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Growth of the Ass's Ear Abalone (*Haliotis asinina* Linné) on Heron Reef, Tropical Eastern Australia

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Abstract. Growth of ass's ear abalone (*Haliotis asinina*) was measured *in situ* (mark–recapture of adults) and in aquaria (juveniles) on Heron Reef, Queensland. A growth curve ($y = 4{\cdot}27l^{2{\cdot}03}e^{-u}$, where y is the growth rate, l is the shell length, and $u = 0{\cdot}27l^{0{\cdot}88}$) fitted to these data indicated a sigmoidal age–length relationship. It is estimated that *H. asinina* may grow from 2 mm to 35·6 mm in shell length in six months and 55·0 mm in one year. These growth estimates are consistent with temporal shifts in the size–frequency distributions of juveniles in the field. Peak growth rates, estimated at over 120 mm year^{-1} in young abalone (approximately 3–4 months of age), are the highest recorded for any abalone species.

Resumen. Se midieron las tasas de crecimiento de abulón oreja de burro (*Haliotis asinina*) *in situ* (marcaje–recaptura de adultos) y en acuario (juveniles) en el Arrecife de Heron, Queensland. Se ajustó una curva de crecimiento ($y = 4.27\, l^{2\cdot03}\, e^{-u}$, donde y es la tasa de crecimiento, l es la longitud de la concha, y $u = 0.27l^{0\cdot88}$) la cual mostró una relación sigmoidal entre edad y longitud. Se estima que *H. asinina* puede crecer desde 2 mm a 35·6 mm en longitud de concha en seis meses y hasta 55 mm en longitud en un año. Estas estimaciones son consistentes con el cambio temporal en las distribuciones tallas–frecuencias de juveniles *in situ.* Las mayores tasas de crecimiento fueron estimadas a más de 120 mm año^{-1} en juveniles (entre 3 y 4 meses de edad aproximadamente), y son las más altas en el mundo para cualquier especie de abulón.

Introduction

The ass's ear abalone (*Haliotis asinina* Linné) is the largest of the tropical abalone species and occurs throughout the Indo-Pacific. In South-East Asia it is an esteemed shellfish (Singhagraiwan and Sasaki 1991*a*, 1991*b*) and constitutes a large percentage of Hong Kong abalone imports (M. Rudd, personal communication). However, the species has been neither harvested nor grown commercially in Australia. High rates of growth and survivorship of juvenile *H. asinina* raised in tanks have been achieved in Thailand, but growth rates slowed rapidly after the first year to give a predicted maximum shell length (L_∞) of 60·3 mm. This estimate is much lower than the maximum size observed *in situ.* Individual animals have been measured at lengths of over 90 mm off Samet Island in Thai waters (Singhagraiwan and Sasaki 1991*b*) and at 111 mm on Heron Reef, eastern Australia (McNamara, unpublished data).

Variation in maximum size of abalone between geographically separated sites is not unusual and is documented for most abalone species (review by Day and Fleming 1992). Some of the factors that underlie spatial variation in growth in the field (e.g. variability in water temperature and quality, food variety and availability, etc.) may account for the stunted growth of the abalone cultured in Thailand (the only place where *H. asinina* growth has been studied to date). The present work examines growth rates of *H. asinina* in the natural environment on Heron Reef at the southern end of the Great Barrier Reef and therefore provides an estimate of potential growth rates for aquaculture ventures in Australia.

Materials and Methods

In all, 451 *H. asinina* adults (adults are defined as > 42 mm shell length, which is the approximate size of sexual maturity; Singhagraiwan and Sasaki 1991*a*, 1991*b*; McNamara unpublished data) were captured at night between March 1993 and July 1994 in the outer coral–algal subzone of the reef flat (Mather and Bennett 1993) on the southern side of Heron Reef (23°27′S,151°55′E). Abalone were tagged through one of the open tremata with individually numbered 'T-bar' clothing tags. Their shell lengths were then recorded to the nearest 0·02 mm before release at the site of capture. Animals were recaptured and remeasured periodically until the end of August 1994 and size-specific growth rates derived from these data.

Owing to the problems associated with marking and recapturing small animals (e.g. it is difficult to fix tags without affecting growth and survival, and the likelihood of recapture is low), the growth rates of juvenile abalone (2–42 mm shell length) were measured in aquaria. Young *H. asinina* specimens (2–36 mm SL) were collected monthly by using 1% ethanol in sea water as anaesthetic (Prince and Ford 1985). The diluted ethanol was applied for 10 min in 20-L buckets containing rubble collected from the reef flat and slope (0–10 m depth) to the south of Heron Reef. Each juvenile collected by this procedure was placed into a 15-L aquarium maintained at 23–26°C. Three other small abalone (32 mm, 39 mm and 42 mm SL), collected while adults were being sought at night, were also placed in the aquaria. Rubble covered with a variety of algae (e.g. *Hypnea pannosa*, *Laurencia* sp., *Lobophora* sp. and others) was provided as a source of food and replaced weekly in an attempt to provide the abalone with a diet that

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reflected the natural availability of algae in the field. Abalone were acclimated in aquaria for 10 days and their growth monitored subsequently over periods of up to two months to determine individual growth rates.

The von Bertalanffy curve (von Bertalanffy 1960) was modified to produce a new curve of the form

$$growth\ rate = a(length)^{b}e^{-c(length)^{d}},$$

which was fitted by a least-squares approximation to the combined data obtained from the juveniles and adults. A sigmoidal length *v.* age relationship was then obtained from the integral of the inverse growth curve:

$$age = \int \frac{e^{c(length)^{d}}}{a(length)^{b}}\, d(length)$$

Given the complexity of the mathematics required to obtain this integral, the relationship was estimated by using the trapezoidal approximation (i.e. by using cumulative small areas under the inverse growth rate curve).

H. asinina spawns over the late summer months on Heron Reef, with the final spawnings occurring in late March to early April (McNamara, unpublished data). Thus, monthly shifts in the size–frequency distributions of juvenile abalone (collected by using the anaesthetic as described above) were examined from May to August 1994 in an attempt to track the growth of a new cohort of juveniles. These results were compared with the growth rates of juveniles in aquaria to assess the suitability of measuring growth of captive juveniles in this way.

Results

Sixty-eight juvenile abalone in the size range 2–36 mm SL were captured with anaesthetic over the period May–August 1994. Only 17 of these animals, plus the three other juveniles collected on night reef walks, survived the aquaria. For the adults, 59 tagged animals were recaptured over the period of the study. Size-specific growth rates (Fig. 1) were extremely high for young *H. asinina* between 2 and 20 mm SL (up to 163 mm^{-1}) but much lower in adult animals (0–30 mm^{-1}). From the sigmoidal age *v.* length relationship derived from the fitted growth rate curve, it is estimated that *H. asinina* may grow from 2 mm to 35·6 mm SL in 6 months, to 55 mm in a year, and to approximately 75 mm in three years.

The size–frequency distributions of juveniles collected by using anaesthetic (Fig. 2) show a clear increase in average and modal size from May to August. The growth rate of the juvenile population was calculated from these distributions by determining the monthly increase in average size. These size-specific growth rates were found to be slightly (but not significantly) lower than those estimated from growth rates obtained in aquaria, and the trend was more pronounced in the larger juveniles (Fig. 3).

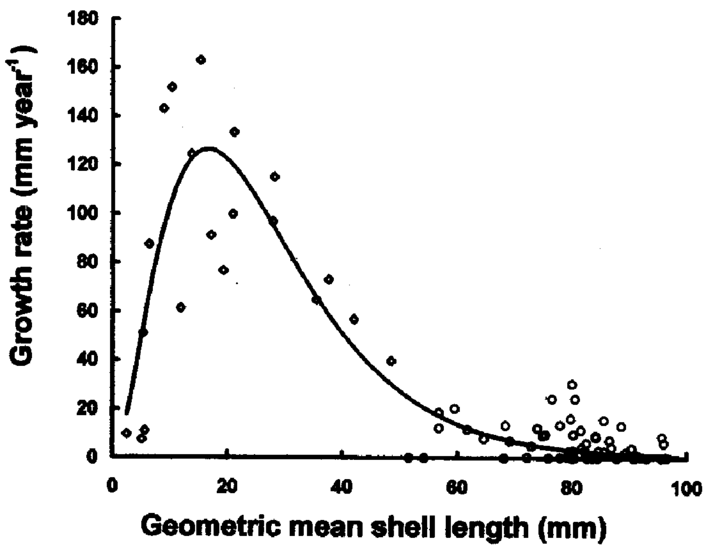

Fig. 1. Individual growth rates for (○) tagged *H. asinina* adults *in situ* and (◇) juveniles in aquaria plotted against geometric mean shell length (i.e. the average shell length of each individual animal over the period during which growth was being monitored). Fitted curve: $y = 4{\cdot}27l^{2{\cdot}03}e^{-u}$, where y is the growth rate, l is the shell length (2·5 mm < l < 98·5 mm), $u = 0{\cdot}27l^{0{\cdot}88}$ and $r^2 = 0{\cdot}88$.

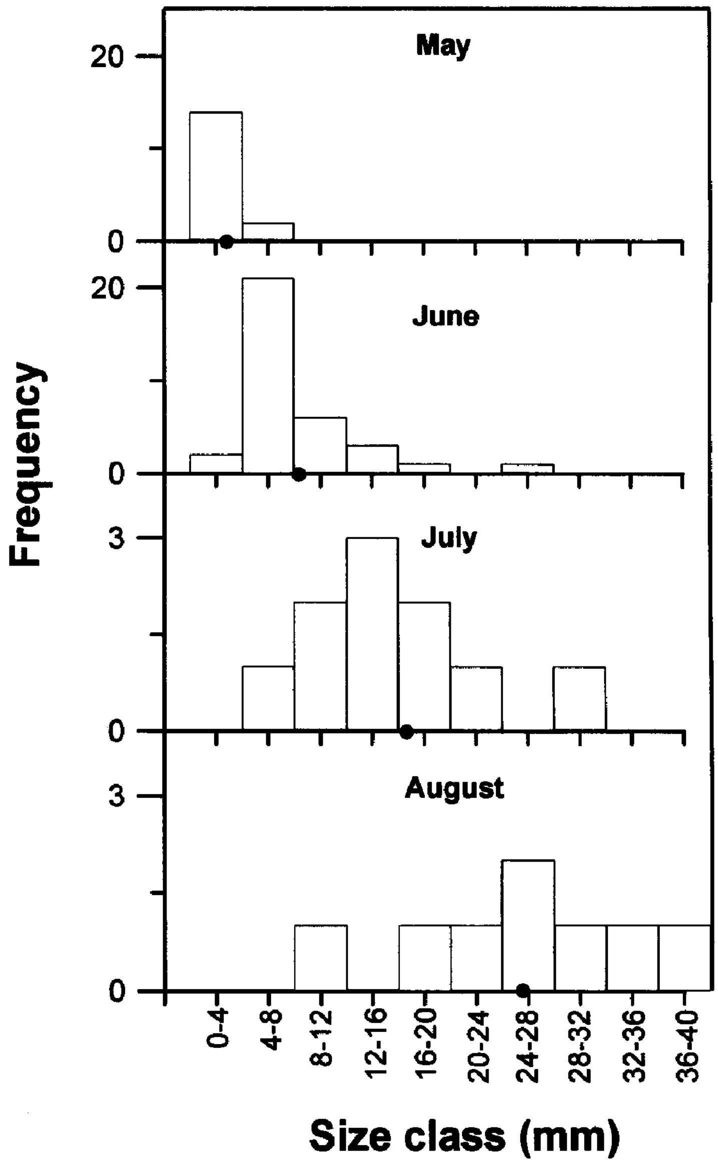

Fig. 2. Size–frequency distributions and (●) average size of the juvenile abalone population sampled with the aid of anaesthetic on Heron Reef between May and August 1994.

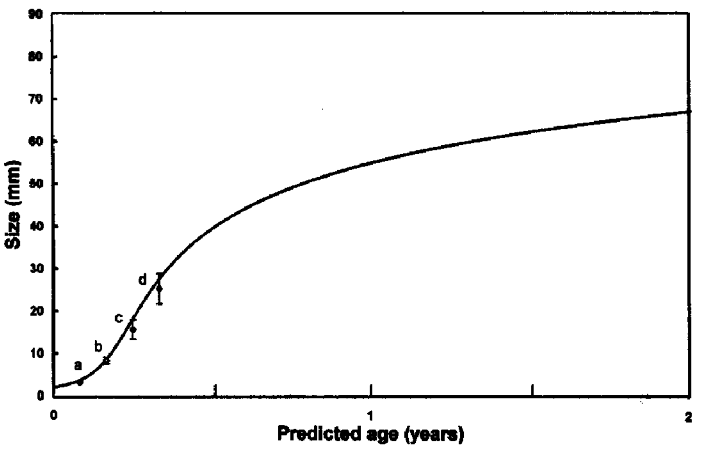

Fig. 3. Predicted size *v.* age relationship calculated by trapezoidal approximation from the size-specific growth rates (see Fig. 1) and the average shell length of the juvenile abalone population sampled with the aid of anaesthetic (± standard error). There is no significant difference between the size of the juvenile population sampled and the predicted size from the growth curve for any of the monthly samples: *(a)* May ($0{\cdot}5 < P < 0{\cdot}9$ with 15 d.f.), *(b)* June ($P > 0{\cdot}9$ with 34 d.f.), *(c)* July ($0{\cdot}5 < P < 0{\cdot}9$ with 9 d.f.), and *(d)* August ($0{\cdot}5 < P < 0{\cdot}9$ with 7 d.f.).

Discussion

The growth rates of *H. asinina* estimated in this study are the highest reported for any species of abalone. These estimates exceed those of Singhagraiwan and Sasaki (1991*b*) for adult *H. asinina* grown in tanks in Thailand, although the growth rates are almost identical for the two studies up to about 6 months of age. Day and Fleming (1992) indicate that three of the major factors that contribute to determining abalone growth rates are water temperature, diet and spawning activity. The lower growth rates observed in the adult abalone in Thailand may be due to any one or a combination of these factors.

In the Thai study, abalone were fed solely on *Gracilaria salicornia* after 2·5 months of age and their growth slowed rapidly approximately five months later. There are other examples showing that diets consisting of single species lead to reduced growth rates in the long term. For example, *H. rubra* fed on any one of several single-species diets ceased to grow after 50–200 days even when growth was high at the start of the trials (Day and Fleming 1992). Compared with mixed diets, there is a greater chance that single foods lack essential nutrients necessary to facilitate high growth rates over a long period (Duncan and Klekowski 1975). The mixed diet available to abalone on Heron Reef (over 20 species identified in gut samples; McNamara, unpublished data) may supply the necessary nutrients to sustain growth over a longer period.

Differences in water temperature and/or spawning activity between Heron Reef and Thailand may also account for the decreased growth rates. An increase in water temperature is normally thought to contribute to an increase in growth rates (e.g. Chen 1984), but secondary effects of increased temperature may act to reduce growth (Day and Fleming 1992). High water temperatures may coincide with the spawning season of some abalone, and Sakai (1960, 1962) showed that growth rates for *H. discus hannai* slowed during gonad maturation even though water temperature was high. *Haliotis asinina* is known to spawn throughout the year in Thai waters (Singhagraiwan and Sasaki 1991*a*) but only during late summer on Heron Reef when water temperatures exceed 25–26°C (McNamara, unpublished data). Given that the present study was undertaken during the winter months, the growth rates recorded may be higher than those from the Thai study because the adults in the present study were not developing reproductive tissue.

The slightly but consistently lower estimates of growth rates for juveniles obtained for the monthly size distributions relative to those obtained from growth in aquaria may be an artefact of sampling, because no abalone over 36 mm SL were collected by using anaesthetic. This bias occurs because larger animals tend to seek shelter deeper within the reef structure and do not normally occur in the surface rubble where juveniles are commonly (but not exclusively) found. As the average length of animals in the cohort grew over time, fewer juveniles were found in the rubble samples (Fig. 2). If this occurs as a result of a size-dependent shift in microhabitat, then relatively fewer of the larger juveniles in each sample will be collected using this method. This will then result in an underestimate of the average length of the juveniles *in situ*, which will be exaggerated as the cohort grows in size.

The results of this study show conclusively that *H. asinina* has the potential to grow to market-sized 'cocktail' abalone (ie. 50–60 mm SL) within 12–18 months. These high growth rates identify this species as one with great potential for aquaculture development.

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