

**ASSESSING GROWTH OF NORTHEAST ARCTIC COD BY A
BIOENERGETICS MODEL**

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ABSTRACT

This paper represents an attempt to elucidate how fish body size differences and metabolic costs alter the relationship between growth and consumption using a bioenergetics model. The results show that the daily growth increments of Northeast Arctic cod are considerably reduced when the consumption is adjusted for metabolism and activity cost. Consequently, the cost of the standard metabolism, specific dynamic action, swimming activity, spawning losses, egestion and excretion must be first covered before any energy is available for growth. Otherwise, individual growth rate is overestimated with extremely high food conversion efficiency.

INTRODUCTION

Fish bioenergetics approaches have been used widely during the last ten years to address consumption and growth patterns of fish populations in nature (Collie, 1987; Cacho et al., 1990; Cacho, 1990; Wildhaber and Crowder, 1990; Fox, 1991; Masser, et al, 1991; Wahl and Stein, 1991; Arrhenius and Hansson, 1994). In addition, it can be used as tools to estimate waste loads from aquaculture operation for interpreting changes in water quality (Axler et al., 1993). In intensive fish culture system the relationship between growth, metabolism and feeding is being used to predict the outcome of various management strategies (Schoor, 1991).

Until recently (Ajiad et al., 1994), there were no published bioenergetics model for cod in the Barents Sea to predict growth from a given consumption based on stomach contents and to study cod, capelin, shrimp and herring interaction from a bioenergetic perspective.

I.M.R. bioenergetics model provided the Arctic Fisheries W. G. with growth prediction for Northeast Arctic cod, and for 1994 and 1995 our growth prognosis for the short term prediction shows a good fit between the model output and the observed data. (Anon., 1996)

In this paper we use a bioenergetics model for cod in the Barents Sea to elucidate how body size differences and metabolic cost affect the relationship between growth and consumption based on stomach data collected during winter 1994.

MATERIAL

The data sources are cod stomachs content data collected by the Norwegian research vessels during winter survey 1994 in the Barents Sea.

METHOD

Temperature

Following the MULTSPEC approach by using climatological data adjusted by yearly variations in the Kola section at a depth of 100 m to be representative of temperature value in the stomach data file for each individual fish.

Consumption

The daily consumption (grams) of the major prey items is estimated for each individual fish by Santos's evacuation model (dos Santos, 1990).

MAXIMUM CONSUMPTION

The maximum consumption per day can be approximated from field consumption data. By plotting for each individual fish the daily consumption in calories against fish weight in grams and then fitting a regression line through the upper limit of the points in the plot, the weight dependence of the maximum consumption on a caloric basis can be found (Ajiad et al., 1994). The relationship was described as:

$$C_{max} = 68.84 * w^{0.934} \quad (1)$$

C-consumption(cal/day)

w-fish weight (gr)

The P value which is the fraction of the maximum consumption is calculated by dividing actual (observed) consumption for each fish by C_{max} . The daily consumption in calories is defined as proportion of a possible maximum consumption at any weight.

$$C_d = C_{max} * P \quad (2)$$

The bioenergetics model can be expressed as :

$$\frac{dw}{dt} = C_d(1 - f - u) - M - S_l \quad (3)$$

where:

C_d —daily consumption in calories

f-energy egested (feces)

u-energy excreted (ammonia and urea)

M-total metabolism

S_l —spawning losses

$$M = m_s + m_d \quad (4)$$

m_s is the standard & activity metabolism, and m_d is the specific dynamic action.

The m_s is a function of fish weight, temperature (T) and swimming speed:

$$m_s = a_2 * w^{b_2} * e^{mT} * e^{0.0234*0.2*l} \quad (5)$$

l is the fish length (cm) and 0.0234 is coefficient of metabolism versus swimming speed (Rao, 1971).

The spawning losses for the mature part of the cod population can be estimated as:

$$S_l = a_3 * l^{b_3} * E_w * C_g / 180 \quad (6)$$

E_w is the wet weight in grams of one egg and C_g is the caloric density of one gram ovary.

Table 1 below summarizes parameter values applied in equations 4, 5 and 6 together with sources.

Parameters	value	Sources
a_2	0.16	Karamushko (1989)
b_2	0.7834	Karamushko(1989)
m	0.0723	Karamushko(1989)
a_3	0.0125	Kjesbu(1988)
b_3	4.27	Kjesbu(1988)
E_w	0.00164	Kjesbu(pers.comm)
C_g	1000	Jobling(1982)
m_d	1.38(daily ration 2%)	Karamushko(1989)
	1.55(daily ration 4%)	Karamushko(1989)
	1.94(daily ration 6%)	Karamushko(1989)
caloric density capelin	1309	Santos and Jobling
caloric density herring	1619	(1995)
caloric density shrimp	1166	
caloric density krill	952	
caloric density red fish	832	
calorc density haddock	761	
caloric density polar cod	785	

RESULTS

Estimates of daily energy requirements during first quarter of 1994, in terms of standard metabolism, maximum consumption, P value, activity multiplier (swimming activity), SDA and growth by age groups are shown in Table 2 and Fig. 1A-1F. The balance between daily consumption and the sum of energy losses during one day (equation 3) was used to estimate cod growth during that day and then the expected cod weight the next day.

Table 2. The average of daily energy requirements by cod age groups during first quarter of 1994

Fish age	Consumption (cal/day)	Standard metabolism (cal/day)	Max. consumption (cal/day)	P value	Swimming activity	SDA (cal/day)	T ⁰ C	n
1	215.3	109.2	678.1	0.312	1.055	45.5	3.25	125
2	1117.6	482.6	4050.5	0.243	1.101	209.6	3.25	188
3	3987	1451.6	14803	0.269	1.166	582.5	3.23	260
4	8369	3158.9	37170	0.226	1.241	1229.7	3.21	437
5	12032	5664.5	74604	0.169	1.321	2146.2	3.19	405
6	10672	6599.2	86131	0.127	1.343	2541.2	3.48	32

To demonstrate the effect of the consumption adjustment on the relationship between growth and consumption, four growth options (cal/day) are presented in Table 3. (gr0) is unadjusted growth value and it is equal to the total consumption(90%) in calories per day. (gr1) is the growth value after the consumption is adjusted for the standard metabolism. (gr2) is the growth value after the consumption is adjusted for the standard metabolism and activity and finally (gr3) is the daily growth after the consumption value is adjusted for the standard metabolism, activity and SDA. The growth is positive for all age groups except age 6 at gr3. This can be explained by either that swimming activity was high (1.343 of the standard) or this age group fed at a rate which did not exceed the maintenance cost. Most likely, this is due to the sample size of only 32 observations. Food conversion efficiency (weight gain/90% consumption) decreased markedly from gr0 to gr3 and varied according to fish age once the daily consumption is adjusted for the maintenance costs.

Table 3. Estimated growth (cal/day) during first quarter of 1994 by cod age groups with four adjustment options.

Fish age (year)	gr0 (cal/day)	gr1 (cal/day)	gr2 (cal/day)	gr3 (cal/day)	Fish weight (gr)	Fish length (cm)
1	193.0	77.2	70.2	24.6	11.6	11.4
2	1059	543.9	482	272	79.8	20.5
3	3588.6	2115.5	1852.4	1237.2	316.9	32
4	7532.7	4374.3	3585	2355.5	845.8	46
5	10828	5226.5	3373.3	1073	1782.8	59
6	9604	2917	569	-1971	2076	63

Fig. 2 shows the plot of the relationship between growth (cal/day) as predicted by bioenergetics model against observed daily consumption 90%(cal) during first quarter of 1994 by age groups. The parameters value of the regression lines are presented in Table 4. There is considerable scatter in (b), (c), and (d) compared with (a) and the degree of scatter is closely related to variation in fish body weight within the age group. From Table 4, it is quite clear that the slope and the intercepts are not equal across cod age groups and deviated according to the growth adjusted options. In general, the slope of the relationship between growth and the consumption is high and closer to one for age 3 and older during the first quarter in connection with spawning period of capelin in the southern area of the Barents Sea.

Table 4. Parameters value of growth (y) in cal/day versus consumption (x) in cal/day by fish age groups during first quarter of 1994.

Fish age	gr1	gr2	gr3
1	$y=0.856x-88.74$	$y=0.843x-93.27$	$y=0.768x-124.28$
2	$y=0.893x-403.12$	$y=0.875x-445.34$	$y=0.810x-586.4$
3	$y=0.9274x-1214.22$	$y=0.910x-1416.75$	$y=0.867x-1847.58$

4	$y=0.9602x-2858.3$	$y=0.9461x-3541.6$	$y=0.9195x-4570.8$
5	$y=0.9714x-5293.8$	$y=0.9593x-7015.7$	$y=0.9423x-8980.6$
6	$y=0.997x-6658.5$	$y=0.996x-8996.7$	$y=0.9949x-11527$

To evaluate the effects of changes in temperature on the output of bioenergetics model in general and the growth rate of cod in particular, we increased the temperature value in the stomach data file one °C for each individual fish and then compared the results with the previous run (Table 2). The results are shown separately for each age group in Table 5. The mean consumption value increased 13.8% in age 1 and 9.8%, 8.35%, 11.57%, 10% and 23.7% in age 2, 3, 4, 5 and 6, respectively. Daily growth increments increased 0.516 grams/day for age 5 and 0.339, 0.161, 0.008 and 0.004 grams/day for age 4, 3, 2 and 1, respectively. Cod at age 6 years, when increasing temperature one degree resulted in increasing losses in weight (— 2.6 grams/day versus —1.9 grams/day) as expected.

Table 5. The average of daily energy requirements by cod age groups during first quarter of 1994, using a temperature 1°C higher than in the calculation in Table 2.

Fish age (year)	Consumption (cal/day)	Standard metabolism (cal/day)	P value	S.D.A. (cal/day)	gr3 (cal/day)
1	245.2	117.4	0.355	54.1	28.5
2	1293.4	518.1	0.268	222.6	279.9
3	4320.6	1566.3	0.284	630.5	1379.7
4	9338.7	3401.6	0.249	1336.9	2694.3
5	13240.6	6089.2	0.187	2312.1	1589.5
6	13209.4	8443.1	0.131	3134.1	-2649.4

DISCUSSION

From this paper it appears that in Northeast Arctic cod the relationship between growth and consumption is not straightforward. Meaning that increasing

cod consumption will not result in directly increased growth before the maintenance costs are totally covered. If this is not true, cod will grow according to the growth option (growth=consumption) with extremely high food conversion efficiency as predicted by our bioenergetics model, reaching 100% food conversion efficiency as a population mean (Table 3, gr0 & Fig. 2a). Since this is obviously not possible, these results seemingly conflict with those reported earlier about the growth rate of cod either *in situ* or from field observations. According to Kjesbu et al. (1991), when cod fed on moderate ration for a period of 125 days, food conversion efficiency reached 10.9% while the starved cod lost body weight rapidly and after 4 weeks the loss became stable and reached 2.7 g/day. Based on growth equation reported by Smedstad et al. (1994), one kilo cod at 8°C has a specific growth rate 1.67 (%/day). Accordingly a comparable growth rate can be obtained between the output of a bioenergetics model and the *in situ* growth estimates if the costs of standard metabolism, specific dynamic action, spawning losses, swimming activity, egestion and excretion are firstly covered (Table 3, gr3 & Fig. 2d), before any energy is available for cod growth. Otherwise, growth is overestimated with extremely high food conversion efficiency. If the growth rate of the cod population is overestimated, the gain in weight due to growth might exceed losses due to total mortality and this might have effects upon the management actions by increasing TAC as a result of false improvement in individual growth. Based on Table 3, when the total maintenance costs are firstly met (gr3), food conversion efficiency reached 13% in age 1 and 26%, 34%, 31% and 10% in age 2, 3, 4 and 5, respectively.

The previous approximation of activity multiplier (Ajiad et al., 1994) is back calculated from assimilation and observed growth. In the present paper we used activity multiplier as a function of cod swimming speed 0.20 l/s (Arnold et al., 1994). From Table 2 it is clear that the activity multiplier is not so high and the magnitude of activity costs is 1.055 in age 1 to 1.343 of the standard metabolism in age 6. Those values are within the range of what was early reported that doubling of the standard rate of metabolism is a useful approximation of activity (Mann, 1978). Hammer et al. (1994) found that two factors simulated the rhythmicity of the swimming behavior in the experimental fish: light intensity and the presence of a current field in the proximity of the fish. Batty et al. (1993) found that in herring larvae, the tail-beat frequency is temperature dependent. Kjesbu et al. (1991) observed that the starved cod swim less than other groups and stay on the bottom, hence swimming activity is a function of stomach fullness. Løkkeborg et

al. (1989) found that cod activity decreased at high current velocities. Kawamura et al. (1988) showed that swimming activity increased in the slower fish when they were in the school.

Results in Table 5 have demonstrated that the temperature affects such overall processes as growth, consumption, metabolism and SDA of Northeast Arctic cod using a bioenergetics model. Our assumption is that the temperature value we used represents the value that is actually affecting the fish during a particular day. However, it is very difficult to measure the temperature affecting cod throughout the year due to vertical migration, or east-west migration of the stock. Furthermore, we do not know the temperature at which cod digest their food nor do we know if cod choose higher temperature when eating large rations than when eating small ones. According to Jobling (1995) when food is limited fish appear to select cool water in order to reduce their metabolic cost. One degree increase in temperature (Table 5) results in significant increase in the consumption, metabolism, SDA, P value and growth. However, the food conversion efficiency remains at the same level in both cases (Table 2 and Table 5). From this observation it may be concluded that the temperature affected the total rate of consumption, the level of metabolism and food turnover but not the percentage of the distribution of food among various metabolic components. By contrast, changes in diet composition, assuming a shift in diet from low to high caloric density prey species or vice versa, influenced both the total consumption and the distribution of food eaten. To illustrate this, assume that the daily consumption of age 1 increased 13.8% (from 215.3 to 245.01), the model predicts an increase in the food conversion efficiency from 13% ($24.6/215.3 \times 0.90$) to 23% ($50.9/245.01 \times 0.90$). This supports the idea that any discussion about the influence of the temperature on growth should also include consideration of food availability (Jobling, 1995) and metabolic costs.

The new version of bioenergetics model might lead to improve the short-term predictions of individual growth, after the activity in this model is replaced by swimming activity rather than constant activity parameters (doubling of the standard metabolism) or back —calculated from growth and assimilation. Further study is required to relate swimming activity to water temperatures since the activity rate represents a variable component of a bioenergetics model for the Barents Sea cod.

ACKNOWLEDGMENTS

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Fig. 1A-1F. Growth in (cal/day) as predicted by a bioenergetics model during first quarter of 1994.

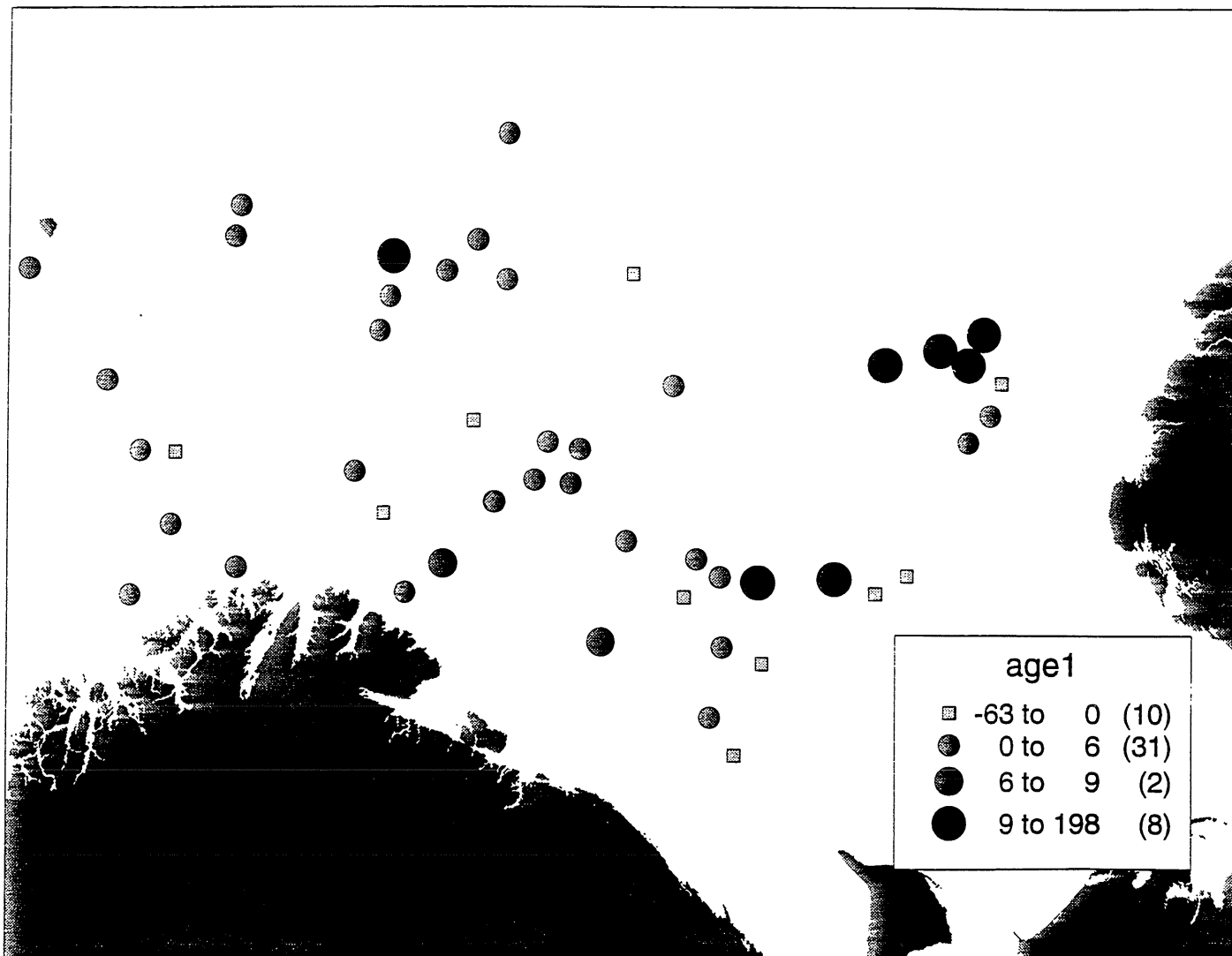


Fig.1A.

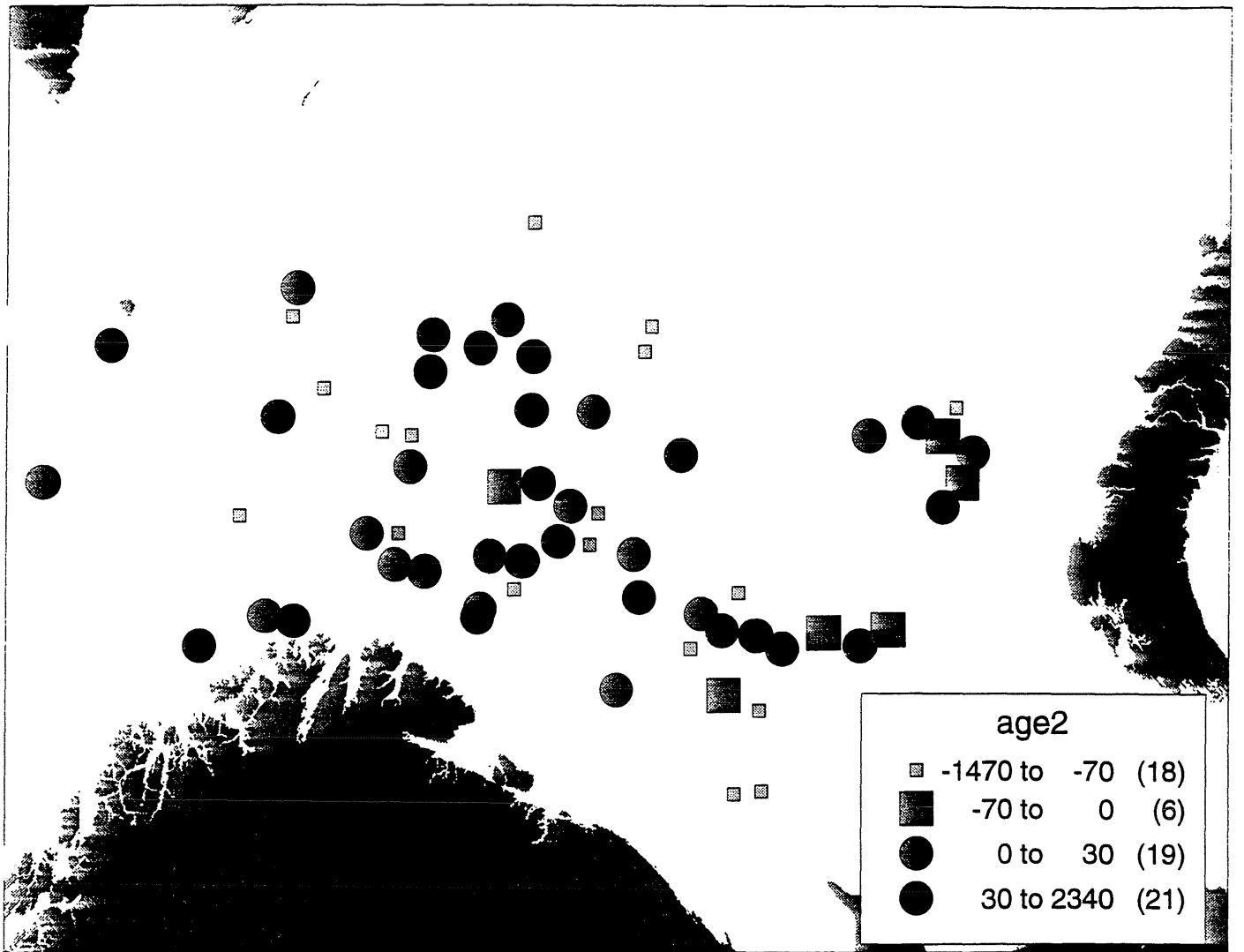


Fig. 1B.

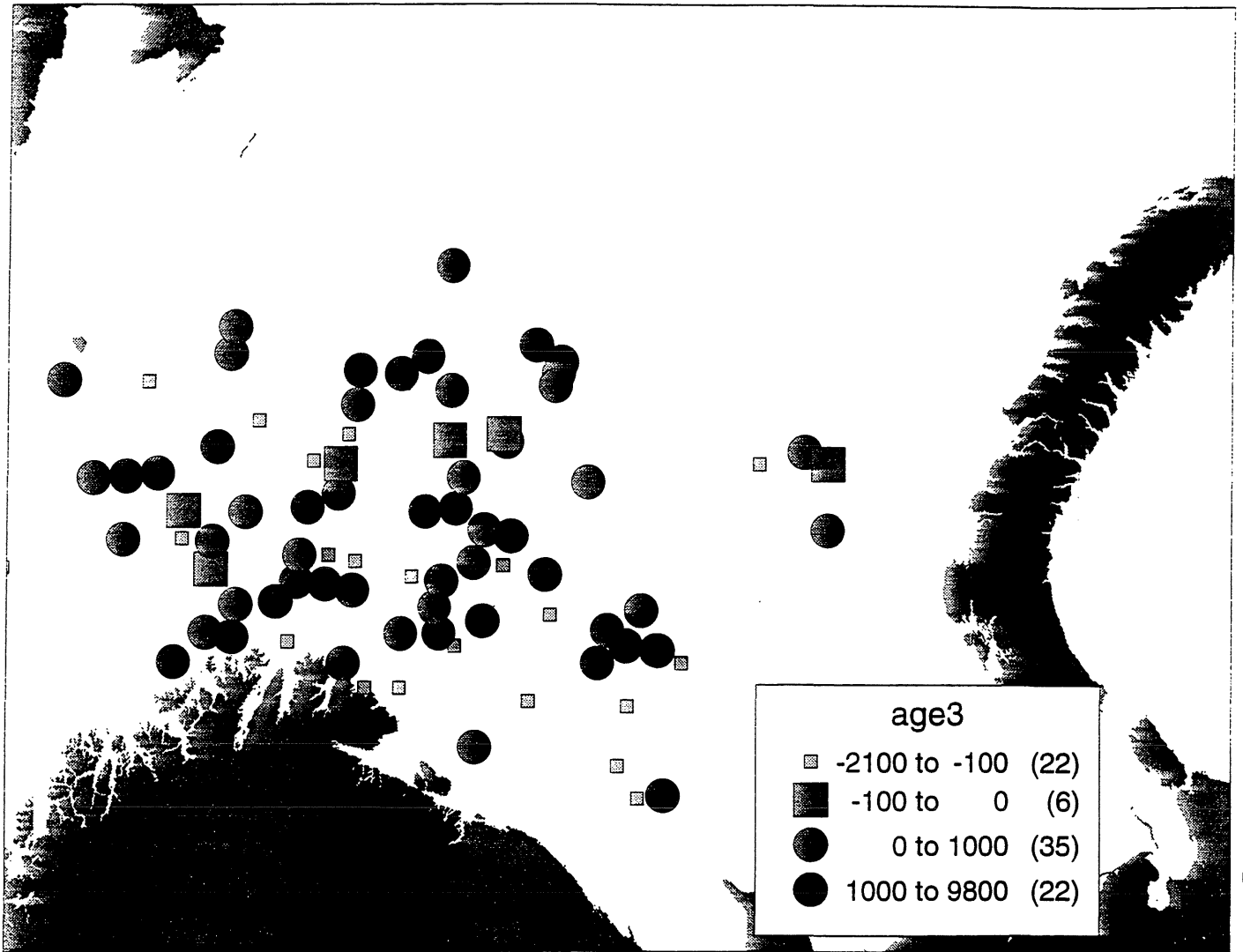


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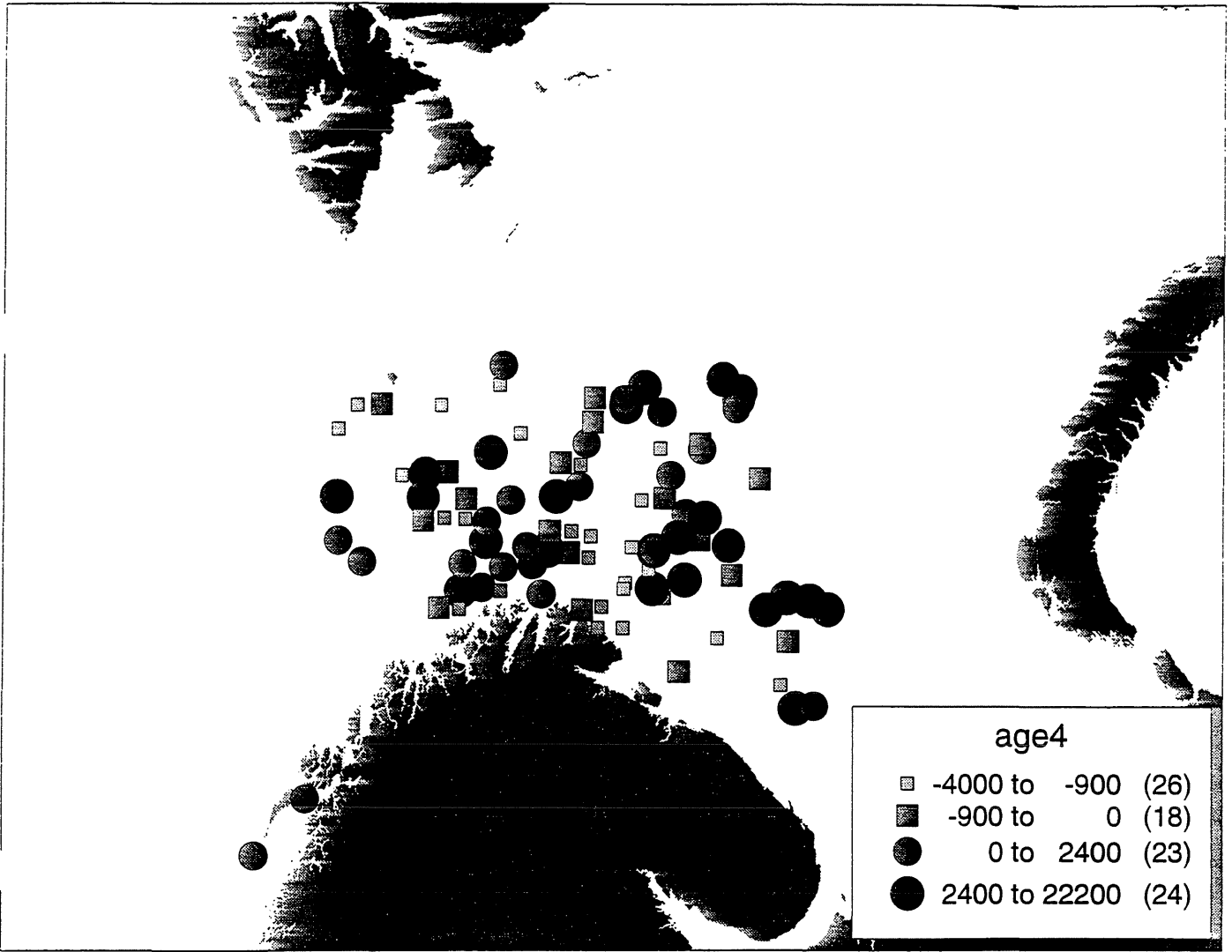


Fig. 1D.

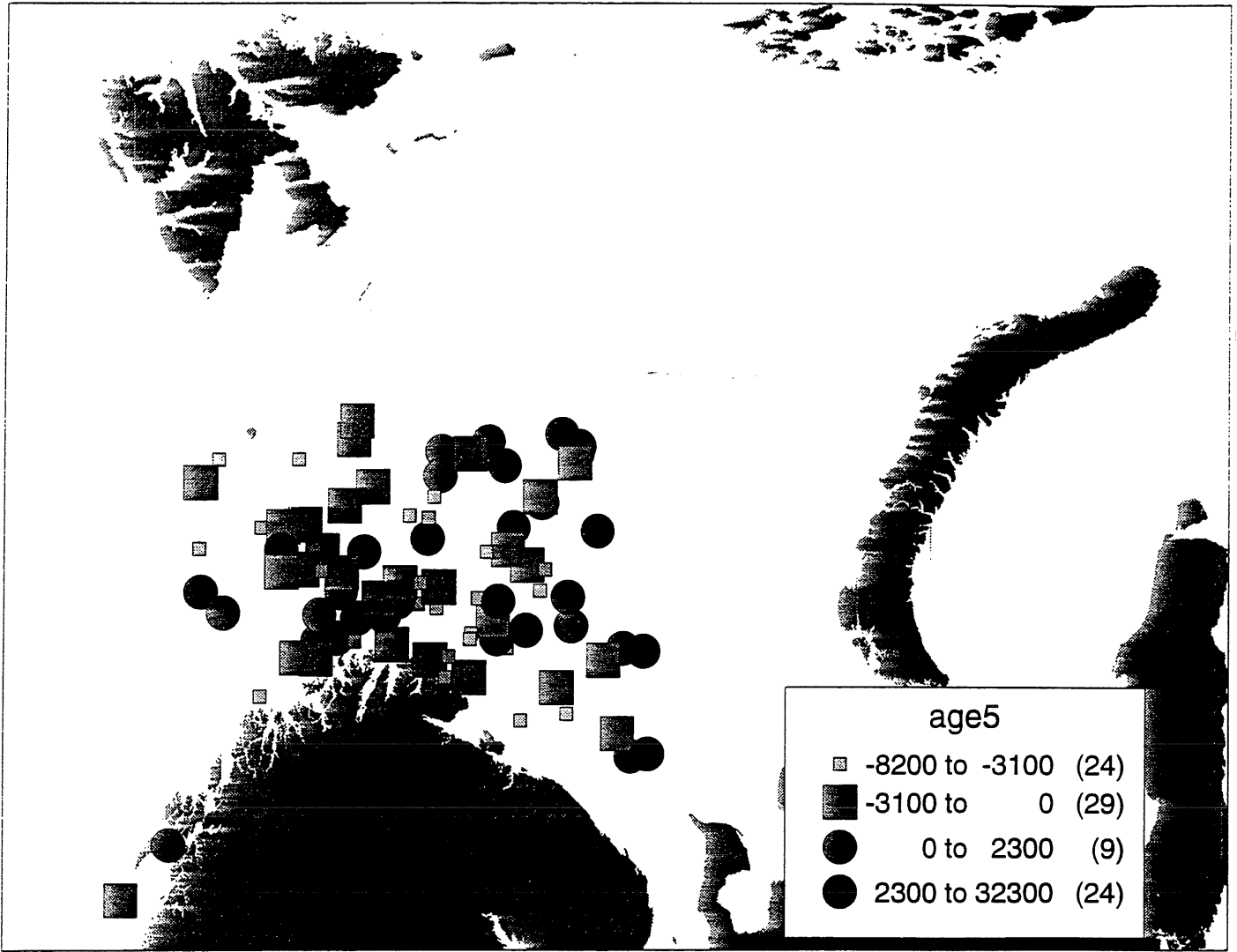


Fig.1E. *Age5* data points for the Pacific Northwest region.

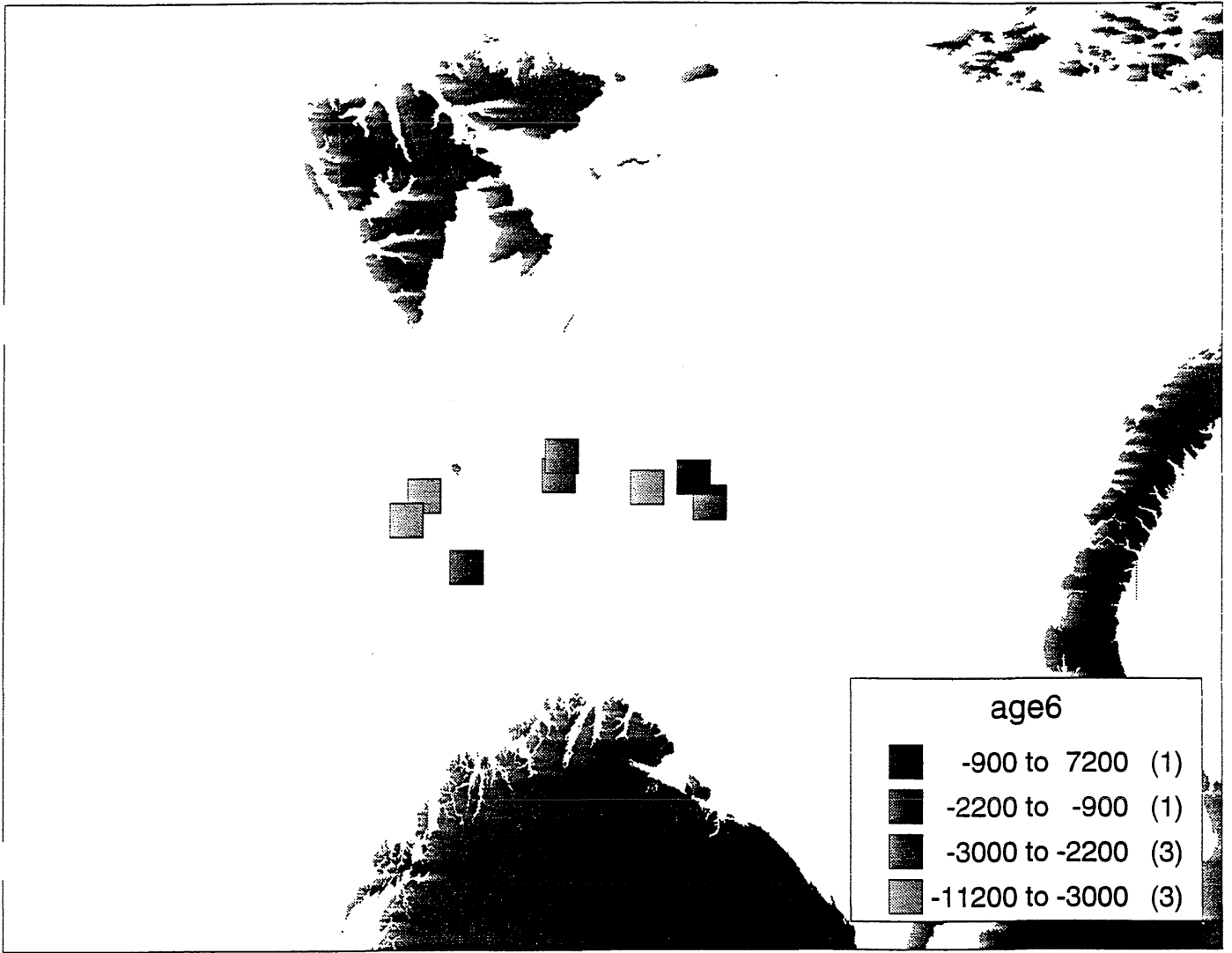
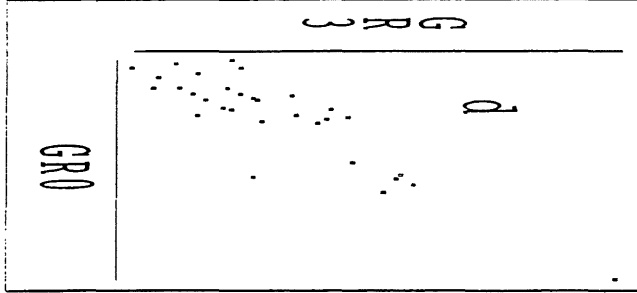
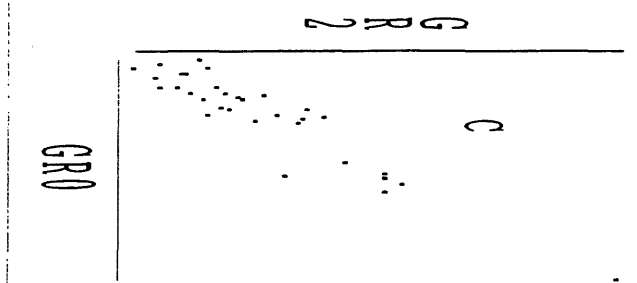
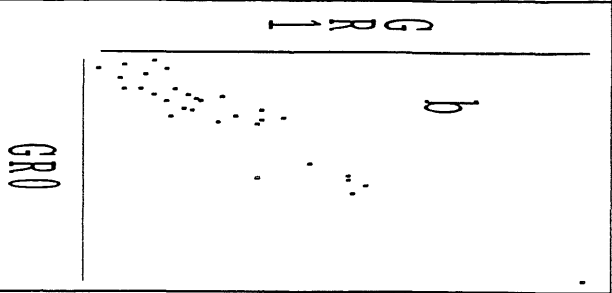
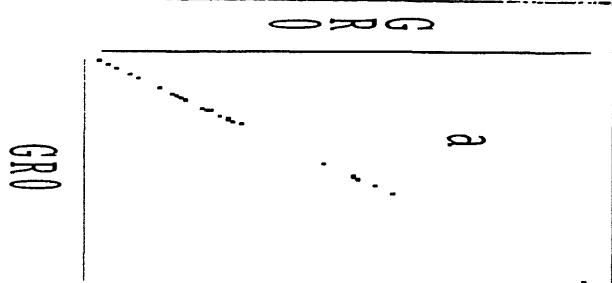


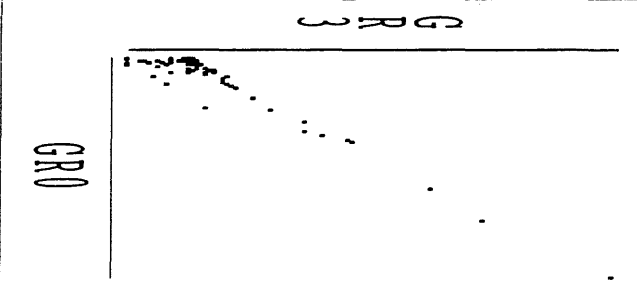
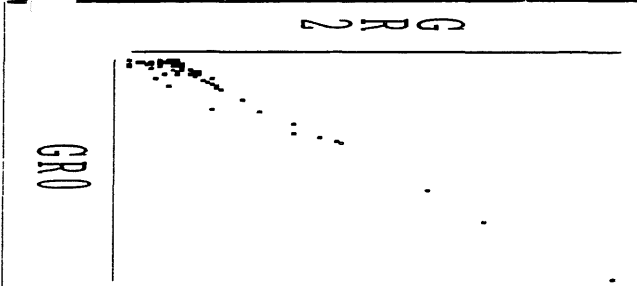
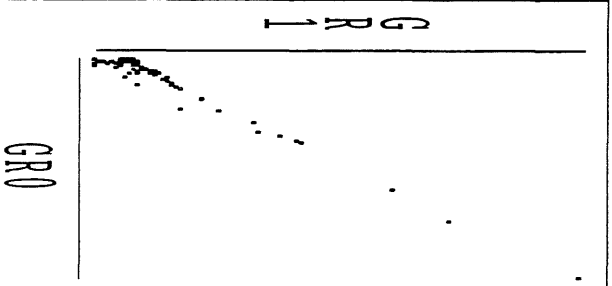
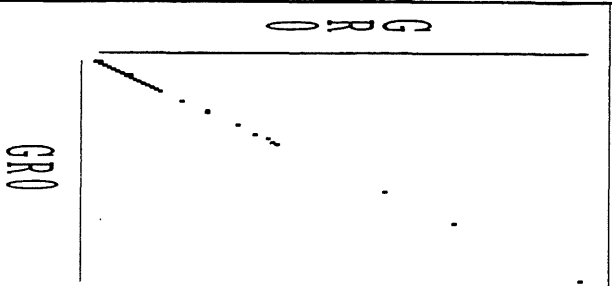
Fig. 1F. Age of the Hawaiian Islands. The map shows the Hawaiian Islands and the age of the islands in millions of years (Ma). The legend indicates the age ranges and the number of islands in each range.

Fig. 2. The relationship between growth (y-axis) in cal/day as predicted by a bioenergetics model against daily consumption (x-axis) in cal/day as estimated from stomachs content data by cod age groups during winter 1994 in the Barents Sea.

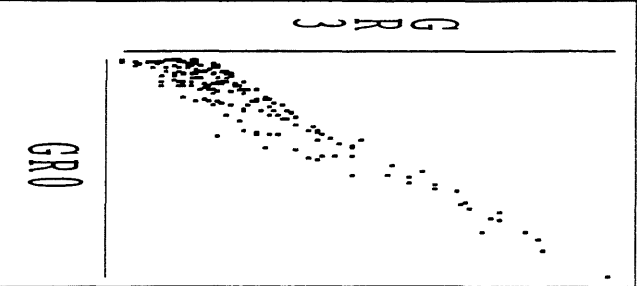
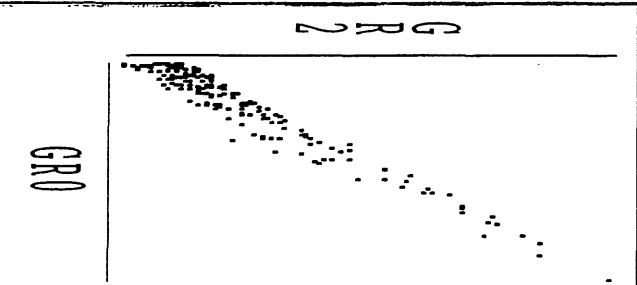
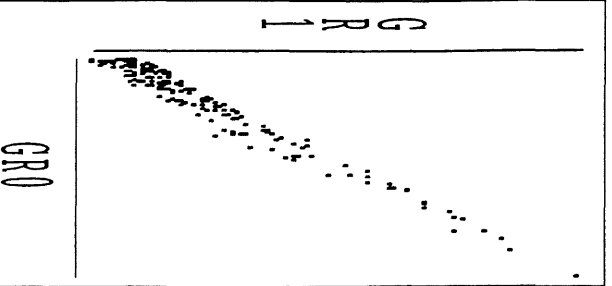
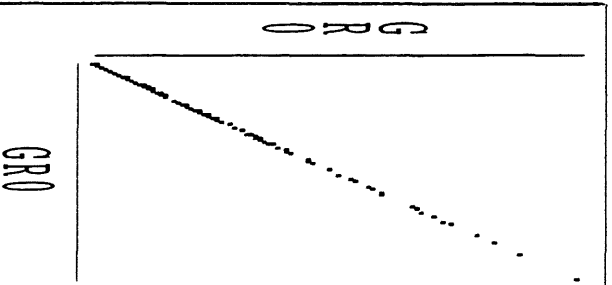
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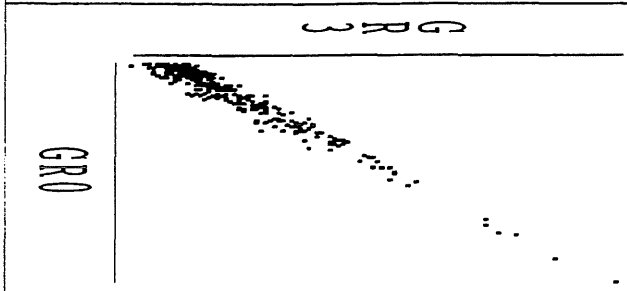
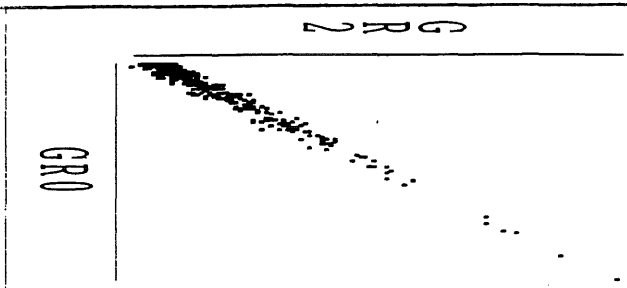
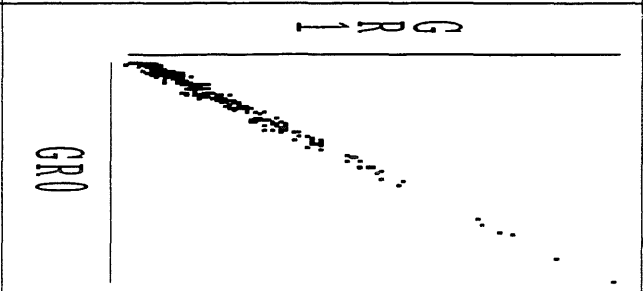
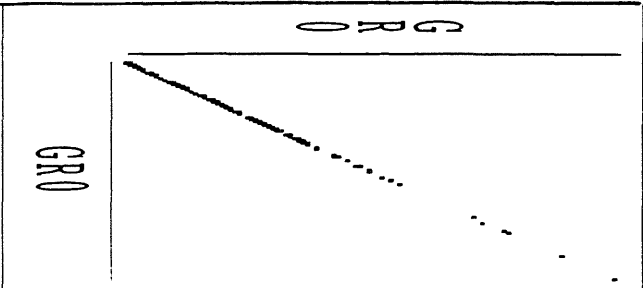
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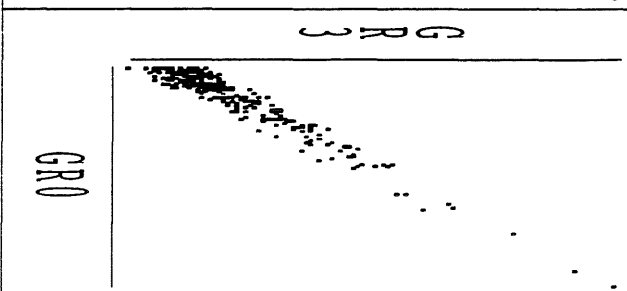
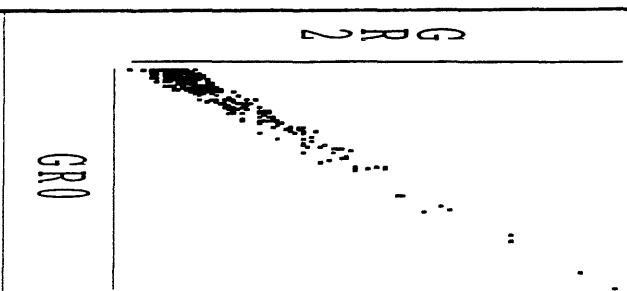
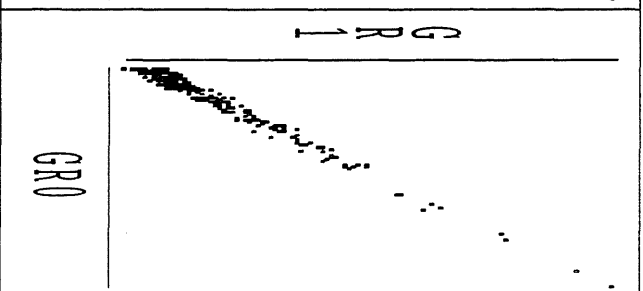
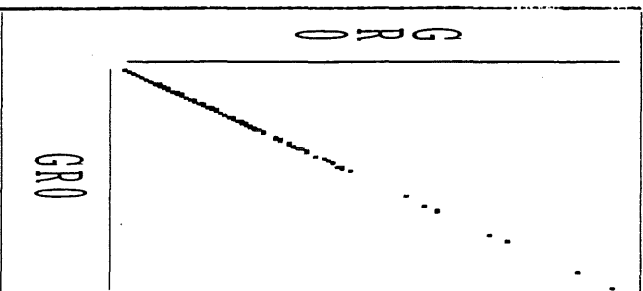
AGE = 3



AGE = 4



AGE = 5



AGE = 6

