First attempts to optimize the mass rearing of whitefish (*Coregonus lavaretus* L.) larvae from Léman and Bourget Lakes (France) in tanks and cages

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Abstract

Whitefish (*Coregonus lavaretus* L.) larvae from Léman (= Lake Geneva) and Lake Bourget (France) have been successfully mass reared in tanks of 50-60 l when fed exclusively on dry experimental and commercial diets. In spring water at 10°C for three initial densities (100-200-400/l) tested, the survival at 35 days fluctuated generally between 30 and 50%. The final number and biomass harvested has been improved by the use of higher water temperature (14°C) or by stocking with high initial density (200-400/l) at 10°C. In Lake Leman, temperature appeared to be the key factor controlling the results of coregonid larvae rearing in submerged illuminated net cages (6 m^3) stocked with 50 000 yolk sac fry and harvested at the end of spring. The results fluctuated greatly when stocking was too early (middle of February to beginning of March). They were improved by delaying stocking, to the period "mid-March - early April" for yolk sac fry or to "end of March-April" when fry prefed on dry diet were used.

Keywords : *Coregonus lavaretus*, larval rearing, cages, tanks, dry food, growth, survival, temperature, lakes, fry.

Premiers essais pour optimiser l'élevage en masse des larves de corégones (*Coregonus lavaretus* L.) du Lac Léman et du Lac du Bourget (France) en bacs et en cages.

Résumé

Des larves de corégones (*Coregonus lavaretus* L.) du lac Léman et du lac du Bourget (France) ont été élevées en masse avec succès en bacs de 50-60 l avec une alimentation sèche exclusive, expérimentale ou commerciale. En eau de source à 10°C et pour trois densités initiales (100-200-400/l) testées, la survie à 35 jours a généralement fluctué entre 30 et 50 %. Le nombre et la biomasse finale récoltés par bac ont été augmentés soit par l'utilisation d'eau plus chaude (14°C) soit par la pratique de fortes (200-400/l) mises en charge en eau à 10°C. Dans le lac Léman la température apparaît être le facteur clef contrôlant le résultat des élevages en cages (6 m^3) immergées, éclairées, mises en charge avec 50 000 alevins vésiculés et les cages vidées en fin de printemps. Les résultats ont été très fluctuants avec une mise en charge précoce (mi-février à début mars). Ils ont été améliorés par une mise en charge plus tardive : de la mi-mars au début avril avec des alevins vésiculés ou à la fin mars et en avril avec des alevins démarrés sur granulés.

Mots-clés : *Coregonus lavaretus*, élevage larvaire, cages, bacs, aliment sec, croissance, survie, température, lacs, alevins.

INTRODUCTION

There is an increasing number of studies indicating that optimized restocking of coregonid (*Coregonus* sp.) juveniles can be an efficient tool to sustain depleted stocks or to build new ones in lakes, reservoirs or cold ponds (Luczinski, 1986; Meng *et al.*, 1986; Salojärvi, 1986; Vostradovsky, 1986; Klein, 1988; Müller, 1988; Rasmussen, 1988). The optimization of restocking by the use of prefed juveniles requires efficient and reliable techniques to rear large quantities of coregonid larvae. As those tiny (9-13 mm) larvae are zooplanktivorous in natural conditions, the rearing can be performed in ponds (Luczynski, 1986; Salojärvi, 1986; Vostradovsky, 1986), in tanks with zooplankton (Flüchter, 1980; Champigneulle *et al.*, 1986*a*) or in cages illuminated to attract zooplankton (Brylinski *et al.*, 1979; Uryn, 1979; Mamcarz and Szczerbowski, 1984; Champigneulle *et al.*, 1986*a* and *b*; Jäger, 1986; Zaugg and Pedroli, 1986). The more recent improvement in the rearing of coregonine larvae appeared a few years ago with the use of special dry food formulations which allowed a substitution for zooplankton (Dabrowski *et al.*, 1984; Dabrowski and Kaushik, 1985; Rösch and Appelbaum, 1985; Bergot *et al.*, 1986; Dabrowski *et al.*, 1986; Luczyinski *et al.*, 1986*a;* Rösch and Dabrowski, 1986). Good results were obtained at laboratory scale (with small batches at low-medium density ≦ 100/l) and generally at a temperature of 14-16°C which is near the optimum for *Coregonus lavaretus*.

In France, applied research on coregonid larvae rearing started in 1983 with the objective to explore the use of the different techniques (Champigneulle *et al.*, 1986*a*) in the context of the two biggest natural lakes (Bourget : 4 500 ha; French part of Lake Leman: 23 900 ha) actually inhabited by coregonids. In Lake Bourget the coregonid stock is near extinction and in Lake Leman yield is unsatisfactority low in comparison with the situation observed in the middle of the century. Restocking with prefed fry was estimated (Champigneulle *et al.*, 1986*a* and Champigneulle, 1988) to be a useful management practice for rebuilding and/or sustaining the concerned stocks as the decrease of fishing effort has had no determinant effect. It appeared that rearing in cages and in tanks with dry food needed a study at a pilot scale (several tens of thousands of prefed larvae produced) in conditions of mass rearing. Indeed published data on mass rearing productions in tanks are still very scarce (Champigneulle *et al.*, 1986*a;* Drouin *et al.*, 1986; Champigneulle, 1988; Rösch, 1988) and the use of high initial density (> 100 larvae/l) needed investigations particularly in the thermic range (9-12°C) of water generally available in coregonid hatcheries supplied with spring or well water. Moreover, as production in cages can greatly fluctuate according to the lakes (Brylinski *et al.*, 1979) and the years (Mamcarz and Szczerbowski, 1984), this technique was tested in the local situation over several years.

MATERIAL AND METHODS

Origin of larvae

Enzyme gene variability studies (Vuorinen *et al.*, 1986; Vuorinen, 1988) suggest that coregonids from Lake Leman and from Lake Bourget are two genetically differentiated forms of the same species *Coregonus lavaretus*. So larvae from Leman (L) and Bourget (B) origin were reared separately. Eggs were collected from wild spawners caught in December on the shore of Lake Leman (from 1983 to 1989) and Lake Bourget (1987 to 1989). The ova of more than ten females 2+ and 3+ were pooled and fertilized with the milt of several tens of males. Eggs were incubated in Zoug bottles with untreated lake water at 5-8°C which is a temperature close to natural conditions for incubation. To allow experimentation, the hatching of some batches was delayed for two-to-four weeks by finishing the incubation in cold water (1-3°C) at the eyed stage. Hatching lasted around one week; trials started the 4th day (day 1 of the experiments) after the end of hatching. The initial mean total length of larvae was between 11 and 12 mm for both origins.

General principle of rearing with dry diets

The success of coregonid larvae rearing with dry diets can generally be determined after one month of rearing, so all the results given in the paper refer to a feeding period of 35 days. The general principle of the rearing system was developed by Charlon and Bergot (1984) and its adaptation to present experiments is described in detail by Champigneulle (1988). Here the rearing unit consisted of two rectangular shaped encased and light grey coloured plastic tanks. The internal tank (56 × 36 × 38 cm) had three lateral screened (mesh size 700 µm) windows. It contains larvae and allows regular total cleaning by transfer of larvae to a clean unit. The volume of water in the internal tank was adjusted to between 50 and 62.5 l according to the different experiments. The water flow of spring water was 5 l/mm for each tank. To prevent bacterial infection a treatment with chloramine T (5 mg/l) was generally practised daily but without stopping water inflow to limit possible stress effects. In 1989 the same rearing system was tested with two bigger units (double semi-spheric tanks with a capacity of 250 l for the internal screened tank).

Dry food was regularly supplied *ad libitum*, between 09.00 and 17.00, with automatic feeders described by Charlon and Bergot (1984). From 1984 to 1988, the dry food (diet 1) used was the experimental diet A described by Bergot *et al.* (1986) which had the following composition: yeast 50%; beef liver 35%; cod liver oil 5%; mineral mix 5% and vitamin mix 5%. In 1989 a commercial diet, Tetra Werke larval starter food A_Z30 (diet 2), was used. The size of particles was inferior to 200 µm as long as larvae were shorter than 15 mm and afterwards they were fed with a mixture 50% size inferior to 200 µm and 50% 200-400 in the case of diet 1 and 200-500 in the case of diet 2.

Experiments of rearing on dry diets

The effect of medium (m.i.d.: 100/l) or high (h.i.d.: 200/l) initial densities was tested at 10°C with Leman Lake larvae (in quadruplicate) in 1986. The effect of temperature (10 or 14°C) and density (m.i.d. or h.i.d.) was tested in 1987 with Lake Bourget larvae (in duplicate for each treatment). The temperature of 14 ± 0.5°C was obtained by a heat pump allowing the warming of spring water. Due to high survival and growth rates at 14°C the larvae were transfered to bigger tanks (300 l) for the last week of rearing.

In 1988, experiments were performed at intermediate (150-160/l) density to ascertain if the survival rate at 35 days at 10°C could be improved in using small amounts of live or frozen lake zooplankton as first food or in complementation to the dry diet 1. In a first trial with Lake Bourget larvae, live zooplankton was used *ad libitum* one day per week (in triplicate) and three control batches were fed solely on dry food. In a second experiment, with Lake Leman larvae, live or frozen zooplankton was exclusively used during the first or the first two weeks (2 tanks for control and for each experimental treatment). Live zooplankton was delivered twice daily and frozen zooplankton was delivered with the technique described by Champigneulle *et al.* (1986 *a*) which allowed a regular supply of zooplankton items in movement.

Experiments were performed in 1989 with Lake Leman and Lake Bourget larvae and with commercial Tetra food A_Z30 diet to learn if the final production in tanks at 10°C could be improved with the use of very high density (v.h.i.d.: 400/l) in comparison with high (200/l) density (two tanks for each origin and density tested). The use of big semi-spheric double tanks (250/l) was tested with h.i.d. (200/l).

General principle of rearing in illuminated cages

The technique of cage rearing has been tested for coregonine larvae during the "end of winter-spring" period from 1983 to 1988 in Leman Lake and from 1987 to 1989 in Bourget Lake. In both lakes, cages had a cubic form with a respective side of 1.8 and 2 m for Leman and Bourget. The cages were submerged in littoral area (depth 15-20 m) under 5 m of water. Mesh size was 0.9 mm and the nets stayed unchanged during the rearing period. The nets were cleaned weekly using a water pump providing a jet of water from inside to outside of cages. A nocturnal illumination was realized in each cage by an electrical bulb (100 W) placed in a water-tight glass bottle.

Experiments of rearing in cages

In Lake Leman inter-year and intra-year fluctuations in cage rearing were studied from 1983 to 1988 with the same initial density of nine yolk sac fry per liter (or 50 000/cage) which is in the range (5-10 larvae/l) of density generally used for the mass rearing in cages during 2-3 months with attracted zooplankton as unique food. The water temperature was measured at 5 meters under the surface. The biovolume of zooplankton caught by a net (diam. 35 cm; mesh size 200 µm) drawn vertically from 50 m to the surface was used as a rough global index of zooplankton abundance in the bay where the cages were located (Balvay, pers. comm.).

The stocking of cages with fry prefed in tanks with dry food was tested in 2 cages in 1988 and 1989 in Bourget Lake (larvae of 5 weeks) and in 1988 in Leman Lake (larvae of 7 weeks). Each cage was stocked with 8 000 to 10 000 prefed fry (23-31 mg) to start with an initial biomass of (200 to 300 g/cage) comparable to the initial biomass when 50 000 yolk sac larvae were used. In Lake Bourget experiment of 1989, a control batch of prefed fry was kept in a tank with dry food. In Leman Lake experiment, one cage was stocked with 9 000 prefed fry (on April 18, 1988) and compared with one cage stocked on the same date with 50 000 yolk sac (issued from hatchery spawners delayed by photoperiod manipulation, Gillet, unpublished) and to cages stocked early (February, 19) with 50 000 yolk sac fry originating from wild spawners.

Collection of data

For most of the trials, the number of yolk sac larvae stocked was estimated by subsampling. In the 1989 experiment with dry diet an exact one-by-one count of stocked larvae was realized. It was also the case for prefed fry stocked in cages. For all experiments the final number is always an exact one-by-one count.

Samples (30 to 150 for each treatment) were regularly taken for growth measurements. The total length of each fish was measured for all samples. The wet weight was individually measured for most samples and for others the mean wet weight was estimated from the weight of the entire sample. The knowledge of initial (wi) and final (wf) mean wet weight allowed calculation of specific growth rate (S.G.R.) on a percentage per day basis as (log wf-log wi) × 100/(tf-ti). The supplemental knowledge of the initial (Wi) and final (Wf) total biomass allowed the evaluation of the net biomass gain rate (N.B.G.R.) during the rearing period as (log W_f - log W_i) × 100/(*tf* - *ti*).

Classical statistical tests were used to find out significative differences (Student's t, Duncan multiple range, Chi-square, and U-Mann-Whitney tests).

RESULTS

Rearing in tanks with dry diets

Influence of initial density (100 *or* 200/*l*) *and temperature* (10 *or* 14°*C*)

In the 1986 experiment, when Lake Leman larvae were reared on diet 1 at m.i.d. (100/l) or h.i.d. (200/l), the survival rate ranged from 21.9 to 39.9% (*table* 1) with no significant difference ($p > 0.05$) between groups at h.i.d. and m.i.d. The average size in batches at h.i.d. (15.6 mm; 18.7 mg) was not significantly different ($p > 0.05$) from the average for the size in batches at m.i.d. (15.6 mm; 17.9 mg). The final density and biomass were significantly ($p < 0.05$) higher for the groups with h.i.d. (*table* 1). The S.G.R. fluctuated little between 2.7 and 3.1% day^{-1} (*table* 1).

In the 1987 experiment with Lake Bourget larvae (*table* 2), for a given density (m.i.d. or h.i.d.) the survival was significantly higher ($p < 0.001$) at 14°C than at 10°C. Size, weight and S.G.R. were significantly better ($p < 0.01$) at 14°C than at 10°C. At 10°C there were no significative differences in length and weight between groups of different initial density. At 14°C, however the final weight was significantly ($p < 0.01$) lower at h.i.d. than at m.i.d. At 10°C the final density and biomass were nearly twice (*table* 2) when h.i.d. was used in comparison with results at m.i.d.

Influences of first feeding with zooplankton

In the experiment of 1988 with Lake Bourget larvae (*table* 3), the inter-tank variation of the survival was rather small (29.7 to 41.0%). The survival observed in tanks fed solely with dry diet 1 (mean: 33.7%) was not significantly ($p > 0.05$) different from the survival (mean: 36.8%) observed in tanks with live zooplankton delivered one day per week.

In the experiment of 1988 with Lake Leman larvae (*table* 4) the inter-tank variation of the survival was high (5.2 to 32.3%). The groups fed solely on dry food or for the first week with frozen zooplankton had a survival (27.1 to 32.3%) significantly better ($p < 0.05$) than the survival (5.2 to 23.2%) observed in other groups (table 4). The substitution of dry food by zooplankton had a more adverse ($p < 0.05$) effect when practised during the first two weeks than when it was practiced only during the first week. The rate of survival at 35 days was significantly worse ($p < 0.05$) when the larvae were prefed with live zooplankton as compared to frozen zooplankton before being given them dry diet 1 (*table* 4).

Table 1. – Results of mass rearing at 10 ± 0.5°C with coregonid larvae (normal hatching: initial weight = *wi* = 6.6 mg) from Lake Leman fed during 35 days in 1986 with diet 1 at high (200 larvae/l) and medium initial density (100 larvae/l).

Stocking		35 days of rearing						
Number	Density (n/l)	Number	Density (n/l)	Survival (%)	Length L ± 2SE (mm)	Weight wf (mg)	Specific growth rate wet weight (% day^{-1})	Final biomass (g/l)
6250	100	1534	25	24.5	15.6 ± 0.3	17.9	2.9	0.4
6250	100	1637	26	26.2	15.5 ± 0.4	18.3	2.9	0.5
6250	100	1659	27	26.5	15.4 ± 0.4	17.2	2.7	0.5
6250	100	1929	31	30.9	16.1 ± 0.4	18.3	2.9	0.6
15500	200	2735	44	21.9	15.7 ± 0.4	18.7	3.0	0.8
12500	200	3013	48	24.1	15.5 + 0.4	18.2	2.9	0.9
12500	200	4469	72	35.8	15.8 ± 0.5	19.4	3.1	1.4
12500	200	4991	80	39.9	15.7 ± 0.5	18.6	3.0	1.5

Influence of a very high initial density (400/*l*)

For Lake Bourget and Lake Leman origins, the mean survival at 35 days obtained with v.h.i.d. (400/l) was 35 and 42%, respectively, which are rather good values. However, they were significantly lower ($p < 0.001$) (of around 10%, *table* 5 and 6) than the survival in the groups with h.i.d. (200/l). Mean size and weight at 35 days were very similar for both h.i.d. and v.h.i.d. densities (*table* 5 and 6) with no clear difference related to initial stocking. We notice, however, that for both origins, the batch with the better growth is always a batch with only h.i.d. The final density and biomass were always superior in groups with v.h.i.d. than in groups with h.i.d. (*table* 5 and 6).

Inter-year variations at 10°*C*

The examination of the production of coregonid larvae in 50-60 l tanks with dry food from 1984 to 1989 (*fig.* 1) indicates that with h.i.d. at 10°C the general range of survival is 30-53%. Compared with

Table 2. — Results of mass rearing in 1987 at 10 ± 0.5°C and 14 ± 0.5°C with coregonid larvae (delayed hatching, initial weight = wi = 5.7 mg) of Lake Bourget origin fed for 35 days with diet I at high (200 larvae/l) and medium initial density (100 larvae/l). In the same column, figures with no common superscript letter are significantly ($p < 0.01$) different (DUNCAN multiple range test).

Temp. (°C)	Stocking		35 days of rearing					Specific growth rate wet weight (% day^{-1})	Final biomass (g/l)
	Number	Density (n/l)	Number	Density (n/l)	Survival (%)	Length L ± 2SE (mm)	Weight wf ± 2SE (mg)		
14	6250	100	5589	–	89.4	22.4 ^{c} ± 0.5	74.4^{c} ± 6.8	7.3	–
14	6250	100	5932	–	94.9	21.4^{bc} ± 0.6	66.7^{c} ± 6.9	6.8	
14	12500	200	10581		84.6	20.5^{bc} ± 0.7	55.8^{b} ± 7.0	6.5	
14	12500	200	11064	–	88.5	20.2 ^{b} ± 0.6	54.1^{b} ± 5.4	6.4	–
10	6250	100	2678	43	42.8	17.9 ^{a} ± 0.6	30.3^{a} ± 3.2	4.8	1.3
10	6250	100	3454	55	55.3	17.3 ^{a} ± 0.4	25.7^{a} ± 2.1	4.3	1.4
10	12500	200	5401	86	43.2	17.1 ^{a} ± 0.5	25.3^{a} ± 3.1	4.3	2.2
10	12500	200	6438	103	51.5	16.8 ^{a} ± 0.7	25.1^{a} ± 3.3	4.2	2.6

Table 3. — Survival of coregonid larvae from Lake Bourget (1988, normal hatching) reared in mass at 10 ± 0.5°C over 35 days with diet I for seven days per week or for six days per week and one day per week with alive zooplankton.

Stocking		Food		35 days of rearing		
Number	Density (m/l)	Diet I days per week	Live zooplankton days per week	Number	Density (n/l)	Survival (%)
8000	160	7	0	2374	47	29.7
8000	160	7	0	2460	49	30.8
8000	160	7	0	3281	66	41.0
8000	160	6	1	2787	56	34.8
8000	160	6	1	2822	56	35.3
8000	160	6	1	3231	65	40.4

Table 4. — Survival of coregonid larvae from Lake Leman (1988, normal hatching) reared in mass at 10 ± 0.5°C over 35 days with diet I or with zooplankton alive (A.Z.) or frozen (F.Z.) during the first or the first two weeks and diet I the following weeks.

Stocking		Feeding during			35 days of rearing		
Number	Density (m/l)	First week	Second week	3th to 5th week	Number	Density (n/l)	Survival (%)
8250	150	diet I	diet I	diet I	2661	48	32.3
8250	150	diet I	diet I	diet I	2237	41	27.1
8250	150	F.Z.	diet I	diet I	2397	44	29.1
8250	150	F.Z.	F.Z.	diet I	1916	35	23.2
8250	150	F.Z.	F.Z.	diet I	1661	30	20.1
8250	150	A.Z.	diet I	diet I	1421	26	17.2
8250	150	A.Z.	diet I	diet I	1228	22	14.9
8250	150	A.Z.	A.Z.	diet I	453	8	5.6
8250	150	A.Z.	A.Z.	diet I	428	8	5.2

Table 5. — Results of mass rearing at 10 ± 0.5°C with coregonid larvae from Lake Bourget (normal hatching; initial weight $wi=5.8$ mg) fed over 35 days with diet 2 (Tetra Az 30) in 1989 with high (200 larvae/l) and very high (400 larvae/l) initial density. In the same column, figures with no common superscript letter are significantly ($p < 0.01$) different (DUNCAN multiple range test).

Stocking		35 days of rearing						
Number	Density (n/l)	Number	Density (n/l)	Survival (%)	Length L ± 2 SE (mm)	Weight wf ± 2 SE (mg)	Specific growth rate wet weight (% day^{-1})	Final biomass (g/l)
20 000	400	7 143	143	35.7	$17.3^{a} \pm 0.3$	$28.7^{a} \pm 1.8$	4.6	4.1
20 000	400	6 822	136	34.1	$17.9^{a} \pm 0.3$	$32.5^{ab} \pm 2.1$	4.9	4.4
10 000	200	4 683	94	46.8	$17.8^{a} \pm 0.3$	$30.9^{ab} \pm 1.8$	4.8	2.9
10 000	200	3 921	78	39.2	$18.5^{b} \pm 0.3$	$36.2^{b} \pm 2.1$	5.2	2.8

Table 6. — Results of mass rearing at 10 ± 0.5°C with coregonid larvae from Lake Leman (1989 delayed hatching; initial weight $wi=8.1$ mg) fed over 35 days with Tetra larval Az 30 (diet 2) with high (200 larvae/l) and very high (400 larvae/l) initial density. In the same column, figures with no common superscript letter are significantly ($p < 0.01$) different.

Stocking					35 days of rearing			
Initial number	Initial density	Number	Density (n/l)	Survival (%)	Length L ± 2 SE (mm)	Weight wf ± 2 SE (mg)	Growth rate wet weight (% day^{-1})	Final biomass (g/l)
20 000	400	8 283	166	41.4	$16.6^{a} \pm 0.5$	$20.7^{a} \pm 2.1$	2.7	3.4
20 000	400	8 563	171	42.8	$17.7^{bc} \pm 0.5$	$23.4^{ab} \pm 2.0$	3.0	4.0
10 000	200	5 266	105	52.7	$17.1^{ab} \pm 0.5$	$22.5^{ab} \pm 2.5$	2.9	2.4
10 000	200	5 252	105	52.5	$18.3^{c} \pm 0.5$	$26.4^{b} \pm 2.6$	3.4	2.8

m.i.d. (100/l) the use of h.i.d. (200/l) allowed a better final density varying generally between 61 and 105 larvae of 35 days per liter (*fig.* 1). The mean final size at 35 days fluctuated between 15.7 and 18.2 mm for all the densities tested (*fig.* 1).

The results obtained in 1989 at h.i.d. with a commercial diet fall in the upper part of the range of survival, size, final density and biomass (*fig.* 1) observed in previous years with experimental diet 1 at 10°C. The results of survival and growth are still good at v.h.i.d. as compared with the results at h.i.d. in the previous years. The use of v.h.i.d. gave the best results of final density and biomass (*fig.* 1). Moreover, in 1989, an important fact was that the use of bigger (250 l) double tanks with h.i.d. gave results that fell in the same range as those obtained in 50-60 l tanks (*fig.* 1).

Rearing in cages

Year to year fluctuations, influence of stocking date in environmental conditions of Lake Leman

The examination of the six years of production in Lake Leman cages stocked with 50 000 yolk sac fry indicates very important inter-year fluctuations in the yield realized in the first half of June. Indeed, the extreme results (average of 2 or 3 cages) were 3 300-43 100 fish/cage, 6.5-86% survival, 160-780 mg mean individual weight, 0.09 to 1.65 kg/m^3 of cage, 0.6 to 4.6% day^{-1} net biomass gain rate (NBGR).

The synthetic index (NBGR) was used to compare the production from stocking (50 000 larvae/cage) until the first half of June of two groups of cages separated according to the stocking period: mid-February to beginning of March (14-16 weeks of rearing) and mid-March to early April (10-13 weeks of rearing). In both groups the NBGR was positively correlated to the mean water temperature (Tm) during the rearing period. Figures 2*a* and *b* give the relationship between T_m and NBGR. For each group, NBGR increased as T_m increased and for a given temperature NBGR appeared higher for the group with a later stocking period (*fig.* 2*a* and *b*).

There were important differences in the size at 10 weeks as, according to cage, the mean total length varied between 17.5 and 36.2 mm (29 to 292 mg for the mean wet weight). Highly significant ($p < 0.001$) positive correlation was found between mean total length at 10 weeks and the mean water temperature during the corresponding period. The relationships between the mean temperature (T_m) and the mean length (L) or the mean weight (W) at 10 weeks are described by the following equations of regression:

$$\underset{(mm)}{L} = -12.023 + 4.988\,\underset{(°C)}{T_m} \qquad (r=0.974,\ p < 0.001)$$

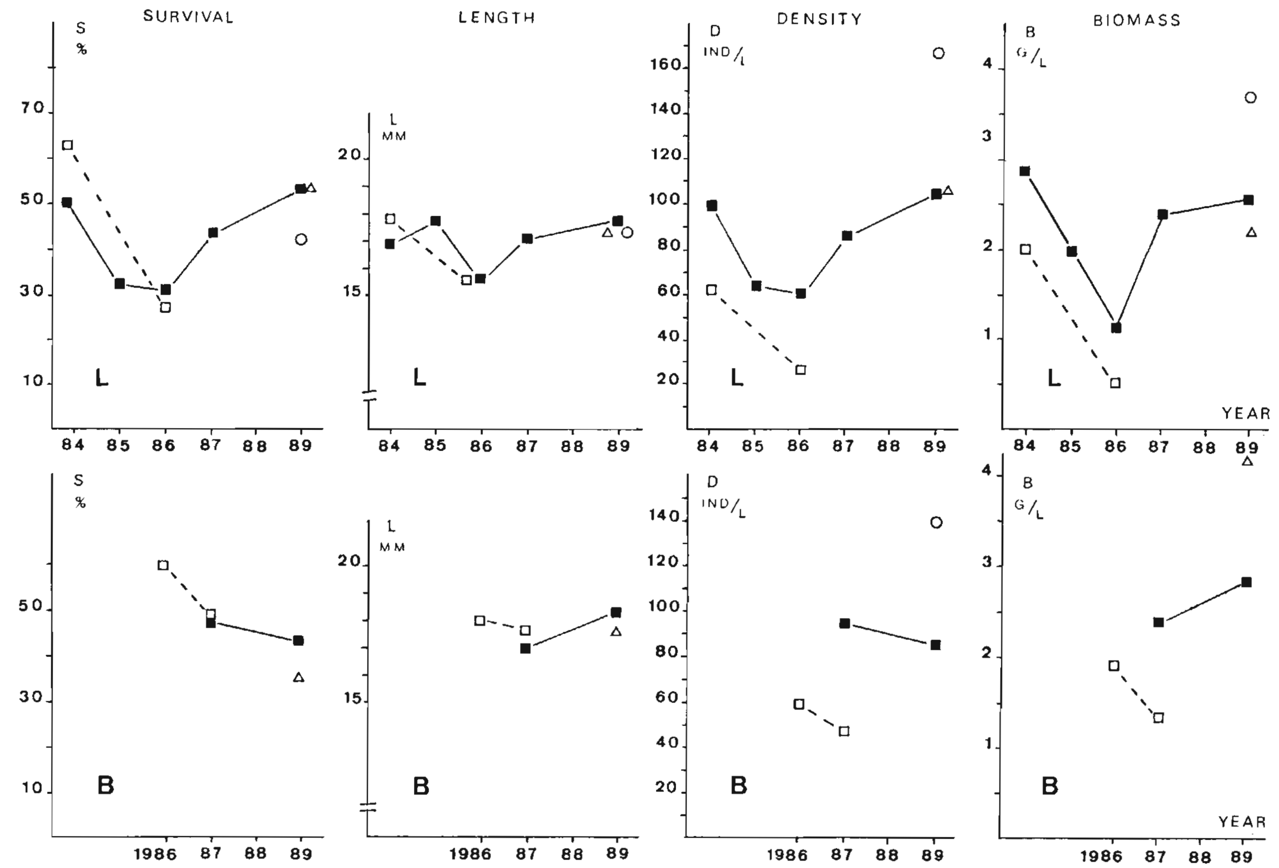

Figure 1. — Synthetic results at 35 days for the mass-rearing of coregonine larvae of Lake Leman (L) and Lake Bourget (B) fed with dry food (diet 1: 1984-1988; diet 2: 1989) in tanks of 50-60 l at 10°C with three initial densities: (□) 100/l; (■) 200/l; (○) 400/l. Additional data: (△) tank of 250 l, density 200/l, temperature 10°C. Each point represents the mean value for 2-4 tanks.

$$\underset{(mg)}{W} = 0.008\,95\,\underset{(°C)}{T_m}^{4.597} \qquad (r = 0.978,\ p < 0.001)$$

Figures 3 *a* and *b* indicate also that the mean length at ten weeks increased with stocking date and at the same time simultaneous increases of mean temperature (5.9 to 9.7°C) and zooplankton abundance index (6.1 to 20 ml) are observed (*fig.* 3 *b*).

Examination of figure 2 indicates that the survival calculated in the first half of June is systematically better (25.3 to 86.2%) in the second group than in the first one (6,6 to 21.0%). But as the rearing period was shorter in the second group we cannot directly conclude a better survival with late stocking. However, in 1983 and 1988, two years with early stocking, the survival was estimated at the end of the first half of the rearing period. For these two years, after 7-8 weeks of rearing the survival was already lower (22 to 25%) than the survival (33 to 86%) observed after a longer period (10-11 weeks) in 1985 and 1986 with a stocking in early April (*table* 7).

First attempts to stock cages with prefed fry

A comparative growth experiment performed in Leman Lake cages in 1988 indicated that yolk sac larvae stocked in mid-April have had an initial growth at 8 weeks significantly higher ($p < 0.001$) (32.9 mm-271 mg) than the initial growth observed (16.3 mm-23 mg) with a stocking 8 weeks earlier (*fig.* 4). Unfortunately if the crop is realized in early June the final advantage in size is in favor of earliest stocking (46 mm against 29 mm, *fig.* 4). In contrast the stocking of cages in mid-April with fry prefed on dry diet 2 until the size 18.8 mm (30 mg) led to a final size in cages similar to the one of fry stocked in cages as yolk fry 8 weeks earlier (*fig.* 4) and their survival in cages was high (87.4%). A two-years experiment (1988-1989) in Lake Bourget cages confirmed the good survival (75.1-85.4%) of fry prefed on dry diet 1 or 2 when they are stocked in cages (*table* 8). However, in contrast to survival, important inter-year fluctuations of SGR and NBGR were noticed with better values observed with the later stocking of 1988.

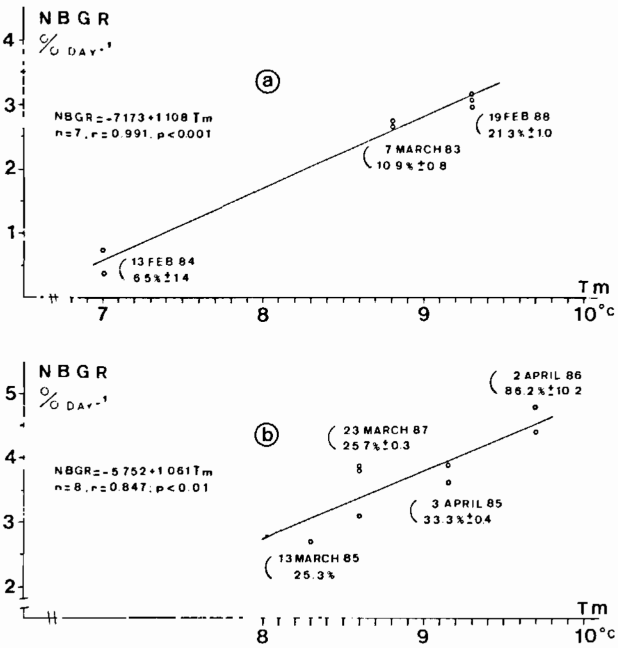

Figure 2. – Relationship between mean water temperature during the rearing (T_m in °C) and the net biomass gain rate (NBGR in % day-1) in cages of Lake Leman emptied in the first half of June and stocked with 50 000 yolk sac fry (L) at two periods: (*a*) mid-February to early March; (*b*) mid-March to early April. Each point represents a cage. In brackets: dates of stocking and mean survival (S% ± SD) in the corresponding cages.

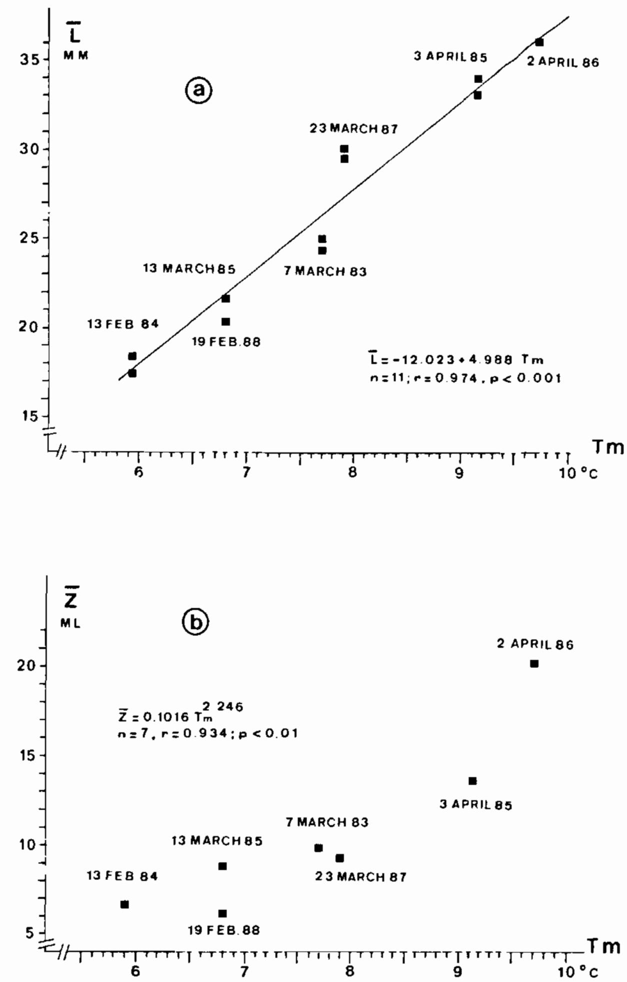

Figure 3. – Relationship between the mean water temperature (T_m in °C) during the first ten weeks of rearing and: (*a*) the mean length at 10 weeks (L) of coregonid larvae in cages of Lake Leman. Each point represents the result of one cage. Dates indicated refer to the stocking with 50 000 yolk sac fry. (*b*) the mean value of zooplankton abundance index (Z in ml).

In 1989 the control group kept in the hatchery on a dry died at 10°C had a good (80.4%) survival but the final mean length and weight were significantly ($p < 0.001$) better in cages (*table* 8).

DISCUSSION

Rearing in tanks with dry food

The present study allows us to conclude that coregonine larvae from Lake Leman and Lake Bourget can be mass reared solely on dry diet with h.i.d. (200/l) at 10°C. Total survival ranged from 30 to 50% and mean size was 16-18 mm at 35 days, values obtained both with an experimental and a commercial diet. Moreover, similar results were also obtained with only a small depression of growth and survival at v.h.i.d. (400/l), a density never tested until now. These results indicate that, when yolk sac larvae availability is not a limiting factor, the final crop in tanks at 10°C can easily be increased in using h.i.d. (≧ 200/l). However, survival up to 80% and mean size up to 19 mm have already been obtained occasionally at low temperature (10-11°C) with larvae from Lake Leman and Bourget (Champigneulle and Rojas-Beltran, unpublished data) or at a larger scale with other whitefish forms fed with the same diets (Rösch and Dabrowski, 1986; Rösch, 1988). In order to stabilize the results at the highest values, the next step of research would be to study more accurately the role played by different factors (microvariations in food composition, behavior, environmental conditions, quality and initial characteristics of larvae...). The role of the temperature during incubation could be studied more accurately as, according to Luczynski *et al.* (1984), cold incubation produced larvae with a larger size and a reduced yolk sac. Experiments of Rösch (1989) with *C. lavaretus* (gangfish form) larvae fed on dry died at 12°C suggest that initial survival and growth are better for larvae delayed in hatching than for larvae hatching earlier.

Table 7. — Evaluation of survival (mean value of 2 cages) in cages of Leman Lake with an early or late stocking of 50.000 yolk sac fry.

Year	Mean temperature (°C)	Mean zooplankton index (ml)	Date of stocking	Age (weeks)	Survival (% ± S.D.)
1988	6.6	5.6	19 Feb.	8	21.8 ± 3.0
1983	7.1	7.6	7 March	7	25.0 ± 4.6
1985	9.1	13.6	3 April	10	33.3 ± 3.9
1986	9.7	20.2	2 April	11	86.2 ± 10.2

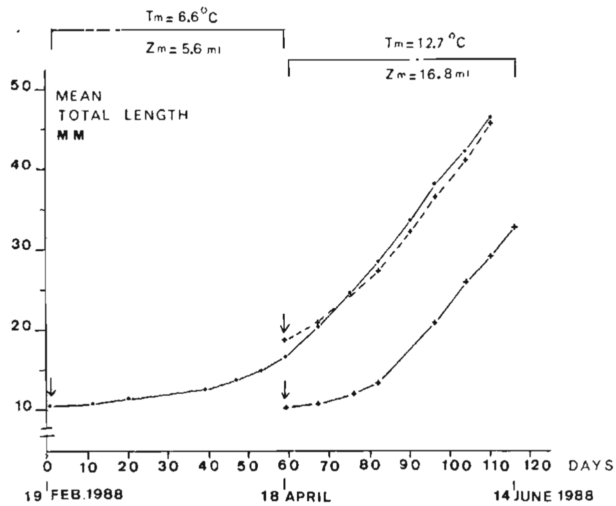

Figure 4. — Growth (mean total length in mm) in Leman Lake cages in 1988 for three different stockings: (●——●) 50 000 yolk sac fry stocked on February, 19; (——) 50 000 delayed fry stocked on April, 18; (+---+) 9 000 larvae prefed (Initial size = 18.8 mm; w = 30 mg) with dry diet 1 and stocked on April, 18. T_m and Z_m, respectively mean water temperature and zooplankton index.

McCormick *et al.* (1971) reared *Coregonus artedii* for 28 days with alive zooplankton. They found that SGR increased (2.4 to 13.5% day^{-1}) from 3 to 18°C. Our results joined to those of Dabrowski *et al.* (1984), Dabrowski and Kaushik (1985), Bergot *et al.* (1986), Fauconneau *et al.* (1986) indicate that for coregonine larvae of Leman Lake the growth with dry food increases as temperature increases from 8 to 18°C. Several studies (Rösch and Dabrowski, 1986; Segner *et al.*, 1988) at low temperature (11-12°C) with the same dry food as in the present experiments indicate a slower growth than with live zooplankton. Rösch and Dabrowski (1986) and Segner *et al.* (1988) indicate that new researches in the field of larval nutrition can still improve the growth on dry diet at low temperatures. The effects of temperature on survival of larvae with dry diets are not yet fully documented, as experiments with dry diets are often performed only at one temperature and density. Moreover, survival is generally compared for a given rearing period and not for a given stage of development. Nevertheless, the use of water with a temperature higher than 13°C can easily improve the efficiency of coregonine larvae rearing on dry diets. So, the determinant effect of temperature justifies a careful technical (heating; recycling) and economical evaluation even in hatcheries supplied with colder (9-11°C) water. In such a case, it would be interesting to test the following sequence: a short-term (two weeks) initial rearing at high density and at optimum temperature (16 ± 2°C) in special tanks when water requirement is still low to get a good start for the majority of larvae; all larvae that started to feed would then be transferred to more classical tanks supplied with "cheaper" water at lower temperature for the second phase of rearing when water requirement increased.

Table 8. — Results of stocking cages of Lake Bourget with fry prefed in tanks on dry food. (*): control batch kept in tanks with a dry diet.

Stocking of prefed larvae			Rearing conditions		Harvest				
Date	Mean weight (mg)	Initial number	Unit	Mean temperature (°C)	Time weeks	Survival (%)	Length L ± 2SE (mm)	Mean weight (mg)	Specific growth rate (% day^{-1})
March 24 1988	23	8 840	cage 1	10.7	9	75.1	57.1 ± 2.1	1 162	8.5
		8 115	cage 2	10.7	9	82.3	55.0 ± 2.0	1 089	8.4
March 9 1989	31	10 000	cage 1	9.7	13	73.4	53.0 ± 0.6	912	3.4
		10 000	cage 2	9.7	13	85.4	55.3 ± 1.3	997	3.8
March 9 1989	31	14 837	2 control tanks* (dry food)	10	13	80.4	45.3 ± 1.2	632	3.4

Recent studies (Rojas Beltran and Champigneulle, unpublished data) indicate that illumination level, and light quality, length of feeding time and tank size can strongly influence initial growth and/or survival of larvae. Moreover, according Rösch (1988), Champigneulle and Rojas Beltran (unpublished data) some results obtained in laboratory experiments are no longer observed at a mass rearing scale. In conclusion, to get results that can be applied at industrial stage new researches could be performed in mass rearing conditions with a good control of environmental factors.

Rearing in cages

Rearing of coregonine larvae in illuminated net cages can be improved by addition of artificial food in the case of surface cages (Mamcarz and Nowak, 1987) when zooplankton availability is low; this technical solution is practicable in well sheltered places. Rearing in cages only with attracted zooplankton gives generally better results in small lakes with a good zooplankton production and quick warming at the end of winter (Brylinski *et al.*, 1979) even if they are eutrophied (Rasmussen, 1988). The present study indicates that improvements are also possible in the case of a large mesoeutrophic lake with a thermic inertia that retards the warming of the water. Indeed in such lakes the temperature appeared to be the key factor in the control of cage rearing success and it is interesting to note that there is the same trend for the natural production of juveniles in such lakes (Gerdeaux and Dewaele, 1986; Eckmann *et al.*, 1988).

In environmental conditions of Lake Leman we conclude that rearing in cages stocked with yolk sac fry gives results that fluctuate too much when practised too early (February or beginning of March) with yolk sac fry. The results (SGR, NBG, regularity) can be improved by a stocking practised a few weeks later (from the middle of March to early April). The results of initial growth are in agrement with those of Luczinski *et al.* (1986 *b*) who found that a small delay in the stocking time of *Coregonus albula* in cages resulted in a faster growth connected to higher water temperatures and more abundant food supply. But as indicated by the 1988 experiment in Leman Lake, if the stocking with yolk sac is too late the final total biomass and individual weight can be much less than in the case of an earlier stocking. Moreover there is the risk of a decrease in the availability of zooplankton of adequate quality required for first feeding. The present study suggests that the use of fry prefed with dry diet can be interesting for a late stocking. They can be stocked in cages with larger mesh size and they achieve a large final size with a good survival rate. The good results obtained here when stocking cages with small (20-30 mg) prefed fry joined to those obtained by Rösch and Eckmann (1986) with bigger fry (80-110 mg) indicate also that fry prefed on dry diets can easily be switched to live zooplankton in semi-natural conditions.

CONCLUSION

Recent works on the use of dry diets for coregonid larvae have improved the techniques and the sites available for the rearing of coregonine juveniles and will probably contribute to an enhancement of coregonine production. If larvae are used to sustain stocks in natural environments, the choice of the mass rearing technique and its optimization must take into account, in each local situation, the cost-efficiency balance for different kinds of restocking (species or form, size, period, number required, quality). The possible advantage of rearing fewer fish to larger size instead of rearing more fish to smaller size should be given more attention in further research. Indeed the recapture rates are generally related to the size at stocking being in the order of some fish per 10 000 yolk sac larvae (Luczynski, 1986; Klein, 1988), increasing to several percent with fry prefed during spring (Meng *et al.*, 1986; Luczinski, 1986; Champigneulle and Gerdeaux, unpublished data) and up to some tens of percent with autumn fingerlings (Luczinski, 1986; Salojärvi, 1986). A lot of research has still to be done in this field.

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