HFSP CASE STUDY

HFSP Program Grant

Characterization of light-dependent rhythmic processes in the marine environment

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Project Title	**Characterization of light-dependent rhythmic processes in the marine environment**
Starting Year	2010
Principal Investigator	Kristin Tesmar-Raible
Collaborators	Angela Falciatore, Tomoko Ishikawa, Paola Oliveri
Countries	Austria, Italy, Japan, United Kingdom
Disciplines	Chronobiology, Marine Biology, Molecular Biology, Systems Biology, Biochemistry, Biophysics
Task	Determine the molecular mechanisms by which marine organisms integrate the diverse light signals and periodicities present in the sea using a comparative, interdisciplinary approach across three evolutionarily distant model species
Key output	Identification of L-Cry as a molecular discriminator of moonlight versus sunlight; demonstration of intrinsic circadian regulation in marine primary producers

In addition to the cited documents, interviews with the researchers and HFSP data were used as sources. Furthermore, quantitative analyses were carried out using the Dimensions Database.

1 Overview

Biological rhythms are a fundamental organizing principle of life, coordinating physiology, behavior, and development with cyclic environmental changes. In terrestrial systems, circadian clocks aligned to the 24-hour day–night cycle have been studied in great detail. In marine environments, however, organisms are exposed to a far richer temporal landscape shaped by daily, seasonal and, critically, lunar light cycles as well as tides.

Despite the ecological importance of these cues, the molecular and physiological mechanisms by which marine organisms integrate multiple environmental time signals were largely unknown at the start of this project. Chronobiological concepts and mechanisms had been largely extrapolated from land-based model organisms, implicitly assuming that the same principles apply in the ocean.

This HFSP-funded project challenged that assumption. Its central objective was to understand how marine organisms perceive, process and respond to complex light-dependent rhythms, and how endogenous biological clocks interact with environmental signals to shape organismal function and ecosystem processes. By establishing experimental access to daily and lunar rhythms in diverse marine systems, the project contributed to the emergence of the field of marine chronobiology.

2 The Project

Daily rhythms driven by sunlight and food availability are well understood in land-based organisms. But the sea adds layers of complexity. Light intensities and spectral qualities shift dramatically with depth. The moon generates its own photocycle with a period of approximately 24.8 hours, overlapping and interacting with the solar cycle in ways that vary by latitude and season. Tidal forces impose additional rhythms in the range of 12 hours. Many marine organisms are known to synchronize reproduction, migration and behavior with the lunar month, but the molecular machinery enabling this had never been characterized. The project was motivated by the hypothesis that this complexity has driven the evolution of specific molecular solutions in marine life – solutions that terrestrial chronobiology, focused on a narrow set of model organisms, had no reason to uncover.

Three species were selected as experimental systems: sea urchins, the annelid worm *Platynereis dumerilii* and diatoms. Together, these systems span different evolutionary lineages and habitats and differ in key traits. Sea urchins, for example, have many light receptors and diatoms are crucial for the oxygen production. The expectation was that studying molecules across a variety of organisms would reveal both shared principles and the marine-specific innovations the project aimed to identify.

At the outset, none of the three species was equipped with the genetic and molecular tools available for standard laboratory models. Functional interrogation of genes, approaches that would today be considered routine using CRISPR-Cas9, had to be developed or adapted for each organism. Mutant analysis proved particularly time-intensive; the PI noted that this was somewhat underestimated at the start of the project, though it was not seen as a fundamental failure.

A technically decisive advance was the acquisition of specialized light sensors capable of distinguishing solar from lunar illumination under controlled laboratory conditions. This shifted the central question about moonlight from a theoretical possibility to an experimentally testable hypothesis. Without the ability to replicate naturalistic lunar light intensities and spectra in the laboratory, it was not possible to ask rigorously whether moonlight functions as a discrete synchronizing signal for biological clocks.

The project’s approach and objectives were met with skepticism in parts of the community, as described by the researcher. The prevailing view was that established model organisms were sufficient and that there was no compelling need for additional, less tractable systems.

The international project team consisted of researchers with varied, complementary backgrounds, necessary to approach the research question. The principal investigator brought expertise in molecular chronobiology and marine animal systems. Through prior conference interactions, a partnership was established with a researcher contributing deep knowledge of microalgal biology, which was essential to the diatom component. What the team initially lacked was expertise in the computational modeling of regulatory networks. This gap was filled by a collaborator with expertise in computational modelling of regulatory networks, supported by another partner with a biochemistry background.

3 Outcomes and Impact

The comparative approach proved productive and yielded several key results: in Platynereis, the cryptochrome protein L-Cry was found to adopt biochemically distinct conformational states under moonlight versus sunlight, providing the first molecular mechanism by which a biological clock can discriminate between solar and lunar light. This resolved the conceptual puzzle about how organisms distinguish two light sources of very different intensities but similar spectral composition and opened the door to understanding how lunar rhythms are entrained at the molecular level. The work also revealed that peripheral circadian clocks can operate with substantial autonomy from central oscillators. This finding has broader implications for understanding how rhythmic regulation is distributed across tissues in animals generally. In diatoms, intrinsic circadian regulation of gene expression and physiology was demonstrated in a major group of marine primary producers, establishing that autonomous timekeeping is not restricted to complex multicellular organisms. The sea urchin work contributed to the comparative analysis of circadian regulatory networks.

Together, the project's findings provided the novel molecular players and mechanistic insights it had set out to identify, while also revealing how marine organisms integrate different light sources and cycles in ways that terrestrial chronobiology had not anticipated. The findings fed into various publications.

The research conducted in the HFSP project has ecological and societal significance. Phytoplankton, including diatoms, are responsible for a substantial share of global oxygen production and represents a major component of the ocean's carbon sink. By improving the understanding of how marine organisms perceive, process and respond to complex light-dependent rhythms, the project laid the foundation for exploring what happens when biological rhythms are disturbed. Artificial light at night, ocean acidification and climate-driven habitat shifts are all capable of impairing biological timing in marine organisms, with potential consequences for productivity, carbon cycling and ecosystem stability. The findings of the HFSP project can therefore inform environmental protection strategies and policies.

Beyond the scientific advances, the project contributed considerably to the growth of marine chronobiology as a sub-discipline in its own right. From the perspective of the funded researchers, the project contributed to generating scientific credibility, training researchers and forming collaborative networks needed to strengthen the field.

Since the project began, dedicated professorships in marine chronobiology have been established in Oldenburg (Germany), Vienna (Austria) and Naples (Italy). Former group members have founded independent research groups. The field is now represented at international conferences, in European and international funding networks for circadian and marine research, and in university curricula.

The project and the broader field it catalyzed have reached audiences well beyond academia. The PI described regular press engagement with outlets including GEO, New Scientist and the Austrian Medical Journal, documentary work with Arte and National Geographic, collaboration with the Natural History Museum in Vienna, and broader community outreach.

The project results and the supported collaboration have also contributed to the founding of two companies. Loopbio develops biological imaging and behavioral analysis software. Marine Breeding Systems specializes in the planning, development, and construction of components and systems that simulate natural processes in mesocosms, particularly for research and breeding. As the PI noted, commercialization had multiple contributing factors, but collaborations initiated through the HFSP project were a key catalyst..

4 Role of HFSP and Conclusion

This project exemplifies HFSP's mission to enable frontier research that reshapes biological understanding and contributes to the emergence of new research fields. The acceptance of high-risk research without requiring extensive preliminary data was described as essential. At the time of the application, the methods needed for the project were not yet established, and no significant prior results existed in the target organisms. HFSP's willingness to fund work at the methodological frontier, provided the question is fundamental and the rationale rigorous, was identified as what makes genuine innovation possible.

The requirement for international and interdisciplinary collaboration was also valued highly. In this case, it was a scientific necessity that the funding structure enforced in productive ways. Participants were compelled to engage across disciplinary and cultural boundaries, and the PI described the lasting effect on her own intellectual perspective and working practices as significant.

Looking back, the PI described the HFSP project as one of the most important in her career and as a foundational moment for the field. A combination of funding (HFSP, University of Vienna, ERC) made the research trajectory and career progression possible, with HFSP occupying a specific role at the point when the risk was highest and the potential hardest to demonstrate.

By creating the conditions to ask unconventional questions about time, light and life in the ocean, HFSP enabled work whose impact has extended well beyond the original grant.

5 Sources

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