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Physiological welfare of commercially reared cod and effects of crowding for harvesting

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ABSTRACT

A greater understanding of the effects of pre-slaughter practices on farmed fish is needed, particularly for more recently farmed marine fish species such as the Atlantic cod, *Gadus morhua*. In the present studies, in order to understand the impacts of crowding prior to harvesting on the physiological well-being of farmed Atlantic cod, we measured blood haematocrit, plasma osmolality, and plasma concentrations of cortisol, glucose, lactate, chloride and sodium of cod held in two commercial sea cages. To investigate any effects of our presence alongside the cages, cod were captured from two non-manipulated cages by rod and line, with a minimal time on the line. Measurements of blood parameters were comparable with those from published laboratory studies, and showed minimal change over the 3 h maximum sampling period. By comparison, a small number of cod that were caught easily in a hand net showed severe osmoregulatory, metabolic and endocrine disturbances. These cod were predominantly mature females, from one cage in which female cod had a low muscle mass (i.e. *K* based on body mass after removal of viscera), which suggests that maturation and spawning of farmed cod, particularly females, may have welfare implications. Plasma cortisol ($ng\,ml^{-1}$) for net-caught cod ($n=9$) was 88.5 ± 20.6 (mean $\pm$ SE) compared to 8.13 ± 3.43 for rod–line-caught cod ($n=54$), and plasma osmolality ($mOsm\,kg^{-1}$) was 383.27 ± 13.03 compared to 338.55 ± 0.73. Two commercial cages, suspended at 15 m depth, were used to investigate the physiological effects of crowding of cod in a sweep net, comparing initial values in line-caught cod to values observed during crowding. The effects of crowding time, gender and cage were examined. In both cages, crowding caused a rapid and sustained elevation of blood haematocrit and plasma lactate concentrations, probably due to increased physical exertion. Plasma lactate peaked at mean concentrations of 4.17 mM and 3.02 mM in the two cages, compared to initial concentrations of 0.29 mM and 0.17 mM respectively. Disturbed osmoregulation during crowding was not accompanied by parallel changes in plasma concentrations of sodium or chloride. Plasma cortisol during crowding reached peak concentrations of approximately 60 $ng\,ml^{-1}$ in both male and female cod but female cod showed a more rapid and prolonged response. Interpretation of our results suggests that cod crowded for harvesting will benefit from (i) reduced cage depth to minimise swim bladder inflation during the sweep and unnecessary exertion, (ii) limiting crowd density as far as practical to reduce bursts of activity, and (iii) minimising the crowding period.

1. Introduction

Concern for the welfare of fish has increased over the past 10 years (Huntingford et al., 2006; Ashley, 2007; Arlinghaus et al., 2007) to a large extent because of the debated possibility that fish can feel pain (Rose, 2002; Chandroo et al., 2004). Noxious stimuli and stressful situations have been shown to affect the behaviour of fish (Sneddon et al., 2003; Ashley, 2007) and recent work suggests that their central processing of potentially painful stimuli leads to prioritization of motivational drivers and modifies normal behaviour patterns (Ashley et al., 2009). Organizations such as the UK Farm Animal Welfare Council (FAWC, 1996), the Royal Society for the Prevention of Cruelty to Animals (RSPCA, 2006), and the Council of Europe (2005) have published welfare recommendations for farmed fish, often based on the 'Five Freedoms': freedom from (i) hunger and thirst, (ii) discomfort, (iii) pain, injury or disease, (iv) fear and distress, and (v) the freedom to express normal behaviour.

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From a physiological perspective, good welfare can be recognized by objective measurement of a range of biochemical and physiological indicators (Arlinghaus et al., 2007). Values falling outside the normal homeostatic range could be indicative of poor welfare, particularly if coupled with physical damage or behavioural changes. However, exposure to some stressors and the resultant physiological response are not equivalent to suffering and may be beneficial, at least in the short term (Pickering, 1998; Huntingford et al., 2006). Nevertheless, repeated exposure to acute stressors or prolonged exposure to poor conditions results in maladaptive responses (Wendelaar Bonga, 1997; Pickering, 1998), and monitoring of multiple components of the stress responses provides valuable insights into the welfare of fish (Turnbull et al., 2005; Adams et al., 2007). Fish showing low blood concentrations of cortisol and normal values for parameters such as plasma osmolality and plasma concentrations of glucose and lactate, as well as adequate growth and condition index are generally considered to be experiencing good health and welfare (Adams et al., 1993; Turnbull et al., 2005). Persistent disruption of homeostasis, on the other hand, results in a reduced appetite, poor growth and condition, and decreased immunocompetence (Adams et al., 1993; Balm, 1997). In this sense, good welfare preserves or enhances fish health and well-being (Arlinghaus et al., 2007).

Farmed fish may be exposed to many potentially stressful events, including confinement at high densities and physical disturbance during transport and handling, which although not necessarily harmful may compromise their quality of life (Pickering, 1998; Barton, 2000; Conte, 2004; Huntingford et al., 2006; Ashley, 2007). The majority of studies of the responses of fish to aquaculture procedures have involved salmonids (reviewed by Huntingford et al., 2006), although studies on newly farmed species have been conducted more recently (reviewed by Ashley, 2007).

In aquaculture, pre-slaughter procedures are recognized as a critical point in the management of fish welfare (Wall, 2001) and have important effects on flesh quality (Bagni et al., 2007; Olsen et al., 2008a). Crowding to increase fish density is usually a pre-requisite for harvesting, and may result in increased physical activity or cause fear and distress. For example, sea bass and sea bream have been reported to increase the use of energy reserves and increase lactic acid production in the muscles during pre-slaughter stress (Bagni et al., 2007). However, there are large variations between species in their responses to crowding or high density (Ashley, 2007; Huntingford et al., 2006). Species that live naturally in shoals or shoal from time to time such as the Atlantic cod, *Gadus morhua* (Morgan et al., 1999) may have a better ability to cope with high densities than territorial species, although other factors such as water quality will interact in determining the effects of long-term changes in stocking density (Ellis et al., 2002; Turnbull et al., 2005).

To date, there have been only a few tank-based studies of the effects of short periods of crowding on farmed Atlantic cod, *G. morhua*. Caipang et al. (2008) examined plasma cortisol and expression of stress-responsive genes after short periods of crowding. Olsen et al. (2008a) reported unexpected tranquil behaviour of cod during acute crowding and no change in muscle pH, which suggests significant differences from salmonids (Olsen et al., 2006). In a further study that imposed a short period of exhaustive chasing, Atlantic cod were reported to be relatively resistant compared to more sensitive salmon and trout (Olsen et al., 2008b). However, tank-based studies do not necessarily provide information that is relevant to farm practices.

In the present studies, in order to understand the impacts of crowding prior to harvesting on the physiological well-being of farmed Atlantic cod, we measured blood haematocrit, plasma osmolality, and plasma concentrations of cortisol, glucose, lactate, chloride and sodium of cod held in two commercial sea cages. Measurements were made prior to crowding, and at timed intervals during an in-cage grading sweep to crowd the cod. Two further non-manipulated cages were used to sample cod over a 2 or 3 h period, without crowding, to assess any effects of our presence at the cage side and natural changes in the parameters measured over the period of crowding. We also examined the physiological and physical status of a small number of cod that were present close to the surface and easily caught from the side of the cage, without chasing, using a hand net.

2. Materials and methods

2.1. Cod

Atlantic cod (*G. morhua*) used for these studies were reared at NoCatch Ltd (formerly Johnson Seafarms) in Vidlin Voe (Outer), Shetland (Lat: 60° 23′ 17″ N, Long: 01° 07′ 21″ W). At the time of the studies (June 2006), the site held approximately 550,000 on-growing cod in seventeen 100 m diameter sea cages, suspended in two parallel lines with approximately 20 m between the cages. Four cages, suspended at approximately 15 m depth, ready for harvesting, were used in these studies. The mean stocking density of cod in these cages was 10.8 $kg\,m^{-3}$. Cod in two cages (A and B) at stocking densities 10.49 and 11.6 $kg\,m^{-3}$ respectively were sampled without cage manipulation, by rod and line fishing, on the first and third days of the studies. Cod in two further cages (C and D) with stocking densities 11.86 and 9.08 $kg\,m^{-3}$ respectively were designated for grading and crowding in a sweep net prior to harvesting on the second and fourth day of the studies, so that sampling days alternated between control and crowded cages. In the crowded cages, a group of 'control' cod were sampled before sweeping was commenced.

The oxygen content of the water in each cage and water temperature was monitored. For crowded cages, the readings were taken within the crowd. Temperature readings varied between 9.6 and12 °C and oxygen varied between 8.3 and 10.2 $mg\,l^{-1}$, but was unaffected by crowding.

2.2. Sampling of cod in non-manipulated cages (A and B)

After a short period of food deprivation (4 days), a common practise prior to harvesting (Ashley, 2007), on-growing cod in commercial cages are readily caught by rod and line (Brown et al., 2008). Cod held in the two non-manipulated cages were caught by rod and line fishing, starting at 10 am on Day 1 and at 9 am on Day 3 of the studies. Fifty-four cod with a mean body mass of 3.22 $\pm$ 0.16 kg were caught during 3 h rod and line fishing of cod in Cage A. In Cage B, 43 cod were caught over a 2 h period; their mean body mass was 2.94 $\pm$ 0.16 kg.

Each cod was killed by percussive stunning within 10–15 s of hooking, and a blood sample was rapidly collected from the caudal vein. Immediately after blood sampling, the gills were severed, according to humane killing protocols. A labelled cable tie was passed through the operculum in order to identify individual fish in later physical assessments. After blood sampling, fish were held in ice slurry until sampling had been completed, and then physical measurements were taken.

Cod reared in sea cages are only rarely visible at the surface, but over the three-hour sampling period, 11 cod (9 in the Cage A and 2 in Cage B) that were present in surface waters, were captured in a hand net.

2.3. Sampling of cod in crowded cages (C and D)

In the two crowded cages (C and D), the mean body mass of sampled cod was 4.98 $\pm$ 0.16 kg ($n = 58$) and 4.42 $\pm$ 0.11 kg ($n = 63$) respectively. Initially, a group of control cod was caught by rod and line, as described for the non-manipulated cages. Four fish were obtained from Cage C and nine were caught in Cage D, within the allocated 20 min period of fishing. Then, the cod in these cages were subjected to grading and crowding, using normal farm practice prior to harvesting. A 10 m × 6 m Flexipanel™ Grading System consisting of