Aquaculture 281 (2008) 49–55

Contents lists available at ScienceDirect

Aquaculture

journal homepage: www.elsevier.com/locate/aqua-online

Promise and pitfalls of locally abundant seaweeds as biofilters for integrated aquaculture

Nicholas A. Paul *, Rocky de Nys

School of Marine and Tropical Biology, James Cook University, Townsville 4811, Australia

ARTICLE INFO

Article history:
Received 25 January 2008
Received in revised form 21 May 2008
Accepted 21 May 2008

Keywords:
Algae
Bioremediation
Caulerpa
Fragmentation
Tropical aquaculture

ABSTRACT

Seaweeds from the genus *Caulerpa* offer promise for bioremediation in integrated tropical aquaculture in northern Australia, as they are common on shallow reefs adjacent to where aquaculture is developing and their propagation is readily manipulated through fragmentation. Fragments of five varieties of *Caulerpa* had high growth rates (between 3 and 7% day^{-1}) and high nitrogen content (up to 3% dry weight/0.2% fresh weight for *Caulerpa taxifolia*) in tank-based culture. These attributes combined confirm the promise for *Caulerpa* in integrated aquaculture, especially as certain species (*Caulerpa lentillifera* and *Caulerpa racemosa*) are valuable products. However, this potential was not realised when *Caulerpa* spp. were cultured in an in situ aquaculture context. Only a limited proportion of fragments (13%, predominantly *C. taxifolia*) persisted during a 6 week in situ experiment in a flow-through settlement (treatment) pond from an 800 tonne year^{-1} fish production facility. Mean growth of persisting pond fragments (less than 0.3% day^{-1}) was much less than concurrent tank cultures (3–7% day^{-1}). The factor most strongly influencing pond culture was the negative (smothering) impact of blooming filamentous algae (*Cladophora* and *Chaetomorpha* spp.). Poor pond growth of *Caulerpa* was further substantiated in an additional test, determining that persistence and growth (or lack thereof) was independent of initial seeding size of fragments. These results suggest that *Caulerpa* culture will not be easily integrated into settlement ponds in tropical aquaculture. However, because some species of *Caulerpa* grew well in tank-based systems (*C. racemosa* grew at >7% day^{-1}) and others are capable of luxury uptake (*Caulerpa serrulata* and *C. taxifolia* almost doubled internal nitrogen in nutrient-rich water), *Caulerpa* species have application in bioremediation of intensive tank-based aquaculture and perhaps treated pond aquaculture effluent.

1. Introduction

Integrated plant–animal aquaculture has developed as an effective mechanism to reduce the level of nutrients in effluent through nitrogen and phosphorous absorption by plants or algae (LaPointe et al., 1976; Asare, 1980; Brown et al., 1999; Chopin et al., 2001; Neori et al., 2004; Lu and Li, 2006; Crab et al., 2007). This process is particularly important for intensive aquaculture, in which dissolved nitrogenous waste (especially ammonium) can accumulate to levels that limit farm output either directly through harming fish (Handy and Poxton, 1993; Metaxa et al., 2006) or indirectly through operational constraints on effluent release (Tacon and Forster, 2003; Carmona et al., 2006). Given the potential negative impacts of aquaculture effluent on natural systems (e.g. Sara, 2007), integrated plant–animal aquaculture is now prominent in environmental management solutions, and will be particularly important to land-based aquaculture with point-source effluent (Naylor and Burke, 2005; Neori et al., 2007).

Marine macroalgae (seaweeds) can effectively strip nutrients from aquaculture effluent prior to its release to the environment (Chopin et al., 2001; Neori et al., 2004). The characteristics that make seaweeds particularly effective as biofilters are high growth rates (which facilitate nitrogen acquisition), pliable reproductive modes and simple habitat requirements. Seaweeds typically have high growth rates in nutrient-rich aquaculture effluent (Neori et al., 2000; Nagler et al., 2003; Hernández et al., 2006; Pereira et al., 2006), as nutrients are no longer a limiting growth factor as they often are in nature (Lobban and Harrison, 1994). Furthermore, some algae have luxury uptake of nitrogen which is stored and accessed as required (Naldi and Wheeler, 1999; Harrison and Hurd, 2001). Luxury uptake limits the impact of variable nutrient loads on algae in nature and, importantly, will enhance nitrogen removal per unit weight of algae in nutrient-rich artificial systems. Seaweed propagation can also be manipulated, including the production and settlement of sexual and asexual propagules (e.g. for nori — *Porphyra* spp.: Chopin et al., 1999; Blouin et al., 2007) and the regeneration of asexually derived fragments (Buschmann et al., 1995; Correa et al., 1999). And as seaweeds grow on a variety of substrata, their culture can be adapted to cage, tank or pond-based systems (Buschmann et al., 1995, 1996; Nagler et al., 2003; Hernández et al., 2006; Matos et al., 2006; Hernández-González et al., 2007).

* Corresponding author. Tel.: +61 7 4781 6842; fax: +61 7 4781 4585.
E-mail address: nicholas.paul@jcu.edu.au (N.A. Paul).

0044-8486/$ – see front matter.
doi:10.1016/j.aquaculture.2008.05.024

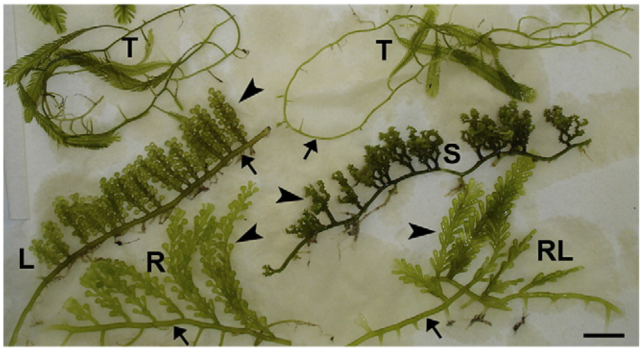

Fig. 1. Habit of *Caulerpa* fragments used in growth experiments. L=*C. lentillifera*, C=*C. racemosa*, RL=*C. racemosa* var. *laetevirens*, S=*C. serrulata*, T=*C. taxifolia*. Note: horizontal stolons (arrows) giving rise to upright fronds (arrow heads). Scale bar, 2 cm.

Despite many marine algae having characteristics amenable to bioremediation, their use is dominated by a small group of seaweeds, particularly *Porphyra*, *Gracilaria* and *Ulva* species (e.g. Chopin et al., 1999; Neori et al., 2000; Msuya et al., 2006; Blouin et al., 2007). These algae have been either selected for integrated feeding applications (using effluent-cultured algae to directly feed cultured animals, e.g. Neori et al., 2000; Troell et al., 2006) or for providing a valuable secondary product (Buschmann et al., 1996; Chopin et al., 1999). Integrated aquaculture has to date had a temperate focus with few examples for tropical regions (but see Nagler et al., 2003; Msuya et al., 2006). Because tropical aquaculture systems and algal biodiversity differ substantially from cold/temperate systems, a greater tropical focus is required to establish seaweed culture as integral to the expansion of tropical aquaculture (including in Australia; Mazur and Curtis, 2006).

In tropical north-eastern Australia – a region adjacent to the World Heritage listed Great Barrier Reef Marine Park – the two main products of aquaculture are pond-reared prawns (shrimp) and barramundi (Mazur and Curtis, 2006). However, suitable forms of integrated aquaculture are for the most part lacking. One reason for this is that the data required for incorporating seaweed culture into integrated operations have not been quantified, specifically the influence on algal growth of site specific conditions, such as temperature, light intensity and regime, and water quality. For this region of Australia appropriate algae for use in integrated aquaculture must also be local, a similar consideration was the premise for *Porphyra* cultivation in North America (Carmona et al., 2006). The use of local seaweeds is essential to environmental sensitivity and to promote aquaculture as a sustainable industry.

In the present study we test the use of local algae in integrated aquaculture, with an emphasis on identifying seaweeds with high growth rates, high nitrogen content and fragmentation as a mode of reproduction, the latter with the intent for a simple and perpetual propagation method. We selected five prominent members of the green algal genus *Caulerpa* from shallow reef habitats near Townsville, Australia, and quantified their growth in two separate tank-based seawater systems. We also examined growth and nitrogen content of these algae cultured in a settlement pond of a fish farm (intensively culturing barramundi, *Lates calcarifer*). This enabled us to draw comparisons between the relatively controlled tank-based systems and the variable environment of a tropical aquaculture pond, and provided an assessment of the relative importance of *Caulerpa* growth and nutrient acquisition for their role in bioremediation.

2. Materials and methods

2.1. Study organisms and field sampling

Caulerpa (Chlorophyta; Udotaceae) is a genus of siphonaceous algae comprised of close to 200 species (Guiry and Guiry, 2008; www.algaebase.org), some of which rely on asexual propagation via thallus fragmentation for their ecological success (Smith and Walters, 1999). Fragmentation and the subsequent attachment of *Caulerpa* spp. have facilitated its invasion of new habitats (Ceccherelli and Cinelli, 1999), suggesting that any local species of this genus could be particularly suitable for propagating in the settlement ponds of aquaculture facilities.

More than ten species of *Caulerpa* are found on the Great Barrier Reef, Australia (Cribb 1996; Benzie et al., 1997) and many are accessible on shallow inshore reefs. *Caulerpa* species were collected from Townsville (19° 15′ 52″ S, 146° 48′ 54″ E) and Magnetic Island (19° 10′ 25″ S, 146° 49′ 40″ E). Five common varieties with distinct morphologies (Fig. 1; *Caulerpa taxifolia*, *Caulerpa lentillifera*, *Caulerpa serrulata*, *Caulerpa racemosa* var. *laetevirens*, *C. racemosa* — previously *C. racemosa* var. *clavifera*, identified using Cribb (1996) with current nomenclature by Guiry and Guiry, 2008) were sampled from five different sites, two at Townsville (Kissing Point & The Strand) and three at Magnetic Island (Nelly Bay, Picnic Bay and Cockle Bay). We assessed the presence/absence of different *Caulerpa* species at these sites and live samples were returned to a closed seawater system prior to use in experiments.

2.2. Tank-based culture

To assess the growth and nitrogen content (two important variables for estimating nitrogen removal in integrated aquaculture) we ran two experiments concurrently under controlled conditions at James Cook University. Growth was quantified as the specific growth rate of algae in two separate but adjacent tank-based closed (recirculating) systems that differed in their water qualities. The level of nitrogen was more than 80 times higher in one system (high N, 1.4 mg/L; Table 1) compare to the other (low N, 0.017 mg/L). Variables for the closed-system experiment (means ± 1SD) were measured on five occasions over the 19 days experimental period (Table 1; the main form of nitrogen was nitrate due to microbial biofilters on both systems). Daily maximum surface irradiances (PAR) in the tanks were >200 µmol photons m^{-2} s^{-1}.

The experimental design comprised of four replicate tanks in each system (high and low N). Each tank contained two samples (fragments) of each of the five species of *Caulerpa*, which were randomly allocated a position on a submerged tray and secured by loosely fitted cable ties. Fragments of algae used were sub-samples of an individual of each species; a growing tip comprised of a section of stolon (horizontal runner) with at least five upright fronds (Fig. 1). We selected a generic type of fragment as opposed to standardising for initial mass across *Caulerpa* species because of the varied sizes and morphologies amongst the algae (Fig. 1). This meant that average initial size (mass) varied between the smaller, *C. taxifolia* (1.3 g) and *C. serrulata* (2.4 g) and larger morphologies, *C. racemosa* var. *laetevirens* (4 g), *C. lentillifera* (4.7 g), and *C. racemosa* (4.8 g). Growth was measured over 19 days of culture in both systems (high N and low N). Four new replicates of *C. serrulata* were added on the second day because of death (see Section 2.6).

2.3. Settlement pond (in situ) culture

Growth of the five species of *Caulerpa* was quantified in a settlement pond at Good Fortune Bay Fisheries Ltd (GFB), a barramundi farm at Guthalungra, Queensland (20° 1′ 46″ S, 148° 11′ 20″ E), approximately 160 km south of Townsville producing ~800 tonnes per annum. This farm

Table 1
Mean values (±1SD) of environmental variables for the culture of *Caulerpa* spp. under three experimental conditions

Environmental variable	Tank culture	Tank culture	Pond culture
	High N	Low N	In situ
Total N (mg L^{-1})	1.4±0.02	0.017±0.02	~1.8
Temperature (°C)	28.7±0.6	27.8±0.9	26.5±3
Salinity (ppt)	36.26±0.6	36.44±0.6	37.50±0.3
pH	8.14±0.09	8.19±0.04	8.46±0.45