Woods Hole Oceanographic Institution

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Summary

The growth energetics of postlarval lobsters (Homarus americanus) fed a brine shrimp diet (Artemia salina; 51% protein, protein:carbohydrate = 5.1) were compared with the energetics of lobsters fed three artificial diets. The artificial diets were pelletized shrimp meal diets, varying in both protein (16.65-23.30%) and carbohydrate content (22.85-31.27%) and the protein:carbohydrate ratio (0.5-1.0). The best growth was measured among lobsters fed the brine shrimp diet and the 23.30% protein diet, followed by the two lower protein diets. The protein efficiency ratios (g wet wt. gain / g dry wt. protein fed) were inversely related to the protein level of each diet.

All diets were assimilated at the same level ($\approx$90%) but there were significant differences in food consumption rates, respiration rates and ammonia excretion rates among lobsters from the four experimental groups. Although all lobsters were given equal rations in grams, the artificial diets were lower in caloric content than the brine shrimp and the pellets were fragmented by the lobsters during the feeding process, resulting in significantly lower ($P < 0.01$) food consumption rates of the artificial diets.

Respiration rates measured immediately after feeding were significantly lower among lobsters fed the three artificial diets than those fed the brine shrimp diet; the increased respiration rate of the latter group of lobsters reflects an increased calorigenic effect

due to the higher protein level of the brine shrimp diet. Ammonia excretion rates of lobsters from the four groups were significantly different from one another ($P < 0.01$) and were directly correlated with the protein level of each diet. The O:N ratios (atomic ratio of oxygen consumed to NH_4^+-N excreted) measured in the four experimental groups were inversely related to the protein level of the four diets, indicating an increased dependence on carbohydrate catabolism for energy production with low dietary protein levels. The reduced growth rates of lobsters fed the two lower protein diets were apparently a result of differences in the amounts of food consumed and not increased energy expenditures or reduced assimilation efficiencies.

Introduction

Mass culture of commercially important carnivorous species, such as the American lobster, will be facilitated by the use of compounded diets. The basic features of such diets would be:

1) that the animal's nutritional requirements are met, resulting in high growth rates and no significant difference in biochemical composition from that of wild populations;

2) that the diets are readily consumed and assimilated by the animal; and

3) that the diets are formulated from commercially available feedstuffs, thus reducing the costs of producing the diets and minimizing the cost of feeding in aquaculture systems.

For an adequate formulation of compounded diets, however, an understanding of assimilation and utilization of various dietary components by an animal is needed.

One of the most essential dietary components is protein. Dietary protein is needed for tissue maintenance and growth, but may also be utilized as an energy source by some organisms. The assimilation and utilization of protein by an animal is affected by the amino acid sequence and caloric content of the dietary protein source and the level of protein intake and physiological condition of the organism (Cowey and Sargent, 1972). Conklin and his co-workers at the University of California, Bodega Bay Laboratory (Conklin et al., 1976, 1977) have conducted an extensive survey of the suitability of various

commercially available protein sources for lobster diets. Artificial diets utilizing shrimp meal, egg albumin or casein as protein sources have been shown to be effective in providing the protein needs of the lobster.

Gallagher et al. (1977) were unable to establish an optimum protein level for artificial diets; although a protein level of 11% was shown to be inadequate, no significant differences in growth of post-larval lobsters could be detected on protein levels ranging from 20% to 60%. Castell and Budson (1974), however, concluded that for adult lobsters high protein levels (> 60%) were needed to prevent losses in weight and maintain body condition. In both studies lobsters were fed artificial diets ranging from 0 to 60% protein as casein and adjusted to the same caloric content by varying corn starch levels (4-65%). Castell and Budson (1974) suggested that the high protein requirement observed in their study was due to either (1) limited levels of an essential amino acid, or (2) the dual role of protein for tissue formation and as an energy source in the diet of the lobster. They favored the latter suggestion, but the extent to which protein was utilized as an energy source was not investigated.

The relationship of protein to other dietary components and the resulting effects on energy partitioning by the lobster have not previously been investigated. Metabolic responses of an organism to various dietary components are important determinants of the physiological processing of calories and nutrients and may provide an index

of energy utilization of a specific diet. This study was undertaken to identify any changes in energy partitioning in postlarval lobsters associated with (1) an artificial diet vs. a natural diet, and and (2) varying protein:carbohydrate ratios of an artificial diet.

Materials and methods

Stage I larvae of the American lobster were hatched at 20°C from eggs held by female lobsters, transferred to fibreglass rearing tanks, described by Hughes et al. (1974), and maintained in flowing seawater at 20-22°C on a diet of frozen brine shrimp *Artemia salina*. Before attaining the postlarval stage, stage IV lobster larvae were removed from the larval rearing tanks and placed in compartmented polypropylene trays. Postlarval lobsters were divided into 4 groups of 100 animals each and maintained in flowing seawater at 20-22°C on one of three artificial diets or frozen brine shrimp. The composition of the four diets is presented in Table 1. The artificial diets were prepared according to the methods described by Conklin et al. (1976). Diet A is the shrimp meal diet formulated by Conklin et al. (1976), modified by the addition of Bernhart-Tomarelli salt mix. Frozen brine shrimp was used instead of live brine shrimp because of the large numbers needed daily and because of the possible variation in composition of live brine shrimp with culture conditions. All lobsters were fed 5% (DW/WW basis) of their body weight per day.

Table 1. Composition of test diets (% dry weight basis).

Ingredient	Diet			
	A	B	C	D
Herring meal[1]	7.77	7.77	7.77	--
Shrimp meal[2]	30.58	26.21	21.84	--
Sweet whey[3]	4.85	4.85	4.85	--
Soybean meal[4]	2.91	2.91	2.91	--
Rice bran[5]	19.42	19.42	19.42	--
Corn starch[4]	8.74	13.11	17.48	--
Brewer's yeast[6]	11.65	11.65	11.65	--
Vitamin mix[4,7]	1.94	1.94	1.94	--
Lecithin[4]	0.97	0.97	0.97	--
Cod liver oil[4]	4.85	4.85	4.85	--
Bernhart-Tomarelli[4] Salt Mix	2.91	2.91	2.91	--
Kelgin[8]	1.94	1.94	1.94	--
Sodium metaphosphate[9]	1.46	1.46	1.46	--
Frozen brine shrimp[10]	--	--	--	100.00

[1] James Farrell & Co., Seattle

[2] Southland Canning & Packing Co., New Orleans

[3] Kraft Foods, Chicago

[4] ICN Pharmaceutical, Inc., Cleveland

[5] Uncle Ben's, Inc., Houston

[6] Millibrew, Inc., Juneau, Wisconsin

[7] Castell and Budson (1974)

[8] Kelco Co., San Diego

[9] Fisher Scientific

[10] Metaframe Co., Newark, California

Molting frequency and length and wet weight after each molt were monitored for the four groups of lobsters for the experimental period of 120 days. Assimilation efficiencies of the four groups of lobsters were measured using both a direct gravimetric method and the indirect Cr_2O_3 technique described by McGinnis and Kasting (1964a,b) and Forster and Gabbott (1971). For assimilation experiments, eight lobsters of the same stage and weight from each group were placed in compartmented trays with 3 mm Vexar^R mesh bottoms; the trays were then placed in 1.5 liter continuous flow assay chambers, supplied with 1 μm filtered seawater. Pre-weighed rations were given to each lobster and the animals were allowed to feed for 4 hours. Uneaten food was collected after the designated feeding period and the seawater was replaced with new filtered seawater. Feces were collected 24 h later and analysed for dry weight and Cr_2O_3 content. Per cent assimilation was determined using the following equations:

for direct gravimetric method,

$$\% \text{ assimilation} = (1 - \text{mg feces/mg food consumed}) \times 100;$$

for Cr_2O_3 method,

$$\% \text{ assimilation} = \left(1 - \frac{Cr_2O_3 \text{ food}}{Cr_2O_3 \text{ feces}}\right) \times 100.$$

Respiration rates and ammonia excretion rates of lobsters from each group were measured at bi-weekly intervals during the experimental period. Respiration rates were measured immediately after feed-

and 24 h later to approximate the active and standard rates of respiration. Oxygen consumption rates of each postlarval stage were measured using a Gilson differential respirometer. Individual lobsters were placed in either 15 ml or 50 ml respirometer flasks with 10 ml filtered seawater; fluted filter paper soaked with 10% KOH was used as the CO_2 absorbent. Oxygen uptake was measured for 90 min at 20-22°C and is reported as µl O_2/h/g wet weight, adjusted to µl of dry gas at standard temperature and pressure. At the end of each set of oxygen uptake measurements, the seawater in the respirometer flasks was analyzed for NH_4^+-N by the method of Solorzano (1969) in order that an in situ estimate of ammonia excretion rates and the O:N ratio could be made; ammonia levels were compared with control blanks and excretion rates are reported as µg NH_4^+-N/h/g wet weight. Caloric equivalents of oxygen consumed and ammonia excreted were 4.825×10^{-3} cal/µl (Brody, 1945) and 1.76×10^{-3} cal/µg (Rossini et al., 1952), respectively.

Each diet was analyzed for total carbon and nitrogen, caloric content and the relative percentages of protein, lipid, carbohydrate and ash. At the end of the 120 day experimental period, lobsters from each group were anlayzed for protein, lipid, carbohydrate, ash and chitin content. Total carbon and nitrogen were measured using a Perkin-Elmer CHN analyzer and caloric content was measured using a Phillipson Oxygen Microbomb Calorimeter. Protein, carbohydrate, chitin and ash content were determined according to the methods

described by Raymont et al. (1964); lipid content was analyzed according to the method described by Marsh and Weinstein (1966).

Energy budgets were constructed for each of the four groups of lobsters, using the bioenergetics scheme devised by Warren and Davis (1967). Significant differences in the various components of the energy budget relative to diet were determined by analysis of variance (Sokal and Rohlf, 1969). The relationship of metabolic activity (oxygen consumption and ammonia excretion) to body size was assessed according to the principles of allometry as described by von Bertalanffy (1964); the allometric equation ($y = a \cdot x^b$) quantitatively describes this relationship and for these experiments, y = metabolic function (respiration rate or ammonia excretion rate), x = wet weight in grams, and a and b = the regression coefficients for each set of experimental data. Significant differences between the regression equations for respiration rates and ammonia excretion rates from the four test groups were determined by analysis of covariance (Sokal and Rohlf, 1969).

Results

Nutrient analysis of the test diets is presented in Table 2. Lipid and ash content of the three artificial diets (A-C) were not significantly different from one another and were similar to the ash and lipid content of brine shrimp (diet D). Protein and carbohydrate content and the protein: carbohydrate ratio were

Table 2. Nutrient analysis of test diets.

Component	Diet			
	A	B	C	D
% Lipid[1]	7.75 (0.25)	7.75 (0.25)	7.75 (0.25)	8.25 (0.25)
% Protein[1]	23.30 (0.50)	19.97 (0.50)	16.65 (0.30)	51.00 (0.50)
% Carbohydrate[1]	22.85 (0.50)	27.47 (0.50)	31.27 (0.50)	9.98 (0.20)
% Ash[1]	21.71 (0.50)	21.50 (0.50)	19.87 (1.00)	17.40 (1.00)
Protein:Carbohydrate	1.02	0.73	0.53	5.11
Calories/mg	2.75	2.75	2.75	3.12
C:N	8.17	9.04	10.17	4.60

[1]All values are mean values of three replicate assays (± 1 standard error).

significantly different in each of the four diets ($P < 0.01$). The artificial diets had a slightly lower caloric content than brine shrimp.

Growth of postlarval lobsters from the four experimental groups is presented in Table 3. There was no significant difference in molting frequency among the four groups. The best growth was measured among lobsters maintained on diets A and D, followed by diets B and C; there was no significant difference between groups A and D or between groups B and C. The best fit slopes of wet weight increases (weight increases/day) of each group are comparable to results obtained by Conklin et al. (1976) in a 90 day feeding trial of postlarval lobsters fed live brine shrimp (0.015 grams/day) but are higher than results obtained in the same experiment with lobsters fed the shrimp meal diet (0.007 grams/day). Survival on the three artificial diets was greater than survival on diet D, possibly due to initial problems with fouling of uneaten brine shrimp; rinsing of frozen brine shrimp with seawater prior to addition to test chambers alleviated this problem and reduced mortality. The weight increases of each stage from the four experimental groups are presented in Fig. 1.

Food consumption, fecal production and assimilation efficiencies of lobsters from the four groups are presented in Table 4. Differences in growth rate among the four groups of lobsters might be explained by differences in food consumption rates (Table 4). The artificial

Table 3. Growth of postlarval lobsters fed the test diets for 120 days.

Measurement	Group			
	A	B	C	D
Initial weight[1] (grams)	0.189 (0.005)	0.193 (0.007)	0.192 (0.009)	0.195 (0.010)
Final weight[1] (grams)	2.572 (0.075)	2.002 (0.110)	1.977 (0.025)	2.487 (0.113)
Weight increase/day (grams/day)	0.020	0.015	0.015	0.019
# Molts	6	6	6	6
% Mortality	3.0	8.0	10.0	18.0

[1]Wet weight, mean of 20 animals (± 1 standard error).

Table 4. Food consumption, fecal production and assimilation efficiencies of postlarval lobsters fed the test diets.

Parameter	Group A	Group B	Group C	Group D
Food given - grams[1]	4.530	3.925	3.950	4.785
- calories[1]	12,450	10,800	10,850	14,950
Food consumed - grams[2]	2.030	1.750	1.760	2.055
- calories[2]	5,585	4,810	4,835	6,410
Fecal production - grams[2]	0.245	0.200	0.180	0.200
- calories[2]	670	550	495	630
Assimilation efficiency - %[3]	88.0	88.6	89.8	90.2
	(1.0)	(0.4)	(1.2)	(1.2)

[1]Total food given during 120 day period.

[2]Sum of average values for each postlarval stage (VI-XI).

[3]Mean values from direct gravimetric and Cr_2O_3 analyses for each postlarval stage (± 1 standard error).

diets were slightly lower in caloric content and were fragmented by the lobsters during the feeding process, particularly pellets of diets B and C, resulting in significantly lower ($P < 0.01$) consumption rates. Assimilation rates of the four diets, measured by both gravimetric and Cr_2O_3 techniques (McGinnis and Kasting, (1964a,b), were not significantly different from one another. In all groups consumption rates were significantly less than the daily ration provided.

The results of respiration rate measurements of lobsters from the four experimental groups are presented in Fig. 2; a summary of the regression statistics for each set of experimental data is presented in Table 5. Weight specific respiration rates were negatively correlated with the wet weight of animals in all four groups. Respiration rates measured immediately after feeding were highest among lobsters from group D and were $\approx$37% higher than the standard respiration rate measured 24 hours later. There was a $\approx$17% increase in respiration rate associated with feeding measured among lobsters from groups A, B and C. Comparison of the regression equations for groups A and D by analysis of covariance indicated a significant difference in respiration rates measured after feeding between the two groups ($F_{(1, 97)} = 64.4$, $P < 0.01$). No significant difference in standard respiration rates was detected among the four test groups.

Ammonia excretion rates of lobsters from the four groups are presented in Fig. 3; a summary of the regression statistics for each set of experimental data is presented in Table 6. Weight specific ammonia excretion rates were also negatively correlated with

Table 5. Regression statistics for respiration rates (μl O_2/hour/gram wet weight) of postlarval lobsters fed the test diets.

Group	$y = a.x^b$				
	a	b	Sy.x	r	N
After feeding:					
A	123.61	-0.371	0.032	-0.931	64
B	124.64	-0.376	0.034	-0.872	53
C	122.51	-0.423	0.032	-0.914	50
D	139.52	-0.384	0.033	-0.899	47
After 24 hours starvation:					
A	111.56	-0.293	0.032	-0.907	56
B	106.75	-0.371	0.035	-0.869	51
C	105.17	-0.407	0.033	-0.902	50
D	104.28	-0.336	0.035	-0.868	45

Table 6. Regression statistics for ammonia excretion rates ($\mu g\ NH_4^+$-N/hour/gram wet weight) of postlarval lobsters fed the test diets.

Group	$y = a.x^b$				
	a	b	Sy.x	r	N
After feeding:					
A	9.62	-0.432	0.033	-0.933	36
B	8.63	-0.590	0.034	-0.920	32
C	6.17	-0.651	0.033	-0.910	32
D	13.41	-0.362	0.032	-0.874	35

the wet weight of animals in the four test groups. Excretion rates of lobsters from the four groups were significiantly different from one another (analysis of covariance: $F_{(3, 134)} = 94.5$, $P < 0.01$) and were directly correlated with the protein level of each diet.

The values for the percentage increase in respiration rate or specific dynamic action (SDA), the O:N ratio (atomic ratio of oxygen consumed to NH_4^+-N excreted) and the protein efficiency ratio (g wet wt. gain/g dry wt. protein fed) for each group of lobsters are presented in Table 7. The O:N ratios and the protein efficiency ratios measured in the four experimental groups were significantly different from one another ($P < 0.01$) and were inversely related to the protein level of each diet.

The calculated energy budgets of stage VI-stage XI lobsters from the four experimental groups are presented in Fig. 4. Because of the fragile nature of lobsters just prior to and following molting, no estimates of energy losses due to increased respiration and exuvia production were determined; the values estimated by Logan and Epifanio (1978) were used in the calculation of the energy budget and it is assumed that these losses would be consistent among the four groups. The values for gross (Q_G/Q_C) and net (Q_G/Q_A) conversion efficiencies of each postlarval stage from the four experimental groups are presented in Table 8 and the results of analysis of variance of these measurements are presented in Table 9. The highest mean conversion efficiencies (both gross and net) were measured among

Table 7. Values for SDA, O:N ratio, food conversion ratio and protein efficiency ratio of postlarval lobsters fed the test diets[1].

Measurement	Group			
	A	B	C	D
SDA - %[2]	17.5	17.1	17.6	36.8
	(1.0)	(0.6)	(0.5)	(1.5)
O:N ratio	16.2	17.3	23.3	12.9
	(0.5)	(1.4)	(1.7)	(0.2)
FCR[3]	1.9	2.2	2.2	2.1
	(0.1)	(0.1)	(0.1)	(0.1)
PER[4]	2.2	2.3	2.7	0.9
	(0.1)	(0.1)	(0.1)	(0.1)

[1]All values are mean values of stage VI through stage XI lobsters (± 1 standard error).

[2]Specific dynamic action.

[3]Food conversion ratio = $\frac{\text{total dry wt. of food fed (grams)}}{\text{total wet wt. gain (grams)}}$.

[4]Protein efficiency ratio = $\frac{\text{wet wt. gain (grams)}}{\text{dry wt. protein fed (grams)}}$.

Table 8. Gross and net conversion efficiencies of each postlarval stage from the four experimental groups of lobsters.

Measurement	Stage	Group			
		A	B	C	D
Gross conversion efficiency[1] (Q_G/Q_C %)	VI	41.5	39.2	41.5	43.5
	VII	48.8	48.1	47.6	45.6
	VIII	42.2	36.1	37.5	39.0
	IX	37.7	36.6	34.3	32.7
	X	37.8	31.6	33.3	34.4
	XI	43.4	36.1	38.5	39.1
Net conversion efficiency[1] (Q_G/Q_A %)	VI	45.8	43.4	45.8	48.2
	VII	54.5	53.3	52.6	50.6
	VIII	46.9	40.0	41.7	43.3
	IX	41.6	40.6	38.0	36.5
	X	42.0	35.2	37.0	38.3
	XI	48.1	40.2	42.7	43.5

[1] All values are mean values of 20 animals.

Table 9. Analysis of variance table for gross and net conversion efficiencies of lobsters from the four experimental groups.

Source of variation	df	MS	SS	F-ratio[1]
Gross conversion efficiency:				
among groups	3	17.7	53.1	--
within groups	20	25.0	499.8	--
total	23	--	552.9	0.71
Net conversion efficiency:				
among groups	3	21.7	65.2	--
within groups	20	30.4	607.8	--
total	23	--	673.0	0.72

[1]Not significant.

group A lobsters (41.9% and 46.4%, respectively); however, there was more variation within the various groups.

The biochemical composition of lobsters from each group is presented in Table 10. There was no significant difference in lipid or carbohydrate content of lobsters from the four groups; however, lobsters from group A had a slightly higher protein content and lower chitin content than lobsters from the other three groups.

Discussion

To maximize both growth and protein efficiency ratios in the American lobster, artificial diets with energy sources in addition to protein must be utilized. Energy production from protein oxidation is both nutritionally and economically wasteful and the protein sparing action of other dietary components must be fully investigated. In several recent studies the role of dietary carbohydrate and lipid in providing the energy requirements of an organism has been explored. Page and Andrews (1973) in their study of the channel catfish found that increasing energy levels (by adding more lipid or carbohydrate) with a constant dietary protein level resulted in improved protein utilization. Adron et al. (1976) obtained similar results with turbot. Clifford and Brick (1978) observed the metabolic responses of the freshwater shrimp Macrobrachium rosenbergii to various levels of dietary protein, lipid and carbohydrate and concluded that higher carbohydrate levels resulted in a greater efficiency of protein utilization. The results of the present study are indicative that

Table 10. Biochemical composition of postlarval lobsters fed the test diets for 120 days[1].

Component	Group			
	A	B	C	D
% H_2O[2]	73.8 (1.6)	74.5 (1.6)	70.5 (0.5)	74.7 (1.9)
% ash[3]	33.9 (2.5)	33.0 (2.1)	36.7 (1.5)	37.8 (1.5)
% protein[4]	84.1 (2.8)	78.2 (1.5)	79.6 (2.6)	80.2 (1.0)
% carbohydrate[4]	1.2 (0.1)	1.3 (0.1)	1.5 (0.2)	1.5 (0.2)
% lipid[4]	4.9 (0.2)	5.4 (0.2)	4.9 (0.2)	5.0 (0.3)
% chitin[4]	10.3 (0.5)	15.1 (1.0)	14.4 (0.3)	13.4 (0.5)

[1]All values are mean values of 6 determinations from stage XII lobsters (± 1 standard error).

[2]% live wt. basis.

[3]% dry wt. basis.

[4]% ash-free dry wt. basis.

dietary carbohydrate levels may induce a protein sparing action in the American lobster as well.

The metabolic responses of an organism to a specific diet and its various components may provide valuable information on the utilization of dietary components. The increase in respiration rate associated with feeding is termed the specific dynamic action and reflects the calorigenic effect of protein catabolism (Krebs, 1964). The highest value for SDA was measured among lobsters fed brine shrimp, presumably due to the high protein level of this diet. No correlation of SDA with dietary protein level was detected, however, among the other three groups of lobsters; equivalent values of SDA were measured from each group. It is apparent that stimulation of SDA in the lobster is a more complex phenomenon than can be described by a simple linear relationship between protein intake and increased metabolism; similar inconsistencies were observed by Nelson et al. (1977) and Clifford and Brick (1978) in experiments with Macrobrachium. A consequence of high protein diets, such as Diet D, resulting in increased values of SDA is the higher energy expenditures associated with respiratory activity and the reduction in conversion efficiency in comparison with the lower protein diets.

The O:N ratio is the atomic ratio of oxygen consumed to ammonia-N excreted and reflects the catabolic balance of carbohydrates, lipids and proteins in the organism (Corner and Cowey, 1968). A low O:N ratio is indicative of high protein catabolism, whereas a high O:N

ratio reflects high lipid or carbohydrate catabolism. The O:N ratios measured in the four experimental groups of this study were inversely related to the protein level of the four diets. The theoretical minimum for the O:N ratio is approximately 8.0 (Conover and Corner, 1968), indicative that an organism is deriving all of its energy from protein catabolism. With a ratio of 12.9 measured among lobsters fed diet D, there is an indication that although protein is the principal energy source, some lipid or carbohydrate may also be utilized for energy. The increased O:N ratios measured among lobsters fed the three artificial diets are suggestive of increased dependence on lipid or carbohydrate catabolism for energy production. Since the lipid level of the three artificial diets was maintained at a constant level, the change in the O:N ratios was apparently due to the sparing action of carbohydrate.

Food conversion ratios and protein efficiency ratios of cultivated organisms are generally based on the increase in weight per amount of food given not the amount of food consumed. If significant differences in the latter two values exist, energetic efficiencies of an organism will be underestimated. In this study consumption rates of postlarval lobsters were $\approx$ 45% of the daily ration provided. Pellet instability of artificial diets and fragmenting whole brine shrimp by the lobster resulted in some unrecoverable loss of all of the diets. Improved stability of the pelletized diets might result in reduced losses and improved growth rates.

Although there were only slight differences in food conversion ratios and conversion efficiencies of the four groups of lobsters, the protein efficiency ratios measured in the four groups were inversely related to the protein level of each diet, providing further evidence for the sparing action of increased carbohydrate levels in the three artifical diets.

Further identification of the responses of the lobster to dietary carbohydrate levels and sources is needed before diets with optimum protein:carbohydrate ratios and protein:energy ratios can be formulated. The findings reported in this study are a preliminary framework from which this problem can be further explored.

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Figure legend

Figure 1. Weight increases at each postlarval stage of lobsters from the four experimental groups; A, B, C and D refer to the specified diets.

Figure 2. Log-log plots of respiration rates and wet weight of postlarval lobsters from the four test groups; closed circles, measurements made after feeding; open circles, measurements made after 24 hours starvation; ------ regression line for fed animals; ——— regression line for starved animals; A, B, C and D refer to specified diets.

Figure 3. Log-log plots of ammonia excretion rates and wet weight of postlarval lobsters from the four test groups; ——— regression line; A, B, C, and D refer to the specified diets.

Figure 4. Energy budgets of each postlarval stage of lobsters from the four experimental groups; A, B, C and D refer to the specified diets; Q_C = calories consumed, Q_G = calories available for growth, Q_R = calories expended in respiration, Q_V = calories unassimilated or lost through excretion, Q_A = calories assimilated, Q_M = calories lost through molting.

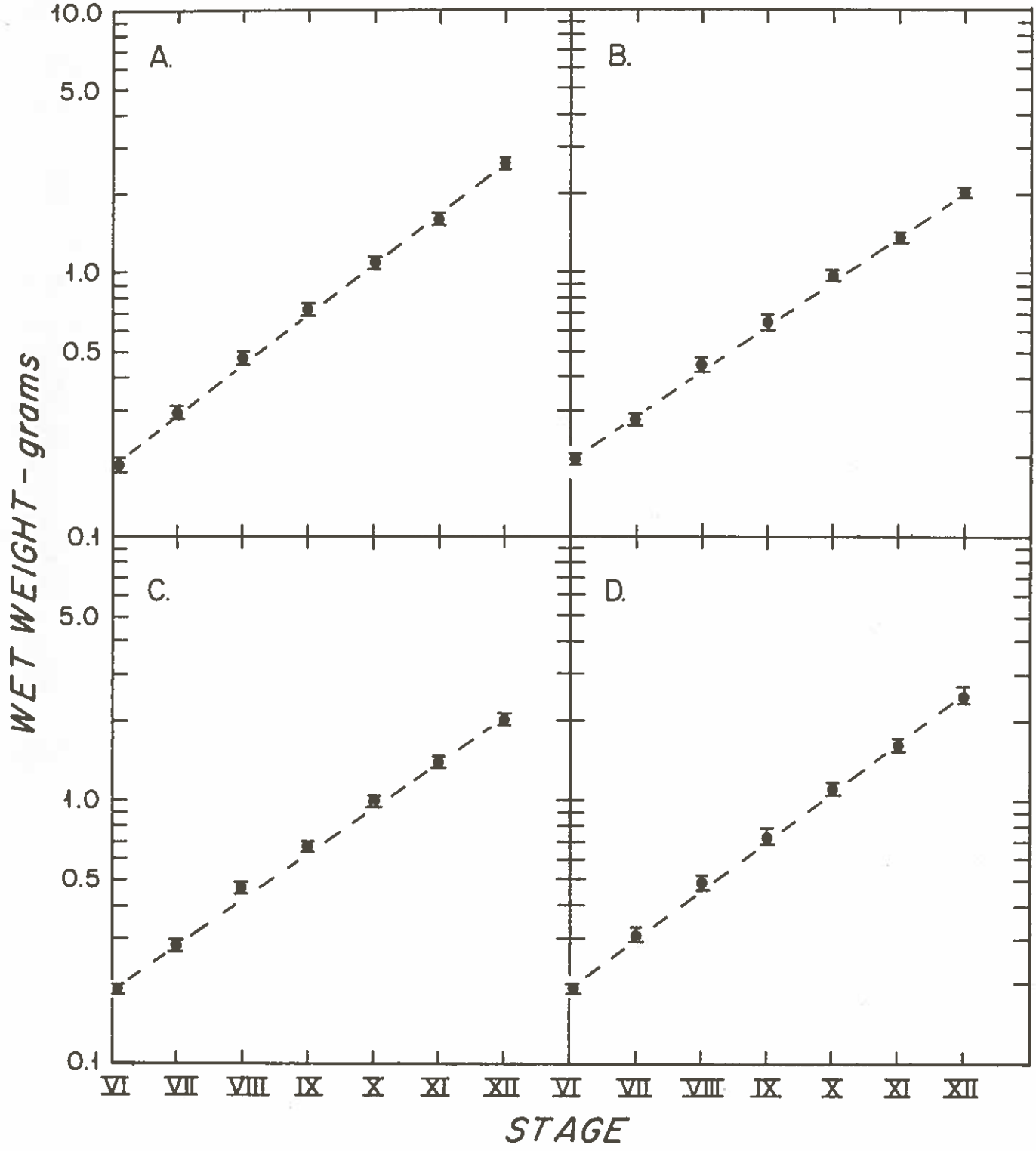
A.
B.
C.
D.
10.0
5.0
1.0
0.5
0.1
WET WEIGHT - grams
VI
VII
VIII
IX
X
XI
XII
STAGE

Fig. 1

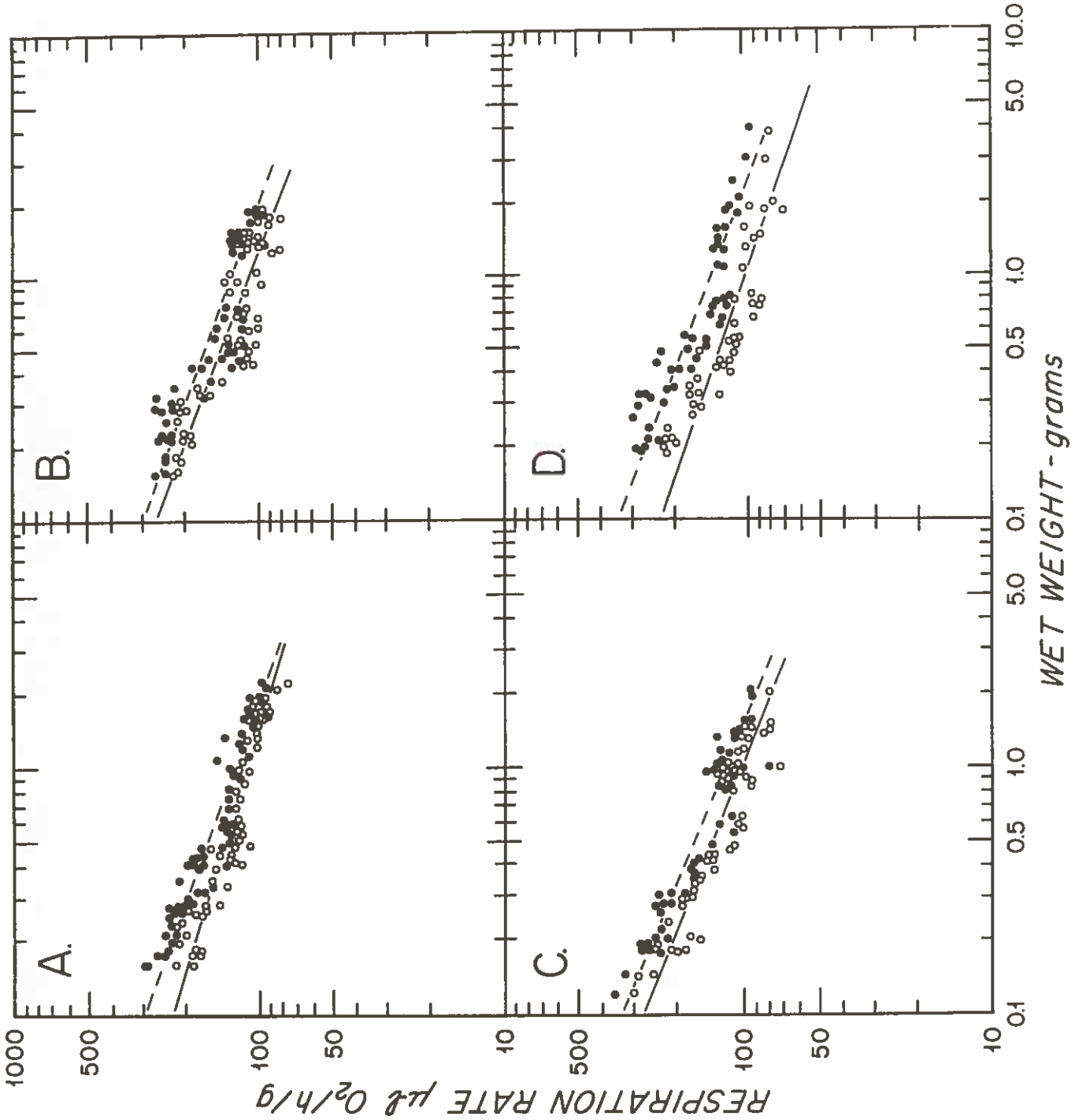
A.
B.
C.
D.
RESPIRATION RATE μl O2/h/g
WET WEIGHT-grams
1000
500
100
50
10
0.1
0.5
1.0
5.0
10.0

Fig. 2

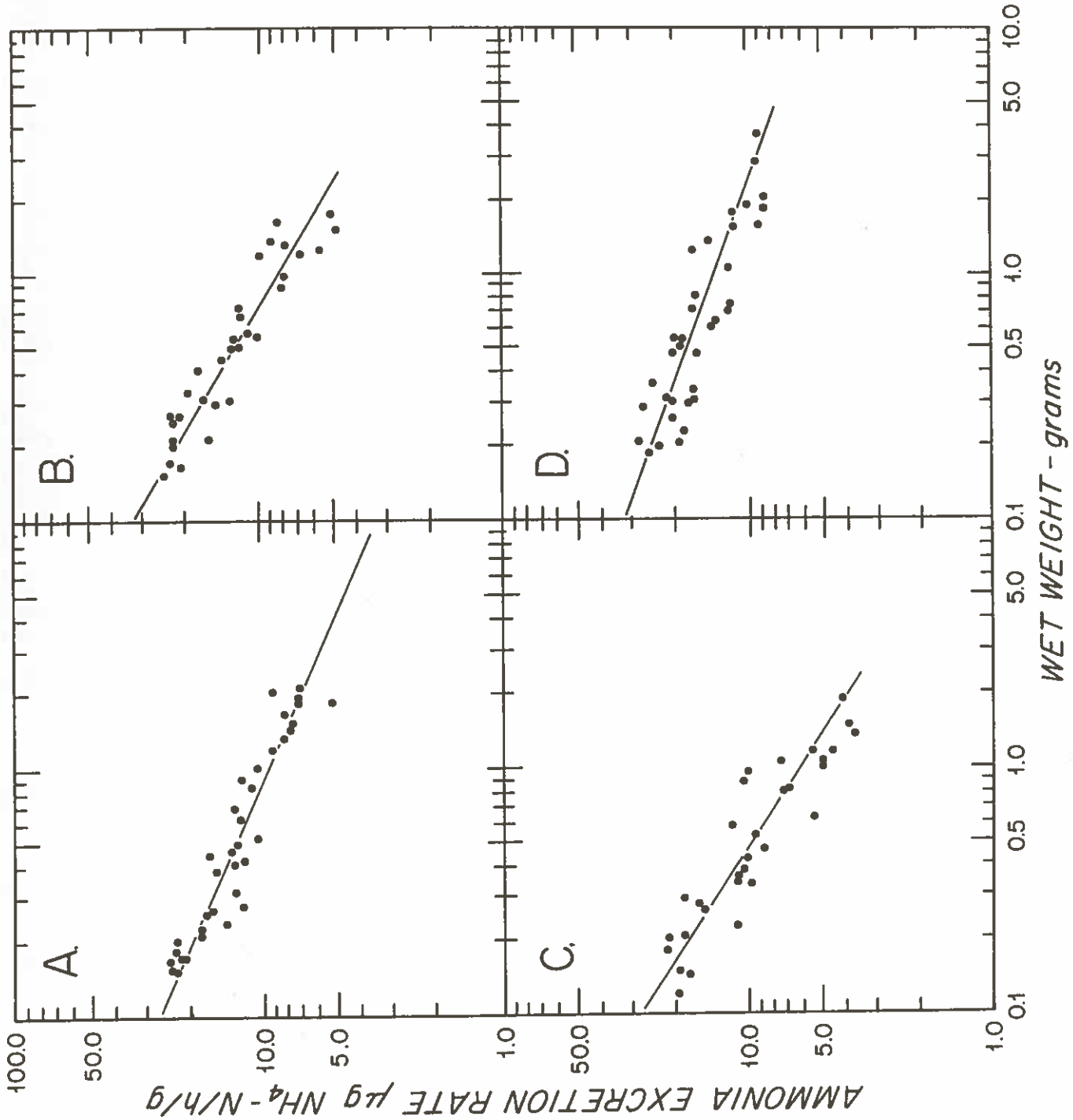
A.
B.
C.
D.
100.0
50.0
10.0
5.0
1.0
50.0
10.0
5.0
1.0
0.1
0.5
1.0
5.0
0.1
0.5
1.0
5.0
10.0
AMMONIA EXCRETION RATE μg NH4-N/h/g
WET WEIGHT-grams

Fig. 3

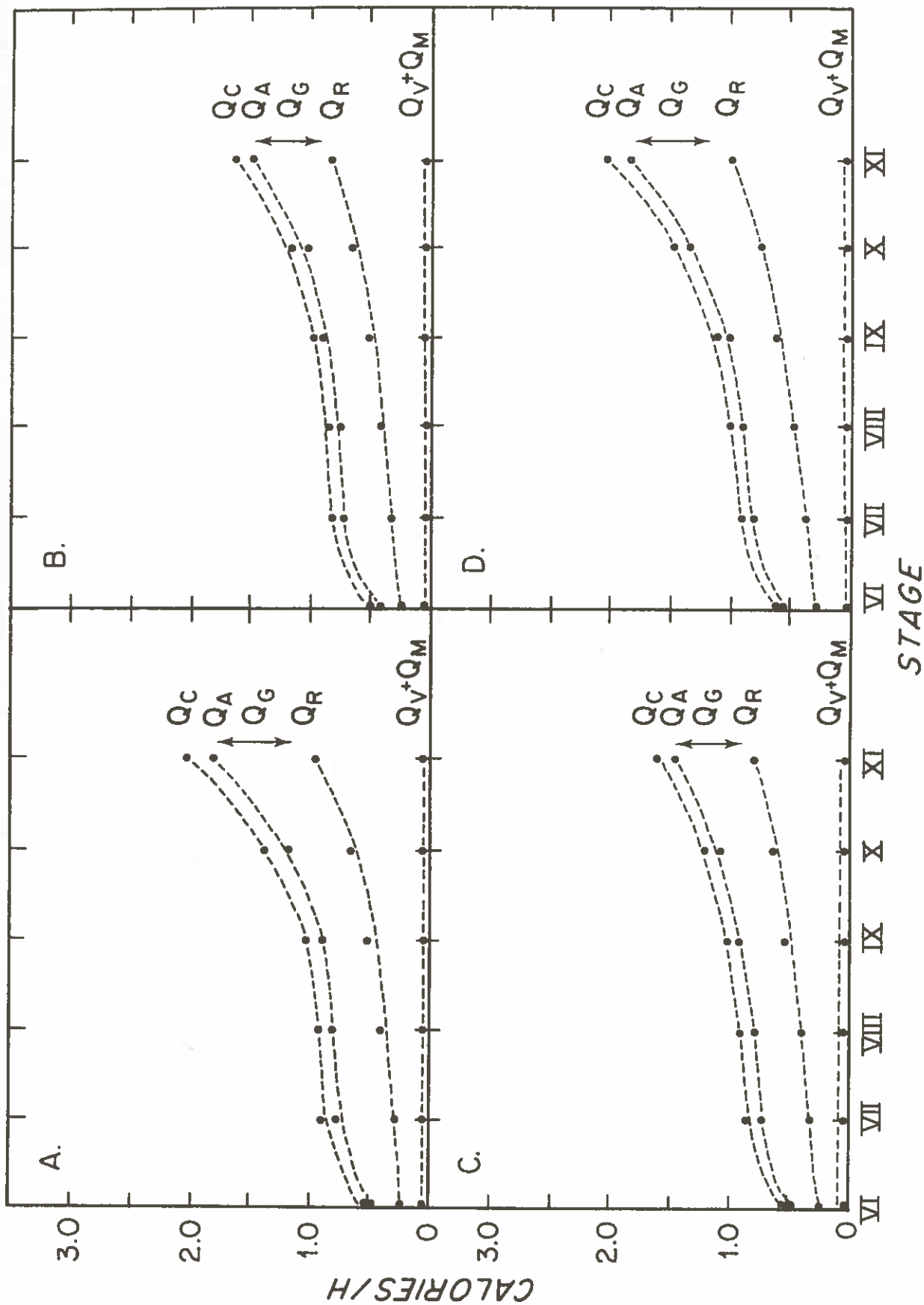
A.
B.
C.
D.
Q_C
Q_A
Q_G
Q_R
Q_V+Q_M
CALORIES/H
STAGE
0
1.0
2.0
3.0
VI
VII
VIII
IX
X
XI

Fig. 4

March 1979

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Woods Hole Oceanographic Institution
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THE EFFECTS OF DIET ON THE GROWTH ENERGETICS OF POSTLARVAL LOBSTERS (HOMARUS AMERICANUS) by Judith M. Capuzzo and Bruce A. Lancaster. 33 pages. June 1979. Prepared for the Department of Commerce, NOAA Office of Sea Grant under Grant #04-7-158-44104.

The growth energetics of postlarval lobsters (Homarus americanus) fed a brine shrimp diet were compared with the energetics of lobsters fed three artificial diets; the artificial diets were pelletized shrimp meal diets, varying in both protein and carbohydrate content and the protein:carbohydrate ratio. The best growth was measured among lobsters fed the brine shrimp diet (51% protein) and the artificial diet with the highest protein level (23.3%), followed by the two lower protein diets (20.0% and 16.7%). The protein efficiency ratios were inversely related to the protein level of each diet.

All diets were assimilated at the same level (~90%) but there were significant differences in food consumption rates, respiration rates and ammonia excretion rates among lobsters from the four experimental groups. Lobsters fed low protein diets demonstrated an increased dependence on carbohydrate catabolism for energy production. The reduced growth rates of lobsters fed the two lower protein diets were a result of differences in the amounts of food consumed and not increased energy expenditures or reduced assimilation efficiencies.

1. Lobsters
2. Aquaculture
3. Artificial diets
I. Capuzzo, Judith M.
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