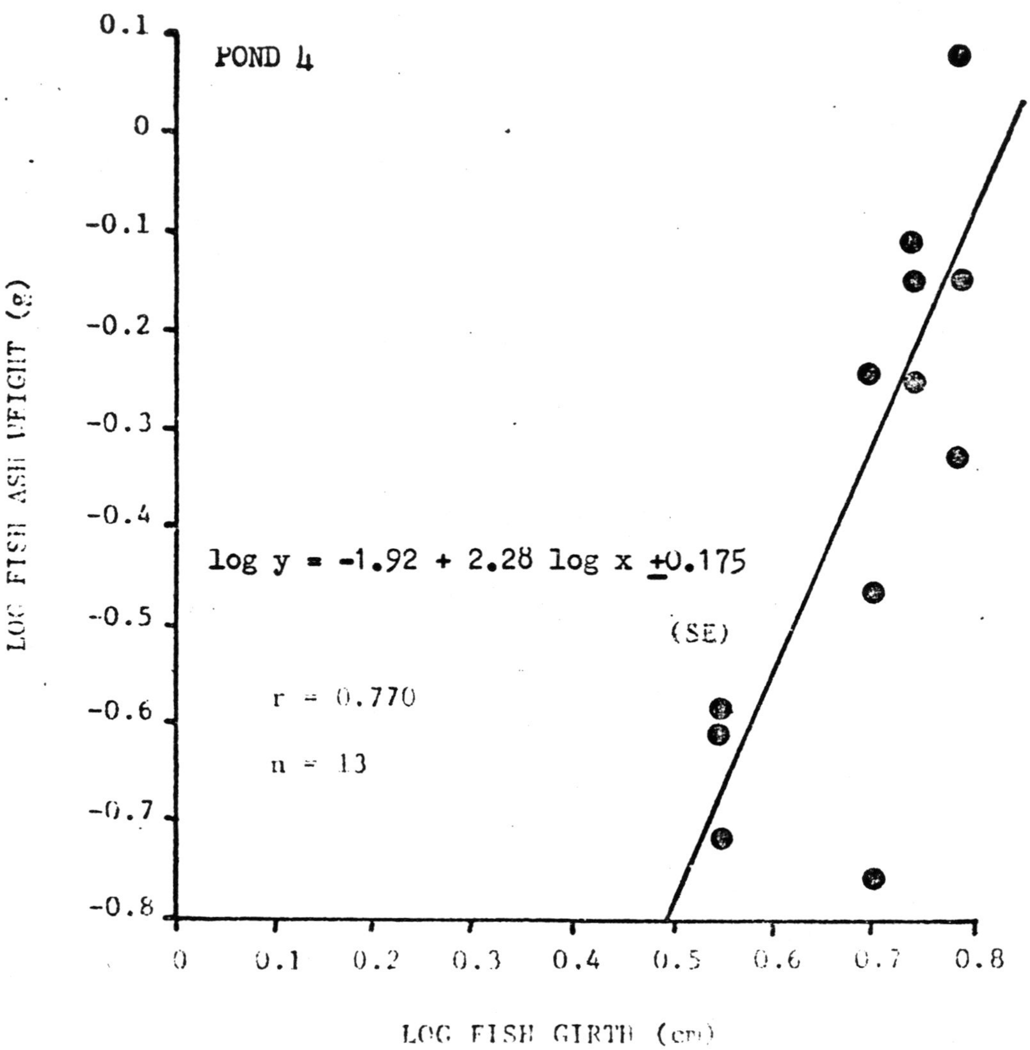

POND 4
log y = -1.92 + 2.28 log x ±0.175
(SE)
r = 0.770
n = 13
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
LOG FISH ASH WEIGHT (g)
LOG FISH GIRTH (cm)

Figure 11. Log fish protein versus log fish girth scatter diagram and regression for pond 4 American eels

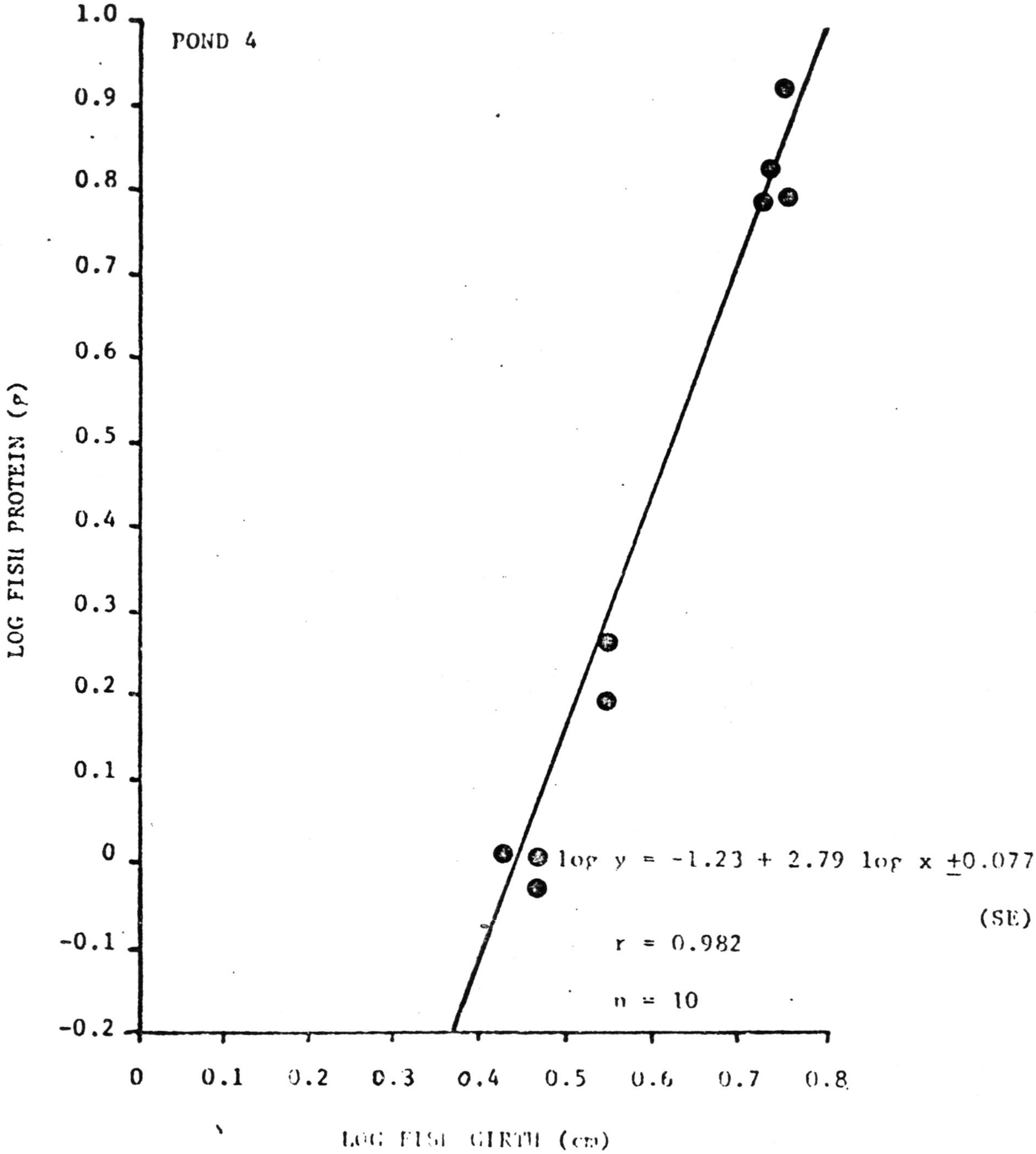

POND 4
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
LOG FISH PROTEIN (g)
log y = -1.23 + 2.79 log x ±0.077
(SE)
r = 0.982
n = 10
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
LOG FISH GIRTH (cm)

Figure 12. Log fish fat versus log fish girth scatter diagram and regression for pond 4 American eels

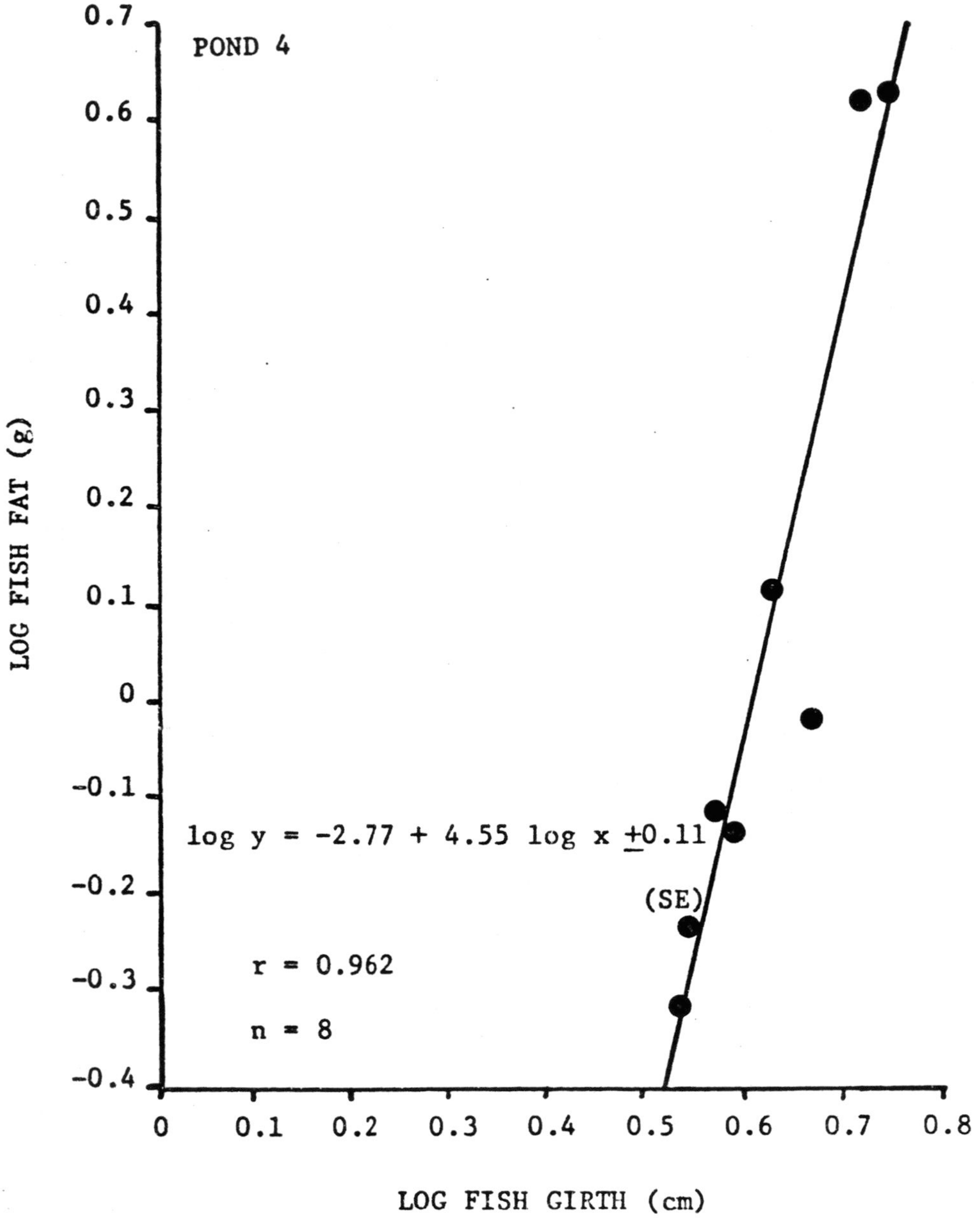

POND 4
LOG FISH FAT (g)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
log y = -2.77 + 4.55 log x ±0.11
(SE)
r = 0.962
n = 8
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
LOG FISH GIRTH (cm)

Figure 13. Log fish fat versus log liver wet weight scatter diagram and regression for pond 4 American eels

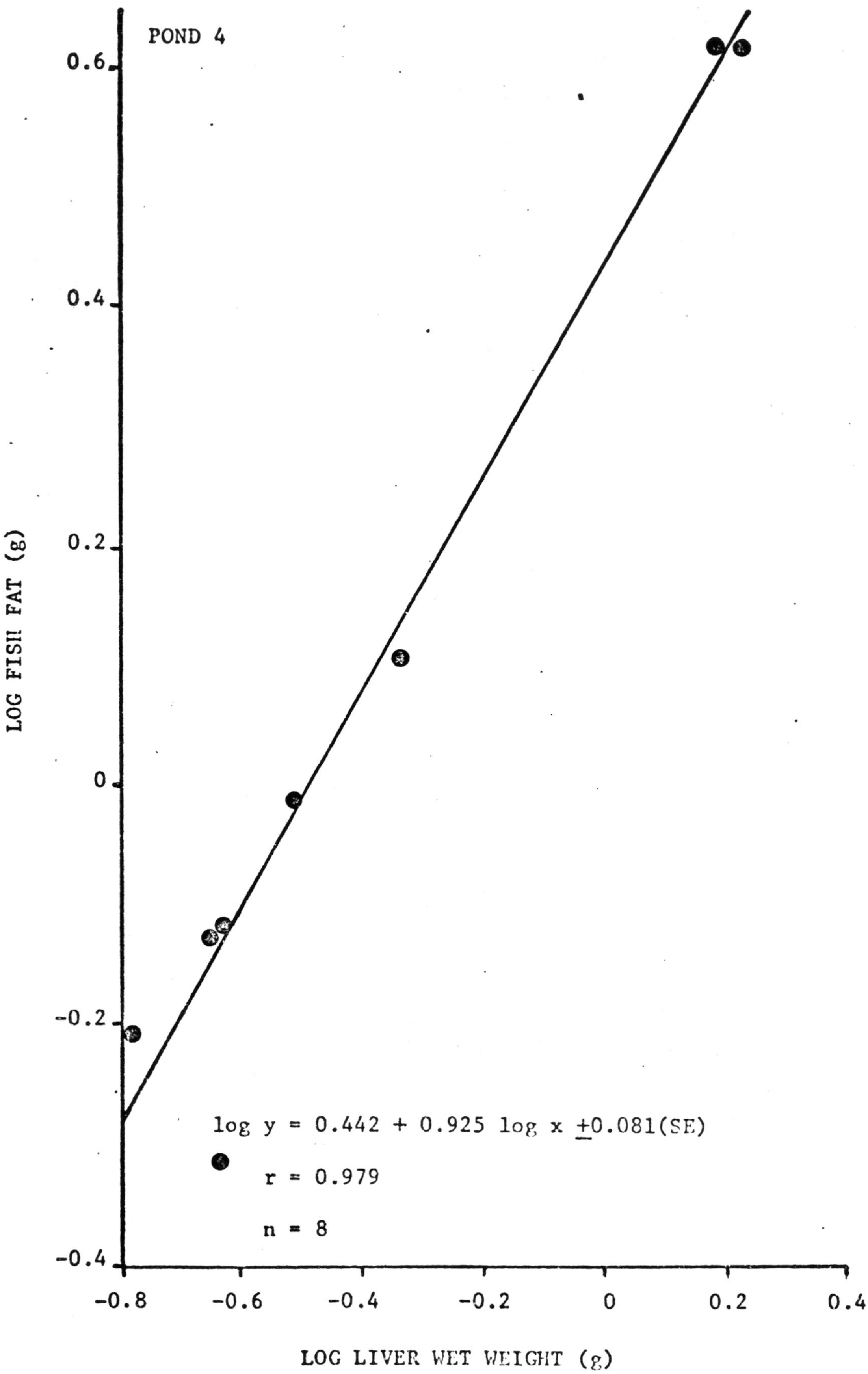

POND 4
LOG FISH FAT (g)
0.6
0.4
0.2
0
-0.2
-0.4
log y = 0.442 + 0.925 log x ±0.081(SE)
r = 0.979
n = 8
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
LOG LIVER WET WEIGHT (g)

Table 6. Estimation of food conversion efficiency in pond 4 American eels.

Protein $\bar{X}$ at start of study (g/g eel)	0.021
Protein $\bar{X}$ at end of study (g/g eel)	3.12
Growth (g protein/g eel/month)	0.258
Total protein consumed (g protein/g eel/month)	0.908
Conversion factor	3.52
Gross growth efficiency	0.284

Table 7. Efficiency or protein absorption by eels maintained in East Carolina University laboratory experiment

Wet Wt. (g)	[a]Total Protein Consumed (mg)	Feces Dry Wt. (mg)	[b]Total N in Feces (mg)	[c]Protein N in Feces (mg)	Protein Absorbed (mg)	Efficiency of Protein Absorption (%)
1.68	75.6	0.60	0.087	0.544	75.1	99.3
1.73	77.9	1.05	0.040	0.250	77.7	99.7
2.73	123.0	1.00	0.056	0.350	122.7	99.7
3.43	154.0	2.00	0.122	0.763	153.2	99.5
3.54	159.0	2.00	0.122	0.763	158.2	99.5
3.98	179.0	2.30	0.104	0.647	178.4	99.7
4.23	190.0	6.90	1.00	6.25	183.3	96.7
4.70	212.0	1.75	0.123	0.766	211.2	99.6
n = 8						
$\overline{X}$ ± CI (confidence interval)						
3.25 ±0.94	146.3 ±41.7	2.20 ±1.67	0.207 ±0.27	1.29 ±1.68	145.0 ±42	99.8 ±0.1

[a]Estimated by Lowry technique (Lowry et al, 1951)

[b]Analyzed by a nitrogen analyzer - Coleman Model 29

[c]Estimated from total nitrogen in feces by conversion factor 6.25

DISCUSSION

Differences in composition between the two eel populations can be explained by both diet and environment. In wild populations, the older, larger fish should exhibit greater dry matter in terms of protein and fat, while smaller, younger fish should consist of less dry matter (Shulman, 1970). The smaller pond eels, however, did not exhibit this pattern but rather the exact opposite. Such a pattern is consistent with other pond studies, and is explained by the pond environment. The protectiveness of the pond, the reduction of energy spent in obtaining food, and the dry matter content of the artificial diet should cause a greater dry matter content in pond fish (Otwell et al, unpublished data; Usui, 1974; Forrest, 1976).

Wet weight is useful in pond eels as a composition estimator. While wet weight is a poor indicator of growth (Gerking, 1954; Shcherbina, 1975; Zeitoun et al, 1976), this variable can be an extremely useful measurement as a predictive component (McComish et al, 1974) since wet weight is a relatively simple measurement to obtain and does not require sacrifice.

Wet weight and length would be expected to reflect changes in tissue composition. As fish increase in size, tissue parameters of protein, fat, and ash content would increase. Sexual associations (spawning activity, sexual products, etc.) could affect tissue composition (Khashem, 1970; Polyakov, 1970) so that size would reflect perhaps inconsistent patterns regarding such components as fat or dry weight during spawning season. With sexually mature fish, caution must be exercised when attempting to predict components from fish size. With sexual factors eliminated, however, size proves to be a reliable indicator of tissue composition. Since the fish in this study were sexually immature (Wenner, 1973), size was a good predictive model.

Dry weight, as Gerking (1954) points out, has disadvantages for prediction. This measurement requires sacrifice, and the 2 major components of dry weight - fat and protein - can vary. Girth is a relatively simple measurement, but it also varies with protein and fat concentrations. Liver wet weight is a good fish condition indicator (Markevich and Shatunovskiy, 1969; Lapin, 1973; Tyler and Dunn, 1976), but it is not reliable as a predictive model of single dependent variables such as total fish protein. Liver composition fluctuates with body composition, so that while the liver size or wet weight may be related to such variables as fish dry weight, the components of dry weight are variable. The liver composition changes constantly with changes in body variables.

Based on growth efficiency determinations, the artificial food is being wasted (Halver, 1972). Protein of the diet is either being lost to the pond, or once entering the animal is not being efficiently converted to new tissue as growth.

Protein Absorption Efficiency

Absorption efficiencies for other species such as the largemouth bass (Micropterus salmoides (Lacepede)) with an average protein N absorption efficiency of 96.5% and the bluegill (Lepomis macrochirus (Rafinesque)) with 97% protein N absorption efficiency have been reported (Beamish, 1972; Gerking, 1955, respectively). With any absorption efficiency determination, several untested factors should be considered before accepting the estimation as a true indication of protein absorption efficiency. These factors include indirect determination of food consumption by individual fish, fish size, inclusion of protein in feces other than protein from the food consumed, and loss of fecal material in collecting for analyses.

Indirect determination of food consumption is a common approach (Gerking, 1955, Deyoe et al, 1966; McComish et al, 1974). Error was introduced in assuming that each of the 8 eels consumed its share of the total amount of protein fed while aggressiveness of the individuals in feeding was not considered. Another undetermined effect was the size of the individual fish. Juvenile fish should show high protein efficiency absorption, while mature fish which are larger decrease in the efficiency with which protein is absorbed. In older, more mature fish, there is also a decrease in tissue conversion of protein, or rather a decline in growth (Paloheimo and Dickie, 1965; Polyakov, 1970). Protein N in the feces which is due to bacteria, mucosa and digestive enzyme additions (Shoherbina et al, 1970; Shcherbina and Kazlauskene, 1971) would also affect protein absorption efficiency estimation. Accepting the rough estimate of protein absorption efficiency as valid, the size eels considered in this study exhibit a very efficient protein absorption of the artificial diet. Economically, this is desirable.

CONCLUSION

1. Pond eels had higher dry weight, more protein and less ash than wild eels. These composition differences are accounted for by differences in the environment and diet.

2. Wet weight was found to be the best predictive variable for protein, fat and ash. Length, dry weight and girth were also good predictive variables for protein, fat and ash provided sufficient sample numbers could be obtained.

3. High absorption of dietary protein occurred in American eels.

4. Much of the dietary protein consumed did not produce growth in the pond eels. This is attributable to the eels being slow growers.

RECOMMENDATIONS

Since I have shown that a large portion of protein in the artificial diet absorbed by the eels was not incorporated into new tissue, the protein/fat/carbohydrate balance in the food should be reconsidered. Perhaps the more expensive protein component could be significantly reduced without loss in eel production.

A more precise method of determining protein absorption efficiency would aid in evaluating the true efficiency with which eels of various stage growths are absorbing protein from the diet, as the method employed in this study is crude at best. Once perfected, samples of eels will yield how efficiently a diet is being utilized by the population and adjustments can be made to obtain maximum efficiency.

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APPENDIX

APPENDIX ABBREVIATIONS

LENG	Length in centimeters
WET	Wet weight in grams
DRY	Dry weight in grams
ASH	Ash weight in grams
PROT	Protein in grams
FAT	Fat in grams
LIVW	Liver wet weight in grams
LIVDR	Liver dry weight in grams
LIVPR	Liver protein in grams
GIR	Girth in centimeters

APPENDIX: RAW DATA

Appendix Table. Data collected for estimating food conversion efficiency and growth in *Anguilla rostrata* from May, 1976 through April, 1977

LENG	WET	DRY	ASH	PROT	FAT	LIVW	LIVDR	LIVPR	GIR
5.5	0.176	0.052	0.005	***	***	***	***	***	***
5.5	0.142	0.028	0.003	***	***	***	***	***	***
6.2	0.167	0.034	0.004	***	***	***	***	***	***
5.7	0.168	0.026	0.002	***	***	***	***	***	***
5.9	0.158	0.026	0.002	***	***	***	***	***	***
6.4	0.422	0.081	0.006	***	***	***	***	***	***
5.7	0.237	0.057	0.004	***	***	***	***	***	***
5.4	0.086	0.014	0.002	***	***	***	***	***	***
5.3	0.122	***	***	0.018	***	***	***	***	***
5.1	0.161	***	***	0.018	***	***	***	***	***
6.1	0.233	***	***	0.030	***	***	***	***	***
6.0	0.265	***	***	0.035	***	***	***	***	***
5.9	0.232	***	***	0.038	***	***	***	***	***
5.7	0.184	***	***	0.024	***	***	***	***	***
5.3	0.104	***	***	0.018	***	***	***	***	***
4.8	0.067	***	***	0.010	***	***	***	***	***
5.6	0.094	***	***	0.007	***	***	***	***	***
5.8	0.190	***	***	0.022	***	***	***	***	***
5.2	0.081	***	***	0.008	***	***	***	***	***
5.9	0.207	***	***	0.032	***	***	***	***	***
5.6	0.187	***	***	0.025	***	***	***	***	***
4.9	0.081	***	***	0.009	***	***	***	***	***
5.8	0.062	***	***	0.006	***	***	***	***	***
5.5	0.149	***	***	0.016	***	***	***	***	***
5.4	0.133	***	***	0.016	***	***	***	***	***
6.7	0.356	***	***	0.035	***	***	***	***	***
5.6	0.158	***	***	0.018	***	***	***	***	***
5.7	0.156	***	***	0.015	***	***	***	***	***
5.8	0.085	***	***	0.013	***	***	***	***	***
5.4	0.179	***	***	0.023	***	***	***	***	***
5.6	0.156	***	***	0.019	***	***	***	***	***
5.5	0.140	***	***	0.015	***	***	***	***	***
5.7	0.118	***	***	0.011	***	***	***	***	***
5.7	0.171	***	***	0.021	***	***	***	***	***
5.8	0.163	***	***	0.027	***	***	***	***	***
5.0	0.078	***	***	0.010	***	***	***	***	***
6.1	0.211	***	***	0.030	***	***	***	***	***
5.9	0.198	***	***	0.025	***	***	***	***	***

Appendix Table. (continued)

LENG	WET	DRY	ASH	PROT	FAT	LIVW	LIVDR	LIVPR	GIR
5.3	0.087	***	***	0.014	***	***	***	***	***
5.3	0.092	***	***	0.013	***	***	***	***	***
5.6	0.187	***	***	0.032	***	***	***	***	***
6.0	0.202	***	***	0.030	***	***	***	***	***
5.9	0.244	***	***	0.040	***	***	***	***	***
6.2	0.173	***	***	0.022	***	***	***	***	***
6.1	0.222	***	***	0.027	***	***	***	***	***
5.5	0.073	***	***	0.009	***	***	***	***	***
DATE: 062376									
7.1	0.487	0.103	0.009	***	***	***	***	***	***
5.5	0.154	0.025	0.003	***	***	***	***	***	***
5.6	0.134	0.031	0.004	***	***	***	***	***	***
6.6	0.309	0.073	0.007	***	***	***	***	***	***
6.0	0.132	0.027	0.004	***	***	***	***	***	***
6.7	0.241	0.051	0.006	***	***	***	***	***	***
6.2	0.248	0.053	0.005	***	***	***	***	***	***
6.0	0.228	0.051	0.005	***	***	***	***	***	***
5.7	0.130	***	***	0.025	***	***	***	***	***
8.0	0.810	***	***	0.096	***	***	***	***	***
5.0	0.115	***	***	0.016	***	***	***	***	***
7.4	0.514	***	***	0.081	***	***	***	***	***
6.7	0.353	***	***	0.057	***	***	***	***	***
6.7	0.311	***	***	0.055	***	***	***	***	***
5.8	0.138	***	***	0.019	***	***	***	***	***
5.7	0.468	***	***	0.034	***	***	***	***	***
5.8	0.197	***	***	0.033	***	***	***	***	***
5.6	0.244	***	***	0.026	***	***	***	***	***
5.1	0.142	***	***	0.020	***	***	***	***	***
5.8	0.193	***	***	0.025	***	***	***	***	***
5.2	0.138	***	***	0.029	***	***	***	***	***
5.8	0.214	***	***	0.033	***	***	***	***	***
6.1	0.249	***	***	0.039	***	***	***	***	***
5.8	0.192	***	***	0.024	***	***	***	***	***
5.5	0.179	***	***	0.031	***	***	***	***	***
DATE: 072176									
6.0	0.274	0.052	0.005	***	***	***	***	***	***
7.2	0.502	0.096	0.009	***	***	***	***	***	***
6.0	0.194	0.036	0.003	***	***	***	***	***	***

Appendix Table. (continued)

LENG	WET	DRY	ASH	PROT	FAT	LIVW	LIVDR	LIVPR	GIR
6.1	0.211	0.043	0.001	***	***	***	***	***	***
6.1	0.252	0.051	0.005	***	***	***	***	***	***
6.7	0.311	***	***	0.041	***	***	***	***	***
6.4	0.262	***	***	0.033	***	***	***	***	***
6.9	0.408	***	***	0.056	***	***	***	***	***
6.3	0.319	***	***	0.045	***	***	***	***	***
6.3	0.288	***	***	0.053	***	***	***	***	***
7.6	0.517	***	***	0.068	***	***	***	***	***
7.0	0.469	***	***	0.057	***	***	***	***	***
6.0	0.191	***	***	0.020	***	***	***	***	***
5.4	0.167	***	***	0.022	***	***	***	***	***
5.9	0.188	***	***	0.022	***	***	***	***	***
6.8	0.348	***	***	0.042	***	***	***	***	***
6.7	0.381	***	***	0.054	***	***	***	***	***
7.6	0.598	***	***	0.070	***	***	***	***	***
6.8	0.377	***	***	0.032	***	***	***	***	***
5.9	0.246	***	***	0.032	***	***	***	***	***
DATE: 082076									
6.1	0.262	***	***	0.025	***	***	***	***	***
6.2	0.207	***	***	0.021	***	***	***	***	***
6.4	0.282	***	***	0.029	***	***	***	***	***
8.6	0.891	***	***	0.072	***	***	***	***	***
6.8	0.359	***	***	0.052	***	***	***	***	***
6.0	0.236	***	***	0.024	***	***	***	***	***
6.4	0.332	***	***	0.029	***	***	***	***	***
6.5	0.389	***	***	0.041	***	***	***	***	***
6.1	0.285	***	***	0.029	***	***	***	***	***
8.0	0.701	***	***	0.065	***	***	***	***	***
6.2	0.298	***	***	0.028	***	***	***	***	***
8.1	0.701	***	***	0.071	***	***	***	***	***
6.5	0.304	***	***	0.033	***	***	***	***	***
6.6	0.248	***	***	0.020	***	***	***	***	***
6.2	0.296	***	***	0.030	***	***	***	***	***
6.0	0.192	***	***	0.026	***	***	***	***	***
6.2	0.248	***	***	0.028	***	***	***	***	***
6.9	0.460	***	***	0.054	***	***	***	***	***
7.2	0.455	***	***	0.055	***	***	***	***	***
7.1	0.458	***	***	0.053	***	***	***	***	***
7.1	0.448	***	***	0.048	***	***	***	***	***
7.4	0.502	***	***	0.056	***	***	***	***	***
6.5	0.322	***	***	0.032	***	***	***	***	***

Appendix Table. (continued)

LENG	WET	DRY	ASH	PROT	FAT	LIVW	LIVDR	LIVPR	GIR
7.6	0.567	***	***	0.053	***	***	***	***	***
7.5	0.554	***	***	0.056	***	***	***	***	***
5.9	0.253	***	***	0.031	***	***	***	***	***
6.9	0.387	***	***	0.034	***	***	***	***	***
5.8	0.170	***	***	0.015	***	***	***	***	***
7.0	0.504	0.240	0.008	***	***	***	***	***	***
7.5	0.621	0.111	0.010	***	***	***	***	***	***
6.4	0.350	0.059	0.005	***	***	***	***	***	***
6.5	0.401	0.074	0.007	***	***	***	***	***	***
6.0	0.184	0.029	0.004	***	***	***	***	***	***
6.2	0.290	0.047	0.003	***	***	***	***	***	***
6.9	0.455	0.093	0.008	***	***	***	***	***	***
5.9	0.260	0.044	0.004	***	***	***	***	***	***
8.9	0.900	0.178	0.017	***	***	***	***	***	***
5.7	0.210	0.034	0.003	***	***	***	***	***	***
DATE: 092976									
8.3	0.764	***	***	0.081	***	***	***	***	***
7.6	0.509	***	***	0.106	***	***	***	***	***
7.5	0.533	***	***	0.089	***	***	***	***	***
7.2	0.438	***	***	0.069	***	***	***	***	***
8.9	0.971	***	***	0.097	***	***	***	***	***
7.3	0.536	***	***	0.057	***	***	***	***	***
7.7	0.622	***	***	0.069	***	***	***	***	***
12.9	3.32	***	***	0.689	***	***	***	***	***
6.8	0.341	0.059	0.004	***	***	***	***	***	***
9.3	1.07	0.198	0.016	***	***	***	***	***	***
6.9	0.476	0.090	0.007	***	***	***	***	***	***
7.2	0.450	0.086	0.007	***	***	***	***	***	***
7.4	0.430	0.078	0.008	***	***	***	***	***	***
7.6	0.520	0.096	0.008	***	***	***	***	***	***
6.7	0.330	0.059	0.003	***	***	***	***	***	***
7.8	0.537	0.106	0.010	***	***	***	***	***	***
7.0	0.402	0.078	0.006	***	***	***	***	***	***
6.5	0.272	0.054	0.002	***	***	***	***	***	***
7.8	0.705	0.164	0.009	***	***	***	***	***	***
6.7	0.348	0.066	0.002	***	***	***	***	***	***
9.3	1.09	0.213	0.018	***	***	***	***	***	***
5.6	0.192	0.032	0.002	***	***	***	***	***	***
6.5	0.298	0.058	0.004	***	***	***	***	***	***

Appendix Table. (continued)

LENG	WET	DRY	ASH	PROT	FAT	LIVW	LIVDR	LIVPR	GIR
8.9	0.861	***	***	0.095	***	***	***	***	***
14.2	5.28	***	***	0.583	***	***	***	***	***
8.2	0.824	***	***	0.085	***	***	***	***	***
11.8	2.89	***	***	0.369	***	***	***	***	***
11.2	2.10	***	***	0.393	***	***	***	***	***
8.1	0.735	***	***	0.086	***	***	***	***	***
7.9	0.735	***	***	0.083	***	***	***	***	***
9.3	1.13	0.220	0.028	***	***	***	***	***	***
11.0	1.82	0.339	0.010	***	***	***	***	***	***
13.2	3.28	0.647	0.034	***	***	***	***	***	***
7.1	0.415	0.084	0.013	***	***	***	***	***	***
12.9	3.50	0.778	0.006	***	***	***	***	***	***
8.6	0.908	0.161	***	***	***	***	***	***	***
7.4	0.405	0.076	0.013	***	***	***	***	***	***
8.6	0.840	0.163	0.017	***	***	***	***	***	***
7.2	0.398	0.079	0.009	***	***	***	***	***	***
7.4	0.493	0.105	0.015	***	***	***	***	***	***

DATE: 032477

LENG	WET	DRY	ASH	PROT	FAT	LIVW	LIVDR	LIVPR	GIR
16.5	5.36	1.14	0.125	***	***	***	***	***	***
13.1	2.68	0.618	0.062	***	***	***	***	***	***
13.3	2.85	0.546	0.062	***	***	***	***	***	***
10.7	1.47	0.283	0.032	***	***	***	***	***	***
10.4	1.35	0.269	0.025	***	***	***	***	***	***
7.7	0.455	0.086	0.010	***	***	***	***	***	***
18.7	9.25	***	***	***	***	0.090	0.015	***	***
21.0	13.1	***	***	***	***	0.210	0.045	0.008	***
17.8	6.25	***	***	***	0.200	***	***	***	***
26.7	28.1	***	***	***	2.48	***	***	***	***
7.8	0.591	***	***	0.056	***	***	***	***	***
12.1	2.38	***	***	0.274	***	***	***	***	***
12.1	2.20	***	***	0.254	***	***	***	***	***
10.6	1.48	***	***	0.160	***	***	***	***	***
20.3	14.4	***	***	2.03	***	***	***	***	***
14.8	4.97	***	***	0.719	***	***	***	***	***
17.6	6.97	***	***	0.992	***	***	***	***	***

Appendix Table. (continued)

LENG	WET	DRY	ASH	PROT	FAT	LIVW	LIVDR	LIVPR	GIR
23.9	28.8	8.39	0.260	***	***	***	***	***	5.0
23.5	27.7	7.34	0.461	***	***	***	***	***	5.0
19.1	14.2	3.49	0.227	***	***	***	***	***	3.5
28.5	52.4	15.2	0.801	***	***	***	***	***	6.0
15.7	6.67	1.71	***	1.31	***	***	***	***	***
14.5	5.72	1.54	***	1.17	***	***	***	***	2.7
15.9	7.41	1.79	***	0.991	***	***	***	***	2.9
17.7	11.0	2.82	***	1.73	***	***	***	***	3.5
24.8	34.5	11.2	0.587	6.22	4.35	1.64	***	0.052	5.3
26.8	40.0	12.6	0.739	7.35	4.40	1.56	***	***	5.5
18.3	13.2	***	***	***	0.740	0.230	0.040	***	3.8
18.7	11.2	***	***	***	0.628	0.160	0.024	0.005	3.5
18.1	12.3	***	***	***	0.711	0.220	0.041	0.015	3.8
20.4	13.1	***	***	***	***	0.234	***	***	3.5
20.1	17.8	***	***	***	1.29	0.460	***	0.019	4.3
18.2	13.7	***	***	***	0.962	0.290	***	0.006	4.5
18.8	12.1	***	***	***	0.483	0.230	0.055	0.010	3.4

Appendix Table. (continued)

DATE: 112576 (WILD EELS)

LENG	WET	DRY	ASH	PROT	FAT	LIVW	LIVDR	LIVPR	GIR
20.7	11.6	***	***	***	***	0.153	***	0.014	***
18.9	8.19	***	***	***	***	0.064	***	0.011	***
38.1	81.9	21.0	2.05	15.1	***	0.830	***	0.381	***
DATE: 032477									
8.9	0.820	0.154	0.014	***	***	***	***	***	***
9.0	0.740	0.139	0.017	***	***	***	***	***	***
8.5	0.655	0.116	0.011	***	***	***	***	***	***
8.7	0.869	0.164	0.017	***	***	***	***	***	***
10.6	1.45	0.288	0.029	***	***	***	***	***	***
9.2	0.734	0.135	***	0.080	***	***	***	***	***
8.6	0.529	0.096	***	0.048	***	***	***	***	***
9.2	0.826	0.154	***	0.080	***	***	***	***	***
8.6	0.675	0.126	***	0.072	***	***	***	***	***
8.5	0.665	0.116	***	0.077	***	***	***	***	***
9.1	0.800	0.147	***	***	***	***	***	***	***
6.6	0.226	0.042	***	0.037	***	***	***	***	***
5.7	0.142	0.026	***	0.019	***	***	***	***	***
5.9	0.160	0.027	***	0.022	***	***	***	***	***
6.8	0.113	0.039	***	0.014	***	***	***	***	***
6.2	0.203	0.032	***	0.026	***	***	***	***	***
6.0	0.184	0.032	***	0.020	***	***	***	***	***
6.2	0.185	0.031	0.002	***	***	***	***	***	***
5.0	0.100	0.015	0.001	***	***	***	***	***	***
5.8	0.136	0.022	0.002	***	***	***	***	***	***
6.5	0.220	0.040	0.004	***	***	***	***	***	***
5.9	0.164	0.027	0.002	***	***	***	***	***	***
6.1	0.171	0.031	0.003	***	***	***	***	***	***
DATE: 041377									
59.5	497.0	130.0	13.4	79.0	29.0	8.63	***	0.434	13.5
40.0	157.0	34.1	3.50	20.4	3.16	3.78	***	***	9.0
37.2	97.2	20.7	3.35	13.2	***	0.850	***	0.050	7.5
53.5	364.0	93.7	7.40	53.0	19.9	5.41	***	0.862	12.0
55.7	424.0	109.7	7.88	44.5	28.9	7.78	***	0.498	12.0