Science of the Total Environment 543 (2016) 214–222

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Impact of different colours of artificial light at night on melatonin rhythm and gene expression of gonadotropins in European perch

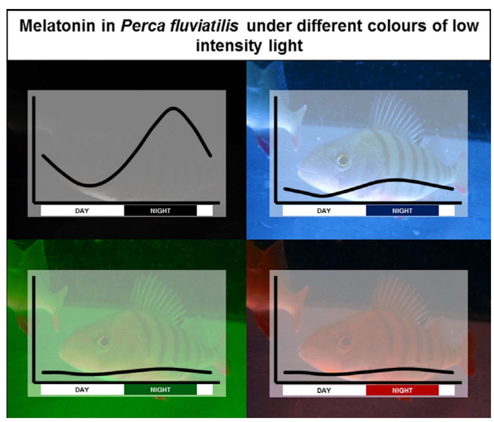
Anika Brüning [a,*], Franz Hölker [a], Steffen Franke [b], Wibke Kleiner [a], Werner Kloas [a]

[a] Leibniz-Institute of Freshwater Ecology and Inland Fisheries, Müggelseedamm 310, 12587, Berlin, Germany
[b] Leibniz Institute for Plasma Science and Technology, Felix-Hausdorff-Str. 2, 17489 Greifswald, Germany

HIGHLIGHTS

- We studied the impact of different wavelengths of artificial light at night on melatonin rhythm
- We examined the effect of different light colours and intensities of white light on gene expression of gonadotropins in perch
- Melatonin rhythm was significantly impaired by blue, green and red light at night, blue light was less suppressive
- Gene expression of gonadotropins was suppressed by white light of 1 lx and higher but not by blue, green and red light

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 1 July 2015
Received in revised form 4 November 2015
Accepted 4 November 2015
Available online xxxx

Editor: D. Barcelo

Keywords:
Perca fluviatilis
Light pollution
Melatonin
Spectral sensitivity
Reproduction
Gonadotropins
Fish

ABSTRACT

The distribution and intensity of artificial light at night, commonly referred to as light pollution, is consequently rising and progressively also ecological implications come to light. Low intensity light is known to suppress nocturnal melatonin production in several fish species.

This study aims to examine the least suppressive light colour for melatonin excreted into the holding water and the influence of different light qualities and quantities in the night on gene expression of gonadotropins in fish. European perch (*Perca fluviatilis*) were exposed to light of different wavelengths during the night (blue, green, and red). Melatonin concentrations were measured from water samples every 3 h during a 24 h period. Gene expression of gonadotropins was measured in perch exposed to different light colours and was additionally examined for perch subjected to different intensities of white light (0 lx, 1 lx, 10 lx, 100 lx) during the night.

All different light colours caused a significant drop of melatonin concentration; however, blue light was least suppressive. Gene expression of gonadotropins was not influenced by nocturnal light of different light colours, but in female perch gonadotropin expression was significantly reduced by white light already at the lowest level (1 lx). We conclude that artificial light with shorter wavelengths at night is less effective in disturbing biological rhythms of perch than longer wavelengths, coinciding with the light situation in freshwater habitats inhabited by perch. Different light colours in the night showed no significant effect on gonadotropin expression, but

* Corresponding author.
E-mail addresses: bruening@igb-berlin.de (A. Brüning), hoelker@igb-berlin.de (F. Hölker), steffen.franke@inp-greifswald.de (S. Franke), wibke.kleiner@igb-berlin.de (W. Kleiner), werner.kloas@igb-berlin.de (W. Kloas).

http://dx.doi.org/10.1016/j.scitotenv.2015.11.023

white light in the night can disturb reproductive traits already at very low light intensities. These findings indicate that light pollution has not only the potential to disturb the melatonin cycle but also the reproductive rhythm and may therefore have implications on whole species communities.

1. Introduction

In December 2013 the UN declared the year 2015 as the international year of light. The initiative focuses on light sciences and its application. But it also raises awareness about 'light pollution'. The distribution and intensity of artificial light at night (ALAN) is consequently rising since the invention of the electric light and progressively also ecological implications come to light (Gaston et al., 2013; Hölker et al., 2010a; Hölker et al., 2010b; Longcore and Rich, 2004; Navara and Nelson, 2007) pointing out the influence of ALAN on flora and fauna and even on whole ecosystems. Historically, research on this topic focused on humans (Griefahn et al., 2006; Kantermann and Roenneberg, 2009) and terrestrial organisms (Davies et al., 2012; Kempenaers et al., 2010; Lewanzik and Voigt, 2014; Nordt and Klenke, 2013; Redlin, 2001; Stone et al., 2009; van Langevelde et al., 2011). The impact of ALAN on aquatic systems has attracted special attention only in recent years (Brüning et al., 2015; Hölker et al., 2015; Meyer and Sullivan, 2013; Perkin et al., 2014b).

The influence of ALAN on fish was studied mainly with regards to aquacultural interests like improvement of growth, decreasing stressful conditions or control of reproductive processes (Biswas et al., 2006; Boeuf and Le Bail, 1999; Davie et al., 2007; Honryo et al., 2013; Kissil et al., 2001). However, the beneficial effects of ALAN in aquaculture might be detrimental for biological rhythms of fish in natural environments, even though ALAN in nature has mostly low light intensities of up to 4 lx (Perkin et al., 2014a; Meyer and Sullivan, 2013).

In contrast to mammals that possess only ocular photoreceptors (Peirson et al., 2009) the circadian rhythm of fish may be controlled by multiple tissues and receptors beside rods and cones. The most important are:

- Deep brain photoreceptors–photoresponsive molecule in the brain that may also respond to photic stimuli (Fernandes et al., 2012; Kojima et al., 2000; Philp et al., 2000)
- The saccus vasculosus may be a sensor for seasonal information and modulates the thyroid system in some fish species (Nakane et al., 2013; Tsuneki, 1992)
- Non-image forming photoreceptors such as melanopsin in the retinal ganglion cells have often peak sensitivity for blue light and horizontal and amacrine cells can possess vertebrate ancient opsin with maximum sensitivity for green. Both may also signal environmental irradiance (Kojima et al., 2000; Peirson et al., 2009; Philp et al., 2000).
- The pineal complex, a part of the brain that is located under a translucent window of the scull, consists of cone-like photoreceptor cells and is therefore light sensitive. I.e. the fish pineal is able to directly transduce light signals into hormonal signals with circulating melatonin as main output (Falcón and Meissl, 1981; Falcón et al., 1992).

However, the circadian control of melatonin production differs in some teleosts (Migaud et al., 2007b). In salmonids it seems to be the pineal alone that controls melatonin production, which is also the case in goldfish, *Carassius auratus* (Kezuka et al., 1992). In this species, melatonin produced by the eyes would not contribute to plasma and CBS (cerebrospinal fluid) melatonin. In contrast, in sea bass (*Dicentrarchus labrax*) and cod (*Gadus morhua*) light perceived by the eyes may regulate melatonin synthesis by the pineal gland through neural projections into the brain (Migaud et al., 2007b). The same study suggested that in Nile tilapia and catfish it is ocular light input alone, that modulates melatonin production, although in Tilapia melatonin production by the pineal gland could be observed ex vivo.

In any case the production of melatonin is suppressed by light, thus melatonin levels are high at night and low during the day. The oscillations and shape of this curve change throughout the year and thereby the melatonin rhythm provides information about day and season. ALAN can impair these rhythms, as reported in several fish species (Bayarri et al., 2002; Brüning et al., 2015; Porter et al., 1999; Vera et al., 2005; Ziv et al., 2007). Most of the studies used higher light intensities as assumed for light polluted freshwater habitats. Perkin et al. (Perkin et al., 2014a) found light levels of up to 1.4 lx in an urban river (River Spree, Berlin, Germany). Intensities of up to 4 lx were found in river Scotio in Columbus, Ohio (Meyer and Sullivan, 2013). In experimental field in Westhavelland, equipped with actual streetlamps, intensities of up to 17 lx where measured in a drainage channel 3 m away from the light sources (Hölker et al., 2015). In the very few studies that investigated the effect of very low ALAN intensities at 1 lx and lower (Bayarri et al., 2002; Brüning et al., 2015; Migaud et al., 2006a; Takemura et al., 2006) a similar impairment of the melatonin rhythm was found.

The photoperiod is one of the most important triggers for the timing of reproduction and consequently reproductive processes are affected by light pollution as well. Reproduction in temperate freshwater fish species is normally initiated by changing the zeitgeber temperature and photoperiod (via melatonin rhythm or other physiological indicators) in the fall. Under natural conditions, the gonadotropins, luteinising hormone (LH) and follicle stimulating hormone (FSH), stimulate gonadogenesis/gametogenesis and thereby the production of sex steroids. Inhibition of melatonin rhythm can implicate a suppression of gonadotropin production. Melatonin is known to be able to alter several components of the hypothalamo–pituitary–gonadal (HPG) axis such as gonadotropins, sex steroids or gonadal maturation (Amano et al., 2000; Bhattacharya et al., 2007; Carnevali et al., 2011; Chattoraj et al., 2005; Khan and Thomas, 1996; Sébert et al., 2008). This is underpinned by numerous studies that used continuous light or altered photoperiods to prevent or delay maturation (Davie et al., 2007; García-López et al., 2006; Porter et al., 1999; Porter et al., 1998; Rodríguez et al., 2005) or to shift spawning incidences (out of season spawning) (Kolkovski and Dabrowski, 1998; Macquarrie et al., 1979; Thrush et al., 1994). However, information about the influence of low intensity ALAN, as it occurs in light polluted aquatic environments on reproductive processes is missing.

When talking about light, the light spectrum is another factor that has to be taken into account. In aqueous environments light propagation differs from terrestrial habitats. In water, each wavelength is attenuated differently. The attenuation also depends on the composition of the water. In general you can say that in sea water short wavelengths are dominant (Clarke, 1956) whereas in most lakes yellow light penetrates the water deepest (Lythgoe, 1988; Wetzel, 2001).

As a result the pineal or other non visual photoreceptors of marine fish have different sensitivities from freshwater fish, resulting from different pigments. Indeed a variety of pigments has been identified so far in fish pineal and other non visual photoreceptors, including rod-like and cone-like opsins, VA- and VAL-opsin (vertebrate ancient and vertebrate ancient long opsin), extra-retinal rod-like opsin and parapinopsin (Bellingham et al., 2003; Blackshaw and Snyder, 1997; Forsell et al., 2001; Kojima et al., 2000; Soni and Foster, 1997). The degree of expression and combination of the pigments in extraretinal photoreceptors seems to be highly species specific and depending on