

Contributions to the Knowledge of the Biology of the Arabian Abalone *Haliotis mariae* Wood, 1828

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خلاصة : يوجد الصفيح العربي في سواحل بحر العرب الصحيرية مرتبطاً بمجمعات الطحالب التي تمثل غذاءها الثباتي الغالب. وبالرغم من الأهمية البيئية وأن الاستغلال التجاري للصفيح يشكل إسهاماً فاعلاً للمصايد العمادية فإن بيولوجية الصفيح تكاد أن تكون غير معروفة تقريباً. تقدم هذه الدراسة نتائج البحوث التي أجريت ميدانياً ومعمليةً بالاستزراع. لتستخلص التوصيات المتعلقة بإدارة أسماك الصفيح التي ربما يتم استزافها. ولقد دلت الملاحظات الميدانية المتزامنة مع قياس العينات المستزرعة بالمعمل أن معدل نمو الصفيح العربي أعلى من أي نوع آخر من الصفيح. أي بزيادة أكثر من 3مم صدفة في الشهر. ويعتبر النضوج الجنسي المبكر جداً الذي أظهرته بويضات الأسر في عام واحد تقريباً شيئاً غير عادي. كما أن بويضات الصفيح العربي المقذوفة تشكل طبقات أحادية مخاطية مثبتة على القاع. بينما الأنواع الأخرى من الصفيح تنتج بويضات عائمة تحت الماء. وتدل الدفاعات الوليدة في الطبيعة والتبييض الدوري للأسماك المستزرعة على أن المواسم الرئيسية لتزاوج الصفيح العربي تكون في الربيع والخريف بعد الأمطار والتماذج السابقة التي طبقت في إدارة أسماك الصفيح بعمان قد افترضت موسماً واحداً للتزاوج في العام تبدأ عند عمر سنتين أو أكثر مع نمو أبطأ. هذه التماذج يجب إعادة إقرارها على ضوء البيانات الجديدة التي تفسر جزئياً عدم استزاف الصفيح كما هو متوقع مع معدلات الصيد المرتفعة حالياً. وبناءً على الاستغلال التجاري المتوقع لاستزراع الصفيح. فإن تجارب التربية المعملية أوضحت إمكانية استعمال التغذية الطبيعية أو الصناعية. شريطة أن تحتوي - بالإضافة إلى العناصر القياسية - على الأعشاب البحرية (ربما الفيكوبلين) اللازمة لتكوين صدفة مقاومة للطفيليات. ولقد دلت الدراسات الأولية، المتعلقة بالتكاثر الصناعي، على أن التبييض والتلقيح، ورعاية اليرقات لا تشكل أي عائق. مراحل النمو من الديدنيلتر وحتى استقرار اليرقات هي الأكثر تعرضاً لهجمات الطفيليات الهدبية القاتلة. ويتطلب التخلص من هذه المشكلة الحرجة المزيد من الأبحاث.

ABSTRACT: The Arabian abalone occurs in the Arabian Sea's rocky coastal zone in association with conspicuous macroalgal communities in which it represents the dominant herbivorous component. Despite such ecological importance and although the commercial exploitation of abalone presents a considerable contribution to Omani fisheries, almost nothing is known about the biology of this species. This report presents results of research carried out in the field and with laboratory cultures, and draws general conclusions related also to the fisheries management of these possibly overexploited abalone populations. Cohort observations in the field and measured increments of cultured specimens showed a growth rate significantly higher than in other abalone species, i.e. greater than 3 mm shell-increment per month. The very early sexual maturity demonstrated by captivity spawnings of approximately one year old animals is also quite unusual. The ejected eggs formed mucous monolayers attached to the substratum whereas other abalone species produce pelagic eggs. Juvenile cohorts in nature and the periodic spawning of cultured animals indicate the major spawning in spring and postmonsoon one in autumn. The models previously applied in fisheries management of abalone in Oman assumed only one spawning per year - the first being at age 2+ - and a slower growth-rate. These models should be reconsidered using the new data, which may partially explain why abalone are less overexploited than one would expect looking at heavy harvesting. In view of a projected commercial abalone cultivation our laboratory rearing experiments showed that both natural and/or artificial food may be used, provided this contains -apart from standard ingredients - the seaweed-borne components (probably phycobillins) required for a normal parasite - resistant shell formation. With regard to artificial reproduction, our preliminary trials showed that spawning, fertilization, and initial larval rearing present no problems. The steps from the pediveliger to larval settlement, however, seem to be fatally exposed to ciliate attacks. Further research is needed in order to eliminate this critical problem.

The haliotid gastropod *Haliotis mariae* Wood, 1828 is considered to be an endemic species (Bosch & Bosch, 1982; Johnson et al., 1992) restricted to the Omani coastal waters of the Arabian Sea (Fig.1). This is the source of its popular name Omani abalone; the local name is sufailah. Considering the feeding dependence of abalone on more or less year-round supplies of adequate red and brown seaweeds, which in turn require appropriate nutrient supplies and a hard

substrate habitat, the truly endemic species' distribution seems to be restricted to the upwelling-affected and rocky coastal zones of the Northern Indian Ocean, i.e., those of Oman, Eastern Yemen, Socotra, and most likely NE Somalia (Barrat et al., 1986; Stirn et al., 1988).

Due to the huge market in Eastern Asia and an extraordinarily high price, commercial abalone exploitation in Oman has steadily increased since the

1950's (Johnson et al., 1992) to reach current annual harvests of > 150 tons gross (i.e. ~ 70 tons of fresh flesh). This is equivalent to > 4 million US\$ of export value, by far the highest economic yield of all Omani fisheries products. This harvest is carried out exclusively by local skin divers, with more than 300 being registered in 1992. The only equipment the divers are using is the simple face mask which is inadequate for the middle ear pressure compensation. Therefore the divers suffer quite often from nasal and ocular bleeding, and some we observed with a typical nystagmus, indicating ruptured eardrum and damaged labyrinth organs of the inner ear. The divers operate in rocky shore areas of Dhofar between Mirbat and Hasik as well as largely around Sharbithat, always in shallow subtidal zones down to about 10 m depth (Figure 1).

The first signs of overexploitation (Johnson & Shepherd, 1992) led the government to introduce a reduced fishing season only during December-January. This was accompanied by the regulation of a minimum legal size of 9 cm shell length. Efficient

implementation of these legal measures should contribute considerably to the protection of natural equilibria in abalone populations. However, these regulations are based on insufficient knowledge about the life history of this abalone species, its stocks, and population dynamics which is extrapolated, almost entirely from the analyses of shell lengths and remains of gonads in the shells of those animals which have been left on the shore after the harvesters had removed the flesh (Johnson et al., 1992; Sanders, 1982; Siddeek & Johnson, 1993).

Having recognized these, i.e. management related problems, the first objective of our research was to contribute a better knowledge about the biology of the abalone under natural conditions and in captivity. In addition, potential Omani interest in commercial abalone cultures led us to initial trials for the artificial reproduction and rearing of this species. Unfortunately, the modest facilities - far from abalone natural habitats - caused considerable technical problems and somewhat lowered methodological standards, including limitations in experimental series, sizes and frequency of samples, etc. However, the total lack of knowledge on the biology of this abalone justifies reporting these preliminary results.

Material and Methods

1. **FIELD WORK:** Two localities in the rocky coastal zone of the Dhofar region, Raaha (Mirbat) and Sadh, were visited in October 1991, February, June, and December 1992, usually in the frame of field training activities. Observations were made by SCUBA diving and recorded by underwater photography on habitat, distribution and behaviour. Living abalone were also sampled, sizes were recorded and selected specimens transported to the laboratory. Macroalgae from abalone habitats were sampled as well, partly for further taxonomic-ecological studies, partly as the food of experimental animals.

2. **GROWTH AND FEEDING EXPERIMENTS:** The juvenile and small adult abalone specimens (shell length: 25-75 mm) used for growth and feeding experiments and as the broodstock for artificial reproduction trials were generally reared in individual chambers. These consisted of rectangular, perspex containers (20 x 10 x 25 cm) with all sides perforated (8 mm holes, 10/dm²). They were placed in all-glass aquaria (60 l) and fitted with a simple recirculation system as shown in Figure 2A. The temperature and salinity were maintained at 25 ± 1 °C and 36 ± 0.5 psu, respectively. The sea water was changed completely twice a month.

The basic diets for experimental animals consisted of freeze-preserved macroalgae from Dhofar shores of the Arabian Sea (mainly the kelp *Sargassioopsis zanardinii* Schiffner and partly *Gracillaria* sp.) with

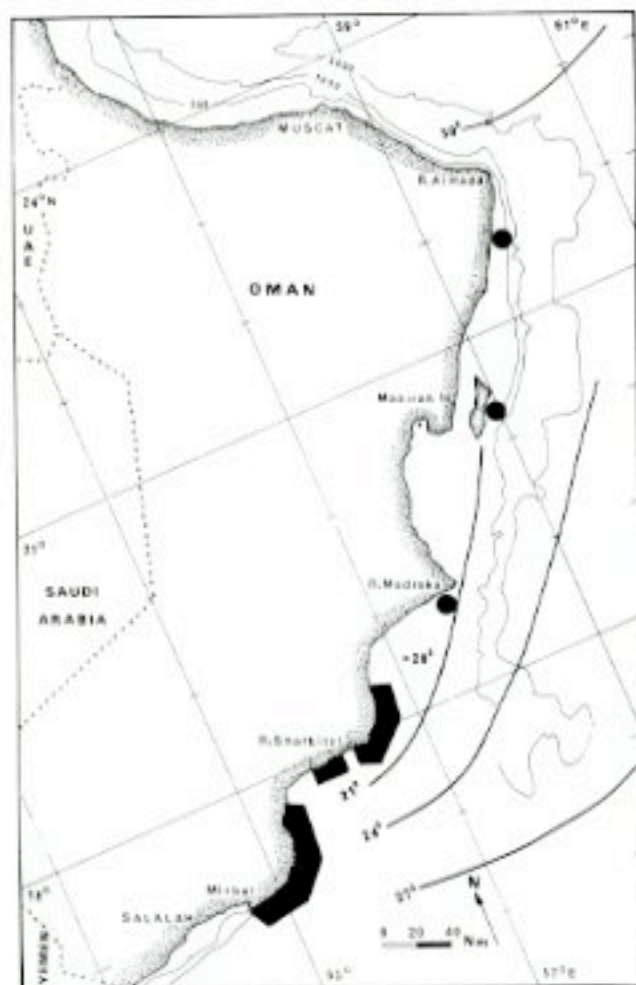


Figure 1. Biogeographical distribution of Arabian abalone in rocky inshore habitats of the Southern Oman which are seasonally affected by upwelling - induced cooling illustrated here by typical summer surface isotherms, (from Al-Mukhani, 1991); the stippled areas show localities of dense populations whereas the circles indicate scattered or rare presence.

regular 30-60% additions of artificial feed (modified formulation of Uki *et al.*, 1985). The artificial feed, in the form of flakes for juveniles and "spaghetti" for adults, was prepared as follows: 4g of Na-alginate acid is dissolved in 130 ml of dist. water, 2 g of white fish meal, 2 g of aquarium fish flakes (also as a vitamin source), 2 g of agar-agar, and 0.5 g of starch are added, homogenized and solidified in 0.1 M CaCl_2 solution; after partial drying (1/2 hour at 60°C) the feed is freeze-preserved. As described below, feeding experiments in which animals were on this artificial diet only showed a nutritional deficiency, presumably in phycobilline pigments. This demand was successfully compensated by offering diatom-cyanobacterial films which were grown on ceramic plates immersed in the standard microalgae-growth-medium "f-2" (Guillard & Ryther, 1962) for 2-3 weeks under artificial illumination (Sylvania "Growlux" tubes, providing 0.2 ly/min).

3. ARTIFICIAL REPRODUCTION: Apart from spontaneous spawning (stimulated by temperature and mechanic stresses during the transportation of brood stock animals), spawning was induced artificially by suddenly increasing or lowering the water temperature by $\sim 5^\circ\text{C}$, or with H_2O_2 - stimulation (Morse *et al.*, 1977). Fertilization steps were carried out according to the technique of Ebert & Houk (1984). After the hatching, the free swimming larvae were transferred for metamorphosis and growth into a semi-sterile recycling system as shown in Figure 2B.

Results and Discussion

HABITAT AND DISTRIBUTION OF ABALONE SUBPOPULATIONS: The endemic *Haliotis mariae* populations are clearly associated with macroalgae-dominated subtidal communities combined with an important component of hermatypic coral assemblages and high-diversity sedentarian macrofauna. The general characteristics and dynamics of this region were described by Barratt *et al.*, (1986). This information and our periodic observations show that during the terminal phase of the summer monsoon period the previously upwelled, hence still nutrient-rich and relatively cool ($<24^\circ\text{C}$) water masses induce an extraordinarily fast and productive growth of macroalgae. This vegetation may occupy up to 25-30% of the available space of the inshore water column and consists of the dominant endemic kelp *Sargassostopsis zardini* (Figure 3) along with codominant species of the genera *Sargassum*, *Cystoseira*, *Spathoglossum*, *Endarachne*, and *Suhria* (deeper bottoms are characterized by the kelp community of *Ecklonia radiata*). Our measurements as well as the data of

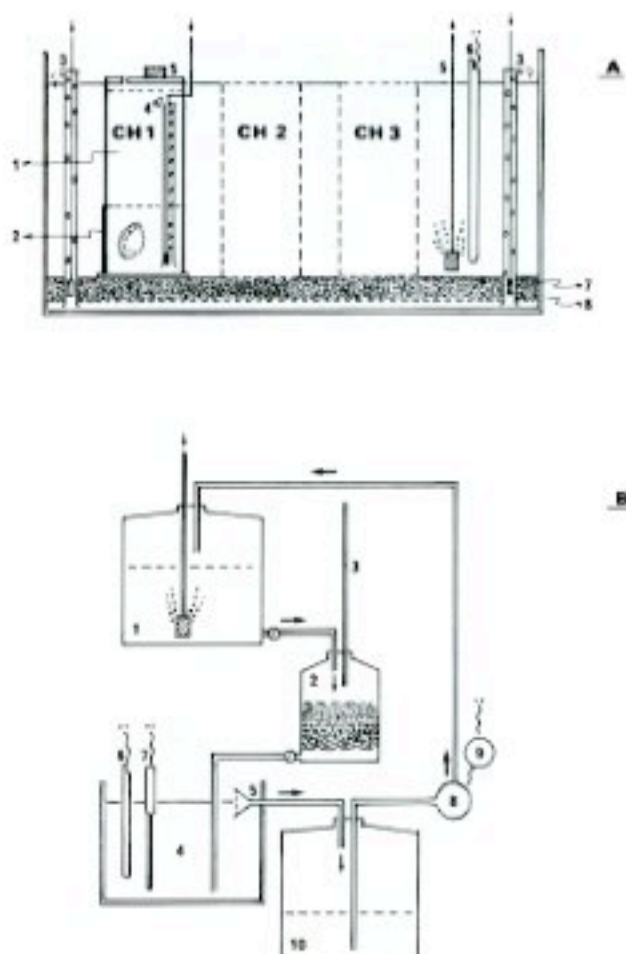


Figure 2. Technical arrangements for experimental growth and reproduction of abalone: A-- Closed system aquarium with the growth chambers ($\text{CH}_{1,2,3}$) for the individual, adult and juvenile abalone: 1 - perforated chamber with a shade zone (2) recirculating airlift and a heavy cover plate (5); 3 - general recirculation system pumping treated seawater from below the bottom sand-biological filter (7 & 8); 5 - ancillary aeration; 6 - thermostatic heater. B-- Semisterile recirculating system for the growth of embryonal and larval abalone stages: 1 - airated reservoir of initially sterilized sea water; 2 - mechanical & biological filter with safety-leveiling tube (3); 4 - larvae growth chamber with heater (6), contact thermometer control (7) and $55\mu\text{m}$ outlet screen (5); 10 - recipient reservoir with centrifugal pump (8) and flow-control timer (9) for uplifting used sea water (scale $\sim 1:20$).

Barratt *et al.*, (1986) show that this vegetation reaches its highest biomass ($5-7 \text{ kg m}^{-2}$ fresh weight) in autumn. This is followed during the winter by a gradual reduction due to grazing and mechanical detachment of mature plants, yet new growth begins already during early spring, both from the holdfasts of the vegetation and by spore-born recruits (Figures 3 and 4). However, throughout the spring season this growth is rather limited, mainly by insufficient nutrient supplies, whereas the grazing pressure remains quite heavy. Consequently, the macroalgal cover and biomass levels are extremely low during late spring which is likely the only short interval of suboptimal food-supplies for

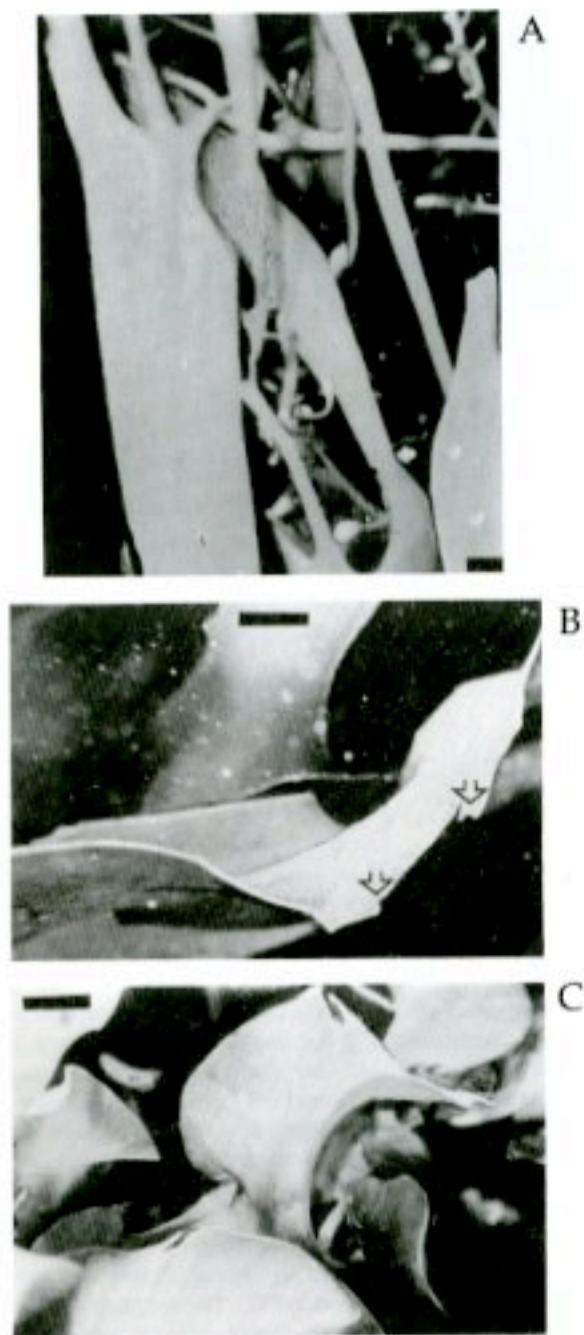


Figure 3. The prevailing food for abalone are large brown seaweeds, particularly the dominant species *Sargassiopsis zanardinii*; (UW photographs; bars 1 cm): A-- an adult specimen; B-- traces (arrows) of abalone grazing; C-- young plants, too, are heavily grazed during the winter-spring season.

abalone and other grazers. Fortunately, the dominating macro-vegetation is accompanied by an unusually rich and diverse component of understory and encrusting algae which is present year-round; the latter, combined with cyanobacterial and diatom films, is also very abundant as epiphytic layers on the mature seaweeds as well as on other substrata. It is probably this source of food that adequately compensates for the temporary shortage in macroalgal food supplies, at least as far as the feeding of juvenile abalone is concerned.

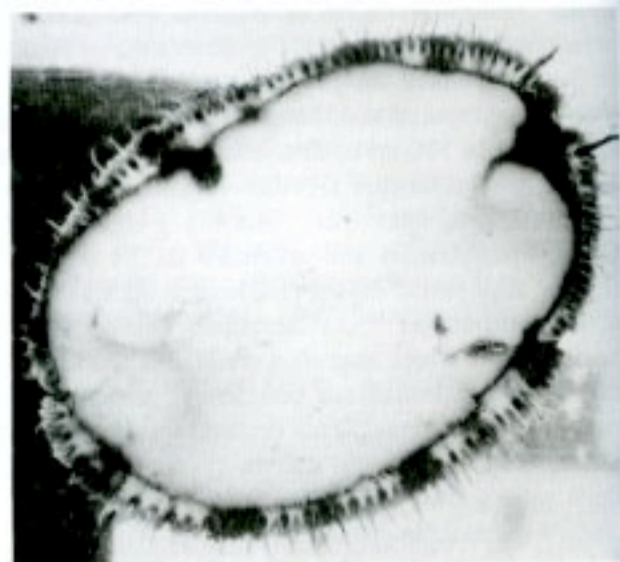


Figure 4. Live specimen of abalone adhered to the aquarium wall showing the edible foot and epipodium with tentacles; natural size.

Considering these conditions in the sense of the trophic basis for the abalone populations, it seems most unlikely that they could ever face any shortage in food supplies. Our feeding experiments show that the abalone promptly and easily adapt to different food items: if provided simultaneously with kelp particles, encrusting macroalgae, and plate-cultured microalga films, they graze on all of them, even in the span of a single night. The seasonal dynamics of the macroalga vegetation and its pronounced spatial and temporal variability can thus be assumed to have little impact on the density distribution of abalone subpopulations and show an aggregation pattern not necessarily bound to prespawning aggregating behaviour as described by a number of authors (Shepherd & Johnson, 1992). The abalone in the surveyed shallow subtidal zones (0-4 m depth) of the Bay of Sath and Raaha were distributed as a rule in aggregations. Among 10 randomly selected sampling surfaces ($\sim 10 \text{ m}^2$ each), 6-8 did not yield any abalone and 2-4 produced 3-5 juveniles (2-4 cm), 1-3 small (4-6 cm), and 0-2 medium-size ($> 6 \text{ cm}$) adult specimens, the largest measuring 7-9 cm shell length. Large abalone were not found in our sampling areas; they were probably removed during previous harvesting seasons. Also, the preferential habitat of adults is generally deeper within the *Ecklonia* community.

The juveniles showed a typical stratified distribution; they were found almost exclusively under boulders in the shallowest zones, provided these were wave-protected enough to prevent the rolling of boulders. Occasionally, yet with high density, juveniles were also found under acroporid stony corals on somewhat deeper bottoms (3-4 m). Small and medium-size adult animals were restricted to deeper

waters (> 1 m below low tide level), the former as a rule under boulders and the latter exclusively in the crevices of the primary rock-substrata. These preferred microhabitats are the places in which water dynamics and geomorphological structures provide optimal conditions for the accumulation of detached macroalgal particles. Although shaded, these substrates also offer an abundant cover of soft and encrusting algal mats.

POPULATION STRUCTURE AND SPAWNING-RECRUITMENT

PERIODS: Although more detailed population studies were not carried out, the basic biometric data shown in Table 1 seem worth mentioning for the lack of pertinent information in the published literature. In addition, the following observations allow the spawning-recruitment seasons to be estimated hypothetically for the first time. Juveniles with a shell-length of 3-4 cm were the dominant fraction of the sampled subpopulations, both in mid-October 1991 and at the end of February 1992, i.e. a time interval of > 4 months. This clearly indicates two distinct recruitment periods and suggests two spawning seasons, one during spring, (the spring spawning hypothesis is also supported by the observed spontaneous spawnings in captivity during March to April 1992 as reported below), and the other in autumn. This is also in agreement with the outputs of size-frequency analyses as reported by Siddeek & Johnson (1993).

GROWTH AND FEEDING OF ABALONE IN CAPTIVITY:

Juvenile (<35 mm) and small adult specimens (<65 mm), collected in the shallow subtidal zone of Sadh in October 1991 and February 1992, were reared for 6 and 2.5 months, respectively. Growth, as shell-length increments, was measured in approximately monthly intervals; the biomass of the soft parts was determined at the end of the experimental study. The data (Table 2) gathered provide new insight into the biology of this abalone species. Compared with other abalone species studied, which are distributed mainly in temperate and subtropical regions and whose usual growth rate is 1.3-1.8 mm (maximum 2.5 mm) shell length increments per month (Day & Fleming, 1992), *Haliotis mariae* shows very high growth rates: typically 3.3 - 4.3 mm, minimum 1.6 mm and maximum 4.8 mm. The aforementioned field observations on the separate occurrences of the equally sized juvenile cohorts during autumn and late winter indicate a growth rate in the same range under natural conditions although perhaps less than the maxima (>4 mm/month) demonstrated experimentally.

The least disturbed experimental animals (no spawning until the terminal rearing stage) that were exclusively fed on protein-rich artificial diets typically yielded the maximum growth rate. These diets were

TABLE 1

Shell lengths and wet weights of total soft parts as averages of all available measurements (N=70) for the abalone *Haliotis mariae* sampled during 1991-92.

Shell Length (cm)	Weight (g)
2.5	1.3
3.0	2.8
4.0	5.1
4.5	5.4
5.0	6.4
5.5	9.0
7.0	25.6
7.5	30.1
8.0	36.6

Note: Shell fraction of the total wet biomass is 32-45%; edible parts make up - 70% of total soft parts.

also clearly chosen by animals over any kind of natural macroalgae that were offered simultaneously in occasional trials. However, the exclusively artificial feeding caused a remarkable side-effect, the "green shell". As early as 4 days after being put on this diet, the animals began to produce new shell-edge layers whose outer surfaces had a strong blue-green colour (a shade resembling the mineral amazonite and the pigment of abalone ovaries, eggs, and early larval stages). The "green shell" (Figure 5A) was produced, without exceptions, as long as abalone were fed exclusively on the artificial diet; within a week of being offered kelp, red algae, or cyanobacterial-diatom films (cultured on ceramic plates) the newly produced shells returned to their normal coloration. The morphological examination of the "green shells" showed that these are devoid of the normal, red-brown periostracum and that the upper layer of the prismatic (calcite) ostracum thus became the shell's outer surface (Figure 5C). This layer normally has a slight and variable pigmentation, probably calcite-cocrystallized metallic porphyrins (Wilbur, 1972), of the same blue-green nuance, although the shade of "green shells" is considerably stronger. According to Shepherd (1991, pers. comm.) this phenomenon has been observed in some cultures of other abalone species, and a few partially green-shell abalone were also found in our samples from natural habitats in the Arabian Sea. The above evidence suggests a certain nutritional deficiency which hinders or totally blocks the normal synthesis of the periostracum protein material or at least its tanning component, i.e. phenoloxidase-induced agglomerates of

TABLE 2

Growth of juvenile *Haliotis mariae* (expressed as shell length increments) reared in a closed-system aquarium during 1991-92 and fed artificial and/or natural food.

EXPERIMENT SPECIMEN	Shell-Length (mm)						▲ L	▲ L'
	Nov 1	Dec 12	Jan 13	Feb 22	Mar 11	Apr 28		
# 01: F/ART + CYDIAT SPA:W: 28/2, 11/3 & 28/3	29	32	36	43	45	52	23	3.8
# 02: M/ART + CYDIAT SPA:W: 28/2, 11/3 & 28/3	-	-	-	31	35	41	10	3.9
# 03: M/ART + CYDIAT SPA:W: 24/4	37	41	49	51	54	63	26	4.3
# 04: F/ART	33	34	41	49	58	62	29	4.8
# 05: F/KELP	31	32	37	42	47	51	20	3.3
# 06: M/KELP	-	-	-	64	65	68	4	1.6
# 07: F/KELP SPA:W: 24/4	-	-	-	59	63	65	6	2.4

Symbols: F-female, M-male, ART-artificial food, CYDIAT-plate-cultured cyanobacterial-diatom film
KELP-natural macroalgae food, SPA:W - dates of spontaneous or induced spawning

▲ L - total shell length increment during 6 or 2.5 months; ▲ L' - monthly increments

guinone derivatives (Brown, 1952). The fact that additions of cyanobacteria and red algae to the artificial diet promptly allow normal shell production suggests a hypothesis in which the missing nutrient might be phycobilines, i.e. typical pigments of the above plant groups. Since the "green shell" phenomenon - without or with significantly reduced periostracum - most likely decreases resistance of abalone against boring organisms and parasites, it might present a potential problem for commercial abalone farming. An improved feed formulation should overcome this.

Food consumption studies provided indication on the feeding requirements of *Haliotis mariae* in general as well as from the standpoint of rearing this species in commercial maricultures. Although abalone were always fed *ad libitum*, the approximate average rates of food consumption were in the range of 6-13% of the wet weight biomass of soft parts per day, i.e. 0.2 - 0.8 g per day.

ABALONE REPRODUCTION UNDER EXPERIMENTAL CONDITIONS - SPAWNING: During the rearing experiments - spawning occurred three times (Table 2). The first spawning, by the same "juvenile" couple, actually occurred in two successive pulses with a four day interval (Table 2: #1 and #2); this was clearly induced by an unintentional increase of the aquarium temperature from = 23-25°C to 27-28°C. The other two spawnings (Table 2: #1 & #2 and #3 & 7) were purposely induced, the first in March by transferring potential spawners from a cool aquarium (23°C) into a

spawning chamber at 28°C, and the second in April by chemical stimulation with H₂O₂ in highly basic sea water (pH 9.2). In all cases the males spawned first, followed by females within one hour. The females' behaviour before the spawning showed a tendency to select a place in the chamber's corners or just below the cover plate. As a consequence, the majority of eggs are ejected towards the walls to which they adhere and form an attached monolayer. According to Shepherd (1991, pers. comm.) no other abalone species is known to produce substratum- attached egg masses; this may present a specific eco-adaptation of *Haliotis mariae*.

Another spawning aspect of *Haliotis mariae*, compared with the life cycles of other abalone species, is an extremely early reproductive maturity. This is followed by first spawning that evidently occurs at an approximate age of 1 year, in contrast to 2+ years as suggested by Sanders (1982). Although the egg-production of ripe "juveniles" is rather modest (in the above cases in the range of 4-8 x 10⁵ eggs per individual spawning), this early maturity must have an important positive impact on the recruitment and the status of abalone stocks *a priori*. This effect will be enhanced because, in reality, only a marginal fraction of 1-2 year old abalone are harvested for regulations provide absolute protection of these cohorts. This phenomenon may explain why abalone stocks are depleted to a lesser extent than one would expect considering the rather heavy exploitation pressure over the last 10 years.

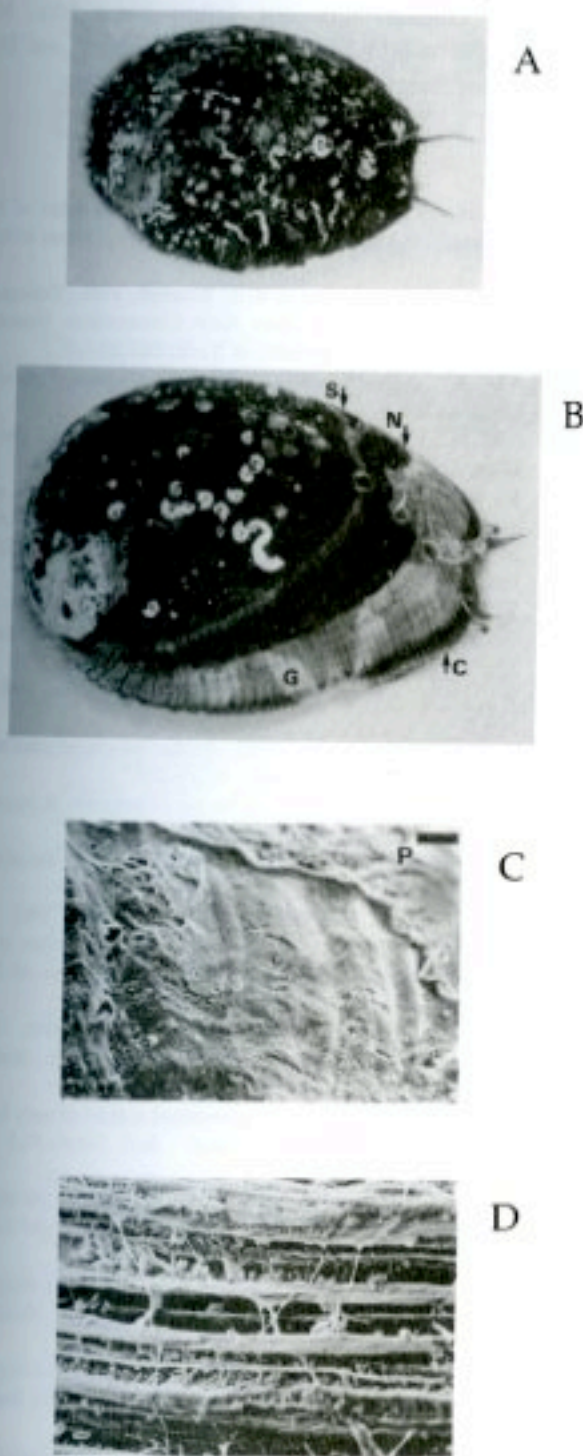


Figure 5. Formation of the "green shell" (G) in captive abalone: A--Juvenile wild specimen at the start of feeding experiments (magnification 2x). B--The same specimen fed in captivity the first 2 months with natural seaweeds (normal shell between marks S-N and 2 months with artificial feed that caused the periostracum - free green shell (G); enriching artificial feed with live cyanobacteria & diatoms caused quickly a normal shell formation (C). C--Surface morphology of the exterior shell surface of the abalone showing the "green" area without and adjacent "normal" one (P) with well developed periostracum layer (scanning electron microphotograph, magnification 400x, bar 200 μ m). D--Surface structure of the periostracum layer on the abalone shell grown in natural conditions (as above).

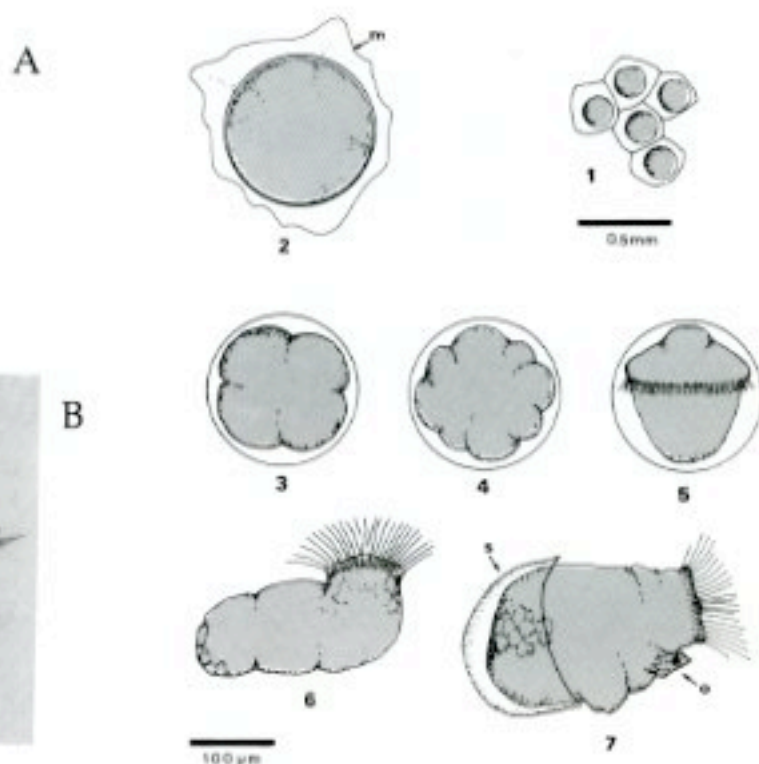


Figure 6. Embryonal and early larval stages of artificially spawned abalone *Haliotis mariae*; explanations in the text.

EMBRYONAL AND LARVAL DEVELOPMENT: Following each of the spawnings described above, most of the ova were apparently fertilized only after becoming attached to the substratum. They remained there throughout embryonal development, including the period the formed, encapsulated trochophores required for the final hatching. The trochophores then actively swam, as a rule towards the subsurface of the water column (never at the very surface), while the subsequent veliger stages again showed a tendency for a near-bottom distribution. As mentioned above, such a substratum affinity, not known in other species of abalone (Fallu, 1991), seems to be a specific characteristic of *Haliotis mariae*. Also, the morphology and temporal phases of larval organogenesis were observed to be somewhat different from other species (Ino, 1952; Seki & Kanno, 1977), however, this might be due to adverse experimental conditions.

The embryonal and larval morphology for *Haliotis mariae* is shown in Figures 6 and 7 with the typical phases as follows: (1) a fraction of the demersal monolayer of eggs which are tightly connected by the mucous coats belonging to individual eggs; (2) a non-fertilized egg with its typically massive mucous coat; (3) cleavage, 2nd division, 1-2 h after fertilization; (4) advanced embryo, 6 h after fertilization; (5) encapsulated trochophore, 12-14 h after fertilization; (6) initial veliger stage; 32-36 h old; and (7) advanced, 48 h old veliger.



Figure 7. The most advanced veliger larval stage of artificially spawned abalone *Haliotis mariae*, 80 hours after hatching, total length 280 μm (opto-transmission microphotograph; the image of cilia enhanced manually).

Unfortunately, further larval stages remain unknown because the veligers did not survive for more than 3 - 8 days. They were massively attacked by bacteria and ciliates, whose sudden outbreaks followed the addition of non-axenic diatom and flagellate monocultures meant for larval feeding. This addition was obviously harmful and most likely unnecessary, since the non-attached stages of the abalone larvae are generally considered to be lecithotrophic. Recently the Marine Science & Fisheries Research Center, Muscat, also produced artificially fertilized larvae which, too, survived only for 3 days (J. Ogawa, pers. comm.). Obviously, even the most elementary steps towards the development of commercial abalone cultures require more research, adequate experimental facilities to carry it out, and more basic knowledge about the biology and ecology of natural abalone populations. Although in this field, too, the first results of our research provide new and useful information, much more systematic research is needed *a priori* and particularly in order to meet the basic requirements of a rational management and protection of natural abalone resources.

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