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Short communication

Effect of different feeding regimes on growth in juvenile Atlantic cod, *Gadus morhua* L.

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ABSTRACT

Different feeding regimes (fasting/re-feeding and reduced feeding) were tested in a 131 day trial with 1400 juvenile (mean ± SE, 132 g ± 1) Atlantic cod (*Gadus morhua*) in order to see if a compensatory growth response could be elicited, and if hyperplastic growth was stimulated during the compensatory growth phase. The Atlantic cod was fed in compliance with the following five feeding (F) fasting (S) schedules: the control group (Cont) was fed 100% according to a commercial growth table every day, the second group was fed 50% for two weeks and 100% for four weeks (S50), the third group was fed 100% every second day and 0% the following day (ALT), the fourth group was fasted one week and fed 100% two weeks (S1W), and the last group was starved two weeks and fed 100% four weeks (S2W). At the termination of the experiment, the body mass of the fish in the control, ALT and S50 groups were significantly higher than the fish in S1W and S2W groups. The shorter fasting treatment groups (ALT and S50) consumed significantly less feed (42.9 and 37.5% less feed, respectively) compared to control whereas final weight did not differ between these three groups. Growth rate was highest in the S50 group (0.78% day^{-1}), and lowest in the longer fasting period groups (S1W, 0.59% day^{-1} and S2W, 0.57% day^{-1}). White muscle fibre diameter, white muscle fibre density and the percentage of small fibres below 25 μm was measured in the control and S2W group and did not differ at any sample point during the experiment. There were minor differences between the groups in percentage distribution of fibre diameter classes. The results demonstrate that feeding costs can be drastically reduced without compromising biomass growth by using feeding on alternate days or by periodically fasting and re-feeding juvenile cod.

1. Introduction

Atlantic cod, *Gadus morhua*, has been considered to be one of the most promising candidates for marine aquaculture in Norway. The production of farmed cod has increased from 7000 tons in 2005 to 21 000 tons in 2010 (Anonymous, 2012). However, high production costs combined with decreasing market prices have limited further increase, and production costs thus need to be reduced in order to obtain a cost effective level. Feed costs constitute almost 50% of the production costs in cod farming. Fasting and re-feeding has been explored in many species as a form to enhance the growth both in fish and mammals (Ali et al., 2003; Rehfeldt et al., 2010; Stickland et al., 2004). In the wild, fish species can experience long periods with limited food availability or even total fasting. These periods may last from a few weeks, up to several months, even years (Bélanger et al., 2002; Karlsen et al., 1995; Larsson and Lewander, 1973; Love, 1970). Fasting for longer periods causes substantial mobilisation of body resources for energy compensation (Black and Love, 1986). Compensatory growth is often described as a phase of unusual rapid growth after a period of reduced growth, commonly seen when advantageous conditions are restored (Bélanger et al., 2002; Dobson and Holms, 1984; Hayward et al., 1997; Stefansson et al., 2009). Compensatory growth has previously been reported in several marine teleost fish species such as, pleuronectids (Bejda et al., 1992; Paul et al., 1995; Sæther and Jobling, 1999), Atlantic cod (Bélanger et al., 2002; Jobling et al., 1994; Purchase and Brown, 2001), spotted wolffish (Foss and Imsland, 2002), and Atlantic halibut (Foss et al., 2009; Heide et al., 2006). Experiments have shown that when fish are re-fed after a period of fasting, the re-feeding leads to a rapid increase in muscle liver glycogen content, overshooting the levels in continuously fed groups (Beardall and Johnston, 1985a, 1985b; Black and Love, 1986; Mendez and Weiser, 1993). Foss et al. (2009) obtained

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full growth recovery in Atlantic halibut (>0.5 kg) that were repeatedly fasted for 5 weeks and then re-fed for 10 weeks over a period of three years. Restricted feeding during autumn has been shown to reduce the maturation in haddock, *Melanogrammus aeglofinus* (Hislop et al., 1978) and Atlantic cod (Kjesbu et al., 1991). Enhanced food conversion efficiency in fish undergoing compensatory growth has also been observed (Foss and Imsland, 2002; Jobling et al., 1994; Miglavs and Jobling, 1989; Quinton and Blake, 1990), a matter of significant importance in cost-effective fish farming.

Hypertrophy and hyperplasia are the main mechanisms in fish muscle growth. Hyperplastic growth occurs as an increase in muscle fibre number due to new fibre recruitment (Greer-Walker, 1970; Weatherley et al., 1988) whereas hypertrophic growth occurs in the diameter of existing muscle fibres (Egginton and Johnston, 1982; Greer-Walker, 1971; Young and Cech, 1994). Hyperplastic growth can be divided into stratified and mosaic hyperplasia. Stratified hyperplasia occurs as a process where new muscle fibres are continuously recruited throughout the late embryonic and larval stage, while mosaic hyperplasia occurs as a phase where new recruitment of muscle fibres are intermingled with older muscle fibres of different size (Rowlerson and Veggetti, 2001). In contrast to mammals (see reviews by Brameld and Daniel, 2008; Chang, 2007; Maltin et al., 2001; Picard et al., 2002), fish muscle can grow by hyperplasia during a large part of adult life (Weatherley et al., 1988). Hyperplastic growth is therefore of great interest in commercial aquaculture. In rainbow trout subjected to different ration levels it was observed that hypertrophic growth was predominant in periods of rapid growth whereas hyperplastic growth was more pronounced in periods of slower growth (Kiessling et al, 1991). These results correspond with findings in rainbow trout, *Oncorhynchus mykiss* (Valente et al., 1999), Atlantic cod larvae (Galloway et al., 1999), Atlantic salmon, *Salmo salar* (Johnston et al., 2000) and sea bass, *Dicentrarchus labrax* (Periago et al., 2005).

The aim of the present study was to investigate to what degree different feeding regimes (fasting/re-feeding and reduced feeding) would trigger compensatory growth responses in Atlantic cod, and if hyperplastic growth was stimulated during compensatory growth phase.

2. Materials and methods

2.1. Pre-experimental protocol

Atlantic cod used in the present study originated from a commercial cod hatchery, Sagafjord AS. The eggs hatched on December 2007, and after weaning the fish were transported to the facilities of Bremar AS at Bremanger in Sogn and Fjordane County, Norway and reared under continuous light. On October 7, 2008 a total of 300 000 juvenile cod were moved to Fjord Marin Cod AS facilities, Lismåsøya outside of Brønnøysund. On November 5, 2008, 3000 cod with an average weight of 100 g were moved to the University of Nordland Research Station in Mørkvedbukta, where the experiment took place between January 13 and May 26, 2009. The cod were reared in 1.25 m^2 grey fibre glass tanks with a rearing volume of 1000 l. All tanks were supplied with flow through seawater with a salinity of 35 ± 0.2‰. Water flow was increased in line with increasing biomass during the trial in order to sustain adequate oxygen saturation (>80%). Oxygen and temperature were measured daily in the effluent water of all tanks. Temperature was 7.8 °C (±0.4) and oxygen saturation in the experimental tanks was kept above 80% (±3) throughout the experiment. Before and during the trial, the fish were reared under a simulated natural photoperiod of Bodø (67°16′N, 7 h of daylight on 13 January and 23 h of daylight on 26 May).

2.2. Experimental design

On January 13, 2009, five experimental groups were established, with four fasting groups and one control group. 1400 juvenile cod (mean initial weight individuals ± SE, 132.4 g ± 1.3) were randomly distributed between 12 tanks, each containing 110 ± 10 individuals. In each tank 50 fish were individually tagged (Trovan® Passive Transponder tags, Trovan, Ltd., UK) in order to study individual growth profiles. All treatment groups were duplicated. The cod were fed in compliance with the following four feeding (F) and fasting (S) schedules (see also Table 2): The control group (Cont.) was fed a 100% ration daily, according to a commercial growth table (BioMar AS, Myre, Norway) adjusted to actual growth rates seen in the experiment, the second group was fed 50% for two weeks and 100% for four weeks (S50), the third group was fed 100% every second day and 0% the following day (ALT), the fourth group was fasted one week and fed 100% two weeks (S1W) and the last group was fasted two weeks and fed 100% ration for four weeks (S2W). The experiment lasted 131 days. Schematically the feed experiment was performed in the following manner:

(I) Control: fasted (S) 12 days and fed (F) 119 days
(II) S50: S 13 days, F 50% 37 days and F 81 days
(III) ALT: S 62 days and F 69 days
(IV) S1W: S 45.5 days and F 85.5 days
(V) S2W: S 49 and F 82 days

The cod were fed commercial formulated feed (BioMar 3.5 mm Biomarine Classic Marine 50 and BioMar 5 mm Biomarine Classic Marine 50, Myre, Norway), containing 54% crude protein, 15% crude fat, 9% crude ash. The feed was supplied once a day on automatic belt feeders with a 12 h feeding supply. The feeding was administrated in such manner that no leftover feed was found in the tank bottom after each feeding. Amounts fed were adjusted after each weighing based on growth in the previous period.

2.3. Growth measurements

All tagged fish (n = 600) were anaesthetised (metacaine, 0.05 g l^{-1}) and weighed individually to the nearest 1 g at the start of the experiment on January 13th and then approximately every sixth week (i.e. January 13, March 4, April 15 and May 26), which was at the end of a re-feeding period for the S1W and S2W groups. The fish were starved for 24 h prior to weighing.

Specific growth rate (SGR) was calculated according to the formula of Houde and Schekter (1981):

$$SGR = (e^{g} - 1)100$$

where $g = (\ln(W_2) - \ln(W_1))\,(t_2 - t_1)^{-1}$ and W_2 and W_1 are weights on days t_2 and t_1, respectively.

Hepasomatic index (HSI) was calculated as: HSI = (WL/WB) × 100, where WL is liver weight and WB is total body weight in grams.

Gonadosomatic index (GSI) was calculated as: GSI = (WG/WB) × 100, where WG is gonad weight and WB is total body weight in grams.

Relative carcass mass (RCM) was calculated as: RCM = (WGW/WB) × 100, where WGW is gutted weight and WB is total body weight in grams.

2.4. Chemical analysis

Every 6th week five fish from each tank were sampled and killed with a blow to the head. Fish from the two last sample dates (April and May) were filleted post rigor and homogenized in pooled samples. From the mince, 5 g was measured in duplicates into a tinfoil cup and dried over night. The water content was estimated as weight loss over night at 104 °C (16 h). Liver fat from the May sampling were extracted in pooled homogenized liver samples from each tank using ethyl acetate. The pooled samples were homogenized and 5 g triplicates dried over night, and then extracted using ethyl acetate (NS9402, 1994).