3-D Modeling of Marine Ecosystem Engineers – a Framework for Studying Their Ecological Impact

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1. Introduction

Ecosystem engineers (also termed habitat modifiers or bioconstructors) are organisms that exert important control over resource availability for other biota via modulation of the physical and chemical state of the environment (Jones et al. 1994). Such species create, destroy, and otherwise modify habitats and thereby affect both the resources and the organisms that rely on them, as well as the abiotic stressors they experience. Some ecosystem engineers are new to the systems in which they are present as they invaded from other areas with human aid (intentional or un-intentional). The extent of invasive ecosystem engineers' influence on the environment is a subject of intense scientific study. The marine ecosystems of Israel are strongly influenced by ecosystem engineers, both native and invasive. In the Red Sea, coral reefs and seagrass reshape the local environment, while in the Mediterranean Sea is flooded by invasive, mostly tropical, species (Rilov and Galil 2009), many of which (e.g., bivalves and macroalgae) can be considered ecosystem engineers and thus are expected to reshape the structure and possibly modify the functionality of rocky reefs.

Despite the increase of studies on the ecological impacts of ecosystem engineers, the actual three-dimensional modification of the marine habitat that they create or alter has rarely been addressed. This can be attributed mostly to the difficulty in modelling such modifications, which the marine environment makes even more involved. Thus far, characterization of the ecosystem and its inhabitants was performed via simple image analysis and interpretation, mainly intended to calculate percent cover of the major space occupiers without any information on their actual structural shape. As far as we know, no studies have looked at the influence of invasive ecosystem engineers on fine-scale structural characteristics of the habitat in the marine environment.

In this work, we utilize underwater photogrammetry to quantify the 3-D modifications of natural environments by ecosystem engineers and compare them to native ecosystem engineers. Underwater photogrammetry provides an efficient non-destructive means to document complex environments with limited accessibility. With the growing use of consumer cameras, its application becomes easier, thus benefiting environmental studies which otherwise could not have been materialized. Utilizing cameras for underwater photogrammetry poses however nontrivial modelling problems due to refraction effect and the extension of the imaging system into a unit of both camera and a protecting housing device. In addition, the establishment of reference control networks in such settings is oftentimes difficult. To facilitate the modelling, we developed a model for characterizing the geometric distortions, accounting not only for the multimedia effect, but also for inaccuracies related to the setting of the camera and housing

device. We show that only a few additional parameters are needed to model both elements and to preserve the collinearity relation and that no unique setup is needed for estimating the additional parameters. To alleviate the need for deployment of reference control points, we then extended the coplanarity condition, which requires neither knowledge of object space coordinates nor setting a reference control network (Telem and Filin, 2013). However, the coplanarity relation does not hold in such environments because of the refraction effect, and methods that have been proposed thus far for geometrical modeling of its effect require knowledge of object-space quantities. Thus, a geometrically-driven approach which fulfills the coplanarity condition and thereby requires no knowledge of object space data is developed. Results show that no unique setup is needed for estimating the relative orientation parameters using the model and that high levels of accuracy can be achieved. With the establishment of the orientation, a 3-D reconstruction of the habitat and the influence of the ecosystem engineers on its complexity can be derived.

Figure 1: top: a reef made of the invasive oysters. Bottom; a meadow of the invasive green algae *Codium parvulum*.

To test the applicability of this approach to ecological questions in the marine environment we model the 3-D habitat that invasive engineers on Mediterranean reefs create, and compare some of them to similar native species. For example, we focus on the structures that the large invasive Red Sea oysters *Spondylus spinosus* and *Chama pacifica* create (Fig. 1, top), and compare it to reef areas without the oysters. Similarly, we compare the 3-D structure and complexity that the invasive macroalgae *Galaxaura rugosa* and *Codium parvulum* (Fig. 1, bottom) create to that of native macroalgal species such as *Cystoseira spp.* and *Padina pavonica*. We demonstrate the

approach in both lab and field settings. Future prospects of the documentation will see us moving from the individual species scale to a complete habitat scale to see how these complexity modifications translate to effects on the structure of ecosystems (i.e., reefs). Further extension of this work will see investigation of the spatio-temporal dynamics of the influence of invaders as the oyster reefs probably grow with time and the invasive macroalgae species are seasonal and, their patches seem to grow from year to year.

References

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