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Behavioural variation in cultivated juvenile Atlantic cod (*Gadus morhua* L.) in relation to stocking density and size disparity

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ABSTRACT

The aim of this study was to examine the behaviour and activity of Atlantic cod (*Gadus morhua*) juveniles (~65–120 mm total length) in relation to varying stocking density (~500–2000 fish per m^3) and size disparity under both experimental and commercial hatchery conditions. This was done by using stereovideography to measure fish size and to quantify fish behaviour *in situ*. The swim pattern was more synchronized at higher fish densities (both experimental and commercial conditions), indicating a more pronounced schooling behaviour and possibly also indirectly reduced activity costs and stress levels with increasing fish density. Furthermore, the swim pattern became less synchronized and the relative swim speed increased as fish size disparity increased. This might indicate both elevated energetic activity costs and an augmented stress level with increasing size disparity. However, overt agonistic behaviour was nearly absent at the examined fish densities and size disparities, and negative social interactions are thus unlikely to represent a major cost under such conditions. The general absence of overt agonistic behaviour and the lack of behavioural variation indicative for extreme levels of stress or activity might suggest that the welfare status of the juveniles was not compromised under the examined conditions.

1. Introduction

Technology for the cultivation of Atlantic cod (*Gadus morhua*) is constantly developing, and commercial cod farming is increasing in countries such as Norway, Scotland, Ireland and Canada (Brooking et al., 2006; Moe et al., 2007). About 11,000 metric tonnes of farmed cod was produced in Norway in 2007 (statistics from the Norwegian Fisheries Directorate). The rearing of juveniles to a size that could be transferred to marine net pens in land-based tanks is still a critical part of cod culture. Optimisation of growth and survival during this phase is of major importance in order to reduce costs and to shorten the remaining period until the cod reaches market size.

Increased knowledge about how behaviour and activity of cultured cod juveniles varies according to social conditions could contribute to the improvement of fish welfare and production efficiency; as such variations might correlate with individual stress level and energy consumption (e.g. Sayer, 1998; Morgan et al., 1999; Øverli et al., 2002; McFarlane et al., 2004; Salvanes and Braithwaite, 2006). It is well documented that both acute and chronic stress reduces individual growth and survival in fish culture (e.g. Handeland et al., 1996; Pickering, 1998; Ellis et al., 2002). Behavioural variation might also indicate impaired fish welfare (Sneddon, 2003), as were shown for Atlantic halibut (Kristiansen et al., 2004) and rainbow trout (Chandroo et al., 2004). Finally, behavioural variation is

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often associated with variation in fish growth rate, for instance through increased energetic expenditure during high activity levels as documented in rainbow trout (Li and Brocksen, 1977; Lefranqois et al., 2001) or because behavioural variation correlates with foraging intensity (Boisclair, 1992; Kristiansen et al., 2004). The variation in individual behaviour in fish culture is related to a range of factors, of which stocking density and individual size variations within a culture unit (size disparity) are two of the most important factors.

Variation in stocking density might affect the efficiency of fish farming in several ways. An elevated stocking density may be preferable if it maximizes production capacity per culture volume. However, high densities have resulted in reduced growth rates in several fish species such as rainbow trout (e.g. Holm et al., 1990; Boujard et al., 2002; Ellis et al., 2002), Atlantic halibut (Bjôrnsson, 1994; Kristiansen et al., 2004), sea bass (Saillant et al., 2003), as well as in Atlantic cod (Lambert and Dutil, 2001). This trend is not unequivocal though, and studies of Atlantic salmon (Kjartansson et al., 1988), winter flounder (Fairchild and Howell, 2001), and European sea bass (Paspatis et al., 2003) have reported unaffected or even increasing growth rate (Arctic charr, as shown by Baker and Ayles, 1990; Siikavuopio and Jobling, 1995) with increased fish density. Increased stocking density may also reduce fish survival in aquaculture due to cannibalism (Baras and Jobling, 2002), as shown for winter flounder (Fairchild and Howell, 2001) and grouper (Hseu, 2002). The relationships between stocking density, foraging behaviour, growth and survival might be attributed to varying levels of dominance and agonistic behaviour (Lambert and Dutil, 2001).

Variation in fish size within a population (size disparity) is another important decisive factor for growth and survival, and thus for production efficiency. In commercial farming, grading and sorting of fish according to size is routinely carried out. It is widely believed that size grading results in increased biomass gain, which might be explained by larger individuals being dominant and aggressive towards the smaller individuals, which in turn might lead to suppressed feed intake and/or reduced growth of the smaller fish (Efthimiou et al., 1994; Dou et al., 2004). However, several studies have reported that size grading in fact might lead to unchanged or decreased growth in adult Atlantic cod (Lambert and Dutil, 2001), Arctic charr (Jobling and Reinsnes, 1987; Baardvik and Jobling, 1990), perch (Melard et al., 1996) and turbot (Strand and Øiestad, 1997; Sunde et al., 1998). A large size disparity in a culture unit might under some circumstances also lead to increased mortality due to cannibalism (Baras and Jobling, 2002; Hseu, 2002; Stuart and Smith, 2003).

The relationship between the behaviour of cultured fish, stocking density and size disparity is therefore not straightforward, even though it is thoroughly demonstrated that both stocking density and size variation are crucial factors, which through influencing the individual behaviour, might affect production efficiency in most types of fish farming. Little is known about behaviour of juvenile cod under commercial and large-scale culture conditions *per se*, or how behavioural variation relates to fish welfare and stress level (Salvanes and Braithwaite, 2006). Experimental and small-scale studies with low stocking densities have, however, shown that early experiences during culture might affect shoaling, antipredator, foraging and agonistic behaviour of juvenile cod (Braithwaite and Salvanes, 2005; Salvanes and Braithwaite, 2005; Salvanes et al., 2007). Moreover, cod have been shown to be aggressive and cannibalistic during the early juvenile phase (Blom and Folkvord, 1997; Hoglund et al., 2005). The scope of this study was to investigate if variation in realistic stocking densities and size disparities for commercial culture of Atlantic cod juveniles were associated with behavioural variation indicative for fish welfare, stress level or energetic costs. In order to control for artefacts caused by experimental conditions we examined the behaviour and activity of cod juveniles both experimentally with stocking densities and size disparities similar to commercial production of cod juveniles and in a commercial cod hatchery.

2. Materials and methods

Effects of size disparity and stocking density were examined in controlled small-scale experiments carried out at the NTNU Brattøra Research Center in Trondheim, Norway during two periods (03.05–07.06.2003 and 24.11–12.12.2003). The studies at a commercial cod hatchery were carried out at Cod Culture Norway AS (then owned by Nutreco), situated on the Norwegian West Coast, during two periods (04.10–08.10.2002 and 30.09–3.10.2003).

2.1. Setup and design of the experimental study

Cod juveniles were obtained from a local commercial hatchery (Fosen Aquasenter). The cod juveniles (total length: ~90–120 mm, weight: ~5–12 g) were allowed to acclimatise for 3–4 weeks before the trials were initiated. The experiments were carried out in six circular tanks (diameter: 0.95 m, height: 0.9 m, water depth: 0.55 m, volume: 390 l) with constant water circulation. Fish behaviour was recorded by video cameras through a transparent window in the tank wall (Lexan® polycarbonate: 5 mm thickness, height: 0.5 m, width: 0.6 m). The video cameras were mounted within a non-transparent box that covered the window such that the light conditions in the tanks did not change during recording. The recordings were initiated 4–5 h after introduction of the cameras to give the fish time to recover after the disturbance caused by the positioning of the cameras. Each tank was constantly illuminated by a 25-W fluorescent tube positioned 1 m above the centre of the tanks. This created a light intensity of about 500 lx at the water surface, which was similar to light conditions at a commercial hatchery. The water temperature varied between 8.5 and 9.5 °C during the first period and between 9.5 and 10 °C during the second period. The salinity was 35–36 ppt, and the oxygen concentration ranged from 8.1 to 9.4 mg l^{-1} (oxygen saturation: 92–102%). The water inlet consisted of a vertical pipe with several holes that created a circulating and even current (water flow: 8–9 l min^{-1}). The water current at the surface at the edge of the tanks was maintained at a mean velocity at 0.058 m s^{-1} (S.D.: ±0.004 m s^{-1}).