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Growth and gonad development of the tropical black-lip pearl oyster, *Pinctada margaritifera* (L.), in the Gambier archipelago (French Polynesia)

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Abstract:

The growth and reproductive cycle of cultured black-lipped pearl oysters, *Pinctada margaritifera* (L.), were studied in the Gambier Islands (134°52′ W, 23°07′ S) from September 2002 to August 2003. Temperatures were recorded throughout the year, revealing seasonal temperature variations between 22.3 and 27.8°C. The mean annual chlorophyll *a* value, as computed from satellite data, was 0.188 ± 0.075 µg L^{-1}. To study growth and reproduction, 720 two-year-old individuals were ear hung on long-lines suspended at a depth of 7 m. Samples were taken twice a month to obtain the following measurements: shell height; wet weight of flesh and total oyster; dry weight of adductor muscle, mantle and visceral mass; and glycogen content. Gonad development was also studied by histology on parallel samples. Growth was relatively fast during the first 6 months of the study: average shell height increased from 89.1 ± 9.1 to 119.7 ± 10.8 mm and total weight from 93.4 ± 24.5 to 155.1 ± 33.6 g, between September and the end of March. Subsequently, from April to August, no significant growth was observed for shell and flesh, while the muscle weight decreased significantly. Condition index (CI), defined as the ratio of wet weight of the visceral mass to shell weight, and histological changes in the gonad revealed 3 significant reproductive events of different intensities. The analysis of correlations revealed a specific effect of the chlorophyll *a* concentration on the growth of shell and soma, and one of the temperature on tissue glycogen content. This study also showed also that CI could be an efficient indicator of reproductive events in pearl oyster. It thus appears that the development of gonads goes on throughout the year in the Gambier Islands, without any detectable phase of sexual rest.

Keywords: Pearl oyster – *Pinctada margaritifera* – Growth – Reproduction – Temperature – Chlorophyll – Seasonality – Gambier archipelago

Introduction

Pearl oyster farming in French Polynesia is spread over a large geographical area. Environmental conditions vary between islands in this part of the South Pacific, particularly due to differences in their latitudinal position. Seasonal cycles are more marked in southern Polynesia than further north. The annual reproductive cycle of *Pinctada margaritifera* was studied in the Takapoto atoll of the northern Tuamotu Islands, showing that reproduction occurs throughout the year due to a high average temperature with low seasonal variation (Thielley 1993, Pouvreau *et al.* 2000a). Adequate data on the marine environment and the reproduction of pearl oysters are, however, not yet available for other islands with pearl oyster farming. The largest thermal amplitude in French Polynesia (Salvat *et al*. 2008) is observed in the Gambier Islands (134°52' W, 23°07' S). Although reproduction of *P. margaritifera* still occurs in these islands, its reproductive cycle has not yet been described.

In the southern part of its distribution (Australia), the reproductive cycle of *Pinctada albina* has been observed to be modulated by seasonal temperature variations (O'Connor 2002). The reproductive cycle of the pearl oyster *Pinctada mazatlanica* is also affected by seasonal variations in temperature in Baja California (Saucedo *et al*. 2002), where a period of intense sexual activity is observed in September when water temperature is high. Temperature changes due to El Nino and La Nina events have also been reported to affect the reproductive cycle of *P. mazatlanica* (Garcia-Cuellar *et al*. 2004).

The trophic environment is also known to act on the reproductive status of *P. margaritifera* (Pouvreau, *et al.* 2000b). In French Polynesia, due to low chlorophyll *a* concentrations, the trophic environment is considered oligotrophic. Data on phytoplanktonic pigments have been obtained in the Takapoto atoll in northern Tuamotu (southern hemisphere), where concentration in chlorophyll *a* ranged between 0.05 and 0.46 $\mu g \cdot L^{-1}$ (Delesalle *et al*. 2001).

Very little information on these parameters has been collected for the southern islands (Gambier Islands).

The objective of the present study was to examine the effect of the annual cycle of temperature and chlorophyll *a* concentration on the reproductive cycle of *P. margaritifera*, to determine whether local environmental conditions in the Gambier Islands induce any marked seasonality in the reproductive cycle of this tropical pearl oyster species.

Material and methods.

Gambier Islands

Pearl culture has developed in several sites in the Gambier Islands (134°52' W & 23°07' S), an Archipelago located in southeast French Polynesia (South Pacific).

Environmental data

Temperature was recorded hourly *in situ* using an automatic sensor (TidbiT temp Logger-Onset®). Chlorophyll *a* concentration (*Chl a*) data were derived from radiometric ocean colour provided by the Sea viewing Wide Field of view Sensor (SeaWiFS) onboard the SeaStar spacecraft (McClain et al., 2004). *Chl a* data were provided weekly from September 2002 to August 2003.

Sampling

Growth and reproduction of *P. margaritifera* were studied in pearl oysters reared in the Gambier lagoon (134°52' W, 23°07' S). The cultivation technique was similar to that commonly used in commercial farms. Suspended long-lines were immersed at a depth of 7 m and pearl oysters were ‘ear hung’ on downlines in groups of ten. The reproductive cycle was studied over a year (from September 2002 to August 2003) by systematic sampling of 30 randomly selected individuals every 15 days. These pearl oysters were collected, cleaned of fouling organisms and sent by air to the Ifremer laboratory on Tahiti Island.

Biometry

For all specimens (n = 720), total weight and height of the shell were measured prior to dissection, weighing, sexing and histology. Sex was determined by rapid microscopic observation of fresh gonad smears. Glycogen content was then measured on 5 dried oysters for each sampling and the visceral mass of 15 other oysters was placed in Davidson's fixative for gonad histology.

Total wet flesh weights were obtained after 15 min of draining. After flesh dissection, the same operation was conducted separately on adductor muscle, gills + mantle and the visceral mass (gonad + digestive gland). Condition index (CI) was computed as the ratio of visceral mass weight to shell weight.

Glycogen measurement

Dry tissues of oyster were powdered and a 10-mg sample was then homogenized in 1 ml of de-ionized water. Changes in the glycogen composition of tissue over the year were quantified using the phenol-sulphuric acid method of Dubois *et al*. (1956).

Histology

After dissection, gonadal tissue samples were placed in Davidson's fixative for five days, after which they were preserved in 70 % ethanol. Samples were then dehydrated through a graded ethanol series, embedded in paraffin, sectioned at 3–4 µm on a rotary microtome, stained with Giemsa dye and, finally, mounted on microscope slides. Sections were made in the gonad area, between the proximal end of the gut loop and the base of the foot. Slide preparations were examined with a light microscope to scan the entire gonadal area and assess follicle stages. Reproductive stages of gonad development are based on the description by Pouvreau *et al*. (2000a) shown in table 1.

Statistics

The growth parameters shell height, total weight, flesh and tissue weights and glycogen content in dried tissue are presented on the figures, with vertical bars representing the 95 % confidence intervals. Correlations between environmental and physiological variables were tested using the critical value table for Pearson's correlation coefficient at the 5 % alpha level and 108 df. The null hypothesis was rejected when $r < 0.195$.

Results

Environmental data

Water temperature gradually increased from the end of September up to a peak in March and then declined to its lowest value in August. Mean annual water temperature was 25.42 ± 1.75 °C, with a minimum of 22.3 °C and a maximum of 27.8 °C (Fig. 1a). The annual mean value of *Chl a* was 0.188 ± 0.075 µg L^{-1}, while the maximum value of 0.436 µg L^{-1} was reached in August 2003 (Fig. 1b). The gaps in the data are due to cloud cover.

Pearl oyster growth

Shell height and total weight increased regularly over the sampling period (Fig. 2a, 2b). The growth rates in terms of shell height and total weight were 87.40 µm.d^{-1} and 176.1 g.d^{-1}, respectively. From September 2002 to February 2003, flesh dry weight remained stable (Fig. 2c). A rapid increase then occurred from February 2003 to mid March 2003, followed by a period during which mean flesh dry weight stabilised once more. Muscle dry weight showed large variations over the year, with the highest value in mid-March (Fig. 3). Changes in weight of the visceral mass were recorded twice, in mid-April and mid-August. (Fig. 3).

Gametogenic cycle

The condition index (CI) showed three significant decreases, the first in December, the second in March and the third in June, while two non-significant changes of CI occurred in May and

August (Fig. 4). Three significant increases of CI were recorded during this study; the first time was in October, one month before the first significant decrease, the second time was in April, just after the second significant decrease, and the third in July, just after the third significant decrease (Fig. 4).

The temporal distribution of maturity stages over the year is shown in Figure 5. The three significant CI decreases coincided with increases in the frequency of inactive (0) and early gametogenic (1) stages, and the decrease in frequency of stages 2 to 5, thus meaning that three significant spawning events had occurred. The first spawning event in December was smallest, since the frequency of the stage 0 and 1 was low. The spawning event in March affected > 70 % of oysters, since these were found to be at stage 1 of the maturity index, while in May and June, spawning only affected > 30 %. In August, the non-significant decrease of CI coincided with a 7 % frequency of stage 1.

Sex ratio

The sex of all individuals was determined during this study. Figure 6a illustrates the change in of this protandrous alternate hermaphrodite sex ratio over the year, while figure 6b represents the change in sex ratio according to the size of individuals. On average, 7 % of individuals were female, the highest value being 14 %. Only animals larger than 80 mm were female. The proportion of females increased up to 22 % for individuals larger then 140 mm.

Glycogen content

Glycogen content in muscles significantly increased to 200 mg. g^{-1} between February and May. In February, glycogen content increased significantly in the mantle, while it remained unchanged in the visceral mass (Fig. 7).

Regression analysis

Growth parameters (shell, flesh and tissue) were positively ($p < 0.05$) correlated with Chl *a* (Table 2). Glycogen content in VM and gill-mantle were negatively with Chl *a*, but glycogen content in all tissues was positively correlated with water temperature (Table 2). Data related to reproductive processes (CI) were not correlated with either chlorophyll or water temperature (Table 2).

Discussion

Environmental data

Temperature recordings during this study (2002-2003) revealed an annual thermal amplitude (6 °C) that was smaller than the one observed in 1998-1999 (8 °C) during the strong El Niño-La Niña events. In comparison, the thermal amplitudes observed in the atolls of northern French Polynesia were 2 °C in 1990-1991 (Buestel and Pouvreau, 2000) and 4 °C in 1998-1999 (Pouvreau, 1999). Radiometric ocean colour derived from satellite observations was extracted for the eastern part of the Gambier archipelago in 2002 and 2003. Two difficulties arose. One was due to cloud cover, which interrupted the continuity of the time series. The second was related to the fact that ocean color is derived from radiance leaving the water, which may be influenced by water depth and bottom albedo (Maritorena et al., 1994). Interpretation of Chl *a* variability must therefore to be considered with caution. However, the annual mean (0.19 µg. L^{-1}) and amplitude range of Chl *a* reported here are in agreement with values and seasonal patterns reported in several atolls in French Polynesia from *in situ* measurements (Charpy 1996; Intes et al. 1990). When considering the Chl *a* time series extended to the beginning of 2002 (data not shown), the maximum value of Chl *a* that we report here in August appears to be related to the Chl *a* seasonal cycle. This Chl *a* maximum in austral winter is also a typical seasonal pattern of Chl *a* in Polynesian lagoons (Charpy 1996; Charpy et al, 2009). The large variations of Chl *a* recorded during this study are also

188 consistent with those measured in water samples from another Polynesian lagoon, Takapoto
189 (Buestel and Pouvreau, 2000). These previous authors attributed this high variability to local
190 meteorology (wind and precipitation), which had short-term, and night/day rhythms affecting
191 some parameters (temperature and chlorophyll *a*).

192 ***Growth***

193 Growth rate of pearl oysters seemed to be faster during the first six months of this study since
194 the shell height and the total weight increased by 25 mm and 63 g, respectively, in this period.
195 No further significant changes in growth were then observed from April to August. In the size
196 class considered (2-year-old oysters), shell growth was equivalent to that of oysters studied by
197 Buestel and Pouvreau (1994) in Takapoto, where shell growth was found to be 30 mm over a
198 whole year. Shell growth dynamics of pearl oysters observed in the present work were similar
199 to those found in a study conducted in 1998-1999 in the Gambier Islands (Pouvreau and Prasil
200 2001).

201 Our results showed that pearl oyster growth in the Gambier Islands was correlated with Chl *a*
202 resources, which correspond to food supply, but not with temperature. The comparison of *P.*
203 *margaritifera* growth between oysters reared in Gambier (this study; Pouvreau and Prasil
204 2001) and those reared in Pioneer Bay, north Queensland (18°37’ S, 146°30’ E), Australia
205 (Yukihira *et al*. 2006), reveals a similar annual growth pattern. The two sites have similar
206 temperatures, and a similar conclusion was drawn: that temperature had no significant effect
207 on growth rates of *P. margaritifera* over the annual cycle.

208 Somatic growth pattern showed two phases. From September 2002 to February 2003, the
209 flesh dry weight did not change significantly, but in March 2003 it doubled. Flesh dry weight
210 then remained stable until August 2003. This change was mainly due to muscle increase, with
211 visceral mass and mantle accounting for less. This growth event coincided with the maximum

212 temperature observed during the study, but the examination of correlations only indicated a
213 significant relationship with chlorophyll *a*.

214 ***Reproductive activity***

215 Pearl oyster reproduction was studied by Thielley (1993), and the reproductive cycle was
216 described by Pouvreau *et al.* (2000a) in the Takapoto atoll, northern Tuamotu. These authors
217 showed that, in a fairly stable tropical environment, *P. margaritifera* is a multiple spawner
218 with an opportunistic reproductive strategy that allows investment of any surplus energy into
219 gamete production throughout the year. CI variations in the present study were related to
220 quantitative losses of weight caused by gamete releases, while the histological analysis
221 revealed a degree of synchronicity within the population. Three spawning periods were
222 characterized by significant decreases of CI; these occurred in December 2002, March 2003
223 and June 2003. The decreases of CI corresponded precisely to periods of gamete release, as
224 confirmed by histological examination of gonadic stages. The first gamete emissions can be
225 regarded as resulting from the accumulation of gametes during winter. The second spawning,
226 which occurred when temperature was maximal, involved most of the oysters since
227 histological analysis showed that 80 % of them were at stage 1 or 2. This spawning was
228 followed by rematuration. A third spawning occurred in June, when the temperature
229 descended below 24 °C, as shown by a significant decrease in CI and the stages shown in the
230 histological analysis. After this event, however, 30-40 % of individuals remained at
231 histological stage 1 of maturity and a similar proportion remained at stage 2 until the
232 beginning of August. At the end of August, a non-significant decrease in CI occurred when 7
233 % of the pearl oysters were at histological stage 1; these observations could indicate a
234 spawning event, despite the fact the temperature reached 22 °C.

235 Histology validated the interest of CI as spawning indicator for the pearl oyster. Spawnings
236 were triggered when CI was around 0.08 %. Before each significant spawning event, the CI

values were 0.084, 0.070 and 0.076 respectively in December, March and June. This study has shown that CI was not correlated with temperature and did not offer any new evidence to support the hypothesis that spawnings were influenced by temperature. The greatest variations in CI corresponded to the spawning in December, when temperature increased up to 25 °C; the one in March, when the temperature was maximal (28 °C); and the one in June, when the temperature decreased below 24 °C.

Sex ratio

The proportion of females (7 %) did not differ from the observations made by Pouvreau *et al.* (2000a) in Takapoto. Indeed, for the age/size class considered here (2-year-old oysters, 100-110 mm height), the sex-ratio in Takapoto was 0.1 female/1 male. The evolution noted over the year of our study was typical of this age group, in which the first inversions of sex are normally known to occur (Thielley 1993). The population raised in the Gambier Islands, therefore, did not differ from populations grown elsewhere in this respect.

Glycogen storage

Marine bivalves show cycles of energy storage and utilization that are closely related to gametogenic cycles. Most species are able to store nutrient reserves during periods of food abundance. These reserves are mobilized during periods of food depletion and high energy demand (Bayne 1976; Barber and Blake 1981; Heude-Berthelin *et al*. 2000). During gametogenesis, high-energy demands are made due to maintenance costs and gamete synthesis; these have to be met by the food supply and/or stored reserves. In *P. mazatlanica*, growing on the west coast of the Gulf of California, glycogen stored in the muscle and digestive gland were actively used for gametogenesis (Saucedo *et al*. 2002). In *P. margaritifera*, our results show that glycogen obtained from ingested food was mainly stored in the adductor muscle and secondarily in the digestive gland, to be later used for ATP needs and to produce gametes. We studied the relationship between the glycogen storage cycle and

gametogenesis of the pearl oyster *P. margaritifera* over the annual cycle (September 2002 to August 2003). Glycogen content increased drastically, showing a 20-fold increase in muscle from February 2003 to May 2003. The energy stored in the muscle could also be used at the time of spawning to achieve vigorous valve movement and to increase the pressure on the gonad to expel the gametes. Our result shows that the maximum glycogen content in the muscle corresponded to the spawning period from March to June. Changes in glycogen content were correlated with temperature in the muscle, mantle and visceral mass (digestive gland and gonad), and with chlorophyll in the visceral mass. Our study confirms that mantle tissue has a negligible role in storage of nutrients during reproduction in *P. margaritifera*. Few changes were observed in the visceral mass over the study period. The digestive gland considered as a short term storage organ (Saucedo *et al*. 2002; Vite-Garcia *et al*. 2008) did not accumulate glycogen over a long period.

Conclusion

The main goal of this work was to examine the hypothesis that the highest thermal amplitude recorded in southern French Polynesia could generate seasonal variation of reproduction in *P. margaritifera*. This study was conducted in the Gambier Islands, where pearl farming is an important industry, and has shown that a seasonal cycle in the reproduction of the pearl oysters does not exist in this area. This study showed that CI (wet weight of gonad/shell weight) could be a good indicator of reproductive events in the pearl oyster. It thus appears that the development of gonads goes on throughout the year in the Gambier Islands, without any detectable phase of sexual rest.

Acknowledgments

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References

Bayne BL (1976) Aspects of the reproduction in bivalve mollusks of reproduction. In: M. Wiley, editor. Estuarine Processes, Vol. 1. London, UK: Academic Press. pp. 432-448.

Barber BJ, Blake NJ (1981) Energy storage and utilization in relation to gametogenesis in *Argopecten irradians* concentricus (Say). J Exp Mar Biol Ecol 52: 121-134.

Buestel D, Pouvreau S (1994) Ecophysiologie de l'huître perlière. Approche des relations entre la croissance de l'huître *Pinctada margaritifera* et le milieu dans le lagon de Takapoto. Programme Général de Recherche sur la Nacre. Action de recherche N° 7 : Croissance Milieu, 64pp.

Buestel D, Pouvreau S (2000) La matière particulaire des eaux du lagon de Takapoto : nourriture potentielle pour les élevages d'huîtres perlières. Oceanologica acta, 23:193-210.

Charpy L (1996) Phytoplankton biomass and production in two Tuamotu atoll lagoons (French Polynesia). Mar Ecol Prog Ser 145: 133-142.

Charpy L, Bonin P, Boeuf D, Bouvy M, Champalbert G, Claquin P, Dupuy C, Durieux B, Fournier J, Guasco S, Lefebvre S, Michotey V, Orvain F, Pagano M, Thomas Y, Veron B, Lo-Yat A (2009) Quality and quantity of available food for pearl oyster: a key parameter for a successful culture. 11th Pacific Science Inter-congress, Tahiti, 2-6 March, 2009. ISBN 978-2-11-098964-2.

Delesalle B, Sakka A, Legendre L, Pages J, Charpy L, Loret P (2001) The phytoplankton of Takapoto Atoll (Tuamotu Archipelago, French Polynesia): time and space variability of biomass, primary production and composition over 24 years. Aquat Living Resour 14, 175-182.

310 Dubois M, Gilles KA, Hamilton JK, Rebers PA, Smith F (1956)
311 Colorimetric method for determination of sugars and related substances
312 Anal Chem 28 :350 – 356.

313 Garcia-Cuellar JA, Garcia-Dominguez F, Lluch-Belda D, Hernandez-Vasquez S (2004) El
314 Nino and La Nina effects on reproductive cycle of the pearl oyster *Pinctada mazatlanica*
315 (Hanley, 1856) (Pteriidae) at Isla Espiritu Santo in the Gulf of California. J Shellfish Res
316 23:113-120.

317 Heude Berthelin C, Kellner K, Mathieu M (2000) Storage metabolism in the pacific oyster
318 (*Crassostrea gigas)* in relation to summer mortalities and reproductive cycle (west coast of
319 France). Comp Biochem Physiol B 125: 359-369.

320 Intes A., Charpy-Roubaud C, Charpy L, Lemasson L, Morize E (1990). "Les lagons d'atoll en
321 Polynésie française: Bilan des travaux du programme "Atoll"." Océanographie-notes et
322 documents n°43: 136 p.

323 Maritorena, S., A. Morel, B. Gentili (1994) Diffuse reflectance of oceanic shallow waters:
324 Influence of water depth and bottom albedo. Limnology Oceanography, 39, 1689-1703.

325 McClain CR, Feldman GC, Hooker SB (2004) An overview of the SeaWiFS project and
326 strategies for producing a climate research quality global ocean bio-optical time series.
327 Deep Sea Research Part II, 51, 5-42.

328 O'Connor WA (2002) Latitudinal variation in reproductive behaviour in the pearl oyster,
329 *Pinctada albina sugillata.* Aquaculture 209 :333-345.

330 Pouvreau S (1999) Étude et modélisation des mécanismes impliqués dans la croissance de
331 l'huître perlière, *Pinctada margaritifera,* au sein de l'écosystème conchylicole du lagon de
332 l'atoll de Takapoto (Polynésie Française). Thèse Univ Rennes.

Pouvreau S, Gangnery A, Tiapari J, Lagarde F, Garnier M, Bodoy A (2000a) Gametogenic cycle and reproductive effort of the tropical blacklip pearl oyster, *Pinctada margaritifera* (Bivalvia: Pteriidae), cultivated in Takapoto atoll (French Polynesia). Aquat Living Resour 13: 37-48.

Pouvreau S, Bacher C, Héral M. (2000b) Ecophysiological model of growth and reproduction of the black pearl oyster, *Pinctada margaritifera* : potential applications for pearl farming in French Polynesia. Aquaculture 186:117-144.

Pouvreau, S., Prasil, V., 2001. Growth of the black-lip pearl oyster, *Pinctada margaritifera*, at nine culture sites of French Polynesia: synthesis of several sampling designs conducted between 1994 and 1999. Aquat Living Resour 14, 155-163.

Salvat B, A Aubanel, M Adjeroud, P Bouisset, D Calmet, Y Chancerelle, N Cochennec-Laureau, N Davies, A Fougerousse, R Galzin, E Lagouy, C Lo, C Monier, C Ponsonnet, G Remoissenet, D Schneider, A Stein, M Tatarata, L Villiers (2008). Le suivi de l'état des récifs coralliens de Polynésie française et leur récente évolution. Rev. Écol. (Terre Vie), 63 : 145-177.

Saucedo P, Racotta I, Villarreal H, Monteforte M (2002) Seasonal change in the histological and biochemical profile of the gonad, digestive gland and muscle of the calafia mother-of-pearl oyster, *Pinctada mazatlanica* (Hanley, 1856) associated with gametogenesis. J Shellfish Res 21 :127-135.

Thielley M (1993) Etude cytologique de la gamétogenèse, de la sex-ratio et du cycle de reproduction chez l'huître perlière *Pinctada margaritifera* (L) var cumingii (Jameson), (Mollusques, bivalves). Comparaison avec le cycle de *Pinctada maculata* (Gould). Thèse Univ. Polynésie Française.

Figures

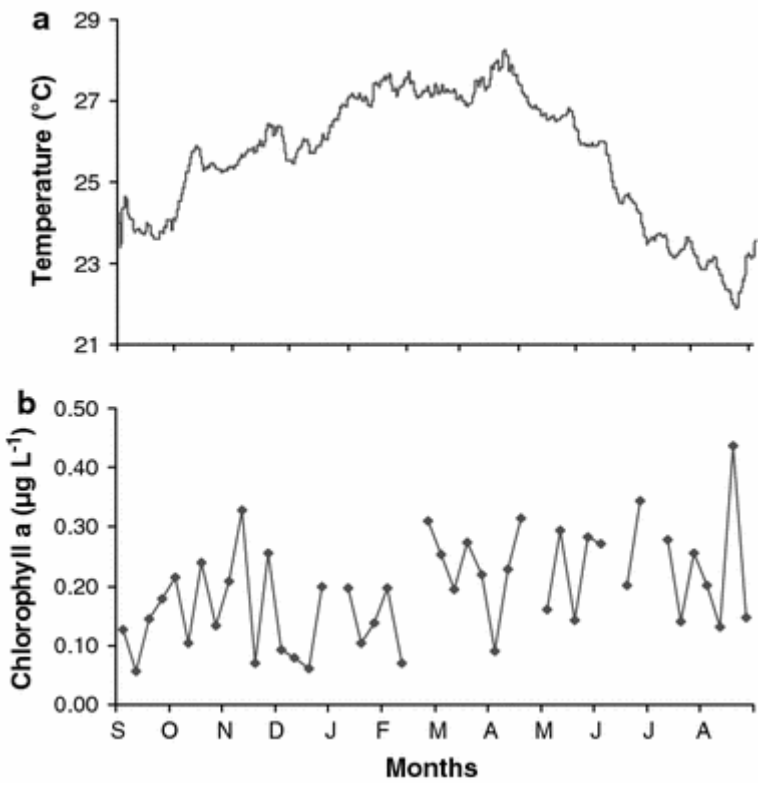

Fig. 1 Variations in temperature (**a**) and chlorophyll *a* (**b**) in 2002–2003 in Gambier Island. Chl *a* concentrations of Gambier Island (134°52′ W & 23°07′ S) were derived from available ocean colour data (SeaWiFS project)

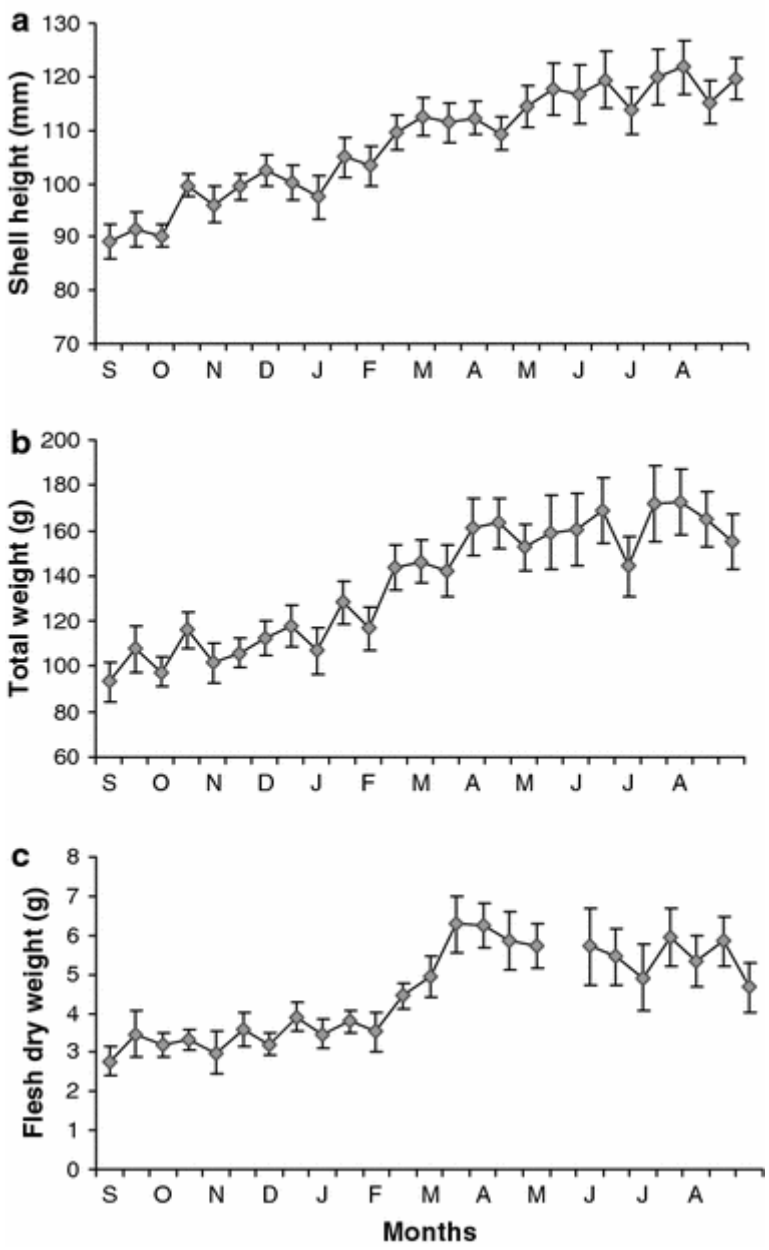

Fig. 2 Shell height (**a**), total weight (**b**) and flesh dry weight (**c**) (mean and confidence interval, α = 5%, *n* = 30) in 2002–2003 in Gambier Island

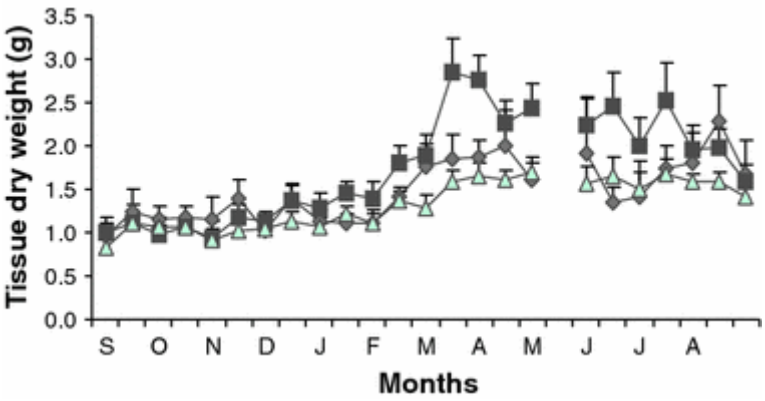

Fig. 3 Tissue dry weight (mean and confidence interval, α = 5%, n = 15) in 2002–2003 in Gambier Island: muscle (grey circles), visceral mass (black rhombuses) and gill-mantle (grey squares)

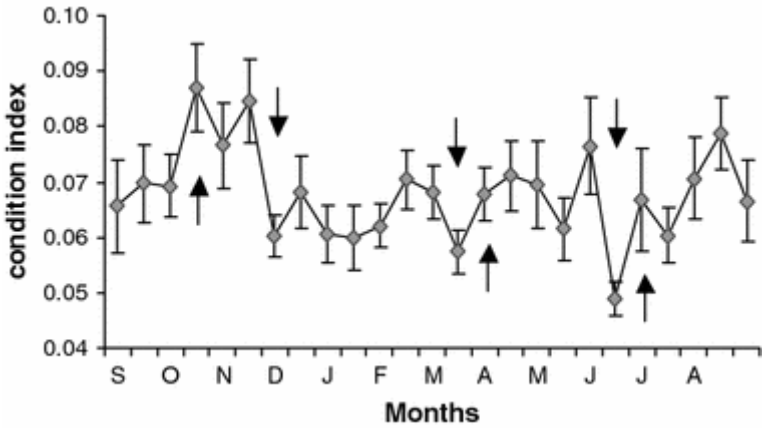

Fig. 4 Condition index (CI) (mean and confidence interval, α = 5%, *n* = 30) in 2002–2003 in Gambier Island (CI = visceral mass/shell weight). *Arrows* indicate significant increase and reduction in conditioning indexes

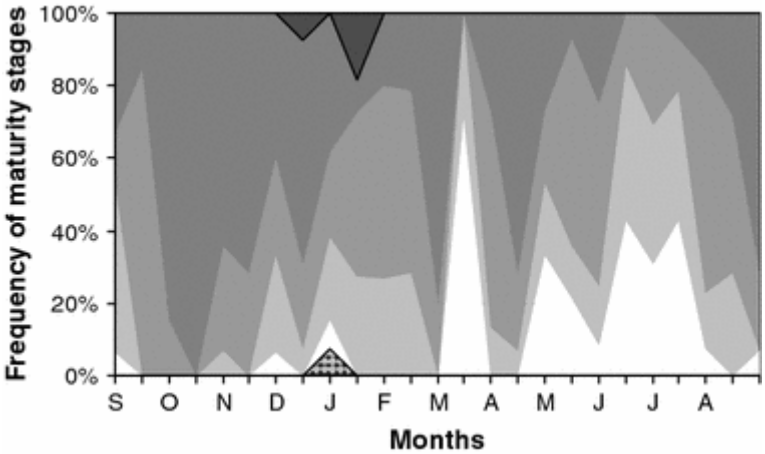

Fig. 5 Histological analysis of the evolution in the frequency of gonadal development stages in 2002–2003 in Gambier Island. *Dotted white on black* = stage 0 (undetermined or inactive), *white* = stage 1 (spawning ripe, distended and confluent follicles, entirely filled), *clear*

grey = stage 2 (actively developing without mature gametes), *mid-grey* = stage 3 (near ripe follicles with mature gametes), *dark grey* = stage 4 (spawning ripe, distended and confluent follicles, entirely filled), *black* = stage 5 (partially spawned, partially empty lumen), (*n* = 15)

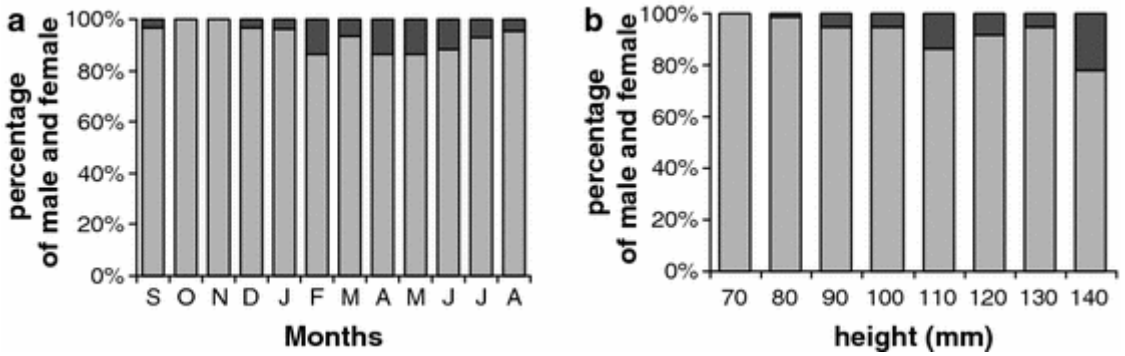

Fig. 6 Sex ratio of *P. margaritifera* in 2002–2003 in Gambier Island (**a**) and according to shell height (**b**). Female = *black*, male = *grey* (*n* = 15)

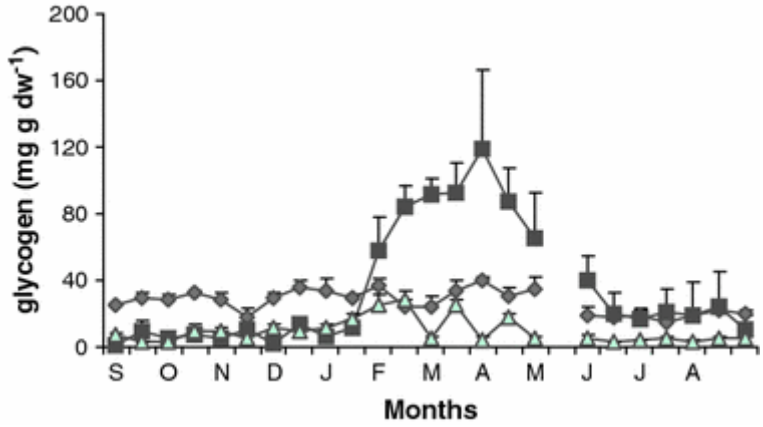

Fig. 7 Glycogen content (mean and confidence interval, α = 5%, *n* = 5) in 2002–2003 in Gambier Island: muscle (*grey circles*), visceral mass (*black rhombuses*), gill-mantle (*dark rhombuses*)

Tables

Table 1 Criteria for histological scoring of gametogenic stages according to Pouvreau et al. (*2000a*)

Histological criteria	**Score**
Undetermined or inactive	0
Early gametogenesis, numerous gonia, small follicles	1
Actively developing without mature gametes	2
Near ripe follicles with mature gametes	3
Spawning ripe, distended and confluent follicles, entirely filled	4
Partially spawned, partially empty lumen	5

Table 2 Correlations of chlorophyll *a* or water temperature (WT) with growth parameters, glycogen content and condition index of *Pinctada margaritifera* off Gambier Island with Pearson correlation analysis (N = 110, α = 0.05)

	Chlorophyll	**Temperature**
Shell height	**0.433**	−0.159
Total weight	**0.351**	−0.107
Flesh weight	**0.239**	−0.138
Tissue weight		
Visceral mass	**0.215**	−0.098
Add. muscle	**0.306**	0.023
Gill-mantle	**0.334**	**−0.363**
Glycogen		
Visceral mass	**−0.310**	**0.602**
Add. muscle	0.113	**0.588**
Gill-mantle	**−0.267**	**0.623**
Condition index	−0.134	−0.043

The significant correlation values are in bold