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OPTIMAL TEMPERATURE OF IMMATURE HALIBUT (*HIPPOGLOSSUS HIPPOGLOSSUS* L.): EFFECTS OF SIZE.

by

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ABSTRACT

The aim of this study was to estimate the optimal temperature for growth and feed conversion for different sizes of immature halibut. In experiment A, lasting for 99 days, six groups of fish of initial mean weight 8 g were grown at the following temperatures: 7.3, 10.0, and 12.8°C, two groups at each temperature. In experiment B, lasting for 216 days, six groups of fish of initial mean weight 140 g were grown at the following temperatures: 5.0, 7.4, 9.0, 11.1, 13.0, and 14.9°C. In experiment C, lasting for 189 days, six groups of fish of initial mean weight 2.9 kg were grown at the following temperatures: 2.4, 4.6, 7.0, 9.8, 12.6, and 15.1°C. Dry feed was used in experiments A and B but capelin and chopped herring in experiment C. The growth rate first increased with temperature and then decreased. The feed conversion factor first decreased with temperature and then increased. Parabolic regressions of the data were used to estimate the optimal temperatures. Optimal temperature for growth decreased with fish size. It was about 13°C for 26 g fish, 11.4°C for 280 g fish and 9.7°C for 3.4 kg fish. Optimal temperature for feed conversion decreased with fish size. It was about 13°C for 26 g fish, 10.6°C for 280 g fish and 5.5°C for 3.4 kg fish. The results suggest that the dome-shaped relationship between growth rate and temperature and also the concave-shaped relationship between feed conversion and temperature become flatter with increased size of fish. A temperature change from suboptimal to nearoptimal temperature resulted in compensatory growth of juvenile halibut. The growth rate of halibut reared at near optimal temperature for the first two years from hatching was good.

INTRODUCTION

Atlantic halibut (*Hippoglossus hippoglossus* L.) well known for its large size, excellent taste and high market prize has now for several years received some attention as an aquaculture species in Norway, Scotland, Iceland, Canada and the Faroe Islands. It is less than ten years since the first halibut fry were produced in a laboratory in Norway and last year only about 100,000 fry were produced in Norway, Iceland and Scotland. The fry production remains the bottleneck for commercial halibut farming.

Some effort has been put into studying the growth potential of this species in relation to diet (Hjertnes and Opstvedt 1989; Berge and Storebakken 1991; Björnsson et al. 1992), stocking density (Björnsson 1992) and seasonal change in temperature (Haug et al. 1989).

The aim of the study was to estimate the optimal temperature for both growth rate and feed conversion for different sizes of halibut.

METHODS

The experiments were carried out in an indoor facility at the Aquaculture Research Station of the Marine Research Institute near Grindavik SW Iceland. Clean ground water of constant temperature (7°C) and salinity (32‰) enters the Station and by heating and cooling the sea water with heat exchangers the desired temperature could be maintained. The water exchange was regulated so that O_2 in the outlet of each tank was always above 6 mg/l. Three growth rate experiments referred to as A, B, and C were carried out. The fish used in experiments A and B belonged to the first year-class (1991) of halibut produced in Iceland, by the private company Fiskeldi Eyjafjardar hf. The fish used in experiment C had been collected in Faxaflói, a large bay in SW-Iceland, in the fall of 1990.

In experiment A, lasting for 99 days (25.11.91-3.03.92), six groups of fish of initial mean weight 8 g were grown at the following temperatures: 7.3, 10.0, and 12.8°C. There were two groups at each temperature, each containing 93 fish. Rectangular fiberglass tanks 90x90cm and 30 cm deep were used. At the end of this experiment the replicate groups were mixed and moved to three circular tanks, 3m diameter, and grown for 70 more days under identical temperature regime.

The fish used in experiment B had been grown at 13°C for several months prior to the experiment. In the experiment, lasting for 216 days (13.05.-15.12.92), six groups of fish of initial mean weight 140 g were grown at the following temperatures: 5.0, 7.4, 9.0, 11.1, 13.0, and 14.9°C. Each group contained 130 fish, ranging in size between 100 and 200 g. Circular fiberglass tanks 2.9 m in diameter and 0.8 m deep were used. One extra group of fish was grown at 16.1°C for the first two months (13.05.-14.07.) and then at 11.1°C for the last five months (14.07.-15.12.). Finally, at the end of this experiment all seven groups were grown at 9°C for 2.5 months (15.12.92-3.03.93) to study the effects of a temperature change on growth rate.

In experiment C, lasting for 189 days (5.03.-10.09.91), six groups of fish of initial mean weight 2.9 kg were grown at the following temperatures: 2.4, 4.6, 7.0, 9.8, 12.6, and 15.1°C. Each group contained 33 fish ranging in size between 1.1 and 6.3 kg. In experiments A and B the fish were fed once a day with dry halibut feed (2-6 mm) produced by Ewos in Sweden, Norway and Iceland. The dry feed consisted of 50% protein, 17% fat, 15% carbohydrates and 8% water. In experiment C the fish were handfed on chopped herring Mondays, Tuesdays and Wednesdays and whole capelin Thursdays, Fridays and Saturdays. The herring contained 33% dry matter and 15% fat whereas the capelin contained 29% dry matter and 13% fat. On Mondays and Thursdays vitamins were added to the diet as described by Björnsson et al. (1992). In all three experiments the fish were handfed to satiation and a care taken not to overfeed.

The fish were weighed individually every 2-3 months. In experiments A and B the fish were not fed for 24 hours and in experiment C for 72 hours before weighing. The fish in experiments A and B were untagged whereas the fish in experiment C were tagged with numbered spaghetti tags to allow growth rate of individual fish to be calculated.

Specific growth rate (G) was calculated as % of body weight per day according to the formula:

$$G = 100(\ln W_2 - \ln W_1)/(t_2 - t_1)$$

where W_1 and W_2 is the weight of the fish at weighing days t_1 and t_2.

Feed conversion factor (FC) was calculated as total food intake in a given period (g dry wt.) divided by the weight increase of the group (g wet wt.) in the same period.

RESULTS

In Table 1 mean weights at different weighing times are shown for the three experiments. Initial and final number of fish, specific growth rate (%/day), food intake, feed conversion factor and temperature are also shown for each experimental period. As expected the growth rate decreased with increased size of fish. The maximum observed daily growth rate was 2.1% for 26 g fish, 0.60% for 280 g fish and 0.25% for 3.4 kg fish. However, the minimum observed feed conversion factor increased with fish size: 0.66, 0.77 and 0.92 respectively (Table 1 A-C).

Fig. 1 shows how specific growth rate changed with temperature for the three size-classes of fish. With only three experimental temperatures for the smallest fish (group A) it was not possible to estimate the temperature optimum for maximum growth (T_{opt}.G) with much accuracy for this group. However, the results suggest that T_{opt}.G is 13°C or higher for 26 g halibut. An unpublished growth study in Norway with halibut fry of similar size showed that growth rate was significantly better at 13°C than at 16°C (Grete Adhof, Sea Farm A/S, personal communication). Therefore, T_{opt}.G for 26 g halibut is assumed to be approximately 13°C.

The parabolic regressions which gave a good fit to the data for groups B and C (Fig. 1, Table 2) suggested that T_{opt}.G was 11.4°C for 280 g halibut and 9.7 for 3.4 kg halibut (Table 3). The dome-shaped curves for groups B and C were quite flat, since the temperature range where growth rate was above 90% of maximum growth rate was 5.6°C for 280 g fish and 6.2°C for 3.4 kg fish.

Fig. 2 shows how feed conversion factor changed with temperature for the three size-classes of fish. It was not possible to estimate the temperature optimum for minimum feed conversion factor (T_{opt}.FC) with much accuracy for group A. However, the results suggest that T_{opt}.FC is approximately 13°C for 26 g halibut.

The parabolic regressions which gave a good fit to the data for groups B and C (Fig. 2, Table 3) suggested that T_{opt}.FC was 10.6°C for 280 g halibut and 5.5°C for 3.4 kg halibut (Table 3). The concave-shaped relationship is also quite flat and became flatter with increased size of fish, the temperature range where feed conversion was below 110% of minimum feed conversion was 5.8°C for 280 g fish and 9.1°C for 3.4 kg fish.

The effects of changing the temperature from one growth period to the next on growth rate and feed conversion factor of juvenile halibut are shown in Fig. 3. The response in growth rate and feed conversion factor to a change from suboptimal to nearoptimal temperature was greater than expected from the "steady state" parabolic relationships. A moderate temperature change near T_{opt} (within the range 7-15°C) had only a minor effect on the growth rate and the feed conversion factor which further supports the flat shape of the curves near T_{opt}.G and T_{opt}.FC.

The parabolic curves in Fig. 3 apply to halibut weighing 280 g but the arrows represent both larger and smaller fish. This size difference has minimal effects on the feed conversion (Fig. 3 B) but since growth rate (%/day) decreases substantially with fish size it has some effects on the results in Fig. 3 A. The 16-11°C arrow, the only one starting above the parabolic curve, represents smaller fish than 280 g (170 g). All the other arrows which represent fish above 280 g (330-610 g) were all below the parabolic curve (Fig. 3 A, Table 1 B). Furthermore, since the weight of the fish increases from one growth period to the next the growth rate increase of each arrow is less than expected for a fish of constant size. This means that the jump in growth rate (corrected for size) when temperature changes from suboptimal to nearoptimal would be even greater than that indicated in Fig. 3 A.

The growth of juvenile halibut at near optimal temperature is shown in Fig. 4.

DISCUSSION

The specific growth rate (G) of the immature halibut declined with increased weight as found for most species of fish (e.g. Brett 1979; Cuenco et al. 1985).

This study suggests that the effect of temperature on growth rate for immature halibut is well described by a parabola. The advantage of the parabolic regression is that it allows the temperature optimum for maximum growth (T_{opt}.G) to be estimated with some accuracy. It also helps to assess how flat the relationship is near T_{opt}.

The decrease in T_{opt}.G with size as observed for immature halibut has also been found for yellowtail (Oshima and Ihaba 1969) for which T_{opt}.G was 27°C for juveniles and 21°C for large adults; Atlantic cod (Pedersen and Jobling 1989) for which T_{opt}.G was suggested to be 9-12°C for "large cod" and 11-15°C for "small cod"; and a mathematical model for fish in general (Cuenco et al. 1985) for which T_{opt}.G decreased by 1-2°C for a 50-fold increase in weight, a change similar in magnitude as that found for immature halibut (a 3°C decrease for a 130 fold increase in weight). The results by Brett et al. 1969 also suggest a slight decrease in T_{opt}.G with increasing age of fingerling sockeye salmon (from 5-7 months (5 g) to 7-12 months (30 g)).

No shift in T_{opt}.G with increasing weight was, however, found in brown trout (T_{opt}.G=13°C, W=11-250 g; Elliott 1975) nor according to the provisionary growth tables prepared for sockeye salmon in fresh water (T_{opt}.G=15-17°C, W=1-50 g; Brett 1974) nor according to the growth tables prepared for Atlantic salmon and rainbow trout (Austreng et al. 1987). The last study was based on multiple regression analysis assuming a linear increase in growth rate with temperature and as a result all their size groups had T_{opt}.G at the highest temperature studied.

The model by Cuenco et al. (1985) predicts that the growth versus temperature curve becomes broader with increasing weight, i.e. the effect of temperature on growth for a well fed fish is greatest at the smallest sizes. In other words growth of smaller fish seems to be more sensitive to temperature changes (near T_{opt}.G) than the growth in larger fish. The present results for immature halibut are consistent with this model. The results for 5-12 month old fingerling sockeye salmon suggest the same (Brett et al. 1969).

The feed conversion factor (FC) of the immature halibut first decreased and then increased with temperature, this gradual change being well described with a parabola. A similar trend has been seen in sockeye salmon (Brett et al. 1969), brown trout (Elliott 1976) and Atlantic cod (Jobling 1988).

The slight increase in the minimum feed conversion factor with weight of immature halibut (a 1.35 fold increase in FC with a 130 fold increase in W) is similar to that found for cod (Jobling 1988).

However, no reference has been found describing a decrease in T_{opt}.FC with weight of fish as that found here for immature halibut.

The present results for immature halibut suggest that T_{opt}.FC is lower than T_{opt}.G. This has also been found for sockeye salmon (Brett et al.

1969) and brown trout (Elliott 1976). A possible explanation might be that as the temperature is lowered slightly below T_{opt}.G the metabolic rate decreases proportionately more than the food intake and therefore proportionately more of the food can be used for growth than at T_{opt}.G.

A short term change from suboptimal to nearoptimal temperature, i.e. from one growth period to the next, resulted in a larger response in growth rate and feed conversion factor than that expected from the "steady state" parabolic relationships. This suggests that a short term temperature change may result in a compensatory growth similar to that observed for young halibut in a poor nutritional condition after a weaning period (Björnsson et al. 1992) and for lean cod during a period immediately following capture from the wild or shortly after spawning (Pedersen and Jobling 1989).

A comparison of the growth rate of juvenile halibut in captivity in western Norway, where the temperature varied from 5-13°C, and in northern Norway, where the temperature varied between 0-13°C, showed that the growth in the western part was more even throughout the year than in the northern part of the country where the growth stopped for a long time during the winter (Haug et al. 1989). However, the growth of the halibut during the summer was much faster in the North than in the West, suggesting a compensatory growth when the temperature changed from suboptimal to nearoptimal as found in the present study.

Compensatory growth following a temperature change from suboptimal to near optimal temperature may in part explain the linear change in growth rate with temperature found for Atlantic salmon and rainbow trout in Norway (Austreng et al. 1987) instead of the parabolic shape found for halibut. As their data were based on fish experiencing a seasonal change in temperature it is likely that the near optimal summer temperatures (14-16°C) following the suboptimal winter temperatures (2-6°C) resulted in a growth spurt faster than expected under steady state conditions. One implication may be that the fast summer growth rates observed for many temperate fish species such as halibut, cod and salmon may not be sustained under steady state optimal temperature conditions for the whole year.

The growth of halibut at nearoptimal temperature for the first two years from hatching was quite good. After one year from hatching the mean weight was about 100 g and two years from hatching it was 800-900 g which is similar or better than the growth of Atlantic salmon (30-40 g and 600-1000 g for respective ages). These results suggest that the growth potential of immature halibut is good considering that no selective breeding for fast growth has yet begun.

CONCLUSIONS

1. T_{opt}.G decreased with the weight of immature halibut
2. Growth rate became less sensitive to a temperature change at T_{opt}.G as the size of halibut increased
3. T_{opt}.FC decreased with the weight of immature halibut
4. Feed conversion factor became less sensitive to a temperature change at T_{opt}.FC as the size of halibut increased
5. A short term temperature change from suboptimal to nearoptimal resulted in compensatory growth of juvenile halibut
6. The growth rate of halibut reared at near optimal temperature was good for the first two years from hatching

The implications are that the fish farmer should apply the best temperature control to his youngest fish. An accurate temperature control of the older fish may not be worthwhile, however, as a seasonal decrease in growth rate due to a suboptimal temperature may be compensated for later on when nearoptimal temperatures are achieved.

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TABLE 1

Mean weight (W) and standard deviation (SD) in g at weighing times and mean temperature (T) in °C, initial number (IN) and final number (FN) of fish, food intake (F) in kg dry wt., specific growth rate (G=% wet wt./day) and feed conversion factor (FC=dry wt. of feed/gain in wet wt.) in a given growth period.

A. Halibut fry (mean wt. 26 g):

Date		7°C	7°C	10°C	10°C	13°C	13°C
25.11.91	W	7.9	8.1	8.0	7.8	8.2	8.0
	SD	1.4	1.5	1.5	1.2	1.5	1.6
7.01.92	W	15.3	16.6	19.6	18.3	25.3	25.5
	SD	3.0	3.0	4.2	3.6	5.4	5.2
	T	7.6	7.6	10.1	10.1	12.9	12.9
3.03.92	W	25.8	28.3	43.6	40.8	67.2	62.9
	SD	6.7	6.8	13.5	11.6	15.5	15.1
	T	7.0	7.0	9.9	9.9	12.8	12.8
12.05.92	W	50.2		100.1		148.4	
	SD	14.2		31.2		34.0	
	T	6.9		10.1		12.8	
	IN	93	93	93	93	93	93
	FN	93	93	92	93	92	93
25.11.91-	G	1.20	1.26	1.70	1.67	2.12	2.08
3.03.92	F	1.39	1.61	2.36	2.25	3.60	3.62
	FC	0.835	0.857	0.716	0.734	0.660	0.708
	T	7.3	7.3	10.0	10.0	12.8	12.8

B. Juvenile halibut (mean wt. 280 g):

Date		5°C	7°C	9°C	11°C	13°C	15°C	16-11°C
13.05.92	W	140	143	138	136	141	143	140
	SD	23	25	24	22	23	23	24
14.07.92	W	186	211	209	204	230	209	202
	SD	29	35	38	38	40	37	36
	T	5.1	7.1	9.0	11.0	13.0	15	16.1
22.09.92	W	219	296	324	329	339	303	355
	SD	40	60	65	76	66	68	74
	T	5.0	7.5	9.1	11.2	13.0	15.1	11.3
15.12.92	W	248	398	502	451	478	439	538
	SD	51	97	106	124	121	127	136
	T	5.0	7.5	8.9	10.9	12.9	14.8	10.9
3.03.93	W	404	562	703	577	577	614	703
	SD	87	139	157	170	155.0	182	201
	T	8.8	9.1	8.9	9.2	8.8	8.9	9.0
	IN	131	130	131	130	130	130	130
	FN	131	130	131	128	127	121	130
13.05.-	G	0.266	0.472	0.597	0.554	0.565	0.519	0.622
15.12.92	F	15.3	27.1	36.5	33.1	36.2	32.8	40.9
	FC	1.080	0.819	0.766	0.820	0.842	0.914	0.791
	T	5.0	7.4	9.0	11.1	13.0	14.9	(12.5)

C. Immature halibut (mean wt. 3.4 kg), W og SD in kg, G shown with 95% confidence limits:

Date		2°C	5°C	7°C	10°C	13°C	15°C
5.03.91	W	3.0	2.9	3.2	3.0	2.4	2.8
	SD	1.1	1.1	1.1	0.9	0.8	1.2
4.06.91	W	3.3	3.5	4.0	3.8	3.2	3.3
	SD	1.2	1.2	1.2	1.0	1.0	1.2
	T	2.6	4.8	7.0	9.7	12.5	14.5
10.09.91	W	3.6	4.0	4.4	4.6	3.5	3.7
	SD	1.4	1.3	1.3	1.2	1.1	1.3
	T	2.2	4.4	7.0	9.9	12.6	15.7
	IN	33	33	33	33	33	33
	FN	33	33	33	31	32	32
5.03.-	G	0.101	0.176	0.191	0.247	0.195	0.162
10.09.91	G-95%	0.083	0.151	0.160	0.212	0.161	0.127
	G+95%	0.119	0.202	0.222	0.281	0.230	0.196
	F	21.3	33.8	42.5	50.6	42.6	38.5
	FC	1.008	0.922	0.992	0.966	1.256	1.336
	T	2.4	4.6	7.0	9.8	12.6	15.1

TABLE 2

Parabolic regressions for two size-classes of immature halibut: (1) Growth rate (G) versus Temperature (T): $G=a+bT+cT^2$ and (2) Feed Conversion factor (FC) versus Temperature: $FC=a+bT+cT^2$.

	Fish size (g)	a	b	c	r^2
G v. T	280	-0.4110	0.1761	-0.007700	0.939
G v. T	3400	0.0080	0.0451	-0.002328	0.911
FC v. T	280	1.7877	-0.1922	0.009073	0.895
FC v. T	3400	1.0881	-0.0506	0.004582	0.906

TABLE 3

Optimal temperature of three size classes of halibut: Temperature optimum for maximum growth (T_{opt}.G), temperature range where growth rate was above 90% of maximum growth (T_{range}.G), temperature optimum for minimum feed conversion factor (T_{opt}.FC) and temperature range where feed conversion was below 110% of minimum feed conversion (T_{range}.FC) as calculated from the parabolic regressions in TABLE 2.

Fish size (g)	T_{opt}.G	T_{range}.G	T_{opt}.FC	T_{range}.FC
26	~13	-	~13	-
280	11.4	8.6-14.2	10.6	7.7-13.5
3400	9.7	6.6-12.8	5.5	1.0-10.1

Fig. 1. Changes in growth rate with temperature for three size-classes of halibut: A. 26 g, B. 280 g, C. 3.4 kg.

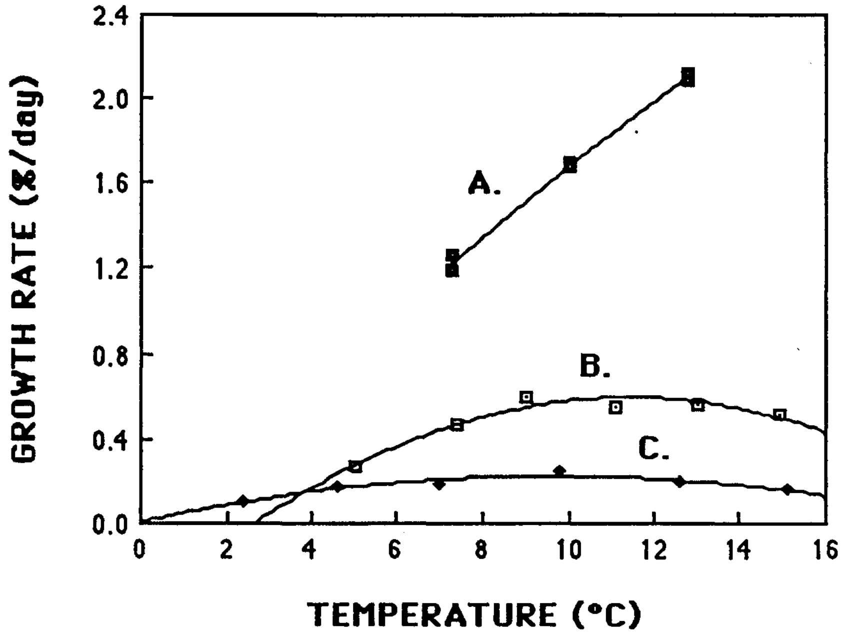

Fig. 2. Changes in feed conversion factor for three size-classes of halibut: A. 26 g, B. 280 g, C. 3.4 kg.

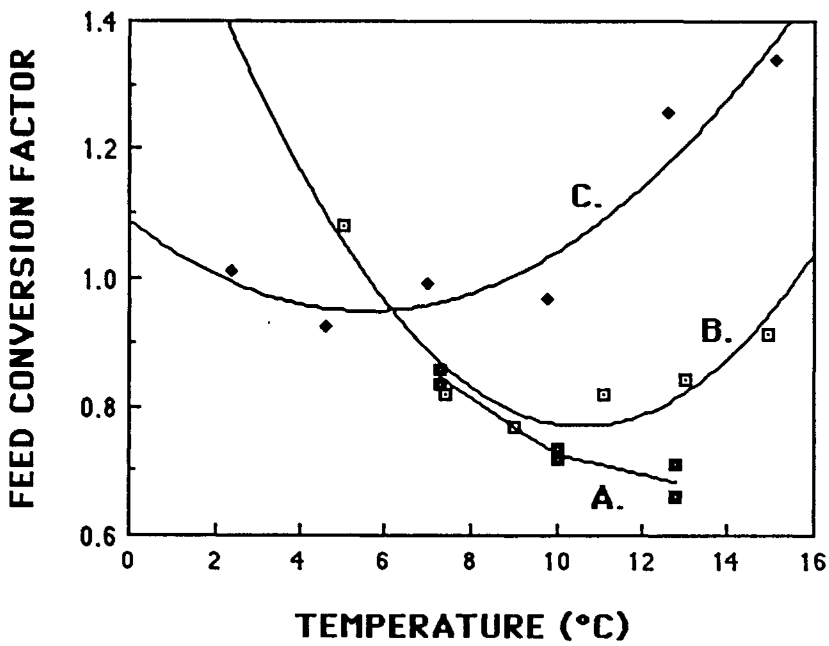

Fig. 3. A response of juvenile halibut to a temperature change from one growth period to the next: A. growth rate, B. feed conversion factor. Parabolic regressions for 280 g fish are also shown.

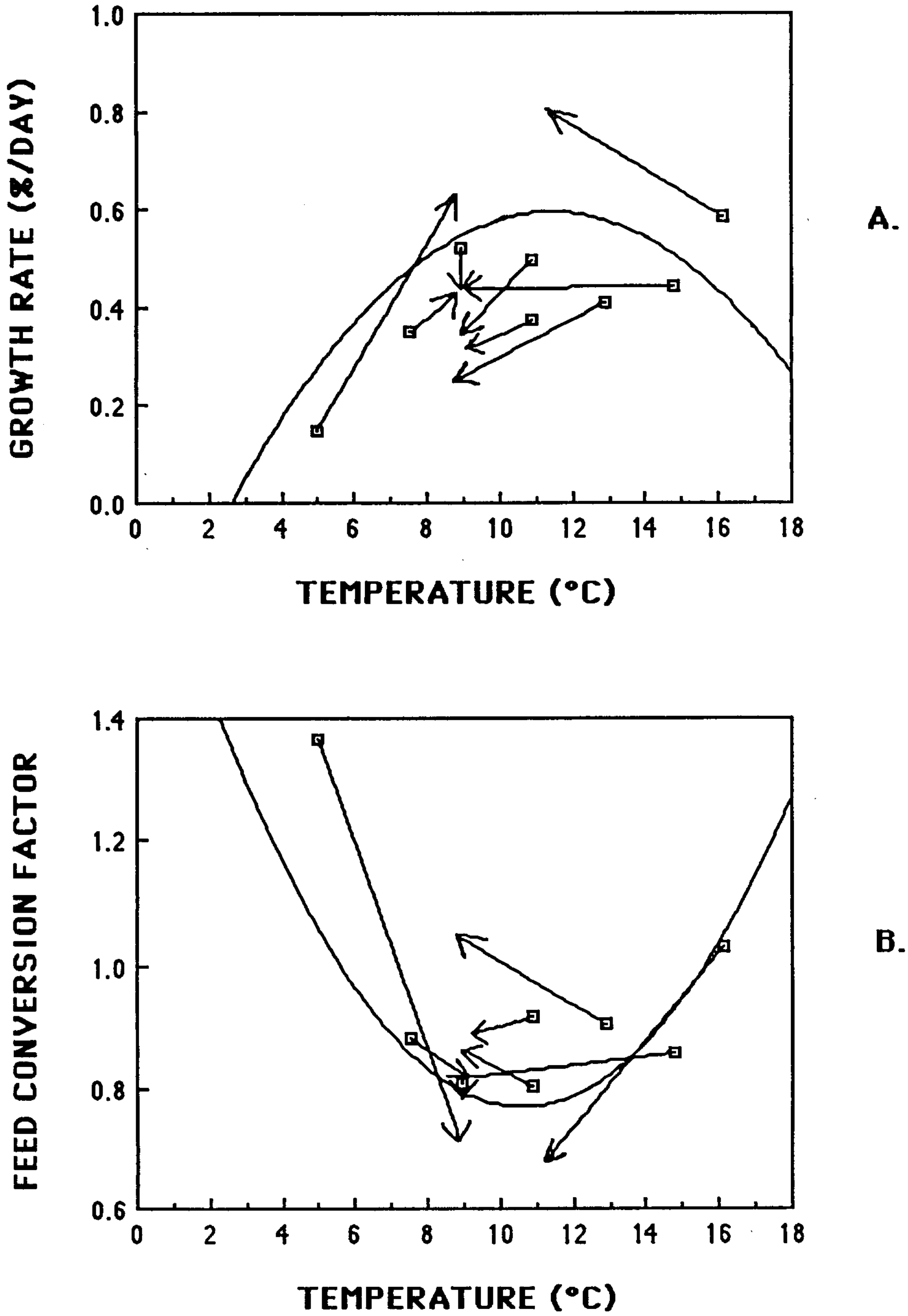

Fig. 4. Growth of juvenile halibut at near optimal temperature. Hatching in April 91.