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LED Lighting and High-Density Planting Enhance the Cost-Efficiency of *Halimione portulacoides* Extraction Units for Integrated Aquaculture

Marco Custódio [1,2,*], Paulo Cartaxana [1], Sebastián Villasante [3,4,5], Ricardo Calado [1] and Ana Isabel Lillebø [1,*]

1 ECOMARE & Centre for Environmental and Marine Studies (CESAM), Department of Biology, University of Aveiro, 3810-193 Aveiro, Portugal; pcartaxana@ua.pt (P.C.); rjcalado@ua.pt (R.C.)
2 Flanders Marine Institute, Wandelaarkaai 7, B-8400 Ostend, Belgium
3 Department of Applied Economics, University of Santiago de Compostela, 15705 Santiago de Compostela, Spain; sebastian.villasante@usc.es
4 Cross-Research in Environmental Technologies (CRETUS), University of Santiago de Compostela, Campus Sur, 15705 Santiago de Compostela, Spain
5 Campus Do*Mar, International Campus of Excellence, Campus Universitario Vigo, 36310 Vigo, Spain
* Correspondence: marco.custodio@vliz.be or mfc@ua.pt (M.C.); lillebo@ua.pt (A.I.L.)

Abstract: Halophytes are salt-tolerant plants that can be used to extract dissolved inorganic nutrients from saline aquaculture effluents under a production framework commonly known as Integrated Multi-Trophic Aquaculture (IMTA). *Halimione portulacoides* (L.) Aellen (common name: sea purslane) is an edible saltmarsh halophyte traditionally consumed by humans living near coastal wetlands and is considered a promising extractive species for IMTA. To better understand its potential for IMTA applications, the present study investigates how artificial lighting and plant density affect its productivity and capacity to extract nitrogen and phosphorous in hydroponic conditions that mimic aquaculture effluents. Plant growth was unaffected by the type of artificial lighting employed—white fluorescent lights vs. blue-white LEDs—but LED systems were more energy-efficient, with a 17% reduction in light energy costs. Considering planting density, high-density units of 220 plants m^{-2} produced more biomass per unit of area (54.0–56.6 g m^{-2} day^{-1}) than did low-density units (110 plants m^{-2}; 34.4–37.1 g m^{-2} day^{-1}) and extracted more dissolved inorganic nitrogen and phosphorus. Overall, *H. portulacoides* can be easily cultivated hydroponically using nutrient-rich saline effluents, where LEDs can be employed as an alternative to fluorescent lighting and high-density planting can promote higher yields and extraction efficiencies.

Keywords: sea purslane; hydroponics; aquaponics; light-emitting diodes; sustainable aquaculture; nature-based solutions; saline farming

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1. Introduction

Halophytes are a group of plants characterized by a range of morphological and physiological features that allow them to thrive in brackish and saline environments [1]. Due to these capabilities, they have been increasingly studied for the treatment of eutrophic saline effluents, especially in the context of Integrated Multi-Trophic Aquaculture (IMTA) frameworks [2–4]. The major benefit of this integration pertains to the uptake and reuse of wasted nutrients generated within the production system [5,6].

Previous studies, using a variety of halophyte species, demonstrated positive outcomes in growth and extraction efficiency of nitrogen (N) and phosphorous (P) in integrated aquaculture settings [3]. This approach is associated with the principles of the circular economy, where aquaculture waste streams are valorized through the phytoremediation, harvesting and commercialization of plant biomass [7]. Several edible halophyte species can deliver food products with distinct organoleptic and functional properties, including vegetable oils and bioactive compounds [8–12]. Moreover, halophytes' relatively