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COMPARISONS OF REARING SYSTEMS BASED ON ALGAE OR FORMULATED FEED FOR JUVENILE GREENLIP ABALONE (*HALIOTIS LAEVIGATA*)

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ABSTRACT In most commercial abalone nurseries worldwide, algal biomass grown on vertical plates becomes inadequate once juvenile abalone reach about 5 mm in shell length. At that stage animals need to be moved into a different tank system and weaned onto a formulated feed or alternative algal diets consisting of diatoms or macroalgae that can provide more biomass for the growing juveniles. Two trials were conducted to compare the growth and survival of juvenile greenlip abalone (5.9 ± 0.6 and 7.1 ± 0.1 mm in initial shell length) in two rearing systems: (1) shallower tanks with or without horizontal shelter, feeding a commercial formulated feed on horizontal surfaces; (2) deeper tanks with plate system feeding algal diets. The second experiment included two algal diets and two abalone stocking densities for one of the algal diets. The first experiment revealed that the algal diet consisting of *Ulvella lens* produced the best growth rates during the first 4 wk of the experiment, when juveniles reached about 9 mm in shell length and seawater temperatures averaged 20.1°C. Growth rates on the *Ulvella* diet declined rapidly thereafter, whereas growth rates on formulated feeds increased, coinciding with a decrease in seawater temperature to 15.2°C at the end of the experiment. The formulated feed produced high growth rates (over 75 μm day^{-1}) once juveniles reached 7 mm in shell length. In the second experiment, the algal diet that included germlings of the green alga *Ulva* sp. produced the highest growth rates (105 μm day^{-1}), indicating that *Ulva* sp. germlings are a suitable additional food source for juvenile greenlip abalone. Growth rates were particularly high towards the end of the experiment when seawater temperatures were above 19°C. Juveniles stocked at higher density (80 juveniles per plate) feeding on one of the algal diets showed reduced growth rates and overall lower average weight gain per individual compared with the juveniles stocked at low density and juveniles in the tank system feeding on formulated diet. In both experiments the survival was higher on the algal diets (77% to 82%) than on the formulated feed (62% to 65%). Culturing and maintaining algae for larger juveniles in the nursery system involved more labor, compared with the tank systems feeding formulated feed, suggesting that in higher labor cost countries, juveniles should be weaned onto a formulated feed as early as possible. We recommend moving animals into a tank system to feed formulated feed once they reach 7 mm in shell length. The weaning process can be delayed (e.g., to 17 mm shell length) by supplementing with macroalgal germlings if the seawater temperature is high and high mortality is expected when weaning onto formulated diets. The algal diet including *Ulva* sp. germlings produced particularly high growth rates when seawater temperature was above 19°C.

KEY WORDS: algae, formulated diet, growth, *Haliotis laevigata*, nursery systems, survival

INTRODUCTION

Most commercial abalone nurseries worldwide rely on diatom biofilms as a food source for post larvae and juvenile abalone (Daume et al. 2000). More recently, it has been shown that the macroalga *Ulvella lens* Crouch can enhance the settlement of the abalone *Haliotis rubra* Leach and *H. laevigata* Donovan and provides a good food source for juveniles >3 mm in shell length. This food source can be further enhanced by inoculation with cultured diatoms (Daume et al. 2004, Daume & Ryan 2004). In Australia, most commercial hatcheries culture *U. lens* to induce larval settlement and as a food source for the juveniles until about 5 mm in shell length when algal biomass becomes inadequate. As juveniles grow, it becomes increasingly difficult to maintain adequate feed on the plates and it is still regarded as a significant bottleneck for the abalone aquaculture industry (Daume 2006). New plates colonized by *U. lens* and diatoms can be introduced every month to combat this problem.

Macroalgal germlings, which can grow on the nursery plates and can provide more biomass, may be a more suitable alternative for the later stages of the nursery phase. Rapid growth rates of 90–130 μm day^{-1} have been reported with germlings (Maesako et al. 1984). Strain et al. (2006) showed comparable growth rates of juvenile greenlip abalone (5–10 mm in shell length) feeding on an algal diet consisting of *Ulva* sp. germlings and *Navicula* cf. *jeffreyi* compared with *U. lens* and *N.* cf. *jeffreyi* mix. Shpigel et al. (1999) demonstrated that juvenile abalone (*H. tuberculata* Linnaeus, *H. discus hannai* Ino) grow better on the green alga *Ulva lactuca* Linnaeus when it is cultured in an ammonia enriched seawater, indicating that the nutritional value of the macroalga can be enhanced in culture. Specific growth rates of 0.6% to 1% body weight day^{-1} have been reported for juveniles 15–18 mm in shell length (Shpigel et al. 1999). Growth rates of *H. roei* Gray juveniles (32 mm in shell length) feeding on enriched *Ulva rigida* C. Agardh were comparable to growth rates achieved on the best performing formulated diet (Boarder & Shpigel 2001).

Alternatively, formulated feed may provide nutrients in a more constant form, independent from seasonal variation in nutritional profile, with the potential to easily increase food biomass as juveniles grow. Growth rates of up to 53 μm day^{-1} for juveniles ranging between 3 and 18 mm and up to 90 μm day^{-1} for juveniles between 7 and 30 mm in shell length have been reported on an unspecified formulated diet (Table 6 in Fleming et al. 1996). Viana et al. (1993) found that juvenile abalone (*H. rufescens* Swainson) of approximately 13 mm in shell length were growing faster on a formulated diet than on the macroalga *Macrocystis pyrifera* (Linneaus) C. Agardh. In contrast, Naidoo et al. (2006) reported that *Haliotis midae* (Linneaus) (35 mm in shell length) grew best on a mixed seaweed diet compared with monospecific diets or formulated feed.

In this study, two experiments were conducted to compare the growth and survival of juvenile greenlip abalone

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(*Haliotis laevigata*) feeding on algal diets to their performance when feeding on a commercial formulated diet. In the second experiment the effect of abalone stocking density on growth and survival of the juveniles was also investigated.

METHODS

The experiments were conducted at a commercial abalone farm, Great Southern Marine Hatcheries, Albany, Western Australia between March and July 2003 and August 2004 and January 2005 for the first and second experiment respectively.

Experiment 1

In this experiment an algal diet (*Ulvella lens*) was tested against a commercial formulated diet (Adam and Amos, Mt. Barker, South Australia; 3 mm Noodle). These diets cannot be fed in the same tank system and hence different tank systems were set up in triplicate (= 6 tanks in total).

Tank Set-up to Test the Formulated Diet

Three experimental tanks (1720 mm × 740 mm) were set-up with a sloping second floor and a shallow water level (150 mm high = total of 190 L) to cover the second floor with seawater (Fig. 1A). The second floor served as a hiding place for juveniles during the day and a feeding platform at night. Three airlines were installed along the tank bottom. Seawater was supplied *via* a spray bar at a constant rate of 6 L min^{-1}. Tanks were stocked with 600 juveniles each (2,000 juveniles per m^2). Juveniles were fed 2% body weight per day (bw day^{-1}) of a commercial formulated diet (Adam and Amos, Mt. Barker, South Australia; 3mm Noodle), which was gradually introduced over three days.

Tank Set-up to Test Algal Diet

Three experimental nursery tanks (1720 mm × 740 mm), set-up with a deeper water level (310 mm high = total of 390 L) were equipped with 3 baskets holding 20 PVC plates (600 × 300 mm) each were used to test the algal diets (Fig. 1B). Each tank was set-up with three airlines running perpendicular to the plates along the tank bottom. Seawater was supplied by a spray bar at a constant rate of 6 L min^{-1}. The incoming seawater was filtered to 1 μm to reduce the development of natural diatoms. *Ulvella lens* was cultured on commercial nursery plates and stocked at a low density of 30 juveniles per plate (1,800 per tank and 84 per m^{-2} of plate).

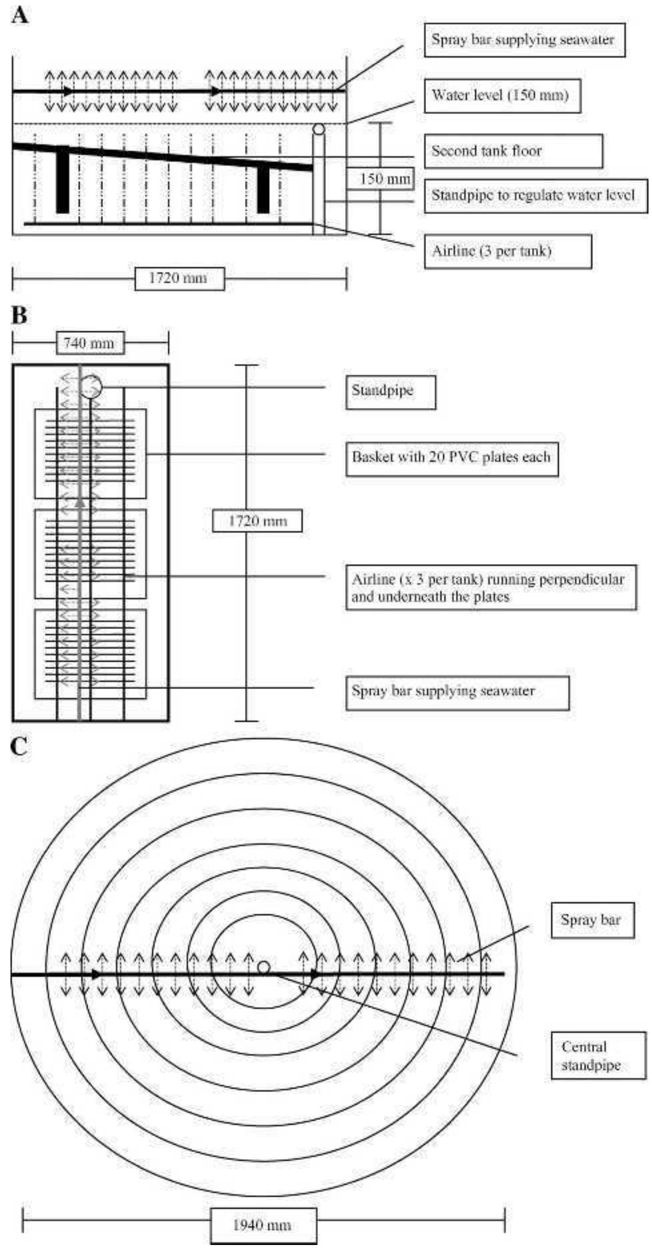

Figure 1. Different rearing system for juvenile greenlip abalone (*Haliotis laevigata*). (A) Shallow rectangular tank with horizontal shelter to feed formulated feed; (B) Deeper rectangular tank with plate system to feed algal diets; (C) Shallow circular tank with varying water levels cascading into a central drain to feed formulated feed.

Algal Culture

Ulvella Lens

The methods for spore collection were adapted from Takahashi and Koganezawa (1988). Plates with large mature patches of *U. lens* and well-developed sporangia were selected, wiped clean to remove any diatom film, and stored in 1 μm-filtered seawater under two layers of 70% shading cloth, two weeks prior to starting the conditioning of the experimental plates. *Ulvella lens* seed plates were then placed between the baskets of the experimental tanks (6 seed plates per experimental tank), whereas the tanks were maintained with no water flow, low aeration and without shading. An f/2 mix that lacked sodium metasilicate and vitamins was applied (40 g 1000 L^{-1} Abasol, Manutech, Port Lincoln, Australia). The release of zoospores is triggered by the increase in water temperature, nutrients, and light. The largest release occurred 4–5 days after the introduction of seed plates.

Diatom Cell Density and Percentage Cover of Ulvella Lens

Eight times during the experiment and 1–4 wk apart, the number of naturally occurring diatom cells and the percentage cover of *U. lens* were estimated under an inverted microscope in 15 randomly chosen fields of view of six plates per tank.

Growth and Survival of Juveniles

Seventy-two juvenile abalone were measured per tank every week. Juveniles averaged 5.95 ± 0.06 mm in shell length at the start of the experiment. The experiment was terminated when juveniles reached 14 mm in shell length in one of the treatments. The survival was estimated at the end of the experiment.

Experiment 2

In this experiment a commercial formulated diet was tested against two algal diets. In addition, one of the algal diets (*Ulvella lens* plus *Navicula* cf. *jeffreyi*) was tested at both high (80 juveniles per plate) and low (40 juveniles per plate) stocking density (= 4 treatments). Different tank systems needed to be utilized to test the formulated diet and the algal diets and hence different systems and diets were set up in triplicate (= 12 tanks in total).

Tank Set-up to Test the Formulated Diet

Three circular weaning tanks (industry design—GSW, Victoria, Australia), 1,940 mm in inner diameter (ca. 300 L) with a central standpipe and supplied with seawater from a spray bar at 6 L·min^{-1}, were used to evaluate the formulated diet (Fig. 1C). The water cascades through 7 steps with an increasing depth from 30 mm at the outer ring to 80 mm at the inner ring.

A subset of juveniles *Haliotis laevigata* (7.1 ± 0.12 mm in shell length) were taken off nursery plates and transferred into weaner tanks. The tanks were stocked with 6,000 animals each (about 2,000 m^{-2}). Juveniles were fed 2% (bw day^{-1}) of a commercial diet (Adam and Amos, Mt. Barker, South Australia; Noodle 3mm), which was gradually introduced.

Tank Set-up to Test the Algal Diets

The same tank set-up was used as in experiment 1. Three experimental nursery tanks were set up for each of the three treatments. Germlings of the green alga *Ulva* sp. were cultured together with *Ulvella lens* and the diatom species *Navicula* cf. *jeffreyi* on commercial nursery plates and stocked at a low density of 40 juveniles per plate. This was compared with a current commercial practice in Australia consisting of *Ulvella lens* plus *Navicula* cf. *jeffreyi*, at low (40 juveniles per plate; 2,400 per tank and 112 per m^{-2} of plates) and high (80 juveniles per plate; 4,800 per tank and 224 per m^{-2} of plates) stocking densities.

Algal Culture

All nursery tanks contained the macroalga *Ulvella lens*. *Ulvella lens* was cultured as described above. However plates in the combined treatment with *Ulva* sp. germlings and the diatom *Navicula* cf. *jeffreyi* had lower % cover allowing other algal species to attach. All nursery tanks (including those of the combined treatment with *Ulva* sp. germlings) were inoculated with the cultured diatom *Navicula* cf. *jeffreyi*.

***Navicula* cf. *Jeffreyi* Culture and Inoculation**

Cultures of *Navicula* cf. *jeffreyi* were established in horizontally laid algal bags and progressively increased in size up to commercial size bags of ca. 1 × 2 m. The diatom culture was harvested during the exponential growth phase (4–6 days after inoculation) and mixed into suspension. Each tank received an f/2 mix (Microalgal Food, Manutech, Port Lincoln, Australia) applied at 40 g 1,000 L^{-1} and 15 L inoculum (ca. 10^5–10^6 cells mL^{-1}). The tanks remained static with low aeration for 24 h and then received low water flow with light aeration for 2–3 days. All nursery tanks were inoculated at the start of the experiment and every 2 wk thereafter before resuming normal flow and aeration. The incoming seawater was filtered to 1 µm to reduce the development of natural diatoms.

***Ulva* sp. germlings**

Ulva sp. thalli were collected from submerged limestone rocks on South Mole in Fremantle, Western Australia. *Ulva* thalli were arranged in layers in-between moist newspaper then refrigerated at 4°C. After 7 days of cold treatment, thalli were taken to the hatchery in Albany. Each tank, already containing plates with *U. lens*, received 10 kg blotted wet weight of *Ulva* sp. thalli. The tanks were filled with f/2 mix that lacked sodium metasilicate and vitamins (40 g 1,000 L^{-1} Abasol, Manutech, Port Lincoln, Australia) and received only light aeration to reduce water motion and allow maximum spore attachment.

The *Ulva* sp. thalli turned pale and disintegrated after spore release. The leftovers were removed from the three tanks after 6 days. The germlings were then cultured for another 4 wk in the same f/2 mix (see earlier), which was exchanged weekly. This treatment was added 4 wk later because of the longer culturing period necessary for the *Ulva* sp. germlings. Juvenile abalone were kept on an *U. lens* and *N.* cf. *jeffreyi* diet in the meantime.

Growth and Survival of Juveniles

Juveniles were measured at the start of the experiment and every 3–6 wk thereafter. One hundred juveniles were measured per weaner tank each time. In nursery tanks six plates were randomly selected per tank and 10 random juveniles were measured per plate (60 per tank). Juveniles were weighed and counted in each tank at the start and at the end of the experiment and the survival and weight gain estimated.

Data Analysis

Statistical analyses were carried out using the STATISTICA computer package. The assumption of normality was checked graphically and using a Kolmogorov-Smirnov test.

Abalone shell length measurements of both experiments were analyzed by repeated measure analyses of variance. Data

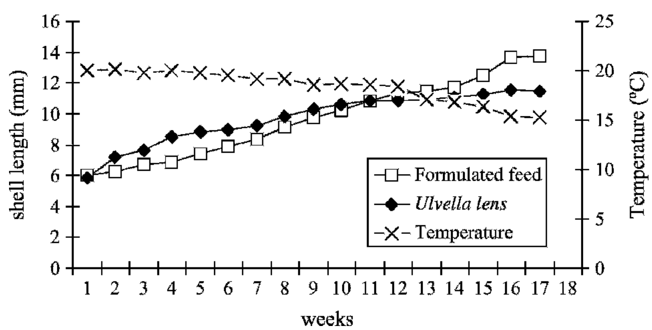

Figure 2. Shell length of juvenile abalone (*Haliotis laevigata*) feeding on formulated feed or a *Ulvella lens* diet, as well as average seawater temperature over a 17 week growing period (n = 3).

TABLE 1.

Growth rates (µm·day^{-1} ± SE), specific growth rates (SGR length % day^{-1} ± SE) and total survival (% ± SE) of juvenile abalone (*Haliotis laevigata*) feeding on a formulated feed or algal diet over the 17-wk experiment.

	Week 4	Week 8	Week 12	Week 17	Survival (%)
Growth rates (µm day^{-1})*					
Formulated feed	39.35 ± 10.3	81.84 ± 13.9	77.61 ± 15.7	82.70 ± 17	65 ± 2.3
Ulvella lens	124.99 ± 15.9	45.85 ± 12.8	38.57 ± 15.2	22.95 ± 13.8	82 ± 3.1
SGR (length % day^{-1})†					
Formulated feed	0.65 ± 0.2	0.79 ± 0.1	0.84 ± 0.1	0.76 ± 0.1	
Ulvella lens	2.17 ± 0.1	1.19 ± 0.1	0.90 ± 0.1	0.68 ± 0.1	

* Between consecutive sampling times and averaged over 4–5 wk.
† Averaged over 4–5 wk.

of the second experiment at 20 and 23 wk and the survival data were analyzed using a one-way ANOVA with Tukey HSD test. Relationships between algal food densities and specific growth rates were explored with a multiple regression analysis.

RESULTS

Experiment 1

Effect of Juvenile Abalone Diets on Growth and Survival

Juvenile abalone feeding on the formulated diet reached 13.77 ± 0.30 mm in shell length, whereas juveniles feeding on *Ulvella lens* averaged only 11.5 ± 0.16 mm in shell length at the end of the experiment (Fig. 2). There was a significant difference in shell length at the end of the experiment (ANOVA, $P < 0.05$).

Growth rates were significantly higher in the *U. lens* treatment between the start of the experiment and week 4, when animals reached 9 mm in shell length and seawater temperatures averaged 20.1°C (Table 1, $P < 0.05$). However, growth rates declined in the *U. lens* treatment and increased in the formulated feed treatment from week 5 onwards, resulting in significantly higher growth rates on the formulated feed between week 13 and 17 (Table 1, $P < 0.05$). This coincided with a decline in seawater temperature between week 12 and 13 from 18.4°C to 17.1°C (Fig. 2).

The specific growth rate (shell length) was highest in the *U. lens* treatment at week 4 (2.17% day^{-1}). The formulated feed treatment produced a growth rate comparable to the *U. lens* treatment between week 9 and 17 (Table 1). The survival was higher in the *U. lens* treatment than in the formulated feed treatment ($P < 0.05$).

TABLE 2.

Percentage cover of *Ulvella lens* and cell density of diatom *Cocconeis* sp. over the 17-wk experiment.

Week	*Ulvella* (% cover)	*Cocconeis* sp. (cells cm^{-2})
2	57.57	990
5	57.17	0
6	54.36	0
7	78.39	0
12	53.06	0
14	75.82	0
15	65.33	0
17	66.88	0

Algal Cover

Ulvella lens cover ranged from 54% to 78% showing variability between all measures (Table 2). *Ulvella lens* released spores regularly every 2–3 wk. The diatom *Cocconeis* sp. appeared on the plates at low cell density (Table 2) only at the start of the experiment. No other diatom species was found on the plates.

Experiment 2

Effect of Juvenile Diets and Stocking Density on Juvenile Growth and Survival

The juvenile abalone fed actively on all algal diets (*Ulva* sp. germling diet, *Ulvella lens* and *Navicula* cf. *jeffreyi*) as well as on the formulated feed. Juveniles on the algal diet with *Ulva* sp. germlings grew significantly larger, reaching 17.82 ± 0.43 mm in shell length after 23 wk (Fig. 3, Tukey posthoc test, $P < 0.05$). Juveniles were smallest in tanks at high stocking density (12.8 ± 0.25 mm).

Over the whole trial period the *Ulva* sp. germling diet produced the highest average growth rate (105.31 ± 8.4 µm day^{-1}, SGR 0.63% day^{-1}), whereas growth rates on the *U. lens* plus *N.* cf. *jeffreyi* diet were comparable to those achieved in the formulated diet treatment (Table 3). Juveniles in the algal

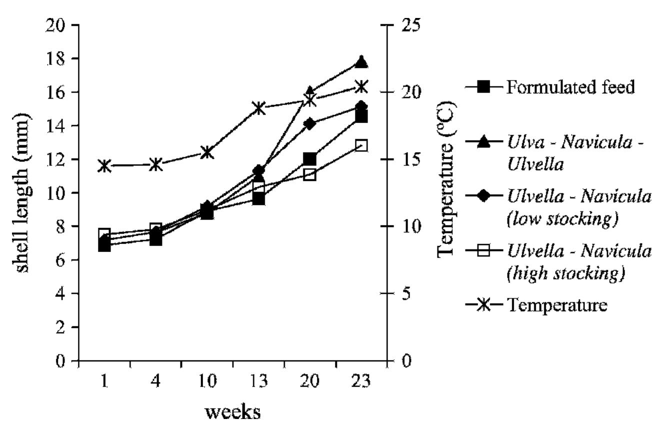

Figure 3. Shell length of juvenile abalone (*Haliotis laevigata*) feeding on formulated feed or algal diets, as well as average seawater temperature over a 23-week growing period (n = 3).

TABLE 3.

Growth rates (μm·day^{-1} ± SE), specific growth rates (SGR length % day^{-1} ± SE), weight gain per individual and survival (% ± SE) of juvenile abalone (*Haliotis laevigata*) feeding on different algal diets or a formulated feed over the 23-wk growing period.

Diets	Growth Rates (μm·day^{-1})	SGR (length % day^{-1})	Weight Gain (g)	Survival (%)
Formulated feed	52.16 ± 8.5	0.47 ± 0.01	0.32 ± 0.01	62 ± 2.4
Ulva - *Navicula* - *Ulvella*	105.31 ± 8.4	0.63 ± 0.02	0.57 ± 0.03	68 ± 8.5
Ulvella - *Navicula* (low stocking)	47.62 ± 8.2	0.48 ± 0.01	0.35 ± 0.02	90 ± 14.1
Ulvella - *Navicula* (high stocking)	34.28 ± 4.9	0.37 ± 0.01	0.19 ± 0.01	73 ± 1.2

system at higher stocking density (80 juveniles per plate) showed reduced growth rates compared with the low stocking density (40 juveniles per plate) and juveniles in the tank system feeding on formulated diet.

During the experiment the average seawater temperature increased from 15.0°C to 20.4°C (Fig. 3). The largest increase in seawater temperature occurred between week 10 and 13 (15.5°C to 18.8°C). During the first three months, when the average seawater temperature was below 16°C, juveniles grew at similar rates in all treatments (Fig. 3, $P > 0.05$). However at week 20 and after the rise in average seawater temperature, juveniles feeding on the combination of all three algae showed significantly higher specific growth rates (0.62% day^{-1}) than juveniles on the formulated diet (0.41% day^{-1}) and juveniles at high stocking density (0.41% day^{-1}) (Tukey posthoc test, $P < 0.05$). In addition at week 23 the combined algal diet produced significantly higher specific growth rates (0.63% day^{-1}) than the formulated diet (0.47% day^{-1}) and *U. lens* plus *N.* cf. *jeffreyi* both at low (0.48% day^{-1}) and high stocking density (0.37% day^{-1}).

The average weight gain per individual abalone was highest in the *Ulva* sp. treatment (0.57 ± 0.03 g per individual) (Table 3). The weight gain was similar in *U. lens* plus *N.* cf. *jeffreyi* treatment at low stocking density (0.35 ± 0.02 g per individual) and in formulated feed treatment (0.32 ± 0.01 g per individual) but lower in nursery tanks with high stocking density (0.19 ± 0.01 g per individual).

Juveniles survived best on the *U. lens* plus *N.* cf. *jeffreyi* diet (90% ± 14.1% and 73% ± 1.2% for low and high stocking density, respectively), followed by the mixed diet including *Ulva* sp. germlings (68% ± 8.5%) and the formulated feed treatment (62% ± 2.4%). However there was no significant difference between the treatments (Table 3, $P > 0.05$).

Algal Density and Cover

Navicula cf. *jeffreyi* cell density declined rapidly as the experiment progressed particularly in the highly stocked tanks (Table 4). The *Ulva* sp. germling density followed a similar trend. Apart from initial levels, algal density peaked at 10 wk, in highly stocked tanks, and at 13 wk, in tanks with lower stocking density. Algal feed density, particularly of the diatom *N.* cf. *jeffreyi*, was significantly lower in highly stocked tanks compared with tanks with lower stocking density towards the end of the experiment but increased again between week 20 and 23. Both *U. lens* and *N.* cf. *jeffreyi* cover and density started lower in the treatment with *Ulva* sp. germling than in the other two treatments and increased as the *Ulva* sp. germling density decreased resulting in a peak at the end of the experiment. The specific growth rate was significantly affected by the *U. lens* and *N.* cf. *jeffreyi* cover and density at the end of the experiment, ($R^2 = 0.95$, $F_{4,4} = 18.11$, $P = 0.01$).

DISCUSSION

The first experiment indicated, that the algal diet *Ulvella lens*, provided on vertical plates in nursery tanks, is a more suitable food source for smaller abalone juveniles (5–7 mm in shell length) than a formulated diet fed in a different tank system. Growth rates of over 100-μm·day^{-1} were achieved on the algal diet during the first month of the experiment but declined continuously as the experiment progressed. This coincided with a decline in average seawater temperature. It is likely that the light intensity declined as well during the experiment in late autumn and winter, both influencing the low occurrence of natural diatoms on the plates. High cover of *U. lens* was maintained during the whole experiment because new spores were released at regular intervals. However, it is likely that the abalone biomass on the plates became too high to sustain adequate growth on an algal diet of *U. lens* only. High growth rates of over 70-μm day^{-1} were maintained with a commercial formulated diet when juvenile abalone reached 7 mm in shell length. Similar growth rates have been reported with different abalone species at similar size (Viana et al. 1993, Fleming et al. 1996, Knauer et al. 1996). In a previous study, growth rates of juvenile greenlip abalone (3–5 mm in shell length) feeding on a formulated diet were very low at the start of the experiment and increased slightly as the experiment continued but *U. lens* diet produced superior growth throughout the

TABLE 4.

Algal feed density throughout the experimental period.

Species	Weeks 0	4	10	13	16	20	23
Navicula sp. (cells cm^{-2})							
high stocking	986	433	806	462	270	0	244
low stocking	1,015	691	654	1,451	350	264	456
with *Ulva*		11,389	2,460	3,047	1,453	840	3,070
Ulvella lens (% cover)							
high stocking	66	59	64	58	54	31	37
low stocking	65	59	75	67	62	57	51
with *Ulva*		21	33	61	57	66	65
Ulva sp. (germlings cm^{-2})							
with *Ulva* (low stocking)		765	300	62	52	38	65

experiment (Daume & Ryan 2004). The current study tested juveniles of larger size in a more suitable tank system.

Results of the second experiment indicate that abalone juveniles readily graze on *Ulva* sp. germlings. The mixed algal diet including these germlings provided the best growth rate (105-µm day^{-1}) and the best weight gain per individual when stocked with ca. 40 juveniles per plate. This result may be due to the additional algal biomass available or to the added nutritional value of the *Ulva* sp. germlings. Similarly, Naidoo et al. (2006) found that juvenile *H. midae* (34.7 mm in shell length) were growing better on a mixed seaweed diet compared with single species diet. Mixed algal diets may provide a better balance of nutrients and single species diets could lack key nutrients needed for growth (Brown et al. 1997). *Ulva* sp. germlings might thus be a suitable and practical additional food source for advanced juveniles in a commercial nursery. Similar growth rates were reported when *Haliotis discus discus* was feeding on germlings of the brown algae *Colpomenia sinuosa* and *Ectocarpus siliculosus* as well as the green algae *Enteromorpha* spp. (Maesako et al. 1984). Strain et al. (2006) reported slightly lower growth rates on a combined *Ulva* sp. germling and *N.* cf. *jeffreyi* diet and did not find a significant difference between that mixture and an *U. lens* and *N.* cf. *jeffreyi* diet in a 14-wk experiment. In the present study we found significant differences in growth rates between the algal diets at the end of a 23-wk experiment. However, we used a diet consisting of a combination of 3 algal species, including *U. lens* to the *Ulva* sp. germling and *N.* cf. *jeffreyi*. It is likely that the higher seawater temperature at this stage of the experiment occurred together with an increase in light intensity resulting in the observed increase in feed density, particularly in the 3 species combined treatment, towards the end of the experiment and higher juvenile growth rates. Growth was strongly affected by the algal food density.

Growth rates of juveniles at low and high stocking density on the same *U. lens* and *N.* cf. *jeffreyi* diet fluctuated with food density. The high stocking density of 80 juveniles per plate in the *U. lens* and *N.* cf. *jeffreyi* diet was sustainable for 13–16 wk when juveniles reached 10 mm in shell length, after which growth rates declined, while the food density declined. However growth rates recovered in that treatment after 20-wk and a slight increase in food density was apparent because of diatom inoculation and additional release of spores of *U. lens* (Table 4). In comparison, in the low-density treatment (40 juvenile per plate) high growth rates were maintained until week 20, after which growth rates declined, whilst the % cover of *U. lens* declined. Results suggest that even when food is provided in excess, growth rates are highly dependent on food density. In addition the results indicate that growth rates can recover under high grazing pressure, at high stocking density, if the food density is enhanced immediately. However, overall growth rates were higher in the low stocking density treatment, suggesting to stock juveniles at lower density to avoid decline in growth rates or further handling.

In both experiments juveniles survived better on algal diets in nursery tanks than in different tanks feeding on formulated feed. However the initial mortality was high (approximately 10% during the first week) particularly in this treatment because of the change in diet and handling and declined in all treatments to less than 1% mortality per week. Further experiments have revealed that providing an algal diet while gradually introducing the formulated diet for the first few weeks will reduce the initial weaning mortality (unpublished data). High survival was observed in the *U. lens* and *Navicula* treatments, particularly at low stocking density. However a large difference in survival occurred between the replicated tanks (evident by the S.E. Table 3), explaining why there was no significant difference in survival between treatments. Similarly, a large difference occurred between tanks in the mixed diet including *Ulva* germlings. Differences between tanks are possibly caused by differences in light intensity across adjacent tanks, which can be seen in abalone nursery environments, resulting in differences in food density, as previously reported by Daume et al. (2004).

Both experiments showed low initial growth rates in the formulated feed treatment. Growth rates increased as the trial progressed and overall were comparable to growth rates achieved in *U. lens* plus *N.* cf. *jeffreyi* diet at low stocking density. Growth rates declined when the seawater temperature increased between week 10 and 13, but recovered once the temperature stabilized. These results indicate that once *H. laevigata* reach a certain size (7–8 mm in shell length) a commercial formulated feed can support adequate growth, however higher mortality can be expected on this diet when first weaned onto the diet and growth rates can decline when seawater temperatures first increase.

Daume and Ryan (2004) suggested that a commercial formulated feed might be suitable for juveniles (*Haliotis laevigata*) larger than 4 mm in shell length. The present study indicates that high growth rates on a formulated feed can be maintained once juveniles, *H. laevigata*, reach 7 mm in shell length. We recommend delaying the weaning process if seawater temperatures are above 19°C to avoid higher mortalities and reduced growth rates. Our results show that juvenile abalone can be maintained on plates to larger sizes (e.g., 17 mm in shell length) with *Ulva* sp. germlings, and higher growth rates can be achieved than on a formulated diet fed in a different tank system, particularly at high seawater temperature (over 19°C).

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