PEARL FARMING RESPONSIBLE OF ITS OWN DEATH ?

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ABSTRACT

Pearl farming doubles the biomass of Pinctada margaritifera in the Takapoto lagoon, since the natural stock is equivalent to the anthropic one ($8x10^6$ individuals). In 1985, a heavy mortality strikes both stocks and other bivalves without any evident releasing factor and no pathogenic vector could be isolated. Thus, the implication of the biotic capacity may be examined through a study of the filter feeding compartment among which five molluscs species represent more than 95% of the benthic component. Their biomass is estimated around 1360 metric tons for a production of 268 tons/yr^{-1}. The anthropic stock means an overloading of 210 tons in biomass exclusively settled between 0 and 10 meters, inducing a 16% increase of the total potential production of these molluscs. The energetic requirements computed show that the farmed animals need about 30% more than the whole natural filter feeding molluscs of the layer. The ecotrophic efficiency of the bivalves feeding from the primary net production is low, around 0.05. This means they contribute poorly to the energetic transfers in the trophic network which are mainly realised in the pelagic component of the compartment. The energetic requirements for the biomass maintenance and the production cannot be assumed beyond a threshold of biomass increase. From that example, the biomass maintenance is affected with a 15% overload in the lagoon and the consequences are severe mortalities.

INTRODUCTION

The Takapoto lagoon (Tuamotu archipelago) has been one of the main pearl farming sites in French Polynesia since the pearl production development. The first grafting experiments were conducted in the early 70's, and the black pearl became the most yielding exported good in 1983. In this atoll, an important natural stock used to coexist with the farmed one. The stocks were of equivalent size, about 8.10^6 individuals each. But in 1985, a high mortality spread over some polynesian lagoons. It struck heavily the spat and the grafted animals of the Takapoto farms, as well as the wild stock, with more than 80% loss in the southern area.
Such phenomenons were still observed on the same species in the Red sea during 1969 and 1973 (Nasr, 1982), in French Polynesia at Hikueru during 1971 (Morizur, 1971), and on P. maxima in western Australia from 1967 to 1977 (Wolf & Sprague, 1978 ; Pass & Perkins, 1985). In French Polynesia, strong mortalities of marine organisms (Corals, giant clams, fishes) may occur following phytoplanctonic blooms such as in Taiaro (1906), in Mataiva (1953) or at Punauuia (1963). No such event has been reported in the Red sea and there was no sign of a bloom in Takapoto.

The study of "ill" specimens by Grizel and al. (1985) provides a description of symptoms very close to those observed by Nasr (1982) showing a perturbation of lysosoms function. The causes could not be determined, and in particular, no pathogenic vector could be isolated, neither in this case nor in that of the Red sea or the Australia. However, Pass and al. (1987) very recently found a bacteria belonging to the genus Vibrio which induces high mortalities in tanks during the transport between the diving areas and the farms. This bacteria is suspected to affect animals stressed by unusual conditions.
On the other hand, Grizel and al. (1985) examined samples taken in five different lagoons, all of which showed cellular alterations at different levels. This observation suggests that all the French polynesian oysters may be affected but that the indured stress causes mortality only in some lagoons. In these lagoons, other organisms suffer too, all filter feeding species in this case, such as giant clams (Tridacna maxima) or small pearl oysters (Pinctada maculata).

The hypothesis of an accidental pollution has to be rejected in view of the geographic amplitude of the phenomenon and the simultaneity of the symptoms is not in favour of the propagation of an infectious agent. The hydroclimatic characteristics show no abnormal divergence compared with the previous years and no obvious general factor accountable for the event has yet been evidenced.

The aim of this paper is not to identify a releasing factor of the so called "disease", but to try to understand why these mortalities occured in some places only.

THE PEARL OYSTER AND ITS ENVIRONMENT

It is generally assumed that the productivity of coral systems is limited by the concentration of entering nutrients, especially in the confined environment of the atolls lagoons (Smith & Jokiel, 1978). According to Polovina (1984), Atkinson & Grigg (1984) and Grigg and al. (1984) however, benthic models suggest that two other mechanisms determine the productivity. The first is the efficiency of energetic transfers within the trophic network which is very high for coral systems, reaching globally 95% in the above example. The second consists of the predation forces, which play a dominant role. That implies that, within a balanced system, the potentialities are exploited close to their maximum in each trophic level.

What are then the most recent important facts which could have altered the trophic network ? The pearl oyster, as a sessile filter feeding organism, is a primary consumer and one needs to locate it among its competitors for energetic requirements.

The competitors

Closed lagoons are characterized by low specific diversity offset by abundance of some dominant species. In Reao (Tuamotu), two species (Tridacna maxima and Halodeima atra) represent 80% of the total biomass (Salvat, 1971). Among the 93 species of molluscs recorded in Takapoto, 10 contribute more than 95% of the biomass or of the abundance (Richard, 1985). 5 of them are sessile and fill the quasi totality of the filter feeding benthic compartment : Arca ventricosa, Pinctada margaritifera, Pinctada maculata, Tridacna maxima and Chama iostoma, (Richard & al., 1979). Only the blacklip pearl oyster is exploited as a resource.

The energetic resource

The pearl oyster diet, said to be non selective, is known only qualitatively, mostly through the study of Nasr (1982). The phytoplancton is the major component of the stomach content and consists mainly of small organisms such as diatoms even if their occurence decrease in the older oysters. But more generally, the food resource for the non selective filter feeding organisms is the suspended or even dissolved particulate organic matter.

In the Takapoto lagoon, its phytoplanctonic component is the best known. Between 1974 and 1978, the average amount of chlorophyll a fluctuated from 0.1 to 0.5 mg.Chl a/m^{-3} . The highest values were recorded during austral winter and were two to five times higher than in the ocean close by (Salvat & Richard, 1985).

Available data on organic biomass and production from the literature show large spatio-temporal variations, but an order of magnitude can be put forward for a production evaluation. Sournia and Ricard (1976) recorded a gross production of 395 mg. C/m^{-2}/d^{-1} at a station considered to be representative of the lagoon, yielding for the whole lagoon a production of order 30 metric tons of carbon per day. Repetitive measures by Charpy (1985) in the Tikehau lagoon over a three years period, revealed production fluctuations in a 1 to 8 ratio, but the author considers an average production of 440 mg.C/m^{-2}/d^{-1}. Having equivalent mean depths, these two lagoons would have close production rates.

However only a fraction of the gross production is available for the primary consumers. The net production is the one to be assessed since it is the actual food resource. Because of the lack of data on the respiratory activity in the water column, the P/R ratio remains unknown. Following Yentsch conclusions (1961), a 2.5 value is considered here. The net primary production would be around 0.237 mg.C/m^{-2}/d^{-1}. Taking into account a 40% content of Carbon in the dry organic matter, the production will be 592 mg.C/m^{-2}/d^{-1} dry weight of phytoplancton. An approximative conversion into wet weight gives an evaluation of 3,6 g/m^{-2}/d^{-1}, i.e. 90,000 tons per year for the whole lagoon. For comparison, the estimations for French Frigate shoals are of order 1.7 g/m^{-2}/d^{-1} (Grigg & al., 1984), and Hirota and al. (1980) found 2.4 g/m^{-2}/d^{-1} in the coastal waters of Hawai. Thus, the potentialities appear to be higher in the atoll lagoons. Takapoto stand between Tikehau (4.5 g/m^{-2}/d^{-1}) and Aitutaki (2.25 g/m^{-2}/d^{-1}) (Charpy's data).

The qualitative and quantitative distribution of this production is stratified in the lagoonal space as shown by Charpy and Lemasson work (in press). The maximum activity is observed in the upper 10 meters which, for C^{14} incorporation rate, represents 70% of the water column and with P/B ratios between 13 and 21. Beneath, between 10 and 20 meters, the P/B ratios decrease, from 5 to 10, and for C^{14} assimilation rate, the layer represents only 25% of the water column. More than the biomasses involved, the point to emphasize is the stratification of the production activity, inducing singularly short turn over times, of order 3 hours for the biomass doubling.

THE FILTER FEEDERS BIOMASS:

The species:

The major component of the filter feeders biomass is represented by five species of sessile molluscs. Richard (1977, 1978, 1983, 1985) studied and deduced biomass and production data for three of these species : Tridacna maxima, Arca ventricosa and Chama iostoma. The same parameters are known for the blacklip pearl oyster through the works of Intès and al. (in preparation). Only P. maculata has not been specifically studied, but the general knowledge of the lagoon allows to estimate its abundance with sufficient precision.

Tridacna maxima (Röding, 1798)

The giant clams live on the hard substrates no deeper than 14 meters. The highest densities reach 20 individuals/m^{-2}, but the average is approximately 6 ind./m^{-2}. The population is estimated at about 14 millions individuals, most of which (9 millions) live near the edges. The total biomass (wet body weight) is assessed to be about 530 metric tons. The productive potential of the population remains low, 120 tons/yr^{-1}, because of the slow growth and a low P/B ratio (0.18).

Chama iostoma (Conrad, 1837) :

This species has been recorded at all depths of the lagoon, with higher densities at mid depth (15-30 meters) on the slopes of the central patches. The population size is about 11 millions of individuals, for a biomass assessment of 80 tons. As in the previous species, a slow growth and a small P/B ratio induce a weak production estimated at 16 tons/yr^{-1}.

Arca ventricosa Lamarck, 1819 :

This species can be seen at all depths everywhere on the hard bottoms, but greater densities are encountered on the small subsurface patches The population counts about 28 millions of individuals on the patches, 7.5 near the lagoon edges and 2.8 millions on the lagoon bottom, i.e. 38.5 millions. The total wet weight, shell included, is estimated to 1550 tons for a biomass of 340 tons. The biological characteristics of the species are very close to those previously seen and the production is low, around 49 tons per year.

Pinctada maculata (Gould, 1850) :

The small pearl oysters are very abundant near the lagoon edges and on the patches, with higher densities in the upper 10 meters. The population is estimated to about 40 millions individuals. Using as basic data the biomass data obtained on young blacklip pearl oysters of the same size, the population biomass can be estimated to about 200 tons. The P/B ratio is supposed to be low in consideration of the longevity of the species and the production estimation is about 40 tons per year.

Pinctada margaritifera Linne, 1758 :
The blacklip pearl oyster can be collected on all the hard substrates, on the edges as well as on the patches. The licit or illicit exploitation of the stock disturbs its bathymetric distribution. High densities may be observed in the upper layer of protected areas, private concessions or legal reserves, but most of the population is distributed within the 20-40 meters depth range. The biomass assessment was realised for each ten meters layer and the total effectives are around 8 millions individuals, representing a total wet weight (shell included) of 1750 tons and a biomass of about 210 tons. The slow growth combined with a low P/B ratio demonstrates a low production rate, estimated to 43 tons per year.

The quantitative data gathered for these five species are given in terms of biomass and production in table 1.
In conclusion, the Takapoto lagoon contains a natural filter feeding benthic biomass estimated to about 1400 tons, and its production is of order 270 tons/yr^{-1}. This biomass is restricted to the hard substrates and its bathymetric distribution needs to be more detailed.

Table 1 : Available quantitative data on the filter feeding molluscs of the Takapoto lagoon.

Species	ARCA	TRIDAC.	CHAMA	P.mac.	P.mar.	TOTAL
Effectives (10^6)	38,5	14	11	40	8	111,5
Total weight(T.)	1550	2700	2000	820	1750	8820
Biomass (T.)	340	530	80	200	210	1360
Production (T.)	49	120	16	40	43	268
P/B	0,14	0,18	0,21	0,2	0,2	-

meters. The large biomass of the giant clams weighs heavily on the results, as the depth extension of the species is limited by the incident light to the 15 upper meters. What is true for the biomasses is also true for the productions because of the P/B ratios which are of the same order for all the species involved.

The exploitation : influence on the biomass :

The exploitation (by skin diving fishermen) of mother of pearl as a raw material for exportation lasted until about 1960 (Intès, 1981). Since then the use of the resource and the impact of the exploitation has changed drastically (Intès, 1984) as the catch is no longer removed from the lagoon but only shifted around.
For this species, supplying the farms with livestock constitutes one of the main controlling factors of the pearl farming development. This is done either by drawing on the natural stocks or by collecting the spat. Spat collecting may be considered as an artificial recruitment added to the natural one. The farming of the animals from both sources lower the natural mortality and enhance the total biomass.
The enquiries realised by the "Service de la Mer et de l'Aquaculture" give an assessment of the total livestock : Around 8.10^6 oysters would be under human control, i.e. the effectives of the natural stock. Since, however, the submarine constructions are built exclusively in the first ten meters, the induced biotic overload affects only that layer.

Other factors acting on the biomass :

French Polynesia was severely damaged by hurricanes in 1982 and 1983. Two of them struck Takapoto : "ORAMA" in February and "VEENA" in April

Table 2 : Bathymetric distribution of the populations of filter feeding molluscs expressed in percentages, biomass, production and productivity.

Species	ARCA			TRIDACNA			CHAMA			P.maculata			P.margari.			TOTAL		Prod.
	%	B	P	%	B	P	%	B	P	%	B	P	%	B	P	B	P	K/Ha
Depth																		
0 - 10 m.	60	204	29,4	80	424	96	25	20	4	50	100	20	7	15	3	763	152,5	320
10 - 20 m.	20	68	9,8	20	106	24	25	20	4	25	50	10	15	32	6,5	276	54	22
20 - 30 m.	10	34	4,9	-	-	-	20	16	3,2	15	30	6	38	80	16,5	160	30,5	10
30 - 40 m.	5	17	2,5	-	-	-	15	12	2,4	5	10	2	37	78	16	117	23	11
40 - 50 m.	5	17	2,5	-	-	-	15	12	2,4	5	10	2	3	5	1,5	44	8	8
Total	-	340	49	-	530	120	-	80	16	-	200	40	-	210	43	1360	268	-

Bathymetric distribution of the biomass :

Assuming that the demographic structure is depth independent, the available data from Richard and Intès allow to outline the populations distribution according to depth strata. The results expressed in terms of biomass, production and productivity appear in table 2.

More than three quarters of the biomass live in the 0 to 20 meters interval and more than half is found in the upper layer, from the surface to 10

1983. These events appear to have had a very light incidence on the natural stocks biomass but they destroyed many farms. The more interesting observation was made during the following years : Spat collecting increased significantly from a maximum of 200 young oysters per collector in 1979 (Grand et al., 1984) to more than 400 in 1984 (pers. observ.), with an average yield multiplied by a factor 3 to 5. The hurricanes seem to have enhanced the recruitment and, thus, the total biomass through a more abundant fall of youngs in the natural environment and through an increase of the livestock. Nevertheless, it remains impossible to estimate the consequences on the natural stock since no stock assessment could be made following the hurricanes.

The anthropic sollicitation :

One can estimate the functional modification induced by farming by assuming that the farmed livestock has almost the same characteristics as the natural one. The relative contribution of the species to the biomass and production for the superficial layer and for the whole lagoon is expressed in percentages in table 3.

Table 3.: Relative contributions of the sessile filter feeding molluscs to the biomass and to the production for the 0-10 meters strata and for the whole lagoon (in percentages).

	Strata 0-10 meters	Lagoon
Natural biomass + farms	973 Tons	1570 Tons
Natural production + farms	195,4 Tons	311 Tons

	ARCA B	ARCA P	TRIDACNA B	TRIDACNA P	CHAMA B	CHAMA P	P.maculata B	P.maculata P	Nat.P.mar B	Nat.P.mar P	Livestock B	Livestock P	Total P.mar B	Total P.mar P
0-10 m.	20.9	15.1	43.6	49.2	2.1	2.1	10.3	10.2	1.5	1.5	21.6	22	23.1	23.5
Lagon	21.7	15.8	33.8	38.6	5.1	5.1	12.7	12.9	13.4	13.8	13.4	13.8	26.8	27.6

Pearl farming, as settled in 1985, requests from the lagoonal environment a production increase of about 16%. But the spatial distribution of the farms is such that the overload is limited to the layer in which the natural oysters are poorly represented. The exploitation constitutes a sollicitation of the pearl oyster potential of more than 1000 % in this zone.
Given that a lagoon is a confined area with a low and limited nutrient input, is its fertility able to sustain such enhanced requirements sollicited in the layer where the interspecific competition is the highest ?

ECOLOGICAL AND ECOTROPHIC EFFICIENCIES :

A rough evaluation of the energetic requirements can be done following Laevastu and Larkin (1981). Considering on the one hand the energetic uptake for the biomass (B) maintenance and on the other hand what is needed to sustain the production (P), the requirements (R) are expressed as :

$$R_i = a_i . P_i + b_i . B_i$$

where a and b are characteristics of the species or the group of species. These parameters are not known for the species involved here and only arbitrary values can be attributed, in view of the P/B ratios. The biomass maintenance would require twice its weight ($b_i = 2$) and the production would need 5 times its annual rate ($a_i = 5$).
This speculation yields a consumption of 5,000 tons per year for all the filter feeding molluscs, with 650 tons for the natural pearl oyster stock and the same for the farmed one. If so, this population shows a very low ecotrophic efficiency (Ricker, 1969) and a very low ecological efficiency (Crisp, 1975). The ecotrophic ratio (consumption/net primary production) would be around 0.05, clearly less than the values usually assumed for the marine organisms (0.6 to 0.7 according to Ricker) or than the 95% computed for French Frigate shoals (Polovina, 1984). The ecological efficiency (molluscs Production/consumption) would be about 0.06 and this value represents only half the experimental one obtained by Chardy and Clavier (1988) for the filter feeders of the New Caledonia lagoon. For comparison, the admitted level of the temperate ecosystems is about 20%.

DISCUSSION :

The lagoon compartments that we considered, phytoplanton an primary consumers, are distributed along a bathymetric gradient which is one of their ecological characteristics. In fact, more than half the biomass lies in the most active primary production zone, the upper ten meters. So, the distribution of the filter feeding molluscs appears to be strongly influenced by the spatial distribution of the M.O.P., and especially by the production rate.

However, the giant clams, reputed to be at least partially autotrophic organisms, weigh heavily on the observed repartition of the molluscs. Excluding this particular filter feeder, 40% of the biomass and production of the sessile molluscs still lies in the superficial strata and the general outline of the system remains very similar.

Considering the molluscs only, it clearly appears that the food consumption would not be a controlling factor because the primary production could sustain 20 times their estimated requirements. However, the low value of their estimated ecotrophic efficiency suggests that they benefit from only a fraction of this production, the main part being consumed by other filter feeding organisms which play the determinant role in the ecosystem. The faunistic structure of the lagoon shows that these organisms should be pelagic, in agreement with Chardy and Clavier's (1988) conclusions that the links between planctonic and benthic system are weak.
This is confirmed by work by Le Borgne and al. (1986) who estimate that zooplancton grazing uses 60% to 140% of the M.O.P. organic production, and that predation may exceed production under particular conditions such as detritus release from the reef.

Moreover, the low ecological efficiency of the molluscs indicates a poor ability for energetic transfers. This again agree with Chardy and Clavier's (1988) conclusions on the benthic primary consumers of the New Caledonia lagoon.

CONCLUSIONS :

The assessments presented above imply that the energy available for the filter feeding molluscs is much more limited than estimates based on primary planctonic production, even though a close relation exists between them as shown by the distribution of the molluscs populations. The availability of the food resource is probably linked to the pelagic functioning in which consumption may exceed production under some circumstances. As a consequence, the benthic primary consumers can only play a secondary role in the lagoonal ecosystem.

The primary consumers have generally long life spans with low P/B ratios. They represent a rather inefficient component of the energetic transfers network, which reduces their ability to compete for food. Food competition occurs at its highest level in the superficial layer where the production processes are most active and where the consumers biomasses are the largest.

In this context, pearl farming modifies the trophic network structure by increasing the total energetic requirements of benthic primary consumers which have low intrinsic abilities and depend upon a food resource limited by the predation in the water column. On the one hand, the food availability is subject to high variations and may be very low. On the other hand the compartment is naturally close to saturation. Under such ecological conditions, regulating mortalities might occur, all the more so as the compartment is more oversaturated in biomass and food deficiency lasts longer. The mortalities recorded in Takapoto which had catastrophic consequences for the pearl farming itself may be a dramatic example of such a regulation.

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