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Habitat complexity influences survival of the vulnerable canopy forming macroalgal species *Gongolaria barbata* in the northern Adriatic Sea

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What are the threats to canopy forming macroalgal species in the Mediterranean region?

Fucalean algal species are declining throughout the entire Mediterranean region primarily due to pollution and urban development (Airoldi et al. 2007) and overgrazing by tropical fishes (Sala et al., 2011, Vergés et al., 2014). There is also increasing observational evidence that sea urchin population explosions may also be contributing to their loss and/or lack of recovery. Within the Adriatic Sea, species that once formed dense 'belts' of forest habitat along the coastline are now sparse and are rapidly declining in diversity (Iveša et al., 2016).

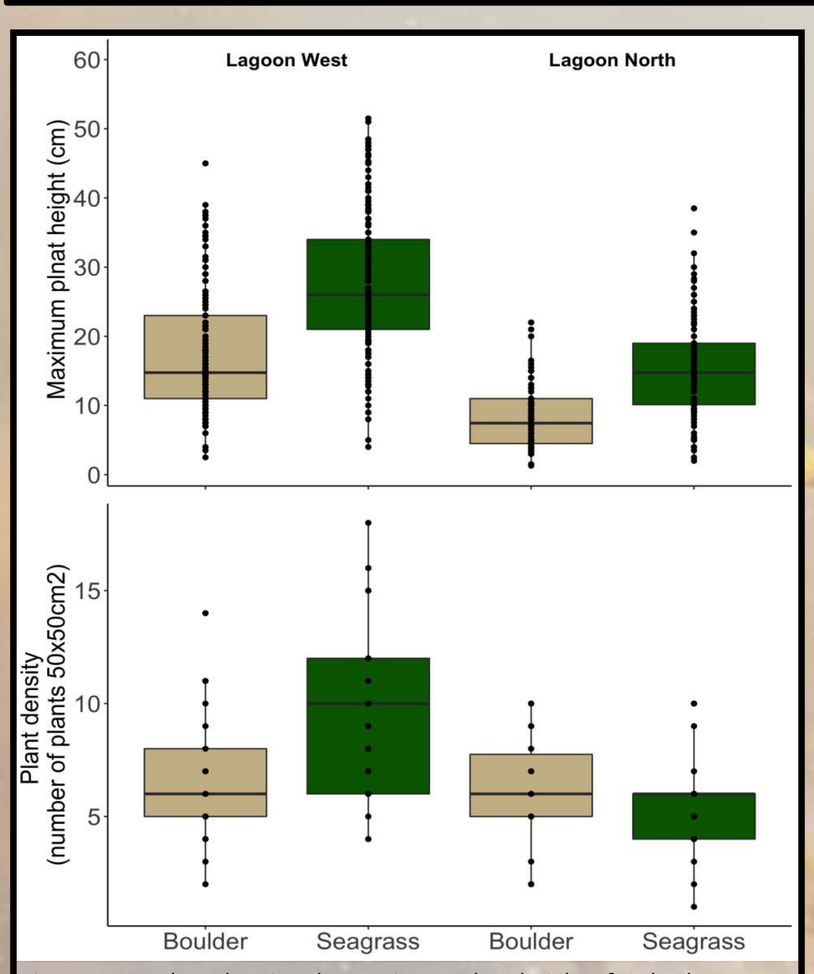

Figure 1: Boxplots showing the maximum plant height of *G. barbata* individuals measured within in situ 50x50 cm quadrats (n = 545 individuals) in both boulder and seagrass habitat within two locations within Šćuza Lagoon (top panel) and the number of plants within each quadrat (bottom panel; n = 78 quadrats).

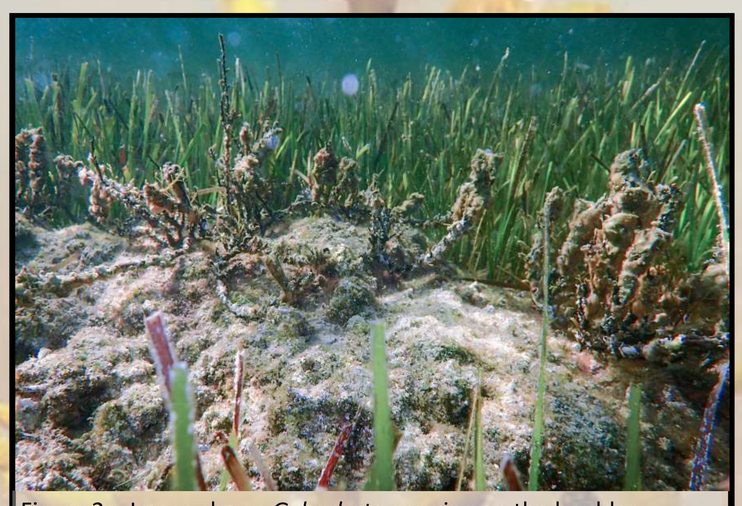

Figure 2a: Image shows *G. barbata* growing on the boulder habitat type.

Figure 2b: Image shows an example of *G. barbata* within seagrass (*Cymodocea nodosa*) habitat.

What are the indicators of survival for at-risk fucalean species in the Adriatic?

Along the Western Istrian coastline in the northern Adriatic Sea (Fig.3), a significant refuge population of a single fucalean species, *Gongolaria barbata,* exists within a unique lagoonal habitat (Iveša et al., 2022). Broadly, this project aims to understand the biotic and abiotic parameters of this lagoon that allow for such a significant population of *G. barbata* to persist where it has been lost elsewhere. We also aim to assess the viability of using a subset of this population as donor individuals for restoration attempts.

In Šćuza Lagoon, *G. barbata* recruits to both exposed boulder habitat (Fig.2a) typical of the limestone habitat throughout the wider Adriatic and to small pebbles that settle among seagrass habitat (Fig.2b). Here, we aimed to investigate whether settlement and growth of *G. barbata* differed between these habitat types of differing complexity.

We counted the density of *G. barbata* individuals and measured their maximum height in situ within six replicate 50 x 50cm quadrats in both seagrass and boulder habitat types. We did this every two weeks over three months in 2022 on both the west and north side of the lagoon.

We found there was a higher density of *G. barbata* individuals within seagrass habitat compared to boulder habitats (Fig.1) and that algae grew to a taller maximum height (by 46% in the west of the lagoon and 36% in the north) when found within seagrass (Fig.1).

These results are significant because they show a reduction in the performance of algae within the boulder habitat type – similar to the limestone habitat along the rocky shore in the Adriatic. A reduction in the height of the algae is important given the annual growth cycle of *G. barbata*, where the reproductive material is contained within the vegetative branches that grow and become fertile in the winter months. This cycle is crucial for population maintenance.

Additionally, we speculate that seagrass habitat provides protection from herbivores and/or a deeper substrate on which to attach, thus reducing air exposure during low tide. Both mechanisms likely allow the algae to reach a greater biomass.

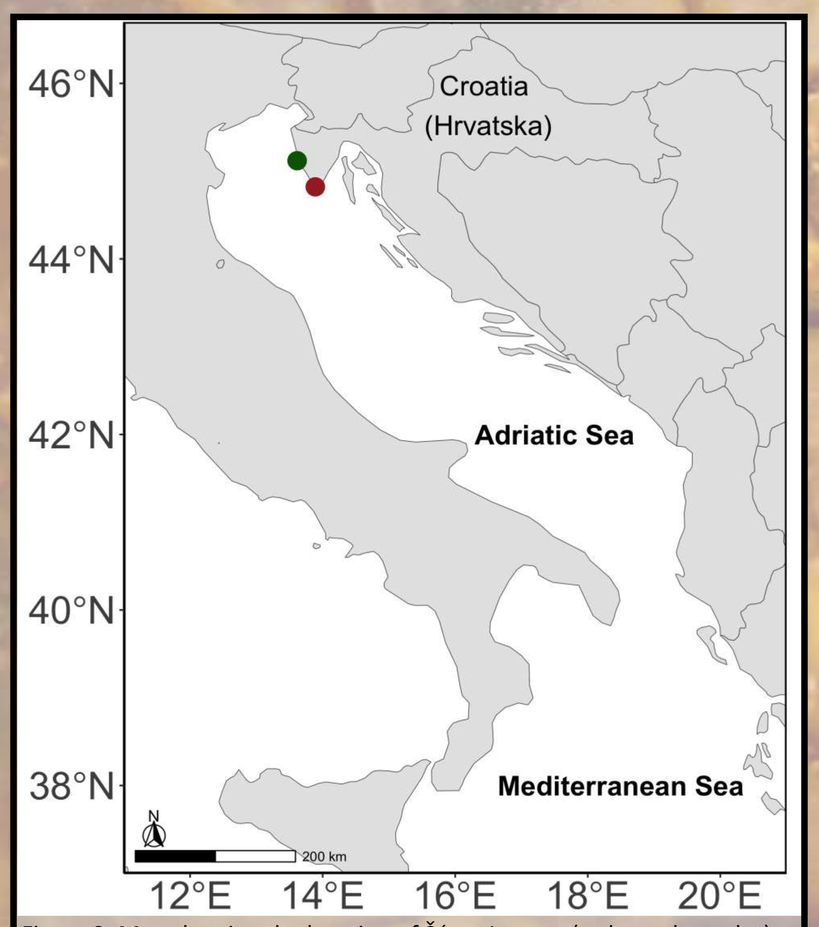

Figure 3: Map showing the location of Šćuza Lagoon (red, southern dot), the potential refuge habitat for *G. barbata*, and Faborso Bay (green, northern dot), the transplant site, in Istria, Croatia. These locations are part of the north Adriatic Sea bioregion, the coldest part of the Mediterranean region.

Is it possible to restore macroalgal forests in the northern Adriatic?

We set up a restoration trial at Faborso Bay, nearby to the Šćuza Lagoon refuge site (Fig.3). *G. barbata* was once present and abundant in Faborso Bay, which is now characterised by low-biomass turfing algae.

We set up 15 replicate transplant plots, 5 x deep (1-2m) plots that were exposed to herbivores (e.g. Fig. 4), 5 x deep plots that were protected from herbivores via cages and 5 x shallow (intertidal) plots that are theoretically exposed to herbivores but where urchins are not yet observed, likely because this area exists on a plateau-like structure.

Early results of this experiment indicate that refuge from herbivores is critical for the survival of transplant individuals. The vegetative parts from all un-caged plots (deep and plateau) were completely removed within 20 days of planting (Fig.4). The cauloids (perennial parts of the algae) however, remained in-tact.

The removal of vegetative branches from individuals within plots on the plateau suggests that herbivores other than urchins may be contributing to canopy loss at this site. Transplant plots will be further monitored and investigation into the local herbivore community will be performed over the coming months.

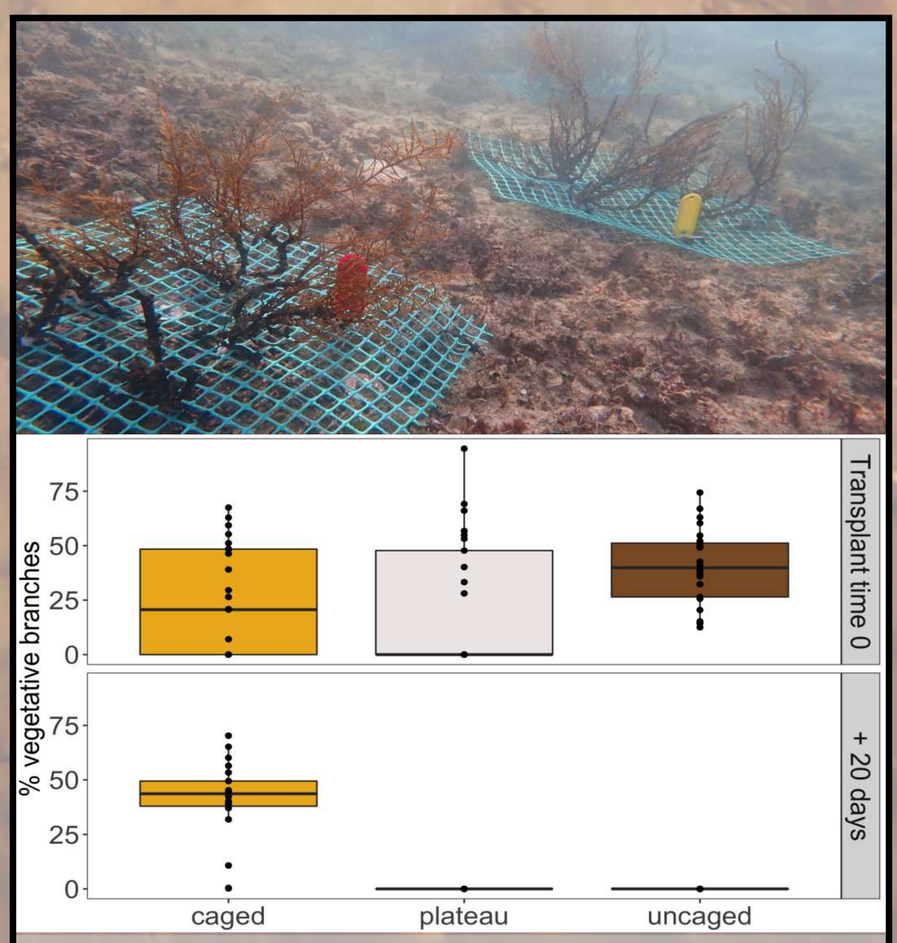

Figure 4: Top image shows an example uncaged restoration plot.
Bottom plot shows the percentage of the vegetative part of individual restoration plants (dots, n = 25 per treatment). Top panel shows data from the time when plots were established and the bottom panel, 20 days later.

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