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Culture of the seaweed *Ulva ohnoi* integrated in a *Solea senegalensis* recirculating system: influence of light and biomass stocking density on macroalgae productivity

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Abstract

A growth model was developed to optimize the management of multi-trophic aquaculture systems by analyzing the influence of light and biomass stocking density (*SD*) in the productivity of *Ulva ohnoi* fed with the effluents from *Solea senegalensis* culture tanks. Growth rates and productivity were determined in three flat bottom algae tanks with different incident photon irradiances (E_0) (163, 280, and 886 μmol photons m^{-2} s^{-1}), photoperiod 12:12 h, and with stocking densities ranging from 82 to 340 g_{dw} m^{-2}. The distribution of photon irradiance in the algae tanks was estimated as a function of the E_0 and *SD*. The results obtained showed that the algae exposed to the highest E_0 (886 μmol photons m^{-2} s^{-1}) and *SD* below 170 g_{dw} m^{-2} showed a strong decrease in their growth rate, together with morphological changes. The model proposed to estimate the specific growth rate (μ_{NET}), on the basis of E_0 and *SD*, assumed that photosynthetic activity is dependent on the local photon flux density and, therefore, spatially distributed in the tank. Non-linear regression used to estimate the growth kinetic parameters showed a standard deviation of the distance between measured and fitted μ_{NET} data values equal to 0.011 day^{-1}. In terms of biomass productivity per unit area (BP_A), the model shows, for each E_0 level, a trend to increase with *SD*, achieving a maximum BP_A, where *SD* can be considered optimal, and decreasing for higher *SD* values. The optimal *SD* and the maximum BP_A achievable can be also determined as a function of E_0.

Keywords *Ulva ohnoi* · IMTA · Growth model · Productivity · Irradiance · Biomass stocking density

Introduction

Green seaweeds belonging to genus *Ulva* Linnaeus (Ulvophyceae, Chlorophyta) have been identified as good candidates for filtering fish effluents due to their capacity to be cultured unattached, their wide environmental tolerances (Cohen and Fong 2004; Bolton et al. 2009) together with their high growth rates and high capacity to absorb nitrogen (Jiménez del Río et al. 1996; Mata et al. 2010). Furthermore, *Ulva* is gaining interest as ingredient for animal feeds and as a source of ulvans, sulfated polysaccharides with uses in biomedical tissue engineering, regenerative medicine, and drug delivery (Lahaye and Robic 2007; Mata et al. 2016). Most of the existing growth models for *Ulva* species have been mainly developed for the management of coasts and estuaries (Bendoricchio et al. 1994; Coffaro and Sfriso 1997; Solidoro et al. 1997; Martins and Marques 2002; Aveytua-Alcázar et al. 2008; Ren et al. 2014).

Ulva ohnoi M. Hiraoka & S. Shimada has been suggested as one of the most suitable species for land-based cultivation, due to its high growth rates, biomass productivity, and nitrogen uptake rates (Yokoyama and Ishihi 2010; Lawton et al. 2013; Angell et al. 2014; Mata et al. 2016).

Solea senegalensis Kaup, 1858, has been shown to be a suitable fish species for growing at very high stocking densities, compatible with those needed for its intensive commercial farming (Salas-Leiton et al. 2008). The rising intensive production of this species in Spain, Portugal, and France (Morais et al. 2016) has increased the interest on developing specific land-based integrated multitrophic aquaculture

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