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RESEARCH ARTICLE

Growth rate and reproduction of a brood stock of European whitefish (*Coregonus lavaretus* L.) from Lake Gaładuś under controlled rearing conditions

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Abstract. The focus of the study was to analyze the effects of the artificial reproduction of whitefish, *Coregonus lavaretus* (L.) aged from 1+ to 4+. It was confirmed that males comprised 64.5% of the brood stock. The males were sexually mature at the age of 1+, while most females were mature at the age of 2+. The females gained weight faster in comparison to the males, and the differences were highly statistically significant ($P < 0.001$). Survival during the period from the first spawning at age 1+ to spawning at age 4+ was 79.6% for males and 59.6% for females. The quantity of eggs obtained, the egg size, and their survival during incubation all increased as the fish aged. The weight of the eggs obtained from fish aged 3+ and 4+ was statistically significantly higher that from younger fish (1+ and 2+) ($P < 0.001$). The results of the current study indicate that exploiting a whitefish brood stock under controlled conditions can begin as early as at age 2+. The highest relative fecundity and largest egg size were obtained in females aged 3+.

Keywords: whitefish, Lake Gaładuś, growth, fecundity

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Introduction

Whitefish, *Coregonus lavaretus* (L.), is one of the most valuable species of Polish ichthyofauna. This species has high environmental requirements, and it inhabits clean, well-oxygenated lakes. In the last century, this species was not only important ecologically, it was also of substantial fishery and angling importance in some lakes (Szczerbowski 2000). In the 1970s, catches of this species in Polish waters exceeded 100 tons, with catches exceeding 10 tons in individual lakes such as Gołdopiwo (Falkowski and Wołos 2007). Whitefish is classified as an endangered species (Witkowski et al. 1999), and catches currently do not exceed 10 tons annually nationwide (Wołos and Mickiewicz 2006). Decreases in the numbers of this fish that are noted in many areas might be linked to overfishing, deteriorating environmental conditions, and limited spawning sites and natural recruitment (Winfield et al. 2004, COSEWIC 2005).

In light of these circumstances, there is an urgent need to maintain the surviving population (Oldenburg et al. 2007); one of the ways to do this is to undertake active protections measures. One of elements of such measures is to create brood stocks under controlled conditions followed by artificial reproduction and then rearing stocking material. Similar measures have produced positive results with migratory whitefish

(Dobosz and Kuźmiński 1997). Since it is increasingly difficult to obtain whitefish spawners from natural lake waters, such endeavors are justified and important as they provide an opportunity to supplement the stocks of this species in aquatic basins and to maintain natural populations.

Creating a brood stock is a long-term and costly process, which is why any efforts aimed at producing high quality, sexually mature fish should be preceded by gathering information regarding what is possible to achieve. It must be kept in mind that such results might differ from those obtained in the wild. This refers in particular to the time required by the fish to achieve sexual maturity and the quantity and quality of the reproductive products that are obtained. Working with fish under controlled conditions presents a range of difficulties including environmental conditions that differ from those in the wild, and fish sensitivity to manipulation. Another issue is the selection of a suitable diet, which is usually different from that of fish in the wild. Subjecting the fish to inappropriate rearing conditions and diets can result in disturbed gametogenesis (Bogdanova 2004) and less effective fish reproduction.

While there is ample information in the literature regarding the growth and fecundity of whitefish in the wild (Trzebiatowski et al. 1988, Heese 1990, Harrod and Griffiths 2004), there is no data regarding the results obtained from brood stocks of this species held under controlled conditions.

One of the few remaining whitefish populations in the inland waters of Poland is that in Lake Gaładuś. At the Department of Sturgeon Fish Breeding (DSFB) in Pieczarki a whitefish brood stock was created using fish from this lake. The aim of the current study was to determine the growth rate of the whitefish, the results of artificial reproduction, and to analyze changes that occurred in the fish as they aged.

Materials and Methods

Eggs obtained from the artificial spawning of individuals caught in the wild at Lake Gaładuś (surface area 728.6 ha, mean depth 12.7 m, maximum depth 54.8 m) in the Suwałki Lakeland (northeastern Poland) comprised the initial study material. The eggs were incubated at the Stocking Center of the Polish Angling Association in Gawrychruda. After reaching the eyed-egg stage, the material was transported to the DSFB in Pieczarki, where the larvae hatched and were reared. The fish were held in recirculating systems from hatch until the age of 1+. Following the first spawning, the individuals were stocked into cement pond measuring 20 x 10 x 2 m (length, width, depth). In subsequent seasons the fish were removed from the tanks only in the spawning season, when they were sorted by sex, and held in manipulation tanks made of artificial materials with volumes of 2 m^3.

The artificial reproduction of whitefish aged from 1+ to 4+ was evaluated in four subsequent seasons using the following criteria:

- number of sexually mature fish – individuals from which milt and eggs were obtained during spawning;
- sex proportion among mature fish;
- quantity of eggs obtained, determined individually for each female and used to calculate the gonadosomatic index (GSI);
- number of eggs in a unit weight – determined separately using samples numbering at least 500 eggs;
- survival of embryos to the eyed-egg stage.

The gonadosomatic index was calculated with the following formula:

$$GSI = W_g \times BW^{-1} \times 100\% \qquad (1)$$

where: GSI – gonadosomatic index (% body weight), W_g – eggs weight (g), BW – total weight of fish (g).

In the first season of the study (fish aged 1+), two feeding experiments were also conducted. Experiment I evaluated the rearing indexes and the maturation of whitefish fed different feed rations. Three feeding treatments were applied: treatment 1P – the feed ration for rainbow trout, *Oncorhynchus mykiss* (Walbaum), at a given water temperature (Goryczko 2001); treatment 0.8P – 0.8 of this amount; treatment 0.6P – 0.6 of this amount. This feed ration was from 0.8 to 1.2% of the fish biomass in group 1P, from 0.64 to 0.96% in group 0.8P, and from 0.48 to 0.72% in group 0.6P. The feed used was REP (Aller Aqua) commercial feed for trout spawners (53% protein, 14% fat, 16.4 MJ kg^{-1} digestible energy). The experiment was conducted from May to November 2005. The fish were kept in rotational tanks with a volume of 0.6 m^3. Each feeding treatment was repeated in three replicates. The initial stocking density was 13 kg m^{-3}. The fish were fed manually three to four times during the day.

Experiment II compared rearing results of whitefish breeders fed two different types of feed; the first was for salmonid spawners – REP feed and the second was for sturgeon – T-XL Sturio (Nutreco) (47% protein, 12% fat, 17.9 MJ kg^{-1} digestible energy). This part of the experiment ran from March to September 2005. The fish in each variant were fed the same feed rations equivalent from 0.6 to 0.75% of fish biomass day^{-1}. The feed was supplied by automatic band feeders.

All of the fish were weighed individually at the beginning and the end of the two experiments, and weight monitoring was performed once per month to determine fish growth.

The following indexes were calculated:

$$FCR = F \times B^{-1} \quad (2)$$

where: FCR – feed conversion ratio, F – quantity of feed supplied (kg), B – increase in fish biomass (kg);

$$CF = 100 \times BW \times SL^{-3} \quad (3)$$

where: CF – Fulton's condition factor, BW – body weight (g), SL – body length (cm);

$$SGR = (\ln (BW_2) - \ln (BW_1))\, D^{-1} \times 100\% \quad (4)$$

where: SGR – specific growth rate (% day^{-1}), BW_2 and BW_1 – mean body weight at the end and beginning of the experiment (g), D – number of rearing days.

Statistical calculations were performed with Statistica 7.1 (StatSoft Inc.). The mean values of the indexes studied were compared with ANOVA single factor tests (Tukey's multiple range test). Differences were statistically significant at $P \leq 0.05$.

Results

Impact of feed ration on whitefish growth and maturation

The fish from group 1P had the highest body weight by the end of the experiment (413 ± 18 g). The body weights in the other groups were 403 ± 9 g (group 0.8P) and 399 ± 7 g (group 0.6P). The differences among the groups were not statistically significant ($P > 0.05$). The mean daily increases in body weight were similar in the treatment groups and fluctuated from 0.12 ± 0.01% day^{-1} in group 0.6P to 0.19 ± 0.02% day^{-1} in group 1P ($P > 0.05$). Fish survival was similar at 91.9 ± 0.9% (group 0.6P), 93.3 ± 1.4% (0.8P) and 94.3 ± 1.7% in group 1P ($P > 0.05$). The size of the feed ration influenced the number of fish that achieved sexual maturity at age 1+. It was confirmed that in the group fed the largest feed ration (group 1P), the greatest number of males, which comprised 61.5% of all the fish in the group, were ready to spawn. In the other two groups, the share of mature males was lower at less than 50% of all fish (46.2% in group 0.8P and 48% in group 0.6P). The differences between groups 1P and the others were statistically significant ($P < 0.05$). Even greater differences were noted among females. In group 1P, there were twice as many mature females at age 1+ than in the other groups ($P < 0.05$), and they comprised 15.4% of all the fish. In this group 76.9% of all the fish aged 1+ (males and females) spawned, while in the other two groups about 20% fewer fish spawned at 53.8% in group 0.8P and 56.0% in group 0.6P.

Impact of feed type on the rearing results of breeders

By the end of the experiment, the fish fed REP feed attained a mean body weight of 408.7 ± 31.0 g. The mean daily weight increase in this group was 0.29 ± 0.02 % day^{-1}. The fish fed T-XL feed had a lower final body weight of 360.6 ± 21.8 g and lower mean daily growth at 0.22 ± 0.02% day^{-1}. Differences in body weight between the groups compared were not statistically significant ($P \geq 0.05$). Survival in both groups was high at 92.0 ± 1.0% (group REP) and 94.0 ± 1.5% (group T-XL). The use of the feed by the fish was expressed in the value of the FCR coefficient and this differed substantially among the groups studied. The values of this indicator were 1.71 ± 0.25 for the fish fed REP feed and 2.51 ± 0.18 for the fish fed T-XL feed, and the difference was statistically significant ($P < 0.05$).

Growth rate and effectiveness of artificial reproduction

There was a higher share of males in the studied spawning population at 64.5% of all the fish. Males achieved sexual maturation faster. At age 1+ milt was obtained from 80.8% of the total number of males (Fig. 1), while only 29.4% of females ovulated. Most of the fish of both sexes spawned at age 2+, with the exception of those exhibiting symptoms of disease or those that were emaciated.

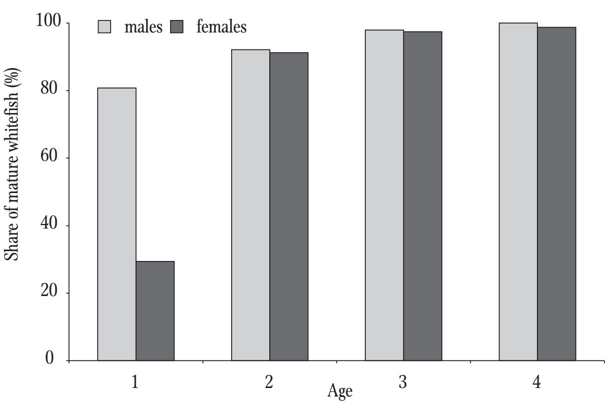

Figure 1. Share of mature whitefish (*Coregonus lavaretus*) in subsequent spawning seasons.

Females grew faster in comparison to males (Fig. 2), and differences in body weight in all age groups were highly significant statistically ($P < 0.001$). This difference became more pronounced in subsequent seasons: at age 1+ female body weight was 28.3% higher, while at age 4+ it was 42.5% higher. The body length of the fish compared from the age groups was also greater in females, but statistically

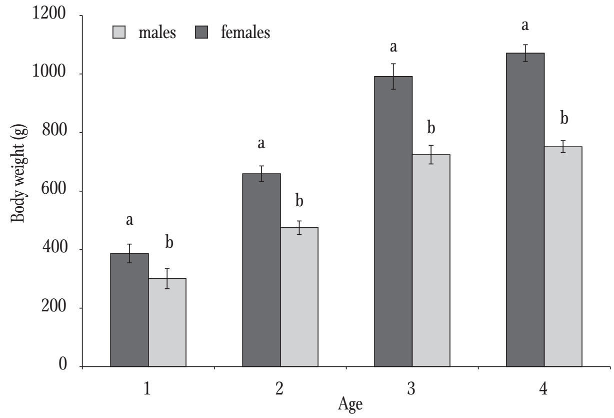

Figure 2. Increases in whitefish (*Coregonus lavaretus*) weight under controlled conditions. Groups with different letter indexes in subsequent years differ significantly statistically ($P < 0.05$).

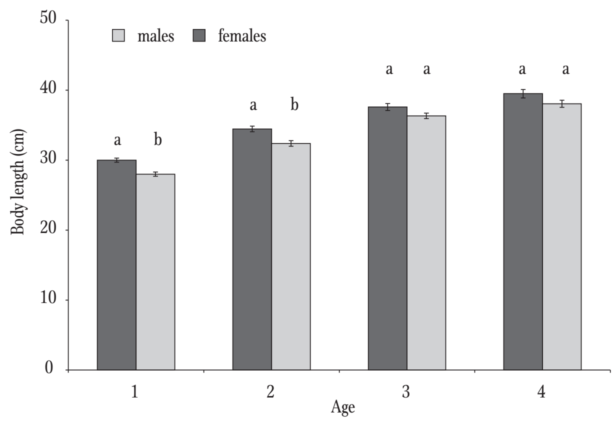

Figure 3. Increases in whitefish (*Coregonus lavaretus*) length under controlled conditions. Groups with different letter indexes in subsequent years differ significantly statistically ($P < 0.05$).

significant differences ($P < 0.05$) were confirmed in individuals aged 1+ and 2+ (Fig. 3). The mean daily increases in body weight decreased as the fish aged. In the third year of life it was 0.15% d^{-1} in females and 0.12% d^{-1} in males. In the fifth year of life growth mostly ceased and was for the two groups respectively 0.02% d^{-1} in females and 0.01% d^{-1} in males. Fish condition, as expressed with Fulton's factor, increased in both sexes until age 3+ (Fig. 4), when the values noted were 1.87 ± 0.07 for females and 1.51 ± 0.03 for males. At age 1+ the condition factor for each of the sexes were similar, and the differences were not statistically significant ($P > 0.05$). However, in fish aged 2+ and older, the condition coefficient for females was statistically significantly higher ($P < 0.001$) than that for males.

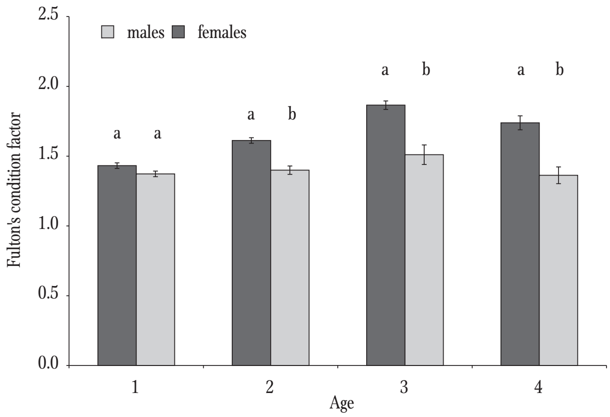

Figure 4. Changes in Fulton's condition factor in female and male whitefish (*Coregonus lavaretus*). Groups with different letter indexes in subsequent years differ significantly statistically (P < 0.05).

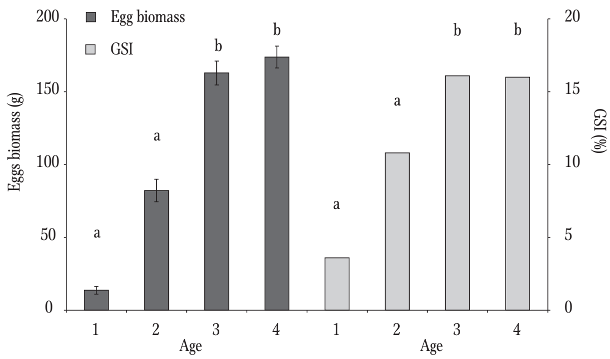

Figure 6. Gonadosomatic index (GSI) and mean quantities of eggs obtained from whitefish (*Coregonus lavaretus*) of different ages. Groups with different letter indexes in subsequent years differ significantly statistically (P < 0.05).

Survival between subsequent spawning seasons was higher among males, but two periods of higher mortality were observed immediately after spawning and during the summer when water temperatures were high (exceeding 20°C). During the period from the first spawning at age 1+ to spawning at age 4+, total survival was 79.6% in males and 59.6% in females (Fig. 5).

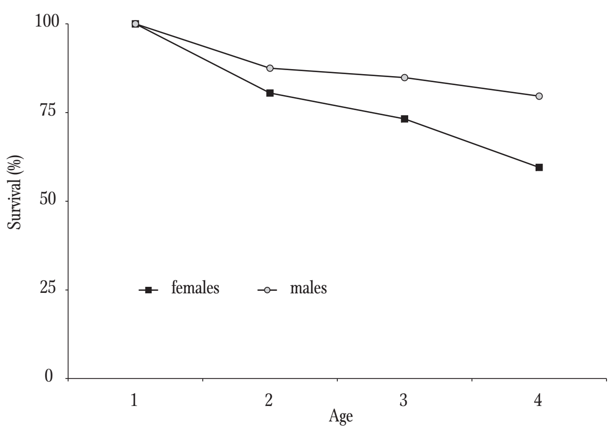

Figure 5. Survival of whitefish (*Coregonus lavaretus*) spawners under controlled conditions.

The quantity of eggs obtained increased with fish age. The average quantity of eggs obtained from females at age 1+ was 13.7 ± 2.6 g, while at age 4+ it was 173.8 ± 7.5 g (Fig. 6). The weight of the eggs at ages 3+ and 4+ has significantly statistically higher than it was in younger fish (1+ and 2+) (P < 0.001). The weight of eggs obtained per 1 kg of female body weight was an average of 3.6 ± 0.5% at age 1+ to 16.1 ± 0.7% at age 3+. The differences among ages 1+ and 2+ and older fish (3+ and 4+) was statistically significant (P < 0.01). The size of the eggs also increased with fish age: in females aged 1+ 168769 ± 1185 eggs comprised 1 kg, while at age 4+ this figure was 148744 ± 3930 eggs (P < 0.05). The quality of the reproductive products also varied with fish age; during the first spawning at age 1+ all of the eggs obtained whitened and survival to the eyed-egg stage was 0%. In subsequent spawning seasons, survival to the eyed-egg stage was 58.5% at age 2+, 62.0% at age 3+, and 64.4% at age 4+.

Discussion

The current state of the whitefish requires stocking, and programs that do this have been ongoing for many years in many areas (Gerdeaux 2004, Aronsuu and Huhmarniemi 2004). Limited possibilities of obtaining spawners from open waters, the necessity of preserving the gene pool, and creating conditions for rearing stocking material annually all require building brood stocks under controlled conditions. This was done for, among other species, migratory whitefish some years ago, and now both commercial catches and obtaining spawners from open waters is possible (Kuźmiński and Dobosz 2007).

The results of the current study indicate that with regard to whitefish from lakes, it is a reasonable undertaking to create a brood stock under controlled conditions. With the whitefish from Lake Gaładuś, it is possible to begin exploiting brood stocks held under controlled conditions as early as at age 2+. At this age nearly all males and females are already sexually mature. Although milt and eggs can be obtained from fish aged 1+, both the number of maturing individuals, especially of females, and the quality of their reproductive products is not yet satisfactory.

It is not unfounded to assume that holding fish under controlled conditions shortens the sexual maturation period in comparison with that in the wild. While there are no data available regarding the length of the maturation period of whitefish in the wild in Lake Gaładuś, it is possible to infer that, as in other lakes of this region, females reach sexual maturity in the fourth year of life (aged 3+) (Szczerbowski 2000, Gustchin and Mataszenko 2006). The faster maturation of fish under controlled conditions might result from the high growth rates of breeders held in recirculation systems that exceeds whitefish growth achieved in the wild (Trzebiatowski et al. 1988).

Beginning in the fourth year, whitefish held in ponds exhibit a cessation of growth in both females and males with a simultaneous decrease in condition coefficient. This might be the result of either genetic predisposition (maximum size achieved) as well as conditions in which the fish live. Whitefish from Lake Gaładuś attain a maximum body weight of over 3 kg (personal observations). The average body weight for females caught in this lake during the natural spawning season was 1578 g, which was much higher than that of the whitefish under the controlled conditions of the current study. Thus, it appears that the limiting factor in fish growth was the rearing conditions. In subsequent seasons, the pond stock of breeders rose continually, and by the fourth year when the fish were ages 4+ they achieved a total weight of 5870 kg ha^{-1}, which could have had negative results, especially since the ponds had no permanent water flow. Confirmation of this can be found in the decreasing condition coefficients of the fish. Migratory whitefish held in flow-through trout ponds were noted to have continually increasing condition coefficients as they aged (Kuźmiński and Dobosz 2007). Decreases in condition coefficients were noted in migratory whitefish females older than 5+ from wild population in the Puck Bay. This was linked to decreasing quantities of eggs in older fish (Kuźmiński and Dobosz 2007). Despite decreased condition coefficients, the quantity of eggs obtained from the whitefish from Lake Gaładuś did not decrease. Similar observations were made of whitefish from the Pomeranian Bay, in which declines in fecundity were not noted until the females had reached an age of 10+ (Heese 1990). In addition to age, there are also other factors that can impact the fecundity and growth of fish. In the wild, these can include the trophic state of the basin, stocking, and selective catches (Hartmann and Quoss 1993, Thomas et al. 2009). Another factor that can influence growth rates in whitefish is the variable behavior of the different years. It has been observed that younger whitefish (1+ and 2+) consume food throughout the day, while older individuals (aged 3+ and 4+) have decidedly shorter feeding periods that are limited to several hours before dusk and after dawn. This could be linked to light conditions, as it has been observed that on sunny days the consumption by younger whitefish of the feed supplied was decidedly weaker. It can be assumed that this corresponds to the behavior of adult whitefish in the wild where they inhabit deeper waters where light levels are relatively low.

The dependency of egg size on fish age has been noted in many fish species (Kamler 2005). Usually, the largest eggs are produced by fish that are of middle age for their species (Bartel 1971, Wilkońska et al. 1993). The largest eggs produced by the whitefish from Lake Gaładuś were from females aged 3+. In older fish, egg size was observed to stabilize, which can also be the result of decelerated growth rates in fish. It was confirmed that the egg size of lake trout *Salmo trutta* m. *lacustris* L. reared in ponds was more dependent on the size of the fish than their age (Bartel et al. 2005). In the case of whitefish, a halted growth rate in body weight did not have a negative impact on the quality of the reproductive products obtained, and survival of the fertilized eggs to the eyed-egg stage was increasingly higher in subsequent spawning seasons.

A negative phenomenon observed during whitefish rearing was considerably higher female mortality; this was especially significant since the females were the minority sex in the brood stock. Similar sex ratios are also observed among coregonids in the wild (Szczerbowski 2000); this, however, can be influenced by other factors, such as the reproductive phase, the time of day, or changes in water thermal regimes (Terlecki and Kempińska 1956, Harrod and Griffiths 2004). Fish deaths occurred primarily during the post-spawning period and were linked to the course of spawning. Higher mortality among females is because of the invasive manipulation they are subjected to during artificial reproduction.

The results of the current study indicate that the nutrition of whitefish breeders plays an important role in their growth and spawning readiness. It appears that the feed ration used in rearing rainbow trout is also suitable for whitefish since a greater percentage of fish achieved sexual maturity in comparison to the fish fed more restrictive rations. In addition to the size of the feed ration, the type of feed and the proportion of the ingredients are also important (Ruohonen et. al. 2003). The results of the current study indicate that feeds for salmonids are more suitable than are those for other species.

The data presented in the current paper are relevant to planning the production of stocking material under controlled conditions. These can also be useful for obtaining eggs from whitefish for the production of caviar. The optimal indicators for eggs (the highest relative fecundity of the fish and the largest egg size) was obtained from females aged 3+.

Rearing whitefish under controlled conditions permitted shortening by one season the period necessary to achieve sexual maturity. High quality reproductive products from both females and males (as confirmed by the high survival rate to the eyed-egg stage) as early as at age 2+. Proof that this resulted from extending the period of intense rearing in its early stages is a comparable rearing study performed at the Stocking Station of the Polish Angling Association in Gawrychruda. This station received fry with a mean body weight on less than 1 g from the Dgał Experimental Hatchery, and a brood stock was also created from them. These fish, which were held at water temperatures that mimic those in nature, achieved body weights at age 2+ that were similar to those of fish aged 1+ at the Dgał Experimental Hatchery, and only about 10% of the females were ready to spawn.

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Streszczenie

Tempo wzrostu i rozród stada tarłowego siei *Coregonus lavaretus* (L.) z jeziora Gaładuś w warunkach kontrolowanego chowu

Celem przeprowadzonych badań było określenie wybranych wskaźników hodowlanych oraz przeanalizowanie zmian zachodzących z wiekiem ryb w czasie chowu stada tarłowego siei w warunkach kontrolowanych. W badanej populacji tarłowej stwierdzono większy udział samców, które stanowiły 64,5% wszystkich ryb. Samce osiągnęły dojrzałość płciową w wieku 1+, a samice w większości w wieku 2+. Samice wykazywały szybszy wzrost masy ciała w porównaniu z samcami, a różnice we wszystkich rocznikach były wysoce istotne statystycznie (P < 0,001). Średnie dobowe przyrosty masy ciała zmniejszały się z wiekiem ryb, począwszy od piątego roku życia uległy praktycznie zahamowaniu i wynosiły odpowiednio 0,02% d^{-1} u samic i 0,01% d^{-1} u samców. Kondycja ryb wyrażona współczynnikiem Fultona rosła u obu płci do osiągnięcia wieku 3+ i osiągnęła wartości 1,87 ± 0,07 u samic i 1,51 ± 0,03 u samców. Poza rybami w wieku 1+ współczynniki kondycji u samic były wysoce istotnie statystycznie wyższe niż u samców (P < 0,001). Przeżywalność między kolejnymi rozrodami była wyższa u samców, przy czym obserwowano dwa okresy zwiększonej śmiertelności: bezpośrednio po tarle oraz w okresie

letnim, przy wysokich temperaturach wody (powyżej 20°C). W okresie od pierwszego rozrodu w wieku 1+ do rozrodu w wieku 4+ przeżywalność całkowita wyniosła 79,6% u samców oraz 59,6% u samic. Ilość pozyskiwanej ikry wzrastała z wiekiem ryb, od samic w wieku 1+ pozyskano przeciętnie 13,7 ± 2,6 g ikry, a w wieku 4+ 173,8 ± 7,5 g ikry. Masa pozyskiwanej ikry w wieku 3+ i 4+ była wysoce istotnie statystycznie wyższa niż u ryb młodszych ($P < 0.001$). Masa pozyskanej ikry w przeliczeniu na 1 kg masy ciała samic stanowiła przeciętnie 3,6 ± 0,5% w wieku 1+ do 16,1 ± 0,7% w wieku 3+. Z wiekiem ryb wzrastała wielkość jaj: u samic w wieku 1+ w 1 kg ikry mieściło się 168769 ± 1185 jaj, a w wieku 4+ 148744 ± 3930 jaj ($P < 0,05$). Jakość produktów płciowych również zmieniała się z wiekiem ryb. Podczas pierwszego rozrodu (w wieku 1+) przeżywalność do stadium zaoczkowania wyniosła 0%. W kolejnych sezonach uzyskiwano przeżywalność do stadium zaoczkowania odpowiednio 58,5% (2+), 62,0% (3+) i 64,4% (4+). Wielkość podawanej dawki paszy wpłynęła na ilość ryb, które osiągnęły dojrzałość tarłową w wieku 1+. Stwierdzono, że w grupie ryb żywionych najwyższą dawką paszy najwięcej samców i samic osiągnęło gotowość do tarła i stanowiły one 76,9% wszystkich ryb. Wyniki przedstawionych badań wskazują, że eksploatację stada tarłowego siei w warunkach kontrolowanych można rozpocząć już w wieku 2+. W tym wieku praktycznie wszystkie samce i samice były już dojrzałe płciowo. Najwyższą względną płodność ryb i największe rozmiary ikry uzyskano u samic w wieku 3+.