TEASPOON - What shapes the TEmporAl Structure of PlanktOnic trOphic dyNamics: a data-driven approach for exploring marine ecosystem functioning

Context. Mixotrophic plankton, ranging from pico- to megaplankton, are prevalent in estuaries, coastal seas, and the open ocean. These organisms combine autotrophy and heterotrophy in the same single cell, thus acquiring carbon, but also nitrogen, phosphorus, trace elements (e.g. iron), trace nutrients (e.g. vitamin). While previously underestimated, they are now recognized as significant members of the global plankton community, contributing to ecosystem functioning in various niches (Leles et al., 2017, 2019; Faure et al., 2019). Recent studies highlight their diverse functional roles and potential to alter understanding of lower trophic level dynamics in food webs (Mitra et al., 2014; Duarte Ferreira et al., 2021). Combining primary and secondary production in a single organism (*i*) radically changes biogeochemical (e.g., by shaping the biological carbon pump; Mitra et al., 2014b) and trophic dynamics involving those organisms (Mitra et al., 2014b; Leles et al. 2018), (*ii*) alters the flows of energy and materials in and out of organisms that form the base of the food chain, and (*iii*) changes the way that we understand - and therefore simulates - ecological processes, from harmful algal blooms and fisheries to global climate change. As a consequence, studying the role of mixotrophic plankton within marine systems has the potential to reform our understanding of marine ecology.

Scientific objectives: The primary goal of this PhD project is to enhance understanding of temporal and spatial variations in mixotrophic plankton communities, a crucial step before modelling. Existing knowledge gaps will be addressed through empirical analysis, particularly focusing on poorly documented temporal variations within and across years. The project aims to tackle common but vital questions regarding mixotrophic plankton: **How important is mixotrophy within planktonic communities? How the interplay of biotic and abiotic factors structures trophic modes and especially mixotrophic plankton communities at seasonal scales?**

SO1. How do the specific and functional characteristics of planktonic communities vary in marine ecosystems?

a. Seasonal study of trophic dynamics in ecosystems with contrasting conditions

Ten time series, spanning latitudinal gradients and originating from diverse environments (e.g., Norwegian fjords, the Baltic Sea, Tyrrhenian Sea) will be investigated. These series comprise microscopic counts of micro-planktonic organisms spanning several years (some extending over 20 years), facilitating the exploration of seasonal variations in planktonic communities while mitigating biases stemming from interannual variations. Additionally, these datasets encompass physico-chemical parameters of ecosystems. By examining a range of study sites, we aim to establish site typologies and identify environmental factors driving variations in trophic modes.

b. Seasonal and interannual dynamics among mixotrophic organisms

Within these trophic modes, our focus will shift to mixotrophic taxa. We will use metabarcoding time series data (among those described in SO1.a) spanning at least four years from seven distinct environments. These environments include Narragansett Bay, BATS, ASTAN, Wimereux, Helgoland Road, LMO, and LTER-MC. Complementing this analysis, we will employ a trait-based approach integrating imaging and genomic data to understand seasonal successions and links between mixotrophy and community traits. We will utilize specific trait databases like the Mixoplankton Database (Mitra et al., 2023). Additionally, metagenomic analysis focusing on pico and nano size classes will be conducted using data from the EMO-BON European program, that cover some of the metabarcoding time series previously described. This approach enables a comparison of different data types and a nuanced analysis of ecosystem functioning.

SO2. How do biotic and abiotic forcings influence the trophic dynamics of plankton communities in marine ecosystems?

a. Quantification of the response of mixotrophs to abiotic forcings

Sites investigated in SO1, along with their abiotic parameters will facilitate: (i) the examination of abiotic drivers influencing trophic modes, determining whether mixotrophy drivers are consistent or vary across contrasting environments; and (ii) the establishment of a typology of mixotrophic organisms based on their

abundances and responses to environmental parameters linked to latitude. We will document how fluctuating resources (temperature, light, stratification, nutrients) impact the presence of mixotrophic organisms. Additionally, we will explore the link with the environment by correlating trophic types with environmental indices derived from abiotic parameters from the water column (e.g., ecosystem maturity, Chl a/phaeopigments) and organic matter descriptors.

b. Quantification of the response of mixotrophs to biotic forcings: interactions within the phytoplankton community and relationships with the zooplanktonic compartment

Leveraging the previously described time series, we will examine the coexistence of species and their trophic modes. Mixotrophic organisms, relying on a wide spectrum of resources, have the ability to overcome limitations resulting from nutrient depletions, providing a valuable food source for zooplankton grazers. We will investigate this trophic interaction using zooplankton imagery, genomics, and microscopic data as explanatory variables in our succession analysis in BATS, ASTAN, Narragansett Bay and Wimereux.

SO3. Trophic dynamics of planktonic communities through the lens of a frugal science: a case study based on data acquired during the Bougainville mission

The Bougainville mission aims to engage citizens, engineers, and scientists in ecology to develop low-cost, open-source plankton measurement instruments for a global understanding of oceanic microbiomes by 2030. The Indian Ocean, particularly the Mozambique Channel, offers conducive conditions for mixotrophs due to factors like oligotrophy and water stratification. Data collected during the Bougainville mission from September 2023 to August 2024 (notably by Thomas Finet (PhD candidate for this project), utilizing imaging and genomics), provides a unique opportunity to study mixotroph roles in western Indian Ocean communities and trophic structure variations between offshore and coastal regions, which are currently poorly characterized.

Adequacy with the Institute / Initiative: This project is in line with the themes of the **IO** (Oceanographic biodiversity, Global changes, Frugal science) and the **FUTURE-OBS** project (PI. **Pr. Eric Thiébaut**, first PhD supervisor of this project, specialist of coastal oceanography and long-term monitoring of marine biodiversity, and Pr. Fabrice Not). FUTURE-OBS aims to develop multi-scale observation strategies, by improving the use of heterogeneous data (e.g., microscopy, imaging, genomics) and developing original numerical approaches to study spatiotemporal dynamics of planktonic ecosystems. Beyond the scientific complementarity of the PhD supervisors (Pr. Eric Thiebaut, Dr Eric Goberville, Dr Lucie Bittner), the outcomes from the project will also benefit from the expertise of international collaborators (**Dr. Marie Fanny Racault and Pr. Corinne Le Quéré**, School of Environmental Sciences, University of East Anglia), who aim to involve mixotrophy in their biogeochemical modelling.

Profile of the candidate: Master's degree in marine science, with a strong background of the ecological processes at play in planktonic communities, and skills in data analysis and computing. The candidate is already identified: Thomas Finet, top of his Master 2 class in June 2023, who is now working for the Bougainville mission (2023-2024). He did his internship under the co-supervision of **Dr. Eric Goberville** and **Dr. Lucie Bittner**, and has a strong expertise in the study of mixotrophic planktonic communities from metabarcoding time series. His long-standing involvement in the implementation of this PhD project, including the collecting and curation of the datasets to be used, makes him the ideal candidate to successfully complete this research.

	1st year		2nd year		3rd year	
	S1	S2	S3	S4	S5	S6
Data processing (gathering, cleaning, integration)						
SO1.a. seasonal and spatial / latitudinal						
SO1.b. seasonal and interannual						
SO2.a. abiotic forcing						
SO2.b. biotic interactions						
SO3. Bougainville / tropical						
Thesis redaction (and 3 publications (*))			*		*	*