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Spawning Success of Farmed Atlantic Cod (*Gadus morhua*): Effects of Photoperiod on Gonad Development in Sea Cages in Eastern Canada

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Abstract

The use of extended daylength to suppress sexual maturation of Atlantic salmon (*Salmo salar*) in sea cages has been successfully adopted by fish farmers. The same methods when applied to Atlantic cod (*Gadus morhua*) however, have been disappointing as gonadal development of cod in sea cages exposed to extended daylength is seasonally delayed but not arrested. Results of a set of photoperiod trials using 20 h and 24 h light in sea cages indicated that between 87-100% of fish achieved sexual maturation. The use of lights did however delay sexual maturation such that females were gravid for several months through summer. Grower diets currently used in Atlantic Canada have led to enlarged livers and this may also have played a role in disrupting normal gonadal development and affected gamete quality. Hepatosomatic indices were also well above those of wild cod. In Canada, the fate of drifting eggs from sea cages has not been evaluated. We discuss some of the biological and environmental conditions in the Bay of Fundy near cod cage sites and make inferences about the potential survivorship of embryo “escapes’. The extent of Atlantic cod farming in Canada is in a preliminary phase with limited concentration in the Bay of Fundy and coastal Newfoundland with no escaped juvenile or adult cod reported to date.

Introduction

Atlantic cod (*Gadus morhua*) mariculture is associated with a high incidence of sexual maturation (Taranger et al. 2006; Trippel et al. 2008). Unlike Atlantic salmon (*Salmo salar*), farmed cod are capable of undergoing breeding behaviour in sea cages and generating viable embryos that 'escape' into the surrounding environment (Bekkevold et al. 2002). The fate of these embryos is largely unknown, though a field study in Norway provided supporting evidence of the existence of escaped cod embryos that developed into larvae (Jørstad et al. 2008). Cod farmers' concern over early maturity stems from reduced production. During spawning and afterwards, fillets become 'jellied' (high water content) and are reduced in market value (Fordham and Trippel 1999). Spawning activity may also lead to elevated mortality, particularly among females that become egg bound. Consequently, considerable attention has been given to inhibit the process of sexual maturation in gadoid mariculture. Salmon farmers have routinely deployed exposure to continuous light to impede sexual maturation. Despite fairly widespread success in controlling gonadal development in Atlantic salmon (Taranger et al. 1995; Harmon et al. 2003), the utility of continuous light to stop early maturation for Atlantic cod has proven to be unsuccessful to date (Taranger et al. 2006; Trippel et al. 2008).

The objectives of this contribution were to undertake previously untested field trials with greater light intensity to (i) evaluate the potential for natural daylength, 20 h, and 24 h light treatments to impede sexual maturation of Atlantic cod, (ii) discuss the probability that farmed cod will spawn successfully, and (iii) outline the potential factors governing offspring survivorship, particularly in coastal areas of the Bay of Fundy where a significant portion of experimental cod farming in Canada has occurred.

Methods

Atlantic cod used were produced in 2006 by GreatBay Aquaculture, Portsmouth, New Hampshire, and stocked as 0+ group into natural photoperiod conditions in nursery cages at Back Bay, New Brunswick (latitude 45^{o} N, 67^{o} W, longitude) (Fig. 1). In October 2007, they were transferred a few 100 m away to nearby (Fundy site) to one of three 20 m x 20 m square cages under (i) natural photoperiod, (ii) 20 h light (lights out from 0000-0400 h), and (iii) continuous light (24 h). Sea cage net depth was 5 m (side walls) with centre depth extended to 7.5 m. Six 800 W metal halide submerged lights were installed in each of the lit cages (three lights were at a depth of 2 m and three lights at 4 m, placed in two 7m sided triangles, one offset from the other). Electricity was supplied by a large-scale gas powered generator on a nearby barge. Lights were manufactured by Aquastar aquaculture machine systems, submersible photoperiod lighting 800 W 220V-50HZ bulb type: halogen metal with Ignitor 11cm diameter 100cm length, bulb life: 12,000 h, colour yield- 90 CRI colour temperature: 6500 degrees K glass type: boro silicato e. 5m m. Cod were sampled from each cage at irregular intervals from October 30, 2007 to August 2009, thus spanning two anticipated spring spawning periods. Body weight, liver weight, gonad weight, and gonadal stage of maturation were recorded on each sacrificed individual (Tomkiewicz et al. 2002). Gonadal stages were grouped as follows: Ripening (III Ripening 1 oocyte recruitment; IV Ripening 2 late vitellogenesis), Spawning (V

Spawning 1 initiation of spawning; VI Spawning 2 main spawning period; VII spawning 3 cessation of spawning), and Spent/Resting (VIII regeneration 1 spent, IX regeneration 2). Sample sizes per gender and date ranged from 3-15 individuals per cage. Published data were used to address the issues related to objectives (ii) and (iii) and are acknowledged accordingly.

Results

Female Atlantic cod under natural photoperiod exhibited an incidence of sexual maturity of 91% (Table 1). Those exposed to 20 h and 24 h light exhibited an incidence of sexual maturity of 87 and 100%, respectively. Male Atlantic cod under natural photoperiod exhibited an incidence of sexual maturity of 90% (Table 1). Those exposed to 20 h and 24 h light exhibited an incidence of sexual maturity of 96 and 98%, respectively.

Under natural light conditions, mature female cod were in spawning stages from January-April and December-April in 2008 and 2009, respectively (Fig. 2). Male spawning stages coincided with females, with a slightly extended spawning season.

In the 20h light treatment, females were in spawning stages from January 15-April 22, 2008 (Figs. 2 and 3), however, on two sampling days mid April, there were no females spawning. Females were also in spawning stages on the sampling date in July, as well as in December 2008. The presence of females in spawning stages in July may be an indication of delayed spawning as a result of the extend light exposure.
In April and August 2009, there were no spawning females, however there were ripening females in April, and fish that were spent/resting in both months, suggesting that the actual spawning events for 2009 may have simply been missed by sampling dates. Males exposed to 20 h light were in spawning stages from January-April 2008 (Figs. 2 and 3), and also in July 2008. Some male fish sampled in December 2008 were found to be in spawning stages, and also in August 2009, however the April 2009 sampling only had ripening male cod.

In the 24 h light treatment, spawning stages occurred in January and April 2008 for both males and females, and also in July for the males. The following spawning season showed males and females in spawning stages starting in December 2008, and through to August 2009 for males, but only as late as April for females. The three cages were not sampled between April and August, so it is possible the spawning stages occurred within that time span but were not recorded because of the lack of sampling.

Gonadosomatic index of adult female and male Atlantic cod under the three lighting regimes are provided in Figure 4.

Discussion

Administration of 20 h and 24 h light exposure did not eliminate the incidence of sexual maturation in Atlantic cod in sea cages in the Bay of Fundy, despite the use of six 800 W

lights per lit cage. Cod exposed to natural photoperiod typically spawned during their normal winter/spring spawning period. Those under extended light exhibited an irregular spawning period with fish releasing mature gametes in winter, spring and summer. Examination of liver weights and hepatosomatic indices of wild and farmed cod indicated enlarged livers of the latter. The unusually high liver weights of cultured cod are presumably associated with the dry formulated feed which has a high energy content and fat level. Lower quality milt is produced by Norwegian farmed cod compared to wild-caught cod (Skjæraasen et al. 2009) and this difference is even more pronounced for similar studies completed in the Bay of Fundy (I. Butts, unpublished data). Egg quality of farmed cod in the Bay of Fundy has not been rigorously studied. However, in the Atlantic Cod Genomics and Broodstock Development Project (www.codgene.ca) the ability to achieve high fertilization rates by stripping F_1 generation females and using sperm of F_1 males is significantly lower when compared to stripping those recently collected from the wild (A. Garber, S. Fordham and E. Trippel, unpublished data). Consequently, the viability of released gametes and chances that successful fertilization is achieved in sea cage cod is very likely reduced compared to similar size, wild cod in natural spawning aggregations. In sea pens, it is very common to have full and half siblings present which gives rise for the potential of inbreeding. Non-avoidance of kin during communal mating has been recently shown for the closely related haddock (*Melanogrammus aeglefinus*) (Trippel et al. 2009). This behaviour of spawning among kin could lead to reduced hatching success, increased deformities and mortalities of offspring. Some females do not undergo normal ovulatory processes with the result that they become 'egg bound' and often die during or within several months post spawning period (E. Trippel and F. Powell, unpublished data). Thus, although 40,000 adult cod may exist in a sea cage, successful gametogenesis, spawning, fertilization and hatching success are quite likely much lower of a similar number of cod in the wild.

Monthly water temperatures at the Fundy cage site and The Wolves are given in Figure 5. Temperatures at the cage site descended from 4 to 0^{o}C from January to April and then rose rapidly in May to reach 12 ^{o}C for much of the summer and early autumn. Water temperatures at The Wolves, further into the Bay of Fundy, followed a similar trend, reaching a slightly higher temperature of nearly 14^{o}C in September. Rearing of eggs at the St. Andrews Biological Station of cod of wild origin at temperatures of 2, 4. 6, 8, and 10 ^{o}C showed reduced hatching success at 10^{o}C (broodstock held at 6^{o}C) (F. Dahlke, S. Politis, M. Peck and E. Trippel, unpublished data). Therefore, fertilized eggs drifting from sea cages in the winter/spring would exhibit higher early survivorship than those released in July. It is not known if the ripe and running females collected in the summer were actually participating in spawning as no dedicated effort was made to conduct plankton tows for eggs near the cages and examine for fertilization success.

Many female and male cod may simply undergo gonadal resorption and not release gametes. For any embryos that do survive from summer spawnings there appears to be a high abundance of a preferred prey item, copepods (Fig. 6). Copepod abundance is higher in summer than April and May. With the high tidal flows in the region (Chang et al. 2007) it is likely that pelagic embryos will drift into the Bay of Fundy from any

spawning event in sea cages and their survivorship will be a function of embryo quality, larval fitness and environmental conditions (temperature, prey, and circulation patterns).

Application of additional light intensity to manipulate sexual maturation and to explore the use of 20 h over 24 h light have not been as promising as hoped for Atlantic cod. A very high percentage of cod mature in sea cages and many are shown to be in a spawning state at various times of the year. It is unlikely that the modest effort of cod culture in eastern Canada to date has augmented recruitment to nearby wild stocks. The extent that this may have occurred is related to the points raised above as well as the current status of neighbouring cod stocks. Coastal stocks that are highly depleted would increase at a disproportionately higher rate than healthy stocks and would be more prone to genetic introgression. It is recommended that tissue samples for genetic analyses be collected of current wild stocks in the vicinity of cod cages to facilitate the appraisal of any potential escaped cod (embryos, juveniles or adults) (Bekkevold et al. 2006). To date, no escaped cod have been reported in eastern Canada through net destruction or other means.

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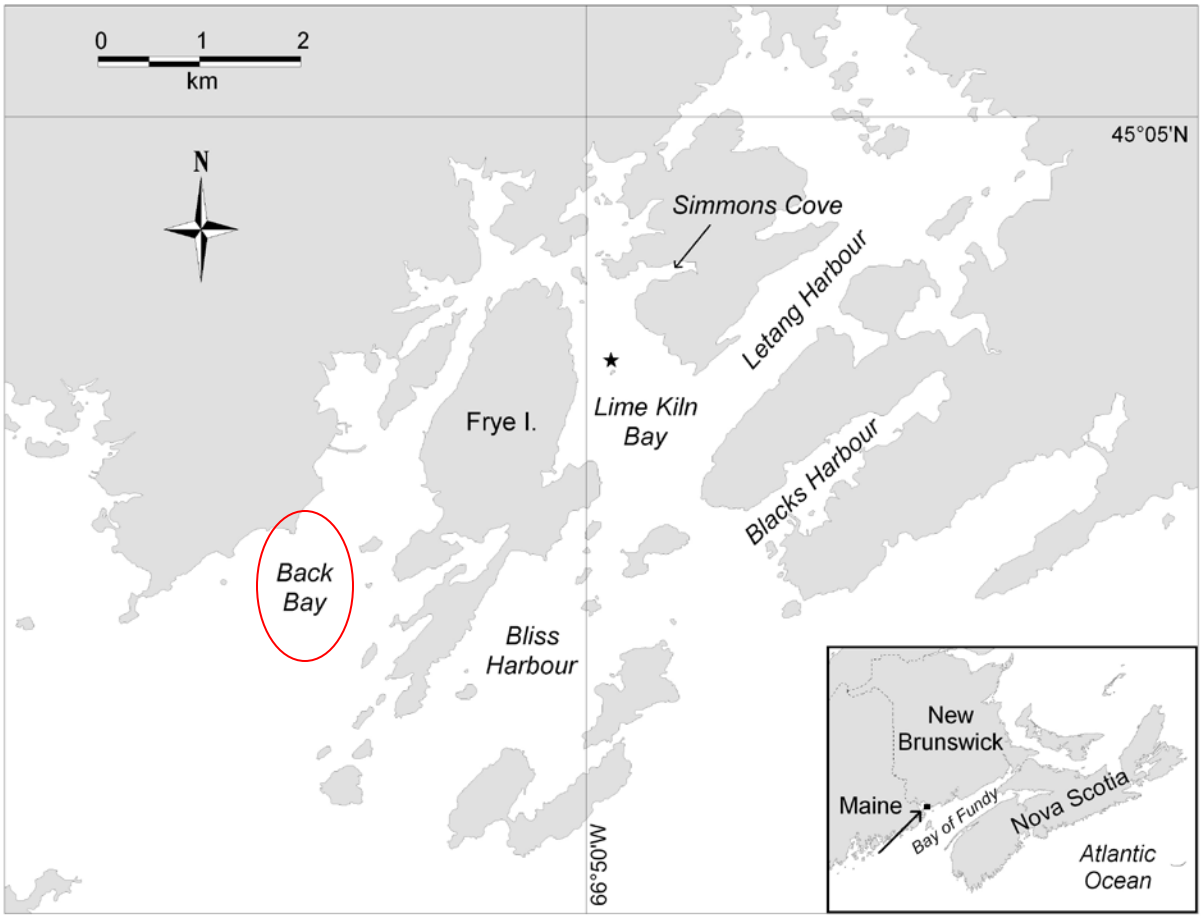

Figure 1. Cod sea cages located in Back Bay, New Brunswick, Canada (Source: J. Martin, St. Andrews Biological Station).

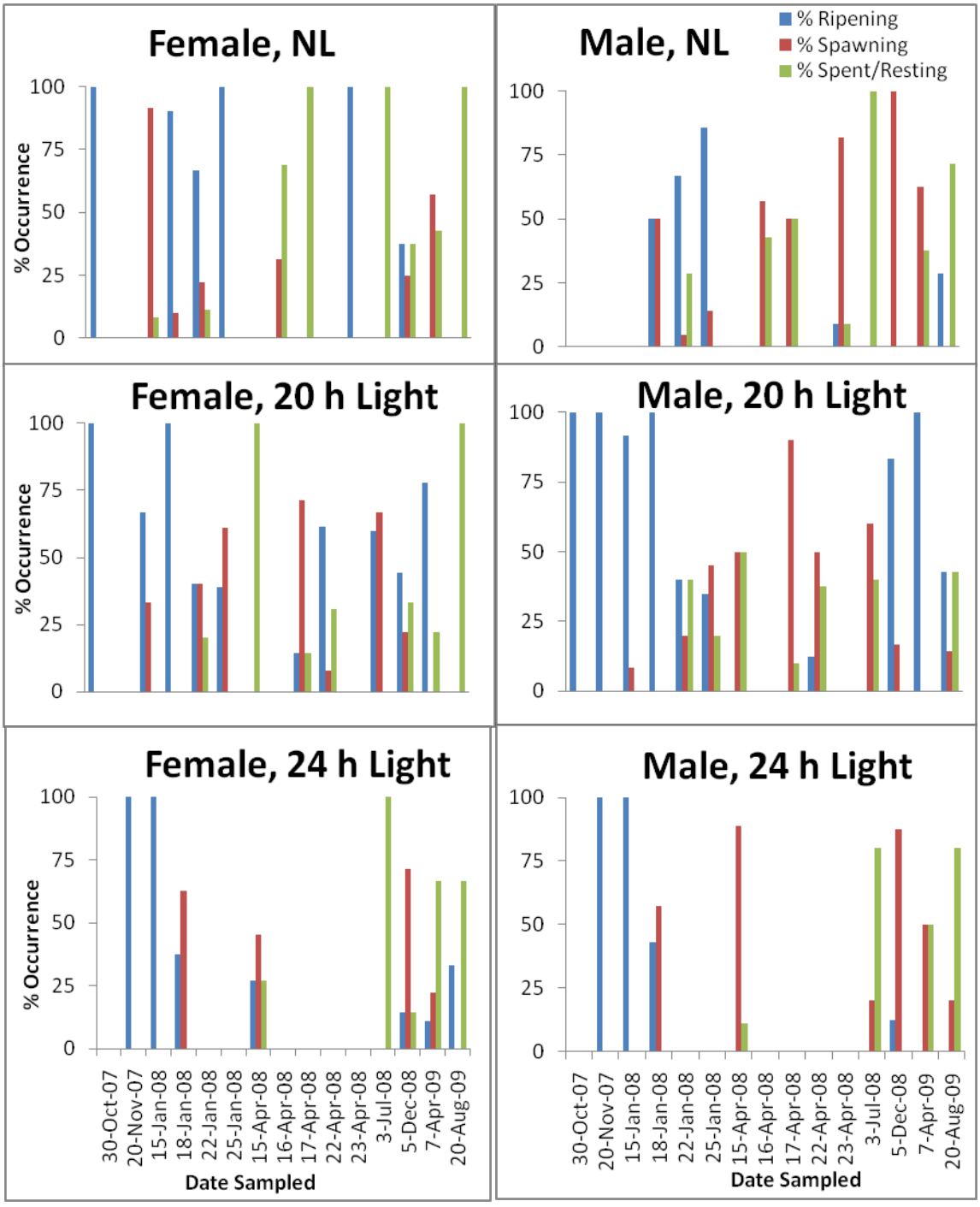

Figure 2. Percent occurrence of three maturation stages (ripening, spawning, and spent/resting) in mature female and male Atlantic cod in each of the three light regimes (natural light- NL, 20 h light, 24 h light) in Back Bay, NB. NL female n=160, NL male n=165, 20h female n=98, 20h male n=117, 24h female n=221, 24h male n=150.

Figure 3. Photographs of ovaries and testes of Atlantic cod collected from the cage exposed to 20 h light (January 2008).

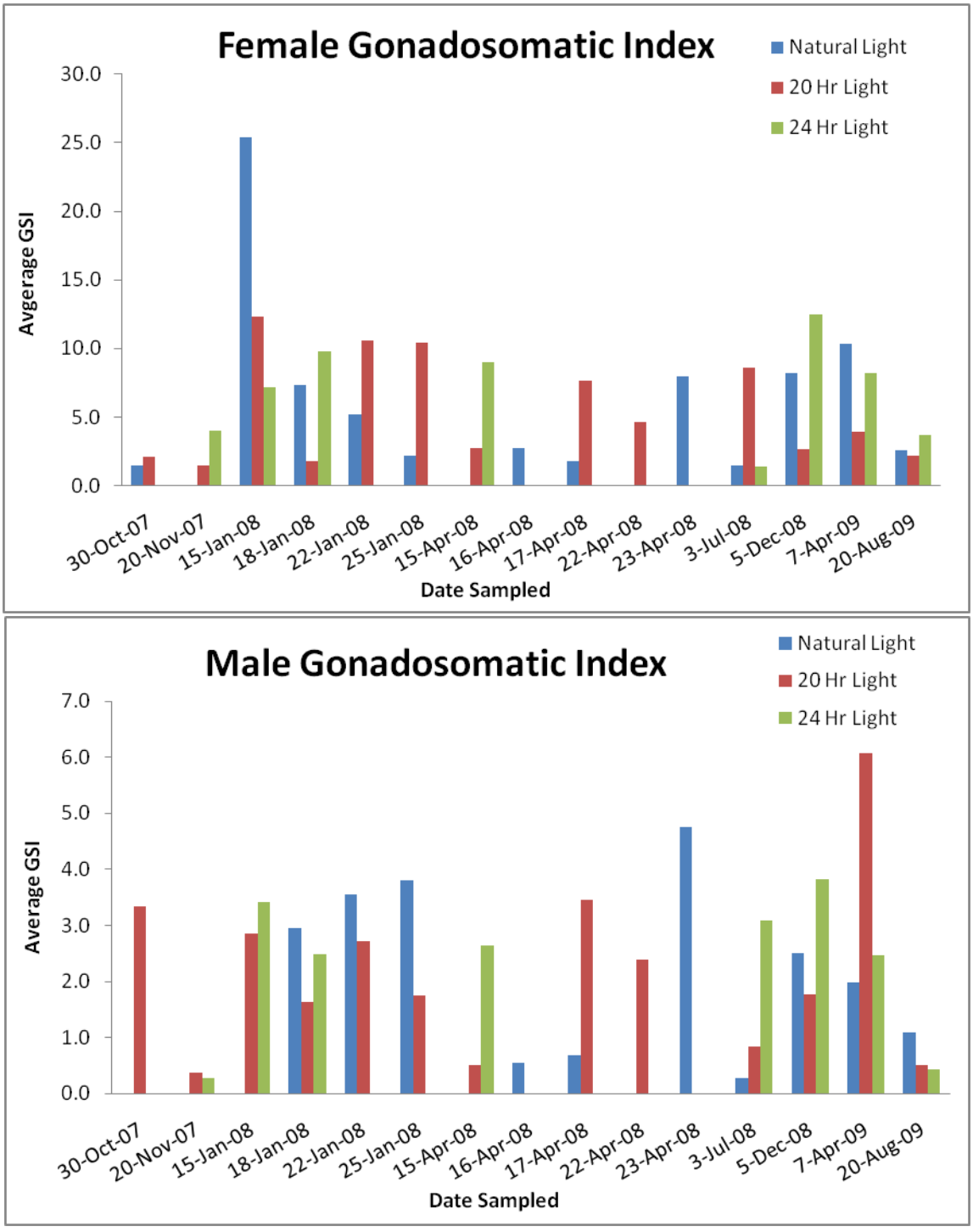

Figure 4. Gonadosomatic index of female and male Atlantic cod exposed to natural light, 20 h and 24 h light in sea cages at Fundy site, Back Bay, New Brunswick in 2007 to 2009. Sample sizes per gender and date ranged from 3-15 individuals per cage.

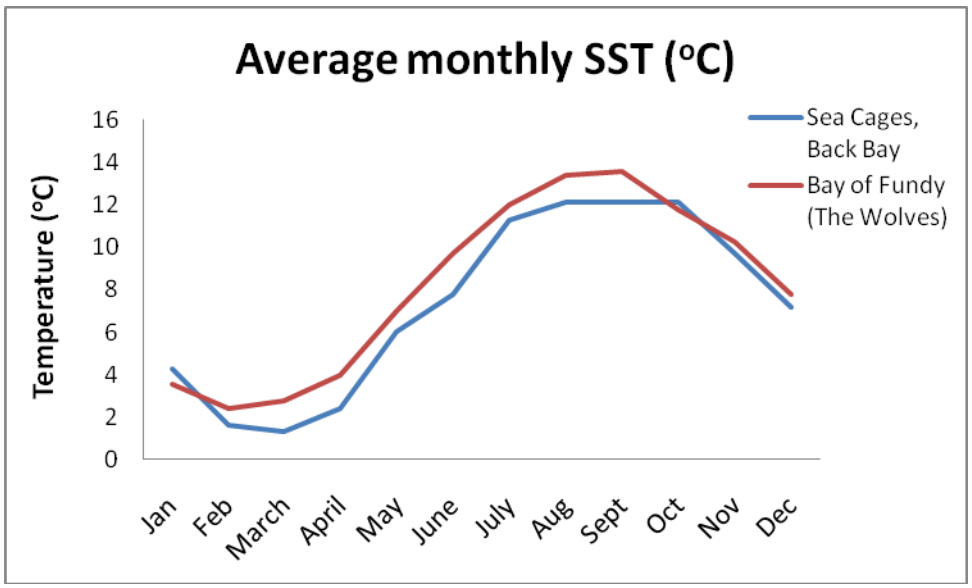

Figure 5. Mean monthly surface water temperature at the Fundy cage site, Back Bay, New Brunswick, and at the Wolves, Bay of Fundy (Source: L. Dickinson, Cooke Aquaculture, Inc., Martin et al. 2006).

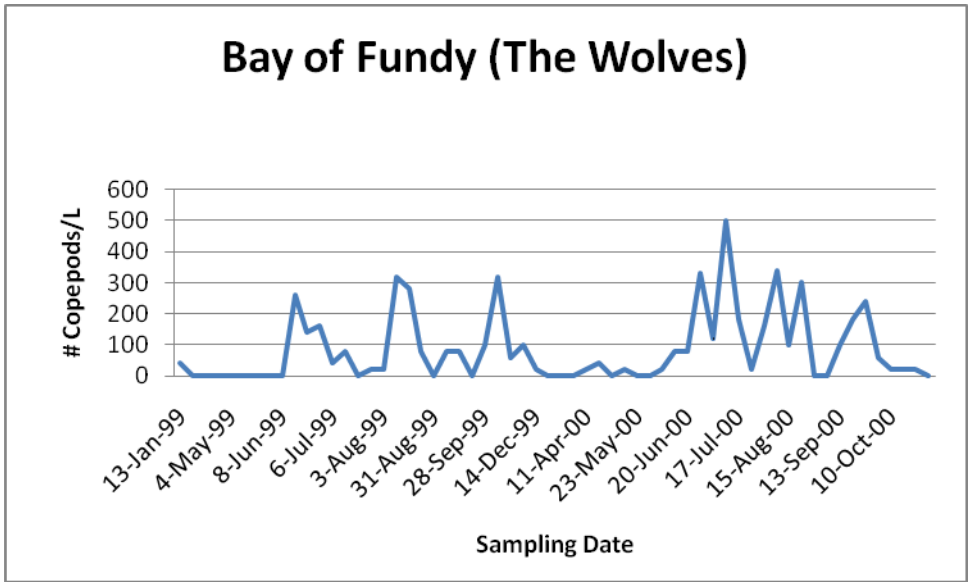

Figure 6. Number of copepods per litre in plankton samples within 10 km of the Fundy site, Back Bay, New Brunswick. Plankton samples were collected in the western Fundy Isles region of the Bay of Fundy, 1999-2000 (Martin et al. 2006).

Table 1. Percent occurrence of immature and mature Atlantic cod exposed to different lighting regimes.

		Female	Male
Natural	Immature	9	10
	Mature	92	89
	Total	101	99
	% Mature	91.1	89.9
20 h	Immature	15	5
	Mature	101	115
	Total	116	120
	% Mature	87.1	95.8
24 h	Immature	0	1
	Mature	58	56
	Total	58	57
	% Mature	100	98.3

Table 2. Mean liver weight, body weight and hepatosomatic index of wild female cod (Georges Bank origin) and farmed male and female cod collected from the light trials (all treatments pooled). Data for Georges Bank were collected of mature pre-spawning females during spring (March) DFO surveys of 2006, 2007 and 2008 (Fernández et al. 2009). Data from light trials represent those collected during the January-April period of mature ripening males and females.

		2006	2007	2008	2009
Wild, Female (n=47)	Liver weight (g)	143.88	101.05	70.44	-
	Body weight (g)	3861.41	2493.48	1802.22	-
	HSI	**3.36**	**3.47**	**3.26**	**-**
Farmed, Female (n=72)	Liver weight (g)	-	-	71.69	104.74
	Body weight (g)	-	-	914.60	1620.55
	HSI	**-**	**-**	**7.74**	**6.63**
Farmed, Male (n=71)	Liver weight (g)	-	-	46.48	138.33
	Body weight (g)	-	-	756.29	2163.50
	HSI	**-**	**-**	**5.96**	**5.93**