Larval abalone *Haliotis discus hannai* has a lecithotrophic planktonic stage lasting several days. Energy for the larvae is provided by yolk derived from the egg. Dissolved organic matter (DOM) from ambient seawater is reported to be another energy source for larval *H. rufescens*. When attachment/metamorphosis cues are provided, competent veliger larvae settle on a substratum and subsequently metamorphose into benthic post-larvae. During the metamorphosis, larval abalone shed the velum, develop enlarged gills and foot, and start peristomal shell formation. Post-larval abalone commence particle feeding with radula just after the completion of metamorphosis. During the first days of feeding, post-larvae still have a visible yolk, and it is suggested that initial growth (during the first 10 days after metamorphosis) is still supported by the yolk supply in addition to particle feeding. However, details of this transition in the energy source for post-larvae from endogenous to exogenous nutrition have not been examined. Food limitation during this transition period could have a harmful effect on the subsequent survival and growth. This paper examines the effects of delayed feeding on post-larval growth and survival and evaluates the role of endogenous nutrition during the transition period, to determine the ‘point of no return’ starvation period for newly metamorphosed abalone.

We used two separate batches of abalone larvae termed cultures I and II. The abalone of culture I were hatched in May 1998 at the Iwate Sea Farming Association (Iwate, Japan). Culture II abalone were hatched in October 1998 at the Fukushima Prefectural Aquaculture Fishery Association (Fukushima, Japan). Four days after fertilization at 20°C, the veliger larvae of both cultures were transported to the Tohoku National Fisheries Research Institute (Miyagi, Japan) within 5 h. Competent veliger larvae were placed into 6-well polystyrene tissue culture plates (16.8 mL in volume and 9.4 cm² in bottom surface area per well; Corning, New York, USA) at densities of 40–60 individuals per well with 5 mL of 0.45 μm-filtered seawater (FSW) containing 150 μg/mL each of Penicillin G sodium and Streptomycin sulfate BP. These veliger larvae were induced to metamorphose by the addition of 1 mM γ-aminobutyric acid (GABA). Plates were incubated at 20°C, at a light intensity of 23 μE/m² per s with a 12L:12D photoperiod, for 4 days. Less than 30% of the initially introduced veliger larvae metamorphosed into post-larvae at 2 days after the addition of GABA, but more than 70% metamorphosed at 4 days after the addition of GABA. Larvae that had not metamorphosed were removed, and only the post-larvae were used for the experiments. The day following a 4-day metamorphosis-induction period was termed Day 0.

Survival of post-larvae was significantly affected by the feeding delay in both cultures (Fig. 1). However, survival of post-larvae was significantly affected by the feeding delay in both cultures (Fig. 1). However,
Day 12 did not grow after food was provided (ANOVA, $P>0.05$).

The starvation period beyond which post-larvae could not recover was different between the two batches. In culture I, post-larvae fed on and after Day 4 suffered reduced growth and survival rates. In contrast, culture II post-larvae fed before Day 8 showed no large effect of starvation on survival and growth. The energy sources for veliger larvae are considered to be a yolk reserve derived from the egg and DOM absorbed from seawater.\(^2\)\(^-\)\(^4\) The different results in the starvation tolerance observed in the two batches could be caused by difference in quality of larvae such as yolk reserves, and/or difference in the DOM concentration of the natural seawater used for the rearing of swimming larvae. Further research is needed on the egg quality and DOM concentration affecting post-larval survival and growth.

The initial growth without particulate food observed in this study was also reported for \(H. \) \(rufescens\)\(^5\)\(^-\)\(^12\) and \(H. \) \(iris\).\(^13\) The visible yolk area of newly metamorphosed \(H. \) \(iris\) was greatly reduced during extended post-larval starvation (Roberts R, pers. comm., 1998). In this study, much of the visible yolk had disappeared after 10 days of starvation. Thus, normal development up to 400 \(\mu\)m SL without feeding could be supported by the yolk supply. Post-larval \(H. \) \(discus \) \(discus\) show massive mortality by the size of 500 \(\mu\)m SL when they lack food in hatcheries.\(^8\) Under experimental conditions, \(H. \) \(discus \) \(hannai\) less than 500 \(\mu\)m SL died when fed an unsuitable food source.\(^14\) From these previous findings and the results of this study,

**Fig. 1** Survival curves for first-feeding post-larval \(Haliotis \) \(discus \) \(hannai\) raised from different batches (culture I and II). Each curve traces the survival of a group fed on different days after metamorphosis. Symbols indicate the mean percentage of survivors in three (culture I) and six (culture II) replicates $\pm$SE.
Fig. 2 Growth curves for first-feeding post-larval Haliotis discus hannai raised from different batches (culture I and II). Each curve traces the shell length of a group fed on different days after metamorphosis. Symbols indicate the mean shell length in three (culture I) and six (culture II) replicates ±SE. The mean shell length of each replicate was calculated using the shell length of 10 randomly selected, live individuals (except where less than 10 animals remained alive).

It is considered that the energy source of post-larval abalone is gradually transferred from yolk supply to particulate food after metamorphosis by the size of 400–500 μm SL. Several days of food limitation after metamorphosis lead to a failure to shift to exogenous feeding.

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