CHRONOBIOLOGY

Timing requires the right amount and type of light

The quantity of UVA/deep violet light varies seasonally and affects locomotor activity in a marine annelid, providing cues for phenology in addition to those provided by change in photoperiod.

Bettina Meyer, Lukas Hüppe and Laura Payton

The daily 24-hour cycle of light and darkness and the annual 12-month cycle of changing day length, or photoperiod, constitute the two major and highly predictable cycles of the biosphere. Organisms have adapted to these cycles by developing endogenous clocks. Biological clocks are also crucial for inter- and intra-specific interactions, and consequently play a major role in the functionality of ecosystems. The internal circadian clock (derived from the Latin phrase 'about a day') enables organisms to track daily changes in their environment, and is the most studied and best mechanistically understood timing system[1]. Further, by sensing the photoperiod, a circannual ('about a year') clock allows organisms to anticipate and prepare for seasonal changes in their environment. Impressive examples of this periodic timing of biological processes — known as phenology — in animals include the seasonal migration of birds and mass spawning events of corals in the ocean. However, while patterns of animal phenology are often well described, there is an overall lack of understanding of the underlying timing mechanisms, especially in marine organisms, despite some recent advances[2,3]. We do know that light forms the dominant signal in resetting both circadian and circannual clocks. Besides the duration of light exposure (the photoperiod), recent results show that wavelength composition (light quality) has a role in the entrainment of circadian rhythms[4], suggesting it might also provide a cue for seasonal timing.

Writing in *Nature Ecology & Evolution*, Veedin Rajan et al. provide evidence that the spectral composition of light varies between days with the same photoperiod and could provide an additional cue for seasonal timing in terrestrial and marine environments[5]. By analysing long term in-situ measurements of light quality (spectrum) and quantity (intensity) in the Mediterranean Sea, the authors show that in contrast to the photoperiod, spectral light composition does not change symmetrically over the year. These seasonal spectral differences are particularly pronounced for shorter wavelengths, especially in the range of UVA/deep violet light (Fig. 1).

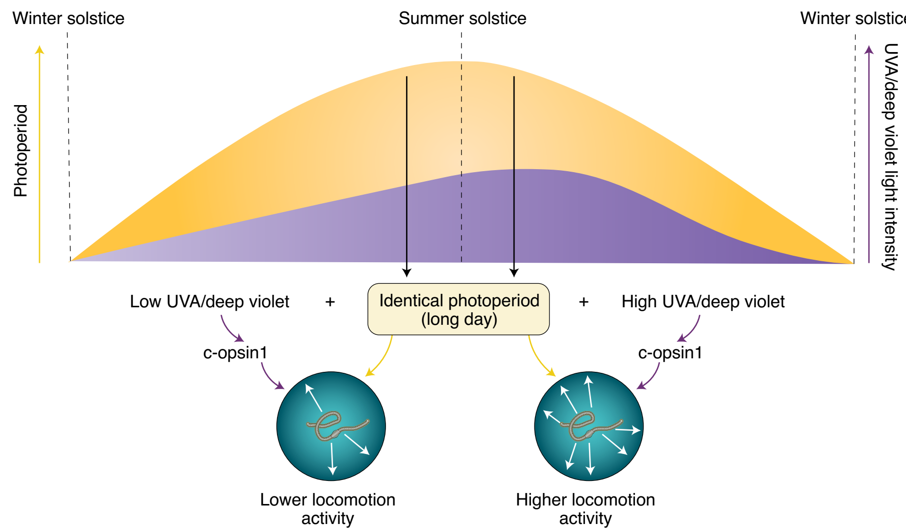

Fig. 1 | The light spectrum could support the fine-tuning of annual timing. Veedin Rajan et al. suggest that UVA/deep violet light provides an additional cue (to the change in photoperiod) for seasonal timing in the marine annelid *P. dumerilii*. They report that in the worm's marine habitat, the photoperiod changes symmetrically over the year but intensity of UVA/deep violet varies asymmetrically, such that days with the same photoperiod at different times of year experience different UVA/deep violet light intensities. The authors show that cultured worms exposed to an identical photoperiod but varying conditions of UVA/deep violet light exhibit different locomotor activity, and that this is mediated by the photoreceptor c-opsin1.

Taking these findings to the laboratory, Veedin Rajan and colleagues investigate a potential effect of UVA/deep violet light on organisms using cultures of the marine annelid *Platynereis dumerilii*. The authors show that the diel locomotor activity (which is also affected by the photoperiod) of these worms kept under long-day conditions changes according to the amount of UVA/deep violet light they are exposed to (Fig. 1). In contrast, worms under short-day conditions do not react to the presence of UVA/deep violet light. These findings suggest that seasonal variations in UVA/deep violet light, and more generally in the light spectrum, could add to the information provided by the photoperiod and thereby support the fine-tuning of annual timing.

The authors then extended our rudimentary existing knowledge of light perception in marine organisms. They confirmed that the non-visual photoreceptor c-opsin1, which has previously been related to depth measurements in *P. dumerilii* larvae[6], responds strongest to UVA/deep violet light in adult worms, and they also characterized its cellular signalling cascade. They then repeated the same locomotor activity experiments using mutant worms that lack this photoreceptor. The locomotor activity of the mutant worms was no longer affected by the presence of UVA/deep violet light, confirming that *P. dumerilii* c-opsin1 can mediate the sensing of differences in these short wavelengths. Additionally, the authors discovered notable changes in the gene expression and protein level of key neurohormones, neurotransmitters and metabolic enzymes in mutant worms.

Strikingly, these changes differed according to the photoperiod the organisms experienced. Together, these data provide evidence that UVA/deep violet light levels can drive the animal's hormonal status and further point towards an interplay between photoperiod and UVA/deep violet light signalling.

As ecosystems are under increasing pressure from anthropogenic activities, the need to understand the mechanisms of seasonal timing is urgent. Rapid changes in temperature caused by global climate change alter the seasonal dynamics of some biotic (for example, primary production) and abiotic (for example, sea ice) environmental cycles. Additionally, there are numerous reports of warming-induced latitudinal shifts in species distribution, exposing organisms to more extreme seasonal light regimes[7,8]. However, the photoperiod, which is the main synchronizer of seasonal timing[2], remains unaffected by global warming. Consequently, mismatches may occur in interactions that have been finely tuned over evolutionary time scales between organisms and their environments[8,9].

Laboratory experiments are well suited to study general mechanistic principles of endogenous timing mechanisms, but organisms and their temporal systems (daily, seasonal and others) have not evolved under such conditions. Therefore, the intersection of laboratory-based chronobiology and field-based marine ecology is essential. This intersection needs to focus on 'ecosystem model organisms' that unify the characteristics of a classical laboratory model organism (such as genetic tractability, clear rhythmicity on diel and seasonal scales) with the ecological importance of key species (such as those playing a fundamental role in marine ecosystems). However, studying marine organisms in their real environment, and understanding how different temporal systems interact with each other and regulate physiology and behaviour, is an extreme logistical challenge. The main obstacle lies in the difficulties associated with planning and operating ship-based research, especially at high latitudes which are most affected by anthropogenic climate change. In addition, to predict shifts in marine organisms and ecosystems due to climate change, endogenous clocks as drivers of life cycle functions need to be incorporated into model approaches. The authors' study is an important first step towards a mechanistic understanding of the underlying molecular timing mechanisms of marine animal phenology. ❐

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References

1. Förster, C. *e-Neuroforum* **1**, 17–22 (2010).
2. Helm, B. et al. *Proc. R. Soc. B* **280**, 20130016 (2013).
3. Lincoln, G. *J. Neuroendocrinol.* **31**, e12694 (2019).
4. Lazopulo, S., Lazopulo, A., Baker, J. D. & Syed, S. *Nature* **574**, 108–111 (2019).
5. Veedin Rajan, V. B. et al. *Nat. Ecol. Evol.* https://doi.org/10.1038/s41559-020-01356-1 (2021).
6. Csaba, V. et al. *eLife* **7**, e36440 (2018).
7. Bradshaw, W. E. & Holzapfel, C. M. *Annu. Rev. Physiol.* **72**, 147–166 (2010).
8. Huffeldt, N. P. *Trends Ecol. Evol.* **35**, 652–655 (2020).
9. Kharouba, H. M. & Wolkovich, E. M. *Nat. Clim. Change* **10**, 406–415 (2020).

Competing interests

The authors declare no competing interests.