Available online at www.sciencedirect.com
ScienceDirect
Aquaculture 261 (2006) 993–1002
Aquaculture
www.elsevier.com/locate/aqua-online

The influence of water temperature on spawning patterns and egg quality in the Atlantic halibut (*Hippoglossus hippoglossus* L.)

N.P. Brown [a,*], R.J. Shields [b], N.R. Bromage [a]

[a] *Center for Cooperative Aquaculture Research, 33 Salmon Farm Road, Franklin, Maine, 04634, USA*
[b] *Aquaculture Wales, University of Wales Swansea, Singleton Park, Swansea, SA2 8PP, UK*

Received 31 January 2005; received in revised form 7 August 2006; accepted 10 August 2006

Abstract

A three-year study was conducted to investigate the effects of water temperature on Atlantic halibut broodstock reproductive performance. Two groups of fish held under ambient photoperiod were established onto contrasting temperature regimes. The 'chilled' group were held at below 9 °C from late October and at approximately 6 °C from December until the end of the spawning period whilst the 'ambient' group received no temperature control. The temperature profiles for the 'ambient' group changed over the 3 years but were generally characterised by warmer conditions prior to spawning and an earlier temperature rise in the spring. Total egg production was higher in the 'chilled' group each year. Absolute fecundity was significantly reduced in the 'ambient' group compared to the 'chilled' group every year of the study (0.6 million eggs/female for 'chilled' group vs. 0.3 to 0.4 million eggs/female for 'ambient' group) and egg viability, in terms of fertilisation and hatch rate, was significantly impaired in the 'ambient' group in years 2 and 3 (mean fertilisation rate in the 'ambient' group was between 27.0% and 54.8%; vs. 63.4% to 77.4% in the 'chilled' group, mean hatch rate in the 'ambient' group was between 3.1% and 25.6% vs. 60.7% to 71.7% in the 'chilled' group). Eggs spawned at high temperatures, later in the season were generally of low viability. In the 'ambient' group the spawning season became progressively delayed during the study and average duration of spawning season over 3 years was shorter (between 23.5 to 26.3 days for the 'ambient' group vs. between 30.5 and 41.2 days for 'chilled' group). It is hypothesised that high temperature during the vitellogenesis period caused a delay in spawning and a reduction in quantity and quality of eggs and that this effect was exacerbated by high temperature during spawning.

Keywords: Atlantic halibut; Broodstock management; Spawning; Temperature; Egg quality

1. Introduction

Captive Atlantic halibut broodstock populations were first established in Scotland and Norway in the early 1980s (Blaxter et al., 1983; Rabben et al., 1986; Smith, 1987). The Atlantic halibut is a batch spawner, producing several batches of eggs in relatively regular intervals of 3–4 days (Smith, 1987; Haug, 1990; Holmefjord and Lein, 1990; Norberg and Kjesbu, 1991; Bromage et al., 2000). Under normal environmental conditions, gonadal growth in the Atlantic halibut starts in early autumn (Haug and Gulliksen, 1988) and spawning occurs between December and April under natural photoperiod (Kjorsvik et al., 1987; Haug, 1990).

* Corresponding author. Tel.: +1 207 422 9096; fax: +1 207 422 8920.
E-mail address: npbrown@maine.edu (N.P. Brown).

0044-8486/$ - see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.aquaculture.2006.08.025

In the wild, the Atlantic halibut spawns in deep water where the ambient temperature is stable and typically between 5 and 7 °C (Kjorsvik et al., 1987; Haug, 1990). Since Atlantic halibut hatcheries are located on land, water supplies are usually derived from surface waters which are generally subject to larger annual fluctuations in temperature. Atlantic halibut reared in Scotland are at the southerly extreme of their E. Atlantic distribution and ambient thermal profiles differ from those experienced by wild stocks.

It is well known that photoperiod is strongly associated with the reproductive cycles of most temperate teleosts (Lam, 1983; Bye, 1984). Manipulation of photoperiod is routinely used to influence natural spawning cycles enabling the production of out-of-season eggs. These techniques are well documented and extensively used for salmonids (Bromage et al., 1993) but have also been applied successfully to marine fish, for example, sea bass *Dicentrarchus labrax* (Carrillo et al., 1989, 1995), Atlantic cod *Gadus morhua* (Norberg and Kjesbu, 1991), turbot *Scophthalmus maximus* (Devauchelle et al., 1988; Stoss and Røer, 1993), Dover sole *Solea solea* (Baynes et al., 1993) and Atlantic halibut (Smith et al., 1991; Holmefjord et al., 1993; Naess et al., 1996).

Water temperature can also exert a strong influence on spawning rhythm and although its influence is thought to be secondary to photoperiod for most temperate species (Bye, 1984; Bromage et al., 1993) there may be an important interaction between the two (Devauchelle et al., 1988). In many studies on photoperiod, the effects of temperature have often not been considered (see reviews by Lam, 1983; Bye, 1984) and where photoperiod regimes are overlaid on normal temperature cycles, the synchronising effects of the latter may be masked (Scott et al., 1984).

Apart from the role of temperature in synchronising gonadal activity, direct effects on gamete quantity and quality have been reported in both captive and wild broodstocks. Examples include marine fish such as Dover sole (Baynes et al., 1993), Senegal sole, *Solea senegalensis,* (Anguis and Canavate, 2005), turbot (Devauchelle et al., 1988), sea bass (Carrillo et al., 1995) and wolffish *Anarhicus lupus* (Tveiten and Johnsen, 1999). Temperature is also known to play a role in the rate of ripening of eggs following ovulation (Billard and Gillet, 1981).

The capital and running costs of controlling water temperature at the throughputs required for broodstock facilities are considerable. The aim of this work was to assess the effects of water temperature on broodstock performance and subsequent quality of gametes to determine whether this is a necessary feature of Atlantic halibut broodstock management.

2. Materials and methods

2.1. Experimental design

This study was conducted at the Marine Farming Unit of Seafish Industry Authority located in Ardtoe, Argyll, Scotland (Lat. 56°46’N, Long. 5°52’W). The broodstock used for this study were wild fish originally caught off Iceland. They began spawning in captivity at Ardtoe within 3 years. Four years after capture the fish were divided uniformly according to weight of females (mean ~ 12 kg), into 2 groups. The groups each consisted of 14 fish, held in 3 vitreous enamelled steel circular tanks (1 of 5.3 m diameter and 2 of 4.6 m diameter) in a water depth of 1.2 m. The sex ratio in all tanks was 1:1 and 6 fish were held in each of the larger tanks and 4 fish were held in each of the smaller tanks. The seven females in the ‘ambient’ group were given codes A1–A7 and those in the ‘chilled’ group were given codes C1–C7.

All tanks received 25 l/min (flow to waste) sea water maintained automatically above a minimum salinity of 33 ppt. The tanks were illuminated by diffuse natural light and thus were under ambient photoperiod. The sea water supplied to the first group, (‘ambient’ group) was at ambient temperature all year. For the second group (‘chilled’ group), the sea water temperature was controlled using a chiller to maintain the temperature below 9 °C from late October and to hold a maximum temperature of approximately 6 °C prior to and during spawning (from December until June). Summer extreme high temperatures were also controlled with chilling.

The fish were fed 3 times per week to appetite on a moist ‘sausage’ diet, the formulation of which is given in Table 1.

Table 1
Formulation of feed given to broodstock halibut during study

Ingredient	Quantity	Supplier
Dry components		
Norse LT 94 fishmeal	5 kg	Trouw Aquaculture, Northwich, U.K.
Vitamin mix	200 g	Trouw Aquaculture, Northwich, U.K.
Vitamin booster	100 g	Trouw Aquaculture, Northwich, U.K.
Binder (Guar gum Emulcol “U”)	100 g	Trouw Aquaculture, Northwich, U.K.
Wet components		
Herring	6 kg	Local supplier
Squid	3 kg	Local supplier
Cod roe	3 kg	Local supplier
Oil (30% PUFA fish oil)	300 g	Isaac Spencer and Co Ltd, Fleetwood, U.K.