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The effect of continuous light and compressed photoperiods on growth and maturation in lumpfish *Cyclopterus lumpus*

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A R T I C L E I N F O

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A B S T R A C T

From an aquaculture point of view, control of the sexual maturation cycle is critical for a sustainable production of the species. For year-round reliable production of juvenile lumpfish of the appropriate size for stocking salmon cages, there is a need for basic and applied knowledge on the control of sexual maturation in cultured lumpfish broodstock. Lumpfish (initial size 219 g and 16.9 cm) were reared under advanced simulated natural photoperiod (SLDN, control group) for Tromsø (70°N). In addition there were two groups exposed to continuous light from April 2014 to January 2015 (PP3) and from April 2014 to April 2015 (PP6) followed by 8 week decline in hours of light from 24 to 4 h (autumn signal) and subsequent 8 week rise from 4 to 24 h (spring signal). Exposure of lumpfish to continuous light followed by an autumn-spring signal stimulated somatic growth and affected age at first maturity in females. The growth enhancing effect of continuous light lasting for approximately six months in females compared to one month in the males. Spawning colouration and running milt was seen in males in all three photoperiod groups from September 2014 onwards indicating that maturation started prior to the experimental treatment. In the females spawning time, egg volume and hatching success varied between the photoperiod groups. No spawning occurred in the SLND group, whereas spawning was seen in both PP female groups 3–6 months after the onset of short autumn-short spring photoperiodic signal. Hatching success was higher in the PP3 group (83.4%) compared to the PP6 group (72.3%). The current findings are the first step in the development of photoperiod regimes which may provide simple and effective off-season maturation in lumpfish.

1. Introduction

Lumpfish (or lumpsucker) *Cyclopterus lumpus* L. 1758 is widely distributed across a large area on both sides of the North Atlantic Ocean: from Nunavut, Hudson Bay and Labrador to New Jersey and Bermuda in the Western Atlantic, to the Barents Sea, Iceland and Greenland and the Iberian Peninsula in the Eastern side (Vasconcelos et al., 2004; Bañón et al., 2008; Pampoulie et al., 2014). Female lumpfish are targeted by spring coastal fisheries where their roe is harvested and used as caviar substitute (Kasper et al., 2014). Spawning of lumpfish often takes place in shallow sub-tidal waters when temperatures reach around 4 °C (Collins, 1976; Daborn and Gregory, 1983). Natural spawning in lumpfish occurs in spring and early summer (April–July, Davenport, 1985; Mitamura et al., 2012; Kennedy et al., 2015).

Recently the lumpfish has been suggested as a cold-water cleaner fish for removal of sea lice from Atlantic salmon, *Salmo salar*. Initial results are very promising with up to 93–97% less sea lice infection (adult female lice) in sea pens with lumpfish (Imsland et al., 2014a, 2014b, 2014c, 2015a, 2015b). Interest in use of hatchery reared

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lumpfish has increased rapidly concurrent with the species use as biological delouser on Atlantic salmon. There is; therefore, a need for year-round production of lumpfish juveniles. To reach that goal, out-of-season production of eggs is needed. Year-round production of eggs and juvenile will be important for optimal utilization of production facilities. In addition, there will be demand for lumpfish for sea lice control throughout much of the year due to the difference in the natural sea lice occurrence, as well as to match different sea transfer times of the smolts. Development of methods for the management of sexual maturation and spawning is; therefore, necessary.

Photoperiod control of the reproductive process has been successfully applied to broodstock to alter the phase of the annual sexual cycles and hence the spawning time in a range of fish species (e.g. Taranger et al., 2010). Several studies have addressed the effect of photoperiod on growth and maturation in marine species, whereas no published literature exists on the use of photoperiod to control maturation in lumpfish. The process of puberty can be considered as a particular (the first) case of the cyclic reproductive events in the lifespan of the fish. Consequently, it is expected that environmental manipulation altering spawning time in adults may also be effective in altering the onset of puberty in juvenile fish. A range of studies demonstrate that photoperiod manipulation can be an effective tool to delay or advance puberty in farmed fish, e.g. Atlantic salmon (Oppedal et al., 2006), Arctic charr, *Salvelinus alpinus* (Gunnarsson et al., 2012), Atlantic cod, *Gadus morhua* (Imsland et al., 2013a), Atlantic halibut, *Hippoglossus hippoglossus* (Norberg et al., 2001; Imsland et al., 2009), turbot, *Scophthalmus maximus* (Imsland et al., 2003, 2013b; Imsland and Jonassen, 2003), Senegalensis sole, *Solea senegalensis* (Garcia-Lopez et al., 2006), However, the effectiveness of photoperiod protocols differs among species and appears also to be modulated by other factors such as age, feeding, body size, adiposity and the stage of maturation of the fish (Taranger et al., 1999, 2010; Oppedal et al., 2006; Taylor et al., 2008).

As no published literature on photoperiod manipulation and maturation control in lumpfish exist, findings from other marine species from the Northeast Atlantic will serve as an initial model. Continuous light treatment has been found to arrest or delay pubertal development when applied to Atlantic cod in indoor tanks from around mid-summer and onwards (Hansen et al., 2001; Davie et al., 2003, 2007; Karlsen et al., 2006). Further, Imsland et al. (2013a) exposed groups of juvenile cod in open sea pens to continuous light from September to January and from November to May and delayed maturation in cod reared in open sea pens for 6–12 months. A similar delay of maturation by applying continuous light one year before first maturity has been found in Atlantic halibut (Imsland et al., 2009).

Due to interest of using lumpfish as biological delouser for Atlantic salmon recent studies have investigated the growth of the species under varying environmental conditions. Nytrø et al. (2014) investigated growth in juvenile lumpfish attemperatures from 4 °C to 16 °C and found that optimum temperatures for growthdecreased rapidly with increasing fish size from 15.7 °C for 11 – 20 g fish to 8.9 °C for 120 – 200 g fish. The data also indicate a very high growth potential for juvenile lumpfish reared at near optimum temperature for growth as juveniles can ten fold their mean weight in only 76 days. However, at present no published studies exist on the effect of continuous light or other light regimes on growth in lumpfish. In other marine species, there are indications that exposure to continuous light during the juvenile stage may significantly affect subsequent growth and age at maturity (Imsland and Jonassen 2003, 2005; Imsland et al., 2009, 2013a, 2013b). However, in some cases prolonged exposure to continuous or extended light regimes may reduce growth and food conversion efficiency (e.g. Stefánsson et al., 2002), so the period of extended or continuous light must be synchronized with the internal rhythms of the fish in order to achieve increased growth and/or lower maturity. Studies on Atlantic cod *Gadus morhua* L. have shown that constant light in indoor systems throughout the juvenile stage has a growth-promoting effect and reduces the incidence of maturation in indoor tanks (Hansen et al., 2001). For Atlantic cod in sea pens, exposure to continuous light at different times during the production cycle resulted in enhanced growth and delayed maturation, especially during autumn and winter one year prior to first maturation (Imsland et al., 2013a). Based on findings from other marine species we hypothesize that rearing juvenile lumpfish at continuous light will enhance growth during the late juvenile phase. If maturation is triggered at a certain size threshold as seen in many teleosts (Imsland et al., 1997a) the enhanced growth will alter the age at 1st maturation in lumpfish.

The rationale behind the chosen light regimes in the current trial, was to investigate possible seasonal and size/age related change in sensitivity to photoperiod and the directional effect of photoperiod on growth and maturation. Accordingly, a study was performed where 1 + juvenile lumpfish (initial weight 219 g) were reared under simulated natural photoperiod (LDN, control group) with expected first spawning in spring 2015. In addition, there were two groups exposed to continuous light from April to January (PP3-group) and from April to April the year after (PP6-group).

The objective of this study was to investigate if exposure to continuous light followed by abrupt decline in hours of light from 24 to 4 h (autumn signal) and a subsequent rise from 4 to 24 h (spring signal) can be used to control the spawning season in lumpfish. A second objective was to investigate how continuous light affects the growth properties of lumpfish during the late juvenile phase. Based on the effect of light period on controlling maturity in other species we predict that a short period of continuous light followed by an autumn-spring signal will stimulate somatic growth and maturation in lumpfish thereby reducing age at first maturity.

2. Materials and methods

2.1. Pre-experimental protocol

Sexually mature wild lumpfish (20 females and 5 males) were caught by Akvaplan-niva staff in gill nets in Sandnessundet outside Kraknes, Troms County, Norway during April–May 2013. Eggs from each female were stripped and eggs from two females fertilized with sperm from one male producing 10 half-sib families. The fertilized eggs were incubated at 3.5–5.3 °C at Akvaplan-niva research station at Kraknes (APN-K) and later transferred to 200 l incubators where they hatched between 20–24th June. The juveniles were reared in replicate tanks (230 l) at 10–11 °C and simulated natural photoperiod (LDN) for Tromsø (N 69° 40′), from hatching in June 2013 to tagging and experimental start-up in April 2014. The juveniles were initially fed with Gemma Micro (150–500 µm, Skretting, Norway). After 30 days, the juveniles were fed with 500–800 µm dry feed pellets (Gemma Wean Diamond, Skretting, Norway). After approximately 60 days the juveniles were fed with Gemma Wean diamond 2.0 mm (Skretting AS, Stavanger, Norway) and pellet size increased according to size following the producers recommendation.

2.2. Experimental set-up and rearing conditions

On 30th April 2014 all lumpfish (N = 180) with an average (± SD) weight of 219 g (± 77 g) and length of 16.9 cm (± 0.5 g) (were anaesthetized (benzoak 80 mg l^{-1}) and tagged intraperitoneally with a Trovan® Passive Integrated Transponder and distributed among six 1.6 m^3 tanks at APN-K with 30 fish in each tank. Light in all tanks was supplied using two 18 W fluorescent daylight tubes positioned in the centre of the tank-cover. Photoirradiance at the tank bottom was approximately 15.3 µmol m^{-2} s^{-1}.

Two tanks were reared under simulated natural photoperiod for Tromsø that had been moved three months forward (SLND), in order to advance spawning, prior to start of the experiment in April 2014. Four tanks were reared under continuous light (LD24:0). The daylength in