Deep-learning of the Arctic shallows — Computer vision applied to investigate benthic ecological succession.

Rock-encrusting organisms (or 'lithophiles') are very common in hard-bottom shallows of Arctic fjords. Lithophiles are the first to settle and grow in newly available space after a disturbance occurs (keels of icebergs scouring the seabed, for example), a process called primary succession. Space on hard substrate is a fundamental resource, and the struggle for space is a key aspect of succession shaping the structure of lithophile assemblages. The predominantly bidimensional geometry and (sub)circular growth patterns of lithophiles facilitate their identification and edge-recognition in high-resolution photographs, therefore making it relatively easy to measure their growth and follow through time. Modern computer vision and image analysis are increasingly being used in the marine imaging community to enhance automation and accelerate the acquisition of accurate data for complex ecological analysis. **The main aim of this project is to implement state-of-the-art deep-learning architectures to a long-term imagery dataset and to produce accurate algorithms capable of automating measurements and predictions to study growth, spatial competition outcomes, and its influence on benthic ecological succession in a rapidly changing high-Arctic environment.**

Long-term and historical datasets are imperative to understanding the response of natural systems to ongoing and increasing environmental change. In this project, we will use a curated imagery dataset of high-resolution overlapping photographs registered under the scope of a long-term underwater experiment (2009–2023) utilising standardised artificial substrata (settlement plates) in Isfjorden (78°N, European Arctic). The tasks planned in the project include: <u>1) Image acquisition</u>: photographs of rocks and 10-year-submerged panels will be registered using a full-frame mirrorless camera with built-in focus stacking and a 90mm 'true' macro-lens. At least 25 overlapping photographs per panel will enable a high-res photomosaic and will be batch-processed for image enhancement. <u>2) Annotation:</u> image dataset will be fully annotated (labelled) based on lithophile identity and competition interaction outcomes (win/loss/draw), relying on a computer vision model for accurate edge recognition. <u>3)Segmentation</u>: a convolutional neural network (U-Net architecture) will be used to deal with the advanced classification problem, this model was developed to cope with two challenges; relatively low number of training data, and the need of *instance segmentation* (correctly separating two colonies in conflict of the same species). <u>4) Ecological data interpretation</u>: model selection will be made using the information-theoretic (IT) approach in an attempt to identify and select a parsimonious model which in turn will allow valid inferences.

Only few studies have focussed on the biological response to climate change on the shallow subtidal assemblages in polar regions using long-term standardised experiments, and little is known about how interspecific and intraspecific competition works in systems where there are many competing species. These questions of theoretical ecology are expected to be answered through the evaluation of long-term experiments using machine-learning tools. The originated dataset will be formatted to make them findable, accessible, interoperable, and reusable.

An image generated by the deep-learning model DALL·E 2 (left), and a 'historical track' of a 9-year-old panel (right) to study ecological succession of rock-encrusting benthos. Prompt for the AI-image was: "*An underwater scientist taking photos of rocks within an Arctic kelp forest, include a computer applying machine learning, style impressionism.*"