

## The growth of post-weaning abalone (*Haliotis midae* Linnaeus) fed commercially available formulated feeds supplemented with fresh wild seaweed

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### Abstract

The effect of five formulated feeds, supplemented with fresh wild seaweed on the growth of post-weaning juvenile abalone (6 - 20 mm shell length), *Haliotis midae* Linnaeus was investigated by means of a growth trial at a commercial abalone farm over a period of 11 months. The experiment included 10 diet treatments with two replicates each (n = 50 individuals per replicate). The first five diet treatments comprised of four fishmeal-based formulated feeds: Abfeed®, Adam & Amos® 'a', Adam & Amos® 'b' and Adam & Amos® 'c'; and an all-seaweed-based formulated pellet: FeedX. The additional five diet treatments comprised the formulated feeds above, supplemented with fresh, wild seaweeds; the kelp, *Ecklonia maxima* (5-15% protein) and *Ulva lactuca* (3.7-19.9% protein). The fishmeal-based protein feeds produced significantly better growth than the all-seaweed-based protein feed, FeedX (0.49±0.03 SGR; 27.15±0.02 DISL; 0.864 final CF). Abfeed® (1.00±0.02 SGR; 60.79±0.04 DISL; 1.312 final CF) performed best of all the formulated feeds. Supplementation with fresh wild seaweed, however, significantly improved growth of all abalone with supplemented Abfeed® (1.05±0.02 SGR; 63.61±0.05 DISL; 1.447 final CF) outperforming all supplemented feeds. More striking though was that the condition factor of abalone fed that feed (FeedX) that performed particularly poorly in the growth trials was dramatically improved by supplementation. The results of this study show that supplementation with fresh wild seaweed enhances the growth of abalone reared on formulated feeds.

**Key words:** Abfeed®, Adam & Amos®, diet, formulated feed, growth, *Haliotis midae*, seaweed, supplementation.

### Introduction

Kelp as a feed is either absent, scarce or insufficient to sustain the current commercial production of abalone (Anderson *et al.* 2003, Viera *et al.* 2005, Johnston *et al.* 2005, Anderson *et al.* 2006, Troell *et al.* 2006) and this has prompted research into the production and use of various artificially formulated feeds. In South Africa, two formulated feed brands are currently in production. Of the two feeds, only Abfeed® (Marifeed Pty Ltd., South Africa) comes close to meeting the nutritional requirements of *Haliotis midae* Linnaeus and is consequently the most widely used formulated feed in South Africa. A number of studies (e.g. Britz *et al.* 1994, Britz 1996a, b) have shown that Abfeed® dramatically improves growth over other feeds. Recent research by Naidoo *et al.* (2006) has shown that incorporating fresh, protein-enriched seaweed combinations into the diet of *H. midae*, may significantly improve growth even over formulated feeds. With the exception of Knauer *et al.* (1996), all these studies have concentrated on grow-out juveniles (abalone with a shell length > 20 mm); none so far have attempted to test different feed combinations on the growth of post-weaning juvenile abalone (abalone with a shell length > 6mm, but < 20 mm).

Besides the two formulated feed brands under production in South Africa, a number of other formulated feeds have been imported into South Africa (e.g. Adam & Amos® - Adam & Amos Abalone Foods Pty Ltd, Australia) for testing on local abalone farms. As far as we are aware, no published data exists on the effects of different internationally available formulated feeds on the growth of commercially farmed *H. midae*. In addition, feeding strategies are rapidly evolving and there is a need to test different feed combinations. This study was therefore designed to determine the comparative performance of the two commercially available South African formulated feed brands and one Australian brand, and the effects of wild seaweed supplementation of the formulated feeds on the growth of post-weaning *H. midae*.

## **Material and Methods**

The research was conducted at the Jacobsbaai Sea Products (17° 53' 12.5" E, 32° 58' 2.5" S, Western Cape, South Africa) commercial abalone farm. Moderately aerated seawater with a flow rate of 1400 ±100L.h<sup>-1</sup> was supplied at 14.5±2.5°C in concrete production tanks (5500 x 1300 x 550mm; length, width, depth). The flow direction within each tank was alternated weekly to compensate for end effects. Abalone were grown in culture baskets (800 x 570 x 250mm; length, width, depth) subdivided with

vertically orientated feeding plates to increase the surface area. A horizontal feeder plate (600 x 380mm) was centrally positioned above the vertical plates. Culture baskets had perforations (5mm diameter) at their bases to allow for downward circulation. This design provided optimum access to feed with no visible feed wastage.

### *Experimental animals*

Post-weaning juvenile abalone from the same broodstock pool were supplied by the Jacobsbaai Sea Products commercial abalone farm. All abalone used were spawned in July 2003 and were approximately six months old at commencement of the experiment. Prior to commencement of the experiment, the abalone underwent a 2-week conditioning period and were fed only *Ecklonia maxima* (Osbeck) Papenfuss and *Ulva lactuca* Linnaeus. The abalone were then subdivided into two replicate baskets of 1000 individuals per replicate, per diet treatment. The initial weight and shell length of the abalone were measured at  $0.295 \pm 0.005$ g and  $12.72 \pm 0.015$ mm respectively. Thereafter, both body weight and shell length were measured monthly.

### *Diets*

Ten (10) diet treatments were tested during the experiment of which five comprised formulated feeds; Abfeed® (Marifeed Pty Ltd, South Africa), Adam & Amos® 'a' (AAa), Adam & Amos® 'b' (AAb), Adam & Amos® 'c' (AAc) (Adam & Amos Abalone Foods Pty Ltd, Australia) and FeedX; and five the formulated feeds supplemented with fresh wild seaweeds *Ecklonia maxima* (5-15% protein) and *Ulva lactuca* (3.7-19.9% protein). The first four formulated feeds comprised of animal-based protein while FeedX was an all-seaweed-based protein feed. Most formulated feeds are protein enriched, containing fishmeal as the primary source of protein (Fleming *et al.* 1996, Folke *et al.* 1998, Guzmán and Viana 1998). All formulated feeds tested were sent away to an independent laboratory (Animal Production Laboratory, Institute for Animal Production, Department of Agriculture: Western Cape, Elsenburg) for compositional analysis (see Table 1). The approximate dry dimensions of the various feed pellets are specified in Table 1. The additional five treatments comprised the kelp *E. maxima* because it is the natural diet of *H. midae*. *Ulva lactuca* was also selected because previous studies (e.g. Schoenhoff *et al.* 2003, Najmudeen and Victor 2004, Naidoo *et al.* 2006) had shown that, when used as a supplement, it resulted in significant increases in growth. *Ulva lactuca* also has a

broad global distribution (Silva *et al.* 1996, Stegenga *et al.* 1997) and is locally readily available (Robertson-Andersson 2003). Experimental animals were fed the formulated feeds 2-3 times per week as per the manufacturer's prescription per mean abalone body weight. The seaweeds were fed *ad libitum* i.e. there was never a lack of either of the two seaweeds in the culture baskets. Tanks and baskets were cleaned every eight days to remove any faeces and uneaten feed.

Table 1. Nutritional analysis and approximate dimensions of pellets of the various formulated feeds including FeedX.

Feed	Moisture (%)	Ash (%)	Protein (%)	Fibre (%)	Fat (%)	Carbohydrate (%)	Dimensions (length:width:thickness) (mm)
Abfeed®	~10	5.6	34.7	1.6	2.4	57.3	17: 9: 1
AAa	~10	7.8	34.2	1.8	2.3	55.2	6: 6: 2
AAb	~10	7.8	28.8	2.1	3.2	60.2	6: 6: 2
AAc	~10	7.6	28.1	2.3	3.3	61.0	6: 6: 2
FeedX	~10	32.9	19.2	10.9	0.7	47.3	40: 10: 2

#### *Sampling and data collection*

The experiment was conducted over 11 months. Monthly measurements of 50 individuals from each of the 2 replicates were randomly taken. Before all weight measurements, abalone were blotted dry to remove excess water. Weight was recorded to 0.01g while shell length was measured along the longest axis to the nearest 0.01mm.

Daily increment increase in shell length (DISL) was calculated using the formula of Mai *et al.* (2001) and Zhu *et al.* (2002):

$$\text{DISL } (\mu\text{m/day}) = [(\text{SL}_t - \text{SL}_i) / t] \times 1000$$

Where  $\text{SL}_t$  = final mean shell length,  $\text{SL}_i$  = initial mean shell length,  $t$  = the feeding trial period in days.

Abalone specific growth rate (SGR in %weight.day<sup>-1</sup>) was calculated as in Neori *et al.* (2000) using the formula:

$$\text{SGR} = \frac{\{\ln(W_f) - \ln(W_i)\}}{t} \times 100$$

Where  $\ln(W_f)$  = the natural log of the final mean weight,  $\ln(W_i)$  = the natural log of the initial mean weight,  $t$  = the feeding trial period in days.

### *Condition factor*

The condition factor, which is an index that was developed to account for the relationship between the weight of abalone per unit shell length, was calculated using the formula of Britz (1996b).

$$CF \text{ (g.mm}^{-1}\text{)} = [\text{BW (g) / SL (mm)}^{2.99}] \times 5575$$

Where CF = the condition factor, BW = the mean body weight, SL = the mean shell length, 2.99 and 5575 are Britz (1996b) constants.

### *Statistical analysis*

Unless otherwise stated, all data are expressed as means  $\pm$  se. Data for experimental replicates were pooled as no significant differences were found between them. Since there was no significant variation around the starting values for both weight and length, and since one factor (diet type) was tested against one variable (growth), a one-way analysis of variance (ANOVA) was used to compare the differences between the final means of all treatments. To test for correlation, the body weight and shell length of abalone from each diet treatment were compared by means of a linear regression test. All results were considered statistically significant at  $P < 0.05$ .

## **Results**

### Growth

Supplementing the formulated feeds with fresh wild seaweed significantly improved the growth ( $P=0.005$ ) of all abalone (Table 2). With regard to the specific growth rate (SGR), supplemented Abfeed® ( $1.05 \pm 0.03$  % weight.day<sup>-1</sup>) performed best. Abfeed® ( $1.00 \pm 0.03$  % weight.day<sup>-1</sup>) on its own also produced a high SGR. There was no difference ( $P=0.9469$ ) in the growth of abalone fed either of the different unsupplemented Adam & Amos® feeds. Abalone fed the animal-based protein feeds fared significantly better ( $P=0.0037$ ) than those fed the all-seaweed-based formulated feed (Figure 1). The relative increase in growth (i.e. difference between the supplemented and its unsupplemented counterpart) was, however, more dramatic for the poorest performing FeedX.

With regard to the daily increment increase in shell length (DISL), the supplemented AAa feed yielded the highest growth ( $67.21 \pm 0.05 \mu\text{m}\cdot\text{day}^{-1}$ ) followed closely by the supplemented Abfeed® ( $63.61 \pm 0.05 \mu\text{m}\cdot\text{day}^{-1}$ ) (Table 2). Unsupplemented FeedX yielded the lowest increase in shell length ( $27.15 \pm 0.02 \mu\text{m}\cdot\text{day}^{-1}$ ).



Table 2. Growth parameters of post-weaning abalone grown on the 10 diet treatments. Diets are ranked by their SGR. Means with the same letter are not statistically different.

Diet	Final weight (g)	Final length (mm)	SGR (%weight.day <sup>-1</sup> )	DISL (µm.day <sup>-1</sup> )	Initial CF (g.mm <sup>-1</sup> )	Final CF (g.mm <sup>-1</sup> )	Correlation		Rank			
							r	r <sup>2</sup>	SGR	DISL	CF <sup>1</sup>	CFdiff <sup>2</sup>
Abfeed®+U/K	9.60±0.21 <sub>a</sub>	33.71±0.34 <sub>b</sub>	1.05±0.02 <sub>a</sub>	63.61±0.05 <sub>b</sub>	0.965 <sub>a</sub>	1.447 <sub>a</sub>	0.95	0.90	1	2	1	0.240
AAa+U/K	8.59±0.23 <sub>b</sub>	34.90±0.34 <sub>a</sub>	1.02±0.02 <sub>b</sub>	67.21±0.05 <sub>a</sub>	0.919 <sub>a</sub>	1.167 <sub>b</sub>	0.97	0.94	2	1	2	0.091
Abfeed®	8.01±0.23 <sub>c</sub>	32.78±0.34 <sub>c</sub>	1.00±0.02 <sub>c</sub>	60.79±0.04 <sub>cd</sub>	1.070 <sub>a</sub>	1.312 <sub>ab</sub>	0.97	0.95	3	4	3	-
AAc+U/K	7.26±0.19 <sub>d</sub>	32.79±0.35 <sub>c</sub>	0.97±0.02 <sub>d</sub>	60.82±0.05 <sub>c</sub>	1.014 <sub>a</sub>	1.189 <sub>b</sub>	0.96	0.92	4	3	5	0.166
AAb+U/K	6.39±0.21 <sub>e</sub>	32.15±0.32 <sub>c</sub>	0.93±0.02 <sub>e</sub>	58.88±0.04 <sub>d</sub>	0.969 <sub>a</sub>	1.110 <sub>b</sub>	0.97	0.94	5	5	7	0.066
AAb	4.90±0.15 <sub>f</sub>	29.79±0.34 <sub>d</sub>	0.85±0.02 <sub>f</sub>	51.73±0.04 <sub>e</sub>	0.993 <sub>a</sub>	1.068 <sub>bc</sub>	0.98	0.96	6	6	8	-

<sup>1</sup> The CF rank is based on the difference between the initial and final CF values.

<sup>2</sup> The CFdiff is the proportion of weight gained by the supplemented feed compared against its unsupplemented counterpart e.g. (final CF of supplemented feed - initial CF of supplemented feed) – (final CF of unsupplemented feed - initial CF of unsupplemented feed).

AAa	4.76±0.13 <sup>f</sup>	28.94±0.28 <sup>e</sup>	0.84±0.02 <sup>f</sup>	49.15±0.04 <sup>f</sup>	0.974 <sup>a</sup>	1.131 <sup>b</sup>	0.98	0.96	7	7	6	-
AAc	4.44±0.12 <sup>g</sup>	27.90±0.24 <sup>f</sup>	0.82±0.02 <sup>fg</sup>	46.00±0.02 <sup>g</sup>	1.170 <sup>a</sup>	1.178 <sup>b</sup>	0.98	0.97	8	8	9	-
FeedX+U/K	4.19±0.17 <sup>g</sup>	27.71±0.35 <sup>f</sup>	0.80±0.02 <sup>g</sup>	45.42±0.06 <sup>g</sup>	0.929 <sup>a</sup>	1.134 <sup>b</sup>	0.97	0.94	9	9	4	0.398
FeedX	1.53±0.06 <sup>h</sup>	21.68±0.25 <sup>g</sup>	0.49±0.03 <sup>h</sup>	27.15±0.02 <sup>h</sup>	1.057 <sup>a</sup>	0.864 <sup>c</sup>	0.99	0.98	10	10	10	-

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Key: SGR = specific growth rate; DISL = daily increment increase in shell length; CF = condition factor; CDdiff = the difference in CF values between supplemented and unsupplemented counterpart feeds; AAa = Adam & Amos® 'a'; AAb = Adam & Amos® 'b'; AAc = Adam & Amos® 'c'; U/K = Ulva and kelp supplementation.



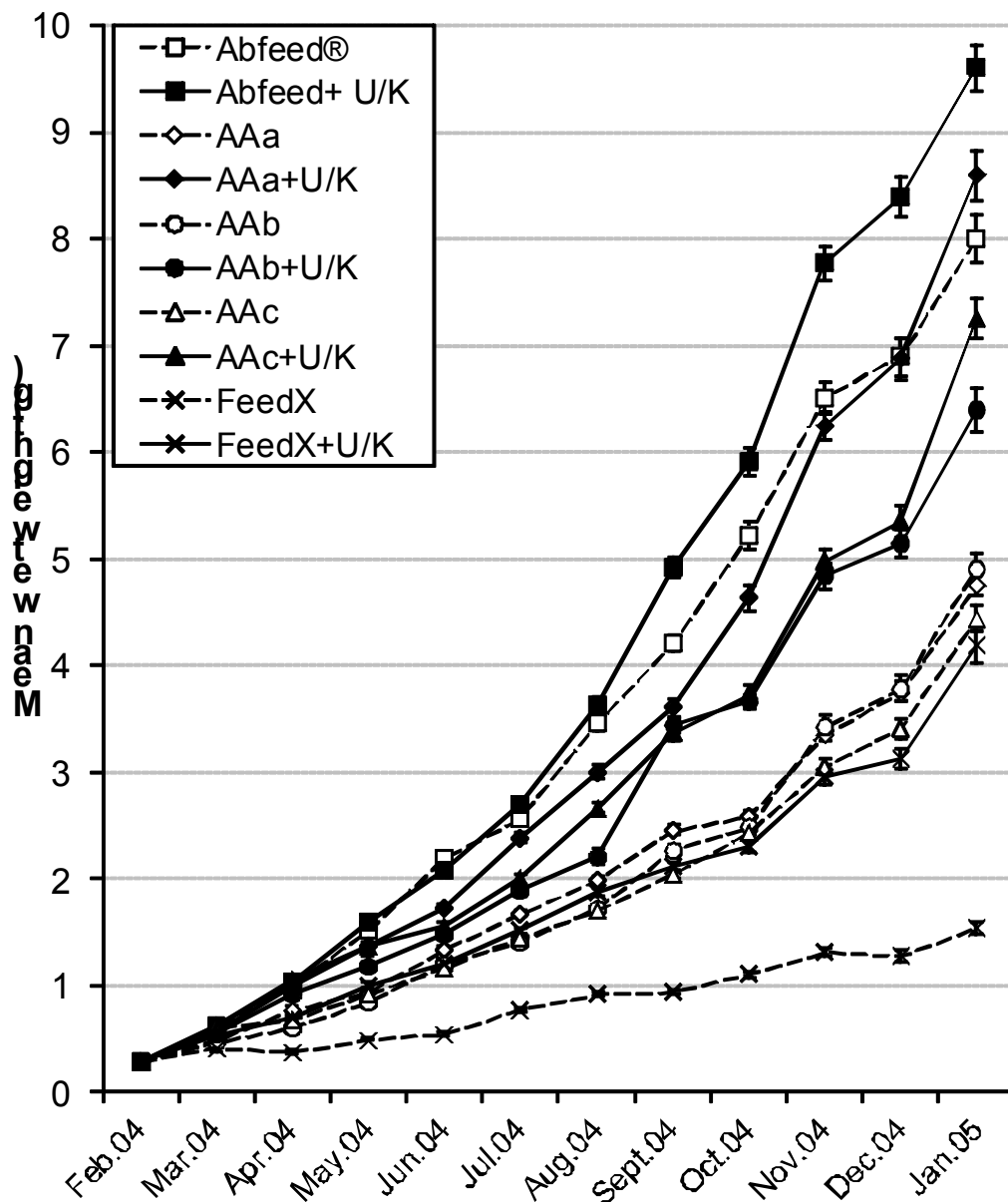


Figure 1. Increase in body weight (mean + se) of post-weaning juvenile *H. midae* grown on five formulated feeds which were then supplemented with fresh kelp and *Ulva lactuca*.

#### Condition factor

Except for the poor performing FeedX that had a negative final CF response, all feeds had improved CF values by the end of the experiment (Table 2). Supplementation with fresh wild seaweed in particular, significantly improved the condition factors of

all abalone. Even more striking was that the condition factor of abalone fed FeedX was dramatically improved by supplementation with fresh wild seaweed, with this feed gaining the largest CF difference (0.398).

## **Discussion**

Supplementing the formulated feeds with fresh wild seaweed significantly improved the growth of all abalone. This was no doubt due to the contribution of fresh seaweeds toward the nutrients that may have been lacking in the formulated feeds. Although fresh wild seaweed typically have low protein contents, (Fleming *et al.* 1996, Robertson-Anderson 2003, Johnston *et al.* 2005), both *E. maxima* (Stepito and Cook 1993, Simpson 1994) and *Ulva* spp. (Schoenhoff *et al.* 2003, Najmudeen and Victor 2004) have been shown to be valuable supplementary feeds that promote good growth in *H. midae*. The relatively high nutritional value of the formulated feeds on the other hand, probably accounted for the enhanced growth recorded with the supplemented diets.

In this study, the all-seaweed based formulated feed (FeedX) performed particularly poorly. It is currently documented that the major nutritional requirements for optimum growth in abalone include the necessary carbohydrate (Nelson *et al.* 2002) and protein ratios (Fleming *et al.* 1996, Guzmán and Viana 1998). While the carbohydrate content of the best performing formulated feed (Abfeed®, 57.3%) and the worst performing FeedX (47.3%) are both within the optimal range for abalone requirements (i.e. 43-48%, Sales and Janssens 2004), differences in their performance may be explained by the differences in their crude protein contents. Although the optimum dietary crude protein requirements of *H. midae* was reported to be about 47% (Britz 1996b), Sales *et al.* (2003) suggested an optimum of around 36%. Not only did FeedX (19.2%) have a substantially lower crude protein content than Abfeed® (34.7%), but animal-based proteins are more readily digested than plant-based proteins (Durazo-Beltrán *et al.* 2003). FeedX consists of dried seaweed and research (e.g. Britz 1996b, Naidoo *et al.* 2006) has already shown that abalone fed only dry seaweed, grow very poorly. The protein and carbohydrate contents of the Adam & Amos® feeds were relatively similar to those of Abfeed®, so these two factors alone could not have accounted for the poorer growth obtained with the Adam & Amos® feeds. Further studies are needed to elucidate these differences. In

addition to the low protein content, a low palatability could also have accounted for the poor growth obtained with FeedX. When the baskets were cleaned, more uneaten bits of FeedX were observed relative to other feeds, indicating that the abalone consumed less of this feed. It is known that less palatable feeds become wasted and because feed intake is low, this results in low growth rates (Kautsky *et al.* 2001, Lee *et al.* 2004). The probable lower palatability of FeedX could have been due to the absence, or reduced effects, of attractants that may otherwise be active in fresh feeds (Fleming *et al.* 1996, Sales and Janssens 2004).

Supplementing the formulated feeds with fresh wild seaweed also resulted in higher CF values. Considering that Boarder and Shpigel (2001) reported that feeding on *Ulva* alone produced relatively low CF values in abalone, supplementing with fresh wild *U. lactuca* alone could not solely have accounted for the recorded higher CF values obtained in this study. On the other hand, Naidoo *et al.* (2006) showed that supplementing Abfeed® with only fresh kelp produced a significantly higher body-weight to shell length ratio relative to Abfeed® on its own. The higher CF values observed for the supplemented feeds are therefore probably due to a compensation of nutrients and attractants lacking in *U. lactuca* by those present in both fresh kelp and the formulated feeds.

In conclusion, this study is consistent with previous work (e.g. Hahn 1989, Guzmán and Viana 1998, Bautista-Teruel *et al.* 2003, Lee 2004) showing that animal-based protein feeds firstly yield better growth rates than seaweed-based protein feeds. The commercially available Abfeed® outperformed all other formulated feeds tested, reflecting it as the better formulated feed for post-weaning *H. midae*. Secondly, supplementing the formulated feeds with fresh wild seaweed resulted in even better growth. The results of this study clearly show the benefits of supplementing existing formulated feeds with fresh seaweed combinations.

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