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RESEARCH ARTICLE

Impact of daily feed rations for juvenile common whitefish *Coregonus lavaretus* (L.), on rearing indicators and oxygen requirements

Krzysztof Wunderlich, Bożena Szczepkowska, Mirosław Szczepkowski, Michał Kozłowski, Iwona Piotrowska

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Abstract. The aim of the study was to determine what impact feeding juvenile common whitefish, *Coregonus lavaretus* (L.), different feed rations had on rearing indexes and oxygen consumption during culture in recirculation systems. Three feeding treatments were applied: 2% (group L), 3% (group M), 4% (group H) of fish biomass. The final juvenile common whitefish weight increased with increasing daily feed rations. Fish from group H (largest feed ration) had statistically significantly ($P < 0.05$) higher body weights (50.3 g) and higher feed conversion ratios (1.14) than did the fish in the other two groups. However, the lowest oxygen consumption (192.9 mg O_2 kg^{-1} h^{-1}) was noted in group L (smallest feed ration). The results of the experiment indicated that the size of the daily feed ration has a significant impact on the rearing results and oxygen requirements of juvenile common whitefish. The optimum daily feed ration for juvenile whitefish weighing 10-45 g and at a water temperature of 18.0°C is 3% of the stocking density.

Keywords: common whitefish, growth, oxygen consumption, RAS

K. Wunderlich [✉], B. Szczepkowska, M. Szczepkowski, M. Kozłowski, I. Piotrowska
Department of Sturgeon Fish Breeding, Pieczarki
Inland Fisheries Institute in Olsztyn
Pieczarki 50, 11-610 Pozezdrze, Poland
Tel. +48 (87) 428 36 66; e-mail: wunda@wp.pl

Introduction

Whitefish, *Coregonus lavaretus* (L.), is a valuable species both commercially and ecologically. It inhabits cold, clean waters in the northern hemisphere. The organoleptic qualities of its meat and eggs mean that it is fished commercially and reared intensively in ponds (Tournay 2006), and is also a popular recreational catch (Aronsuu and Huhmarniemi 2004). Currently, natural whitefish populations are in decline in many countries, and in some places these declines are drastic and threaten the existence of the species (Falkowski and Wołos 2007, Thomas and Eckmann 2007).

Deteriorating environmental conditions, sedimentation at natural spawning sites, (Winfield et al. 2004, Ciereszko et al. 2008), overfishing, predation by fish and birds, and artificial hybridization with other fish of the genus *Coregonus* (Łuczyński et al. 1992) are the leading causes of the current decline in whitefish populations. This is why closed fishing seasons, minimum size limits, and recreational catch restrictions have all been implemented. Whitefish populations are also supported with active protection measures including the creation of brood stocks and stocking programs which use material reared under controlled conditions (Dobosz and Kuźmiński 1997, Wedekind et al. 2007, Szczepkowski 2009a, Szczepkowski et al. 2010).

Recirculating aquaculture systems (RAS) are being used more frequently to produce stocking material of various fish species, including the common whitefish. One of the fundamental problems with these systems is purifying water after its use (Kolman 1999). Choosing the correct devices for water purification requires knowledge of how the fish impact the environment of the RAS. The impact is determined primarily by fish oxygen consumption and waste product excretion (mostly ammonia), which is determined largely by feeding methods and feed quantities and types (Colt and Orwicz 1991, Zakęś 1999). These data are also important for determining safe fish stocking densities, and permit avoiding deficient oxygen and excessive ammonia concentrations. Data is lacking on the impact feeds have on whitefish oxygen consumption, which renders optimizing whitefish rearing in RAS difficult.

The aim of the current study was to determine the impact feeding different feed rations has on the rearing indexes and oxygen consumption of juvenile common whitefish cultured in RAS.

Material and methods

The material for the study was obtained through artificial reproduction of spawners aged 4+ and held in ponds at the Department of Sturgeon Culture in Pieczarki. After incubation and initial rearing conducted according to methods described previously, the fry obtained were stocked into tanks made of artificial material (ST 12–10, SDK, Poland) with working volumes of 1000 dm^3, that were part of recirculating systems. The experiment lasted for 42 days. At the beginning of the experiment, the juvenile were six months old with body weights of W 12.0 g ± 0.1 SD, body lengths of SL 10.3 cm ± 0.6 SD, and total lengths of TL 11.5 cm ± 0.2 SD. The stock in each tank comprised 150 individuals. The biomass of the stock was 1.8 kg, water flow through the tanks was maintained at 18 dm^3 min^{-1}. Water temperature during the experiment was 18.0°C ± 0.7 SD and was close to optimal for this species (Koskela and Eskelinen 1992, Szczepkowski et al. 2006).

Three levels of feeding were applied: 2% (group L), 3% (group M), 4% (group H) of fish biomass. Each variant was conducted in four replicates. The commercial feed used was T – 1.5 Nutra MP (Skretting, France) with 52% protein, 20% lipids, and 19.9 MJ kg^{-1} digestible energy. The feed was delivered by automatic band feeders for 12 hours daily (08:00-20:00). The basic feed ingredients were: fish meal (43.9%), wheat gluten (16.5%), and fish oil (13.2%) (manufacturer's data). During the experiment, water quality parameters were monitored: oxygen content (± 0.01 mg dm^{-3}) and water pH (± 0.01) with a PCD 5500 meter (Eutech Instruments, USA); total ammonia nitrogen CAA determined by direct nesslerization, and nitrite NO_2-N with sulfanilic acid in a Spekol 11 spectrophotometer (Carl Zeiss, Germany) (Hermanowicz et al. 1999). A 24-hour light regime was applied to the tanks during the experiment. Body weight (W ± 0.1 g), body length SL and TL (± 1 mm) measurements were taken from 30 individuals from each group. These measurements were also performed during the experiment every seven days. Before the measurements, the fish were anesthetized with a solution of the anesthetic Propiscin (IFI Olsztyn, Poland) at a dose of 0.7 ml dm^{-3} (Kazuń and Siwicki 2001).

The data obtained was used to calculate the following:

specific growth rate (SGR, % d^{-1})

$$SGR = 100 \times (\ln W_2 - \ln W_1) \times D^{-1},$$

where: W_1 – initial mean body weight (g), W_2 – final mean body weight(g), D – rearing time (days);

Fulton's condition coefficient (K)

$$K = 100 \times (W \times SL^{-3})$$

where: W – fish body weight (g), SL – fish body length (cm);

body weight variation coefficient (CV, %)

$$CV = 100 \times (SD \times W^{-1})$$

where: SD – standard deviation (g), W – fish body weight (g);

feed conversion ratio (FCR)

$$FCR = P \times B^{-1}$$

where: P – amount of feed fed (g), B – fish biomass growth (g)

$$PER = (FB - IB) \times FPS^{-1}$$

where: PER – protein efficiency ratio, IB and FB – initial and final biomass (g), FPS – amount of protein fed (g).

On day 24 of the experiment, daily oxygen consumption OC measurements (mg O_2 kg^{-1} h^{-1}) were taken. These were determined by calculating the differences in oxygen concentration (mg dm^{-3}) at the water inflow O_{in} (mg dm^{-3}) and outflow O_{out} (mg dm^{-3}) in the rearing tanks, the rate of water flow Q (dm^3 min^{-1}) and fish biomass B (kg) according to the formula:

$$OC = (O_{in} - O_{out})\ Q\ B^{-1}$$

Water samples were collected from each tank every two hours in a daily cycle.

Single factor analysis of variance (ANOVA) and Tukey's test (HSD) were used to confirm the significance of differences between mean values of SGR, K, CV, FCR, and OC. Differences were considered significant at $P < 0.05$. Statistica for Windows 7.1 (StatSoft, Inc.) was used for statistical analysis.

Results

The final weight of the juvenile whitefish increased with increasing daily feed rations. Fish from group H that were fed the largest feed ration attained a body weight of 50.3 g, which was statistically significantly higher than that in groups M (43.2 g, $P < 0.05$) and L (29.3 g, $P < 0.001$). The final body weight of the fish from groups M and L also differed significantly statistically ($P < 0.01$, Table 1). Statistically significant differences in body weight were noted in group L after four weeks of rearing, and also after seven weeks between groups M and H (Fig. 1).

The specific growth rate was the greatest in group H at 3.41% d^{-1}. In the other groups, it was significantly statistically lower at 3.05% d^{-1} in group M ($P < 0.05$) and 2.13% d^{-1} in group L ($P < 0.001$). No differences were noted, however, with regard to final total length TL or body length SL among the groups ($P > 0.05$). Fulton's condition coefficient was the lowest in group L and differed significantly statistically from the value of the two remaining groups ($P < 0.01$). No statistically significant differences were noted in the values of variation coefficient CV ($P > 0.05$).

In the groups fed the largest feed ration (group H), the feed conversion ratio (1.14) was significantly statistically higher ($P < 0.05$) than in the other two groups (Table 1). PER in group H was significantly statistically lower ($P < 0.05$) than in the other groups. Survival during the rearing period in all groups was similar and exceeded 93%.

Mean oxygen consumption was the lowest in group L and was 192.9 mg O_2 kg^{-1} h^{-1} ($P < 0.05$),

Table 1

Results of rearing juvenile common whitefish fed with different feed rations (2% fish biomass (group L), 3% (group M), 4% (group H), mean values ± SD; N = 4). Groups with the same letter index in the same row do not differ significantly statistically ($P > 0.05$)

Parameter	Group L	Group M	Group H
Body weight (g)	29.30 ± 1.00[a]	43.20 ± 1.20[b]	50.30 ± 2.20[c]
Total length (cm)	16.70 ± 1.80[a]	19.90 ± 3.70[a]	20.50 ± 1.90[a]
Body length (cm)	13.60 ± 0.50[a]	14.20 ± 0.10[a]	14.80 ± 0.20[a]
Specific growth rate SGR (% d^{-1})	2.13 ± 0.08[a]	3.05 ± 0.08[b]	3.41 ± 0.04[c]
Fulton's condition coefficient (K)	1.34 ± 0.03[a]	1.50 ± 0.01[b]	1.53 ± 0.01[b]
Body weight variation coefficient (CV, %)	23.70 ± 3.20[a]	18.60 ± 2.90[a]	16.10 ± 0.40[a]
Feed conversion ratio FCR	0.95 ± 0.06[a]	0.94 ± 0.02[a]	1.14 ± 0.05[b]
Protein efficiency ratio PER	2.06 ± 0.12[a]	2.06 ± 0.04[a]	1.69 ± 0.07[b]
Survival (%)	93.10 ± 2.20[a]	94.40 ± 1.70[a]	93.90 ± 2.13[a]

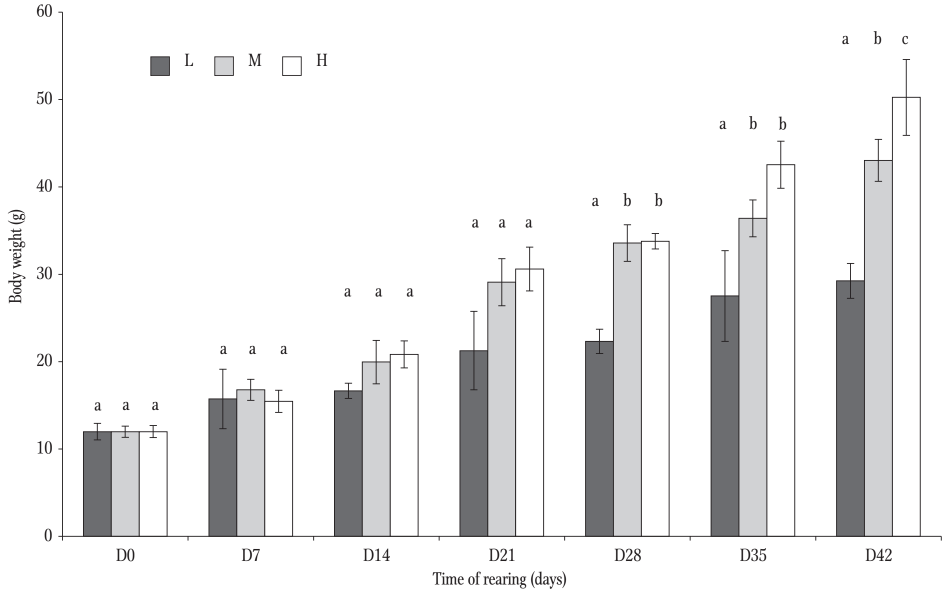

Figure 1. Growth in body weight of juvenile common whitefish fed different feed rations (2% fish biomass (group L), 3% (group M), 4% (group H), mean values ± SD; N = 4). Groups with the same letter index in the same week do not differ significantly statistically (P > 0.05).

while in groups M and H it was 259.6 and 249.6 mg O_2 kg^{-1} h^{-1}, respectively (Table 2). No statistically significant differences in daily maximum or minimum oxygen consumption were noted (P > 0.05). As the feed ration increased, the range of the daily fluctuation in oxygen consumption decreased (Fig. 2, Table 2).

Table 2

Oxygen consumption of juvenile whitefish fed different feed rations (2% fish biomass (group L), 3% (group M), 4% (group H), mean values ± SD; N = 4). Groups with different letter index in the same column differ significantly statistically (P < 0.05)

	Oxygen consumption (mg O_2 kg^{-1} h^{-1})				
Group	mean ± SD	max	min	Difference max-min (%)	Difference max-mean (%)
L	192.9 ± 30.8[a]	234.5	136.9	71.3	21.6
M	259.6 ± 22.5[b]	304.8	222.2	37.2	17.4
H	249.6 ± 17.0[b]	279.1	222.9	25.2	11.8

Discussion

Whitefish is currently a species of great interest to aquaculture (Tournay 2006). Implementing techniques for rearing this species requires determining the optimal feed composition and designing feeding strategies (Ruohonen et al. 2007). It has been confirmed that whitefish prefers feed with high contents of fish meal and fish oil and low contents of vegetable components (Ruohonen et al. 2003). The feed applied in the current experiment met these requirements, although the fish meal and fish oil contents were lower than optimal values. In addition to composition, the size of the feed ration is an important factor affecting the rearing of various fish species. Restrictive feed rations are too small to meet the nutritional needs of the fish, which can lead to part of the stock monopolizing the feed and the formation of a hierarchy among the fish (Jobling 1995). This leads to widening gaps in the size of individuals (Alanärä and Brännäs 1993) and decreased growth rates for

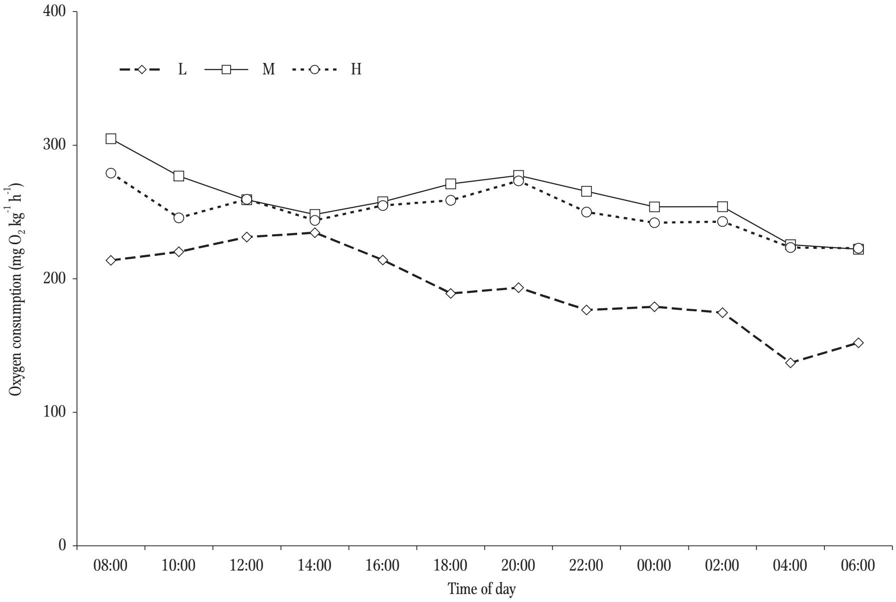

Figure 2. Changes in oxygen consumption by juvenile common whitefish fed different feed rations (2% fish biomass (group L), 3% (group M), 4% (group H), mean values, N = 4).

the entire group. In fish species in which pronounced cannibalism occurs, these size differences lead to increases in this phenomenon (Szczepkowski 2009b). Among whitefish, however, cannibalism is rare in the wild (Skurdal et al. 1985, Tolonen 1997) and during intensive culture (personal observation), and it was not noted during the present experiment. Feed rations that are too large can lead to excess fat accumulation in the muscles and internal organs, and the formation of body deformations (Wolnicki and Myszkowski 2005). Increased feed rations usually have an advantageous impact on fish growth (Hung and Lutes 1987, Fiogbé and Kestemont 2003); however, after the limit known as the maximum level is exceeded under given conditions, the feed is no longer consumed or used for growth (Cotton and Walker 2005).

In the current study, increasing the daily feed ration from 2 to 4% led to increased final body weights of the juvenile whitefish. The level of feeding in group L (2% stock biomass) was too low, which was indicated by the significantly statistically lower values of the condition coefficient, and the greatest size differences among the fish in this group (CV). The study results also indicated that the largest feed ration (4%) did not exceed the level that can be consumed by the fish as was indicated by the significantly statistically higher whitefish body growth with increasingly larger feed rations. Increasing the daily feed ration above 3% did result in a lowered feed conversion ratio and decreased protein utilization (PER). Similar results were obtained during the culture of juvenile pikeperch fed daily feed rations 2 to 6% at various temperatures; the results indicated that the lowest FCR values were obtained in groups fed a 2% ration, while the highest values were obtained at a ration of 6% (Bódis and Bercsényi 2009). The lower FCR values recorded for groups fed less feed might be the result of the better availability of gastric acids for the feed, as well as lower energy losses for feed metabolism.

The size of production in recirculating systems is most often limited by the oxygen content of the water which results from its consumption by the fish. The magnitude of oxygen consumption depends on many factors including water temperature (Parma de Croux 1993, Zakęś 1999, Szczepkowski et al. 2006), or fish size (Jatteau 1997, Szczepkowski et al. 2000a, 2000b). The feed ration also has a strong impact on oxygen consumption (Colt and Orwicz 1991, Zakęś 1999, Thomas and Piedrahita 1997). When the fish are not physically active, the link between oxygen consumption and the ration of feed consumed is limited until the maximum ration is reached (Jobling 1981, Thomas and Piedrahita 1997, Zakęś 1999). The oxygen consumption of juvenile whitefish fed rations ranging from 2 to 4% of stock biomass indicated that the maximum feed ration at a water temperature of 18.0°C was 3%. Increasing the feed ration above this value did not result in increases in mean or maximum values of oxygen consumption. This might indicate that excessive feed above 3% was not consumed by the fish, or, more likely was not consumed to a great degree. Evidence of this was both the better weight gain in the group fed a 4% feed ration and the higher value of the feeding coefficient (FCR). In the group fed the smallest (2% fish biomass) feed ration oxygen consumption was significantly statistically lower than in the groups fed the higher feed rations, which, combined with worse rearing results (lowest final body weight and lowest Fulton's condition coefficient) confirm that this ration was too small to meet the requirements of the fish. In this group, the greatest daily oxygen consumption fluctuations and increased oxygen consumption values after feeding began could have been associated with the greater competition for limited food resources and the increased fish movement required to obtain feed. In the groups fed the larger feed rations, increased oxygen consumption was noted only six hours after feeding began, and the highest values were recorded at the moment feeding concluded.

The amplitude in oxygen consumption fluctuations expressed as the ratio of maximum and mean oxygen consumption (from 1.12 to 1.22) was within a range typical for production systems (Colt and Orwicz 1991), and was lower than the values for salmonids (Westers 1981).

The results of the current experiment suggest that the size of the daily ration has a significant impact on the effects of rearing and the oxygen requirements of juvenile whitefish. The results presented indicate that the optimal daily feed ration for fish in the weight range of 10-45 g, at a water temperature of 18.0°C was 3% of the fish stock. This is confirmed by the rearing results: increased fish body weight, effective feed utilization, and the magnitude of oxygen consumption. Knowledge such as this is of practical importance since it permits obtaining maximum results when rearing juvenile whitefish in recirculating systems and helps in choosing a water oxygenation device.

It is also important to bear in mind another way in which the material reared in this manner is used. Since whitefish is also used to stock open waters, the possible impact of intensive feeding must be considered. Among other things, it is crucial to determine the impact of feeding on fat deposition in fish, which can cause body deformations and decrease the ability of the fish to swim (Wolnicki 2005), but it does ensure there are stores of energy that permits a longer period of adapting to new conditions. This requires further study.

Conclusions

1. The daily feed ration has a significant impact on the rearing results and oxygen requirements of juvenile whitefish.
2. The optimum daily feed ration of fish in the body weight range of 10-45 g and at a water temperature of 18.0°C was 3% of the fish stocking density.
3. The oxygen consumption of juvenile whitefish reared at temperature of 18.0°C oscillated, depending on the feed ration, from 193 to 260 mg O_2 kg^{-1} h^{-1}.

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Streszczenie

Wpływ poziomu żywienia juwenalnej siei, *Coregonus lavaretus* (L.) na wskaźniki chowu i wielkość zapotrzebowania tlenowego

W eksperymencie przeprowadzonym w obiegu recyrkulacyjnym określono wpływ żywienia różnymi dawkami paszy na wskaźniki chowu i konsumpcję tlenu juwenalnej siei. Zastosowano trzy poziomy żywienia ryb wynoszące 2, 3 i 4% biomasy ryb na dobę. Eksperyment trwał 42 dni, materiałem do badań była juwenalna sieja w wieku 6 miesięcy o masie ciała 12 g i długości ciała 10,3 cm. Temperatura wody podczas podchowu wynosiła 18°C. Końcowa masa juwenilnej siei wzrastała wraz ze wzrostem dobowej dawki żywieniowej. Ryby z grupy H (żywione najwyższą dawką paszy), charakteryzowały się istotnie statystycznie wyższą ($P < 0,05$) masą ciała (50,3 g) i wyższą wartością współczynnika pokarmowego (1,14) niż ryby w pozostałych dwóch grupach. Natomiast w grupie L (ryby żywione najniższa dawką paszy), stwierdzono najniższą średnią konsumpcję tlenu (192,9 mg O_2 kg^{-1} h^{-1}). Wyniki eksperymentu wskazują, że wielkość dobowej dawki pokarmowej ma istotny wpływ na efekty chowu i zapotrzebowanie tlenowe juwenalnej siei. Optymalna dobowa dawka paszy dla ryb w przedziale masy ciała 10-45 g, przy temperaturze wody 18°C wynosi 3% obsady ryb.