Blue Economy CRC Research Program 2: Seafood and Marine Products
PhD Project 4.20.008

Unwanted visitors: Biofouling and how to monitor it

Image analysis applied to salmon aquaculture

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Introduction: The biofouling process

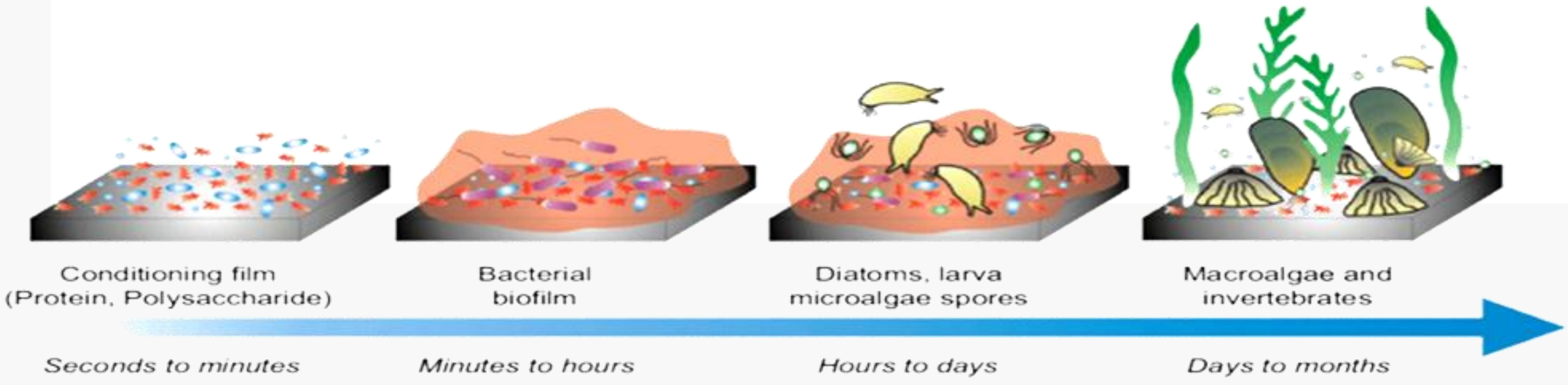

Figure 1: The general stages in the biofouling process with timescale estimates. Adapted from Poornima Vijayan *et al.*, 2022

Figure 2: Mature biofouling assemblages on pylons demarcating the edges of a lease. These structures are rarely cleaned, so climax biofouling can be found here. Footage from March 2023.

Unwanted growth of various aquatic organisms on submerged surfaces is termed "biofouling". Biofouling is a known issue worldwide in all offshore industries such as shipping, offshore energy production and more recently aquaculture. Within the Tasmanian offshore salmon aquaculture sector, biofouling poses significant direct and indirect costs due to infrastructure damages and salmon health issues. Biofouling adds considerable weight to submerged salmon pens, leading to material fatigue and altered hydrodynamic drag forces. Moreover, these biofouling organisms will occlude net meshes, reducing oxygen supply to fish and flushing out of waste products (Bannister et al. 2019). Additionally, certain biofouling species might possess the ability to serve as pathogen hosts, and/or directly harm salmon by releasing nematocysts upon contact.

This complex process starts immediately after surface submersion with molecules randomly sticking to the surface (Figure 1). This conditioning film alters surface properties and provides nutrients to living organisms to colonise it. Many bacteria possess the ability to switch from a motile to a sessile phenotype when a suitable substrate is randomly encountered or actively detected. This biofilm develops from a reversible to a permanent state with a very robust and resistant matrix of Extracellular Polymeric Substances (EPS). This biofilm then serves as a suitable surface for algal spores and microscopic larvae to settle and develop into sessile adults and eventually form a mature, complex and dynamic biofouling assemblage (Figure 2). Understanding and monitoring this successional process *in situ* is necessary to determine the environmental drivers of the biofoulers of highest concern and to eventually predict or steer the biofouling assemblage.

Methods: *In situ* footage from a Remotely Operated Vehicle (ROV)

Video footage is obtained by filming the outside of salmon pen collars and nets, using an ROV. Still images are then obtained from this footage (Figure 3). To capture consistent images, the ROV is kept steady in front of the surface of interest at a constant distance and at a perpendicular angle (Figures 3 & 4). A higher resolution camera (e.g., a GoPro) can reduce the need for pre-processing. Where image quality is poor, image pre-processing to bring out colours and complex details of the biofouling assemblage is conducted where necessary. Image pre-processing can be considered on an image-by-image basis, but some general procedures can be quickly applied to all images with good results and minimal additional time investments. Specifically, removing some of the motion blur in the image due to wave actions, reducing the murkiness induced by the water column and slight brightening of darker areas improve overall picture quality (Figure 4) and thus downstream image analysis effectiveness.

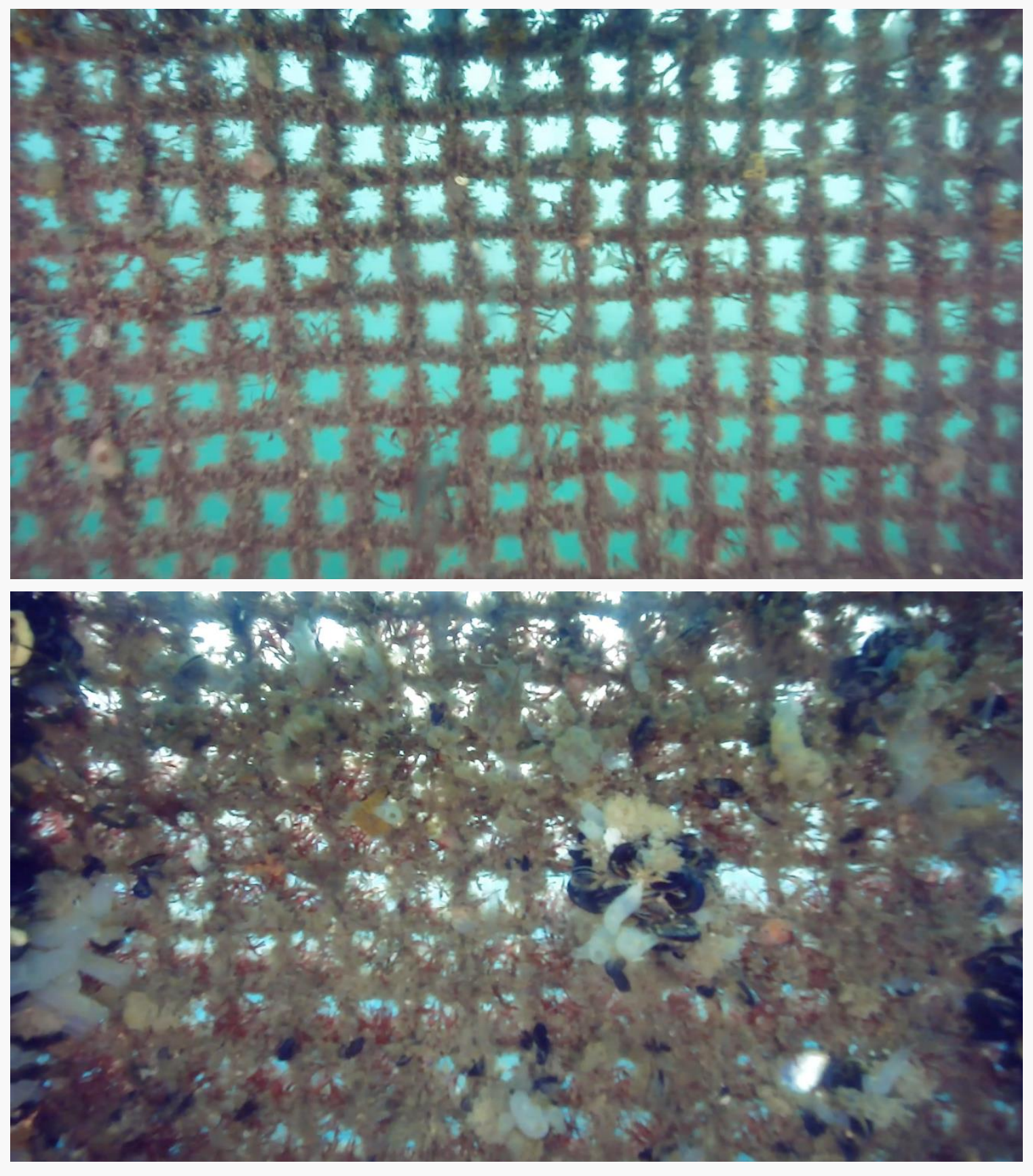

Figure 3: Images taken from raw ROV footage of a pen's net (March 2023).

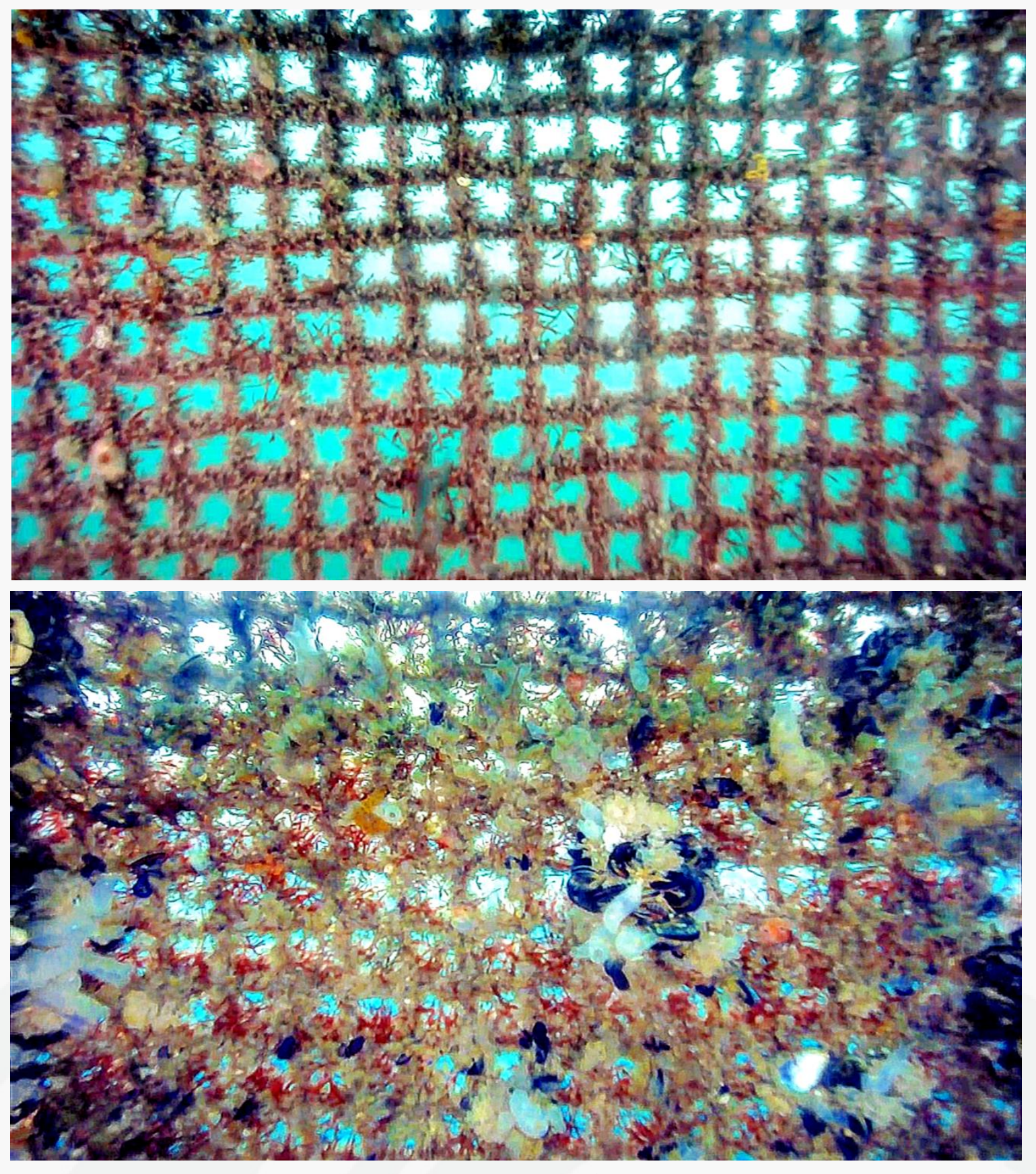

Figure 4: Enhanced versions of the images in Figure 3.

Results: Net occlusion estimation

Before identifying biofouling species, it is useful to assess the overall occlusion of the net's mesh to inform decisions on net cleaning. For this, background pixels (i.e., water) must be separated from non-background pixels (i.e., biofouling and unfouled net). Next, area covered by the net structure must be subtracted from the image to estimate how much mesh area is covered by biofoulers, relative to a clean piece of netting. This workflow can be implemented on ROV and GoPro footage of salmon pen nets as follows:

For ROV camera footage (Figure 5), the contrast and edges between water and the rest of the image are enhanced to obtain more accurate binarizations (Figure 6). High quality GoPro footage can be used without pre-processing steps (Figure 10). A perpendicular angle between the net and the camera is required for accurate estimation of the net's occlusion. A tilted image can be corrected for by projecting to the coordinate system of a perpendicular image (e.g., the reference image) (Figure 11). The images are first segmented using the Color Thresholder application included in the Image Processing Toolbox in MATLAB (The MathWorks Inc., 2023), from which a function is exported to remove blueish pixels (Figures 7 & 12). Ideally, all and only water pixels are coloured black. An active contour technique based on the Chan-Vese model (Chan & Vese, 2001) is applied to improve the initial binarizations, which overlays the initial binarization with the colour image and evolves the curves of this binarization along the object's boundaries (Figures 8 & 13 (left)). The lower quality of ROV camera footage warrants the use of a negative contraction (i.e., expansion) bias during active contouring to fill in the higher number of misclassified regions in Figure 7. To further remove the binarization in Figure 8, a closing operation is applied (Figure 9 (left)). This operation first dilates and then erodes Figure 8 using a small disk-shaped structuring element, allowing for fine-scale corrections. The final binarizations are then overlaid with a binary version of a clean reference net of approximately the same size (Figures 9 (right) & 13 (right)), to estimate a relative Occlusion Score.

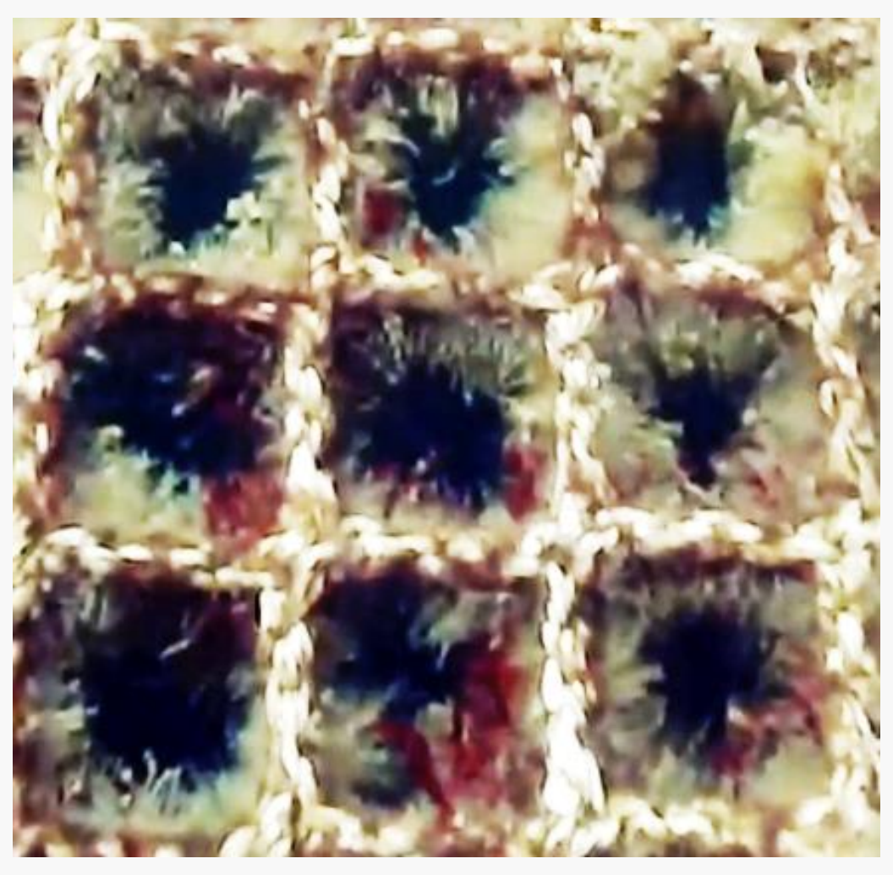

Figure 5: Cropped still image taken from field footage, filmed by Jimmy Hortle during September 2022.

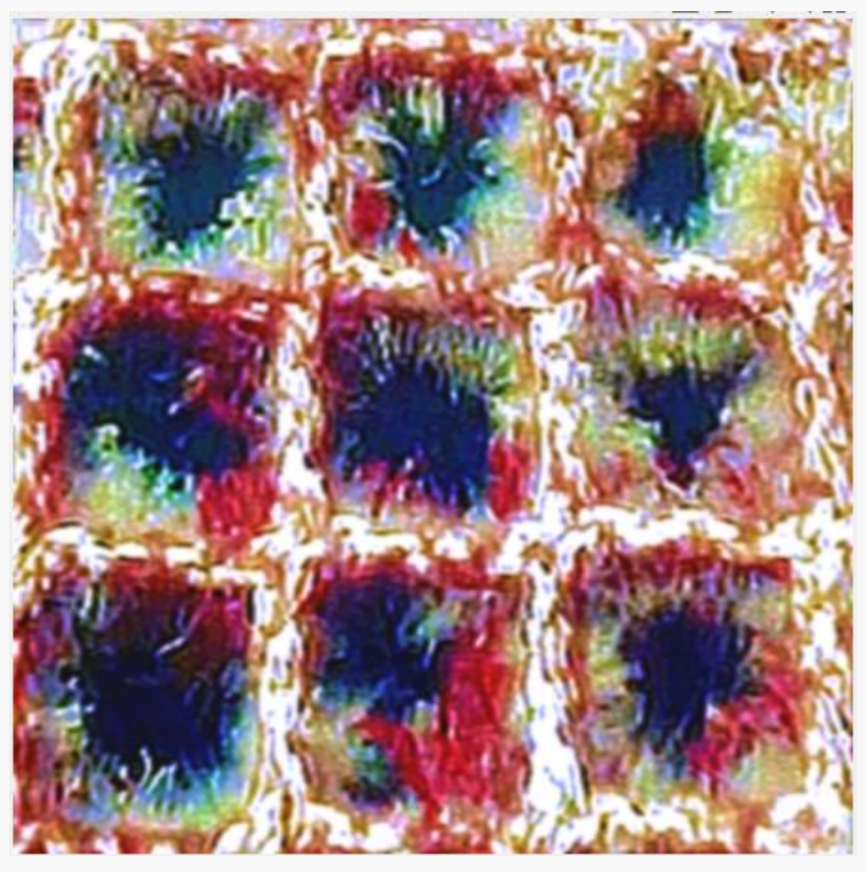

Figure 6: Enhanced version of Figure 5, maximising contrast between water and non-water pixels.

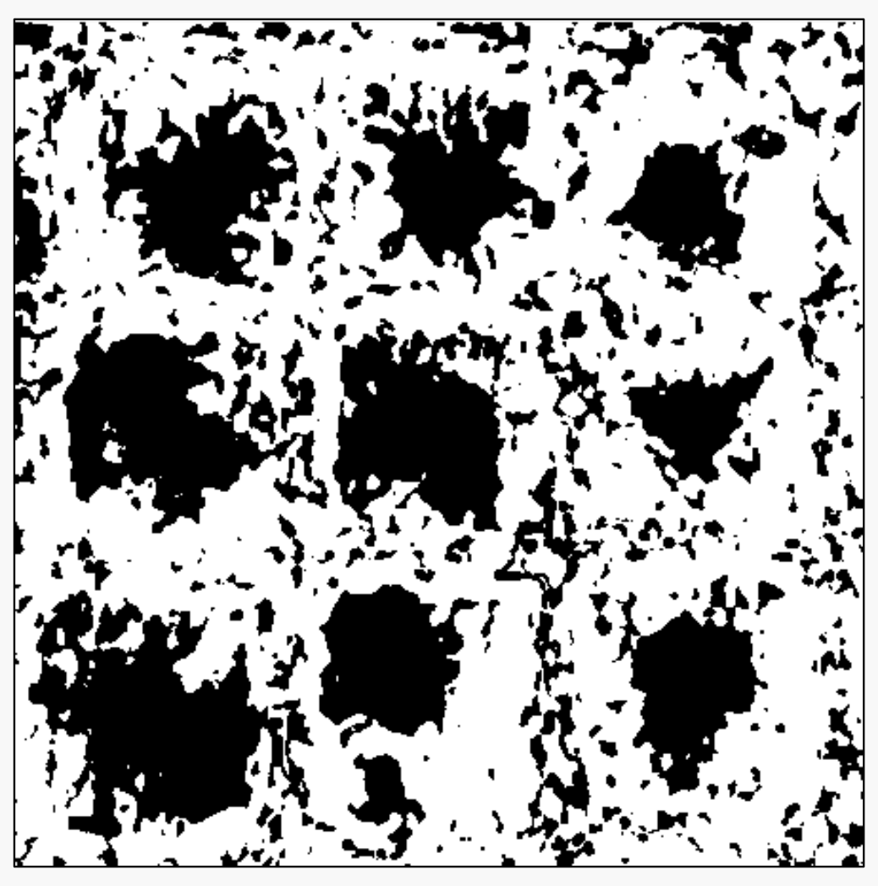

Figure 7: Initial binarization of Figure 6 using a coarse function to remove blueish pixels.

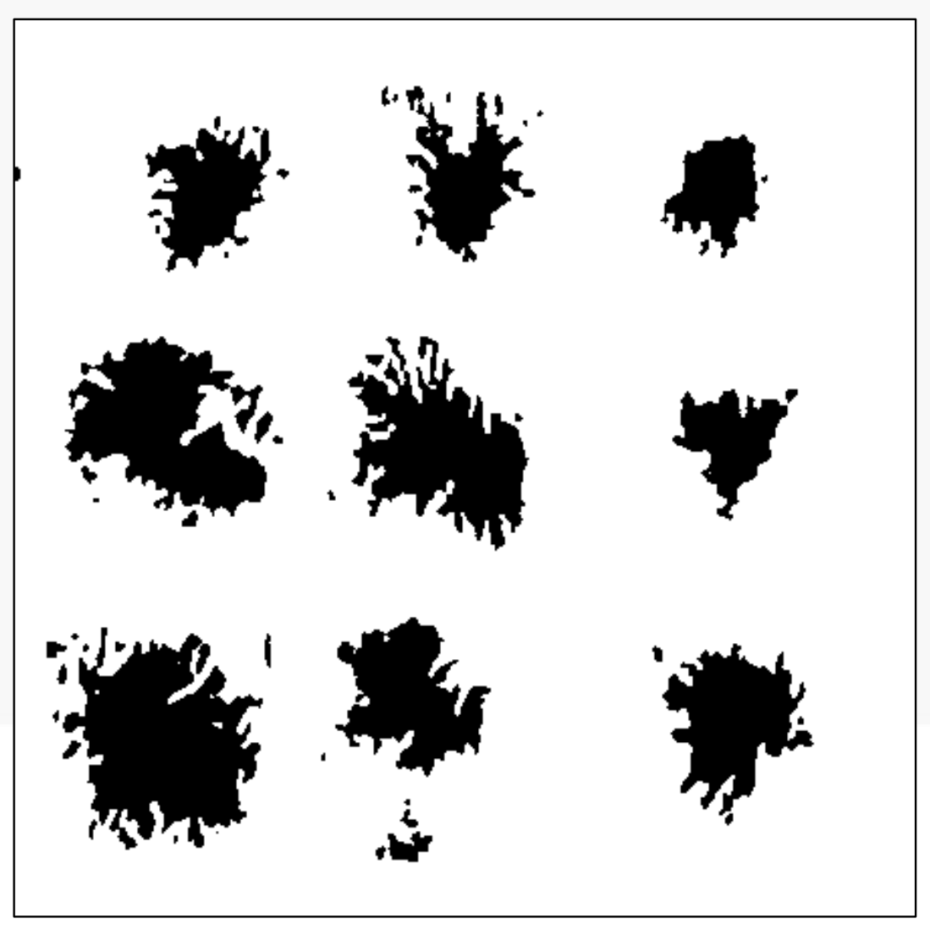

Figure 8: Improvement of the binarization using the Chan-Vese active contour technique with an expansion bias.

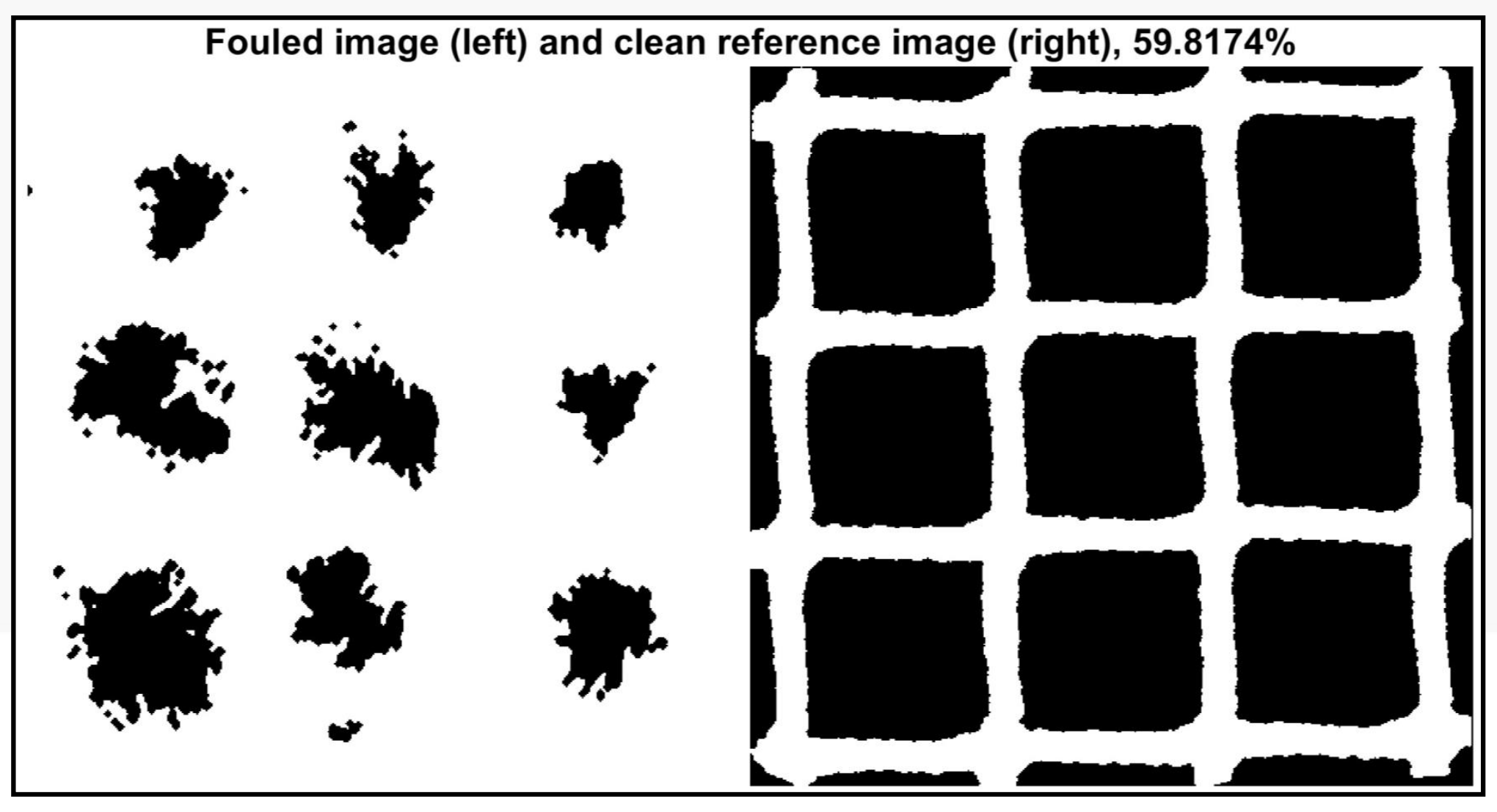

Figure 9: Further binarization improvement of Figure 8using a closing operation (left), and the binary version of the clean reference net (right). The percentage above shows the estimated Occlusion Score.

Figure 10: Cropped still image taken from field footage, filmed with a GoPro during April 2023.

Figure 11: Projecting Figure 10 to a perpendicular angle.

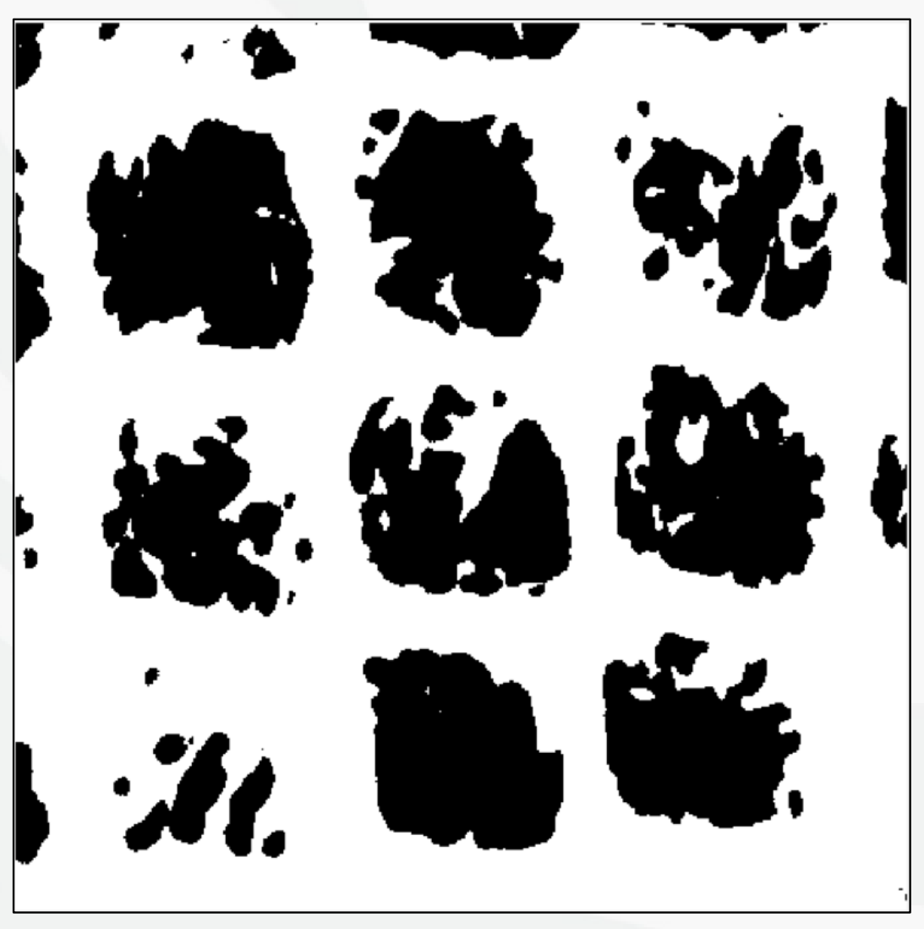

Figure 12: Initial binarization of Figure 11 using a coarse function to remove blueish pixels.

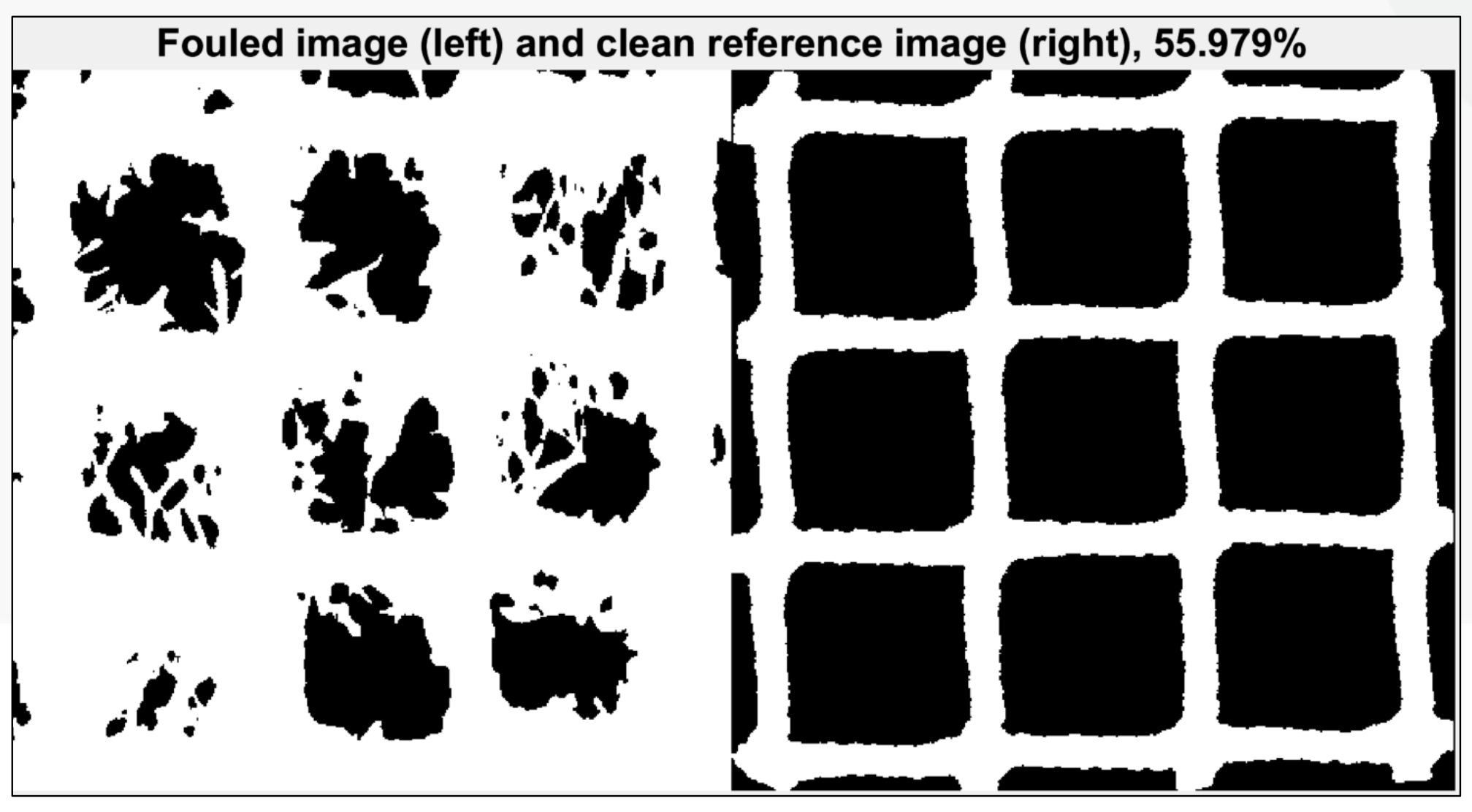

Figure 13: Binarization improvement of Figure 12 using the Chan-Vese active contour technique without bias (left), and the binary version of the clean reference net (right). The percentage above shows the estimated Occlusion Score.

Conclusion

Colour thresholding and binarization of fouled net images have potential to provide rough quantifications of biofouling loads relative to unfouled nets, independent of large training datasets. Quality (i.e., resolution and sharpness) of the source image directly impacts the applicability of this method and the need for pre-processing steps that have a risk of biasing the analysis.

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