Journal of Applied Phycology (2006) 18: 437–443
DOI: 10.1007/s10811-006-9045-7

A comparison of various seaweed-based diets and formulated feed on growth rate of abalone in a land-based aquaculture system

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Key words: abalone, diet, growth, seaweed, *Ecklonia*, *Haliotis midae*

Abstract

The effects of different diets on growth in the cultured South African abalone, *Haliotis midae* (Linnaeus), was investigated. Growth of juvenile *Haliotis midae* was monitored on a commercial abalone farm over a period of 9 months in an experiment consisting of 9 treatments with 4 replicates ($n = 250$ individuals per replicate). The treatments were: fresh kelp (*Ecklonia maxima*) blades (seaweed control); Abfeed® (formulated feed control); kelp + Abfeed®; dried kelp pellets; dried kelp blades; dried kelp stipes; fresh kelp with the epiphyte *Carpoblepharis flaccida*; a mixed diet (*Gracilaria gracilis*, *Ulva lactuca*, and kelp) and a rotational diet (abalone were fed 1 of the 9 treatments for the first week and them kelp for the next 3 weeks). Results show that abalone grow well on all fresh seaweed combinations, but grow best on a mixed diet. The likely reason for the success of the mixed diet is that the red and green seaweed was farm grown, with an increased protein content. Dried kelp in any form produced poor growth. Abalone fed on the mixed diet grew at 0.066 mm day^{-1} shell length and 0.074 g day^{-1} body weight; this corresponds to 24.09 mm shell length and 27.01 g body weight increase per annum. Abalone fed on dried kelp grew at only 0.029 mm day^{-1} shell length and of 0.021 g day^{-1} body weight. Abalone grown on Abfeed® grew at 0.049 mm day^{-1} shell length and 0.046 g day^{-1} body weight which corresponds to 17.88 mm and 16.79 g increase per annum; this is better than the dried seaweed feeds, but poorer than the fresh seaweed combinations. This study shows that seaweed diets, particularly if the diets include seaweeds grown in animal aquaculture effluent, are good substitutes for the formulated feed generally used today.

Introduction

The South African abalone, *Haliotis midae* Linn., is a highly sought-after delicacy in the Far East, which is the destination of 90% of the product from the local fishery (Britz et al., 1994). Of 6 abalone species in South Africa, only *H. midae* is presently fished commercially. Although the South African abalone fishery has existed since 1949, the first attempts at cultivating *H. midae* commercially were only made in 1981 when captured specimens were successfully spawned to produce spat and juvenile abalone (Genade et al., 1988). In 2001, twelve abalone farms, with an estimated investment of US$ 12 million, had been established on the South African coast (Sales & Britz, 2001). By 2003, this had increased to 18 farms, with a projected production of 527 and 700 tons per annum for 2003 and 2004 respectively (Gerber, 2004).

The proper nutrition and the resulting growth of cultured abalone are critical factors in the successful culture of this animal. While *H. midae* can reach a maximum size of about 200 mm shell length at an age of over 30 years in the wild, farm production is aimed towards an average size of only 100 mm, which is currently achieved after 5 years (Sales & Britz, 2001). Abalone growth is extremely slow and often varies with size and age. Diet is therefore very important and it has been shown that different diets produce different growth rates (Leighton, 1974; Britz, 1996a; Guzmán & Viana, 1998; Shpigel et al.,

1999; Boarder & Shpigel, 2001; Bautista-Teruel et al., 2003).

Abalone begin to feed immediately after larval settlement, initially consuming benthic diatoms (Tutschulte & Connell, 1988). As they grow, they begin feeding on macroalgae and in the wild may change from one species of macroalga to another as they mature (Stepto & Cook, 1993). Preferences exist, with red algae being favoured by a number of different abalone species (Tutschulte & Connell, 1988; Shepherd & Steinberg, 1992; Stepto & Cook, 1993; Fleming, 1995). Juveniles begin to eat macroalgae at about 10 mm shell length and will eat from 10 to 30% of their body weight in algae each day and have high feeding rates that are due to the high water content and relatively low protein content of macroalgae (Hahn, 1989).

Research thus far has dealt mainly with the natural diet of wild abalone, single-species diets in culture, and more recently, the production of formulated diets (Simpson & Cook, 1998; Sales & Janssens, 2004). Wild abalone generally feed on a broad selection of algae, normally with at least two species being found in the gut at any one time (Barkai & Griffiths, 1986). This implies that abalone typically select more than just a single species and preferentially choose a mixture of algae. In this study we test the effects of various diets on the growth of juvenile abalone in commercial aquaculture systems, including a formulated feed, dry and fresh kelp, and a mixture of kelp, kelp epiphytes, and farm grown seaweed.

Materials and methods

Experimental animals

Abalone of a specific age class often vary in size because of their different feeding rates. For this reason, juvenile abalone of the same age and similar size were chosen as test animals. Hatchery-reared animals (from the Jacobsbaai Sea Products farm), spawned in September 2002, approximately 22 months old, 34.7 ± 5.8 mm in shell length, and 7.8 ± 3.8 g in body weight, were used to test the growth response of juvenile abalone fed on 9 different diets. Flow-through seawater (700 ± 100 L h^{-1}), moderately aerated, was supplied at a temperature of 15.5 ± 2.5 °C in the holding tanks. Abalone were grown in culture baskets, with a stocking density of 5 kg (±500 individuals) per basket. Each basket was subdivided, using mesh, to produce 2 replicates (a stocking density of ±250 individuals per replicate) and two baskets were used for each treatment, i.e. $n = 4$ replicates. Growth was monitored over a 9-month period.

Diets

The 9 diets consisted of: fresh kelp (*Ecklonia maxima* [Osbeck] Papenf.) blades (seaweed control); Abfeed® (formulated feed control); kelp + Abfeed®; dried kelp pellets; dried kelp blades; dried kelp stipes, kelp with a red algal epiphyte (*Carpoblepharis flaccida* [C.Ag.] Kütz.); a mixed diet (*Gracilaria gracilis* [Stackhouse] Steentoft, Irvine et Farnham, *Ulva lactuca* L. and kelp); and a rotation diet (where the abalone were fed 1 of the 9 treatments for the first week, and then kelp for the following 3 weeks). Abfeed® (Sea Plant Products Ltd, South Africa) is a formulated feed containing fishmeal (55%), starch, *Spirulina* spp. (10%), vitamins and minerals (Fleming et al., 1996). The approximate analysis of Abfeed® is 34.6% protein, 43.3% carbohydrates, 5.3% fat, 1.2% crude fibre, 5.7% ash and ~10% moisture (Sea Plant Products Ltd, pers. com.). All kelp was harvested locally. Kelp was chosen as a seaweed control because it is most commonly used as fresh abalone feed in South Africa. Abfeed® was used as an formulated control feed because it is the most common artificial food pellet used on commercial abalone farms in South Africa. *Ulva lactuca* and *G. gracilis* for the mixed diet were obtained on the farm from a cultured stock grown in abalone and fish (turbot) effluent. These seaweeds grown in abalone and turbot effluent have considerably higher nitrogen content than seaweed collected from local seashores (Robertson-Andersson, 2004; Robertson-Andersson et al., 2006). *Ulva lactuca* grown in these systems has an average protein content of 33.4% when grown in abalone waste, and 36.6% when grown in turbot waste as opposed to 3.7–19.9% in wild *U. lactuca* (Robertson-Andersson, 2004). No protein values were available for *G. gracilis* but it is assumed that farm grown *G. gracilis* will also have considerably higher protein content than wild *G. gracilis*.

Representative animals were selected from each treatment ($n = 30$ at 0–2 months, $n = 40$ at 3–8 months and $n = 50$ at 9 months to compensate for differential growth). Abalone shell length and body weight were measured once a month for 9 months. Daily growth rates in terms of body weight (DGBW) and shell length