An estimate of the energy budget between cultivated biomass and the environment around a mussel-park in the northwest Mediterranean Sea

Christian Grenz, Henri Masse, Abdel K. Morchid, and Alain Parache

This theoretical approach deals with a culture unit of *Mytilus galloprovincialis* in subtidal conditions (50 suspended ropes, 3 m long). The culture cycle lasted 480 days; 180 days from spat to seed size and 300 days from seed to market size. The mean hydrobiological conditions considered in this study were taken from monthly measurements collected over four years. The flow through the system was estimated as $30 \times 10^6 m^3$, carrying $331 \ t$ of particulate matter containing $120 t$ of particulate organic matter, equivalent to an energy of $336 \times 10^9 J$. The retention by mussels was estimated at $77 t$ of particulate matter containing $28 t$ of organic material, equivalent to $78 \times 10^9 J$. The culture unit produced $10.79 t$ of biodeposits containing $1.76 t$ of organic material, equivalent to $10 \times 10^9 J$; $5.42 t$ of mussels containing $276 kg$ of dry tissues, equivalent to $6 \times 10^9 J$ and $130 kg$ of gametes (dry weight) accounting for an energy of $3 \times 10^9 J$. These results are discussed at the level of the whole suspended culture system of an estimate of carrying capacities.

Cette étude est une approche théorique portant sur un ensemble de 50 cordes à moules (*Mytilus galloprovincialis*) colonisées sur une longueur moyenne de 3 m, en conditions subtidales. Le cycle de culture a duré 480 jours divisés en 180 jours de prégrossissement et 300 jours de grossissement au terme duquel le stock est commercialisé. Nous avons considéré des conditions hydrobiologiques moyennes sur 4 années d'observations mensuelles. Le flux entrant dans cette unité de culture a été estimé à $30 \times 10^6 m^3$, transportant une charge particulaire de $331 t$ soit $120 t$ de matériel organique particulier représentant une énergie de $336 \times 10^9 J$. La rétention par les moules a été évaluée à $77 t$ de matériel particulier, soit $28 t$ de matière organique d'une valeur énergétique de $78 \times 10^9 J$. L'unité de culture a produit $10.79 t$ de biodépôts contenant $1.76 t$ de matière organique, soit un équivalent énergétique de $10 \times 10^9 J$; $5420 kg$ de moules contenant $276 kg$ de tissus en poids sec équivalents à $6 \times 10^9 J$ et $130 kg$ de gamètes en poids sec représentant $3 \times 10^9 J$. Ces résultats sont discutés à l'échelle d'une table de culture entière sous l'angle de la capacité biotique du site.

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Introduction

In Mediterranean coastal waters, as well as in salt lagoons, the limited tidal range permits shellfish farming on fixed structures. Those used in this study emerge 2 m above the water surface. Weighted ropes suspended on horizontal rails hang in the water to collect mussel spat of *Mytilus galloprovincialis* (Lmck). In this paper, the exchange balance of energy between a production unit and its environment during the different culture stages is estimated. The purpose is to obtain a better understanding of the carrying capacity concept in order to build a predictive model describing the balance between cultured biomass and the nutritive potential of the site. This model takes into account the circulation of food
(physical model) and the localized capacity for replenishment of this food due to quick turnover through the bacterial loop. This turnover may produce particulate organic matter, dissolved substances, and nutrients able to regenerate primary production (Dugdale and Goering, 1967), supplying filter-feeding bivalves.

Mediterranean conditions are quite different from Atlantic estuarine environments, so it is difficult to apply the results from one (e.g., Héral, 1987) to the other.

This exchange balance is partly based on eco-physical studies reviewed by Deslous-Paoli (1987).

Materials and methods
The theoretical approach considers a culture unit contained between four rails driven vertically into the sediment at 5-m depth and delimiting a 5-m side cube. This cube contains 50 suspended mussel-ropes each 3 m long.

Flow estimates are based on a mean current velocity perpendicular to one side of the cube on a surface of 15 m² (5 m rail x 3 m rope) (Incze and Lutz, 1980). The mean current velocity has been estimated from a set of records collected in the study site, mainly using an Aanderaa recording current meter RCM7.

To smooth the temporal and spatial variability of hydrobiological observations in this coastal area, we have taken monthly mean values calculated from four years of measurements (1984-1987).

The stock of mussels fluctuated according to the different phases of the cultivation procedure. We consider the mussels issued from the spring recruitment in 1984, with a main spatfall observed in April.

The study cycle starts in June and is based on two main periods. The first one, from June to December, from spat to seed, i.e. 180 days period. The second one, from January to October, represents the growing phase from seed to market size, 300 days. At the end of the first phase, the ropes were removed and thinned out; market size mussels were sold.

In our production calculation we have deliberately omitted mortality rate, which is assumed to be low. Most of the time, mortality results from physical damage caused by violent hydrodynamic conditions, but above all, the mortality is compensated by a residual recruitment, widely spread in time. In the evaluation made here, this approximation is acceptable because the primary interest is to quantify the cultured biomass consuming particulate matter.

As no field data on filtration rate were taken as part of this study, we have used published measurements obtained under similar conditions (Borromthanarat, 1986a).

Biodeposition was estimated from samples collected by sediment traps (Grenz, 1989).

The energetic exchange budgets are expressed in Joules; Brody's coefficients (1945) were applied to carbohydrate, protein, and lipid content of suspended matter as well as of faeces and pseudofaeces. Elementary biochemical contents were determined by standard methodology (Parache and Masse, 1987). The energetic value of mussel tissue was determined directly by bomb calorimetry (Morchid, 1987; Morchid and Masse, 1987).

Results
1. Hydrological conditions: liquid compartment
1.1. Hydrodynamics
The hydrodynamic studies show an extremely variable hydrological situation ruled by an interaction between wind-induced and weak tidal-induced currents. Wind is the primary determining factor that controls all hydrobiologic characteristics (Arfi, 1984). From approximately 11 000 measurements, we calculated a mean current velocity of 4.84 cm s⁻¹.

Current direction was variable during periods of strong winds. There was a tendency to form anti-clockwise gyres under northwest winds and clockwise gyres under southeast winds. The observations confirmed Millet's model (Masse and Grenz, 1989).

1.2. Hydrobiological variables
Basic hydrobiological data collected on-site 1984 to 1987 are summarized in Table 1.

We shall consider successively particulate suspended matter (PSM) and particulate organic matter (POM). Brody's coefficients were applied to results from analyses of the biochemical composition (carbohydrate, protein, and lipid contents) in PSM to calculate energy values (see Table 2).

Table 1. Minimum, maximum, and mean values of temperature, salinity, chlorophyll a (Chl.a), and pheopigment (Pheo) contents, particulate suspended matter (PSM) and particulate organic matter (POM), estimated in Carteau from observations performed between 1984 and 1987. n: number of monthly samples, CL: confidence limits (95%).

<table>
<thead>
<tr>
<th></th>
<th>Temperature °C</th>
<th>Salinity g kg⁻¹</th>
<th>Chl.a µg l⁻¹</th>
<th>Pheo µg l⁻¹</th>
<th>PSM mg l⁻¹</th>
<th>POM mg l⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mini</td>
<td>08.5</td>
<td>30.21</td>
<td>00.12</td>
<td>0.00</td>
<td>03.12</td>
<td>00.82</td>
</tr>
<tr>
<td>Maxi</td>
<td>25.5</td>
<td>38.01</td>
<td>12.00</td>
<td>8.29</td>
<td>38.24</td>
<td>22.98</td>
</tr>
<tr>
<td>Mean</td>
<td>15.7</td>
<td>34.85</td>
<td>02.39</td>
<td>1.95</td>
<td>11.04</td>
<td>04.08</td>
</tr>
<tr>
<td>CL</td>
<td>01.4</td>
<td>00.68</td>
<td>00.76</td>
<td>0.70</td>
<td>02.36</td>
<td>01.22</td>
</tr>
</tbody>
</table>
Table 2. Mean particulate biochemical content of sea water and its energy equivalent (calculated with Brody's coefficients), (4 years' observation period between 1984 and 1987).

<table>
<thead>
<tr>
<th>Component</th>
<th>µg dry matter $^{-1}$</th>
<th>J$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proteins</td>
<td>169.72</td>
<td>4.00832</td>
</tr>
<tr>
<td>Carbohydrates</td>
<td>214.79</td>
<td>3.68356</td>
</tr>
<tr>
<td>Lipids</td>
<td>88.89</td>
<td>3.51010</td>
</tr>
<tr>
<td>Total</td>
<td>11.20</td>
<td></td>
</tr>
</tbody>
</table>

2. Mollusc compartment

2.1. Filtration rate
In estimating particulate retention due to filtration activity of the mussels we have assumed that there is not great difference between *Mytilus edulis* and *M. galloprovincialis* and selected a continuous mean filtration rate of $5 \text{ l h}^{-1} \text{ g}^{-1}$ dry tissue weight (Borromhanarat, 1986a).

In sublittoral mussels, filtration may be considered to be continuous because the ranges of temperature and salinity (Table 1) on the site at Carteau had no significant effect on the filtration activity (Riva and Massé, 1983).

2.2. Mussel biomass
To convert gross weights (wet weight of living mussels) to ash-free dry weights (AFDW), a mean factor of 5.1% has been applied. This mean factor is calculated from monthly relations between the different wet and ash-free dry weights (Parache and Massé, 1987) (Table 3).

2.3. Gamete production
The reproductive effort of the mussels has been calculated by Morchid (1987). From these data we have taken the following relations for the estimate of gamete production:

\[ W_g = 1.0050 W_s \]
\[ E_g = 1.1168 E_s \]

where $W_g$ and $E_g$ refer to gamete weight and energy content respectively, and $W_s$ and $E_s$ represent the tissue weight and energy content just before spawning.

The main gamete production occurs in autumn for precocious mussels and between the end of winter and spring for the others. Consequently, the gamete production estimate is based on the second period (January 85–October 85). A mean biomass of 50.7 kg total weight for one rope, corresponding to 129.3 kg AFDW for a culture unit (50 ropes), was representative of the adult stock during the observation cycle, leading to a release of 129.9 kg AFDW of gametes (see Fig. 1).

2.4. Biodeposition
The results are from Grenz (1989) and are based on the relation:

\[ OB = 6.35 \text{ (POM)} + 0.97 \text{ (CV)} + 1.91 \]  

where OB represents faeces and pseudo-faeces production (mg AFDW $^{-1} \text{ d}^{-1}$); POM: particulate organic matter (mg AFDW $^{-1}$); and CV: current velocity (cm s$^{-1}$).

An estimate of OB based on (1) using mean values of 4.08 mg $^{-1}$ (POM) and 4.87 cm s$^{-1}$ (CV) gives:

\[ OB = 32.54 \text{ mg AFDW g}^{-1} \text{ DFW d}^{-1} \] (2)

Based on yearly observations, a mean percentage of 16.55%, corresponding to the organic fraction of total biodeposits (TB in dry matter DM) can be applied. So (2) gives:

\[ TB = 196.62 \text{ mg DM g}^{-1} \text{ DFW d}^{-1} \] (3)

Like gamete production, the biodeposition estimate is based on mean biomasses (B), this time from the two culture periods. Energetics estimates are given in Table 4.

Table 3. Evolution of instantaneous mussel biomass (B), mean biomass in the considered interval ($\overline{B}$), and production (P) in gross weight and in ash-free dry weight (AFDW). *: difference between December 1984 and January 1985. **: difference between January 1985 and October 1985.

<table>
<thead>
<tr>
<th>Period</th>
<th>For one rope (kg)</th>
<th>Culture unit (B $\times$ 50 ropes)</th>
<th>Net exported production</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B</td>
<td>$\overline{B}$</td>
<td>P</td>
</tr>
<tr>
<td>June 84</td>
<td>0.4</td>
<td>35.0</td>
<td>69.1</td>
</tr>
<tr>
<td>December 84</td>
<td>69.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>January 85</td>
<td>20.8</td>
<td>50.7</td>
<td>59.7</td>
</tr>
<tr>
<td>October 85</td>
<td>80.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Discussion

Assuming an energy input of 100% to the mollusc compartment through filtration activity, the proposed model shows the following energy distribution:

- 13% for faeces and pseudofaeces production.
- 12% exported as 8% saleable stock and 4% gametes.
- Allowing 5% energy input for shell and byssus production as well as liquid excretion, 70% of the input energy remains. According to Boromthanarat (1986b), respiration accounts for 46%, still leaving 24% of the input, the destination of which is uncertain. Most of this

Table 4. Biochemical contents and estimate of the energetic biodeposition (based on Brody's coefficients)

<table>
<thead>
<tr>
<th>Components</th>
<th>Biochemical content</th>
<th>Energetic biodeposition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>in % dry matter</td>
<td>in mg g⁻¹ DFW d⁻¹</td>
</tr>
<tr>
<td>Proteins</td>
<td>0.68</td>
<td>1.34</td>
</tr>
<tr>
<td>Carbohydrates</td>
<td>3.89</td>
<td>7.65</td>
</tr>
<tr>
<td>Lipids</td>
<td>0.16</td>
<td>0.32</td>
</tr>
<tr>
<td>Total</td>
<td>4.73</td>
<td>9.31</td>
</tr>
</tbody>
</table>
energy may be recaptured by the liquid compartment, either immediately during bio-deposition or delayed by trapping among the mussels.

The main problem set by this evaluation is that of the circulation of food through the whole rope hanging structure and then through the whole site composed of several rows of these structures.

Theoretically, the production unit under consideration (75 m$^3$) is followed by two similar units breadthwise and nine lengthwise. According to Incze and Lutz (1980), optimal conditions for growth are not found when the seston content is reduced by half due to the cultured molluscs’ filtration. In this particular case, from the second production unit onwards the limit proposed by Incze and Lutz is almost reached. In those conditions food deficiency should be expected in the production units downstream beyond the third position. In reality, the situation seems to be far more complex. For instance, for a given current we have never been able to demonstrate significant differences between POM sampled simultaneously upstream and downstream of a mussel farming structure. This is in contrast to Fraga and Vives (1960), who observed a reduction by 39 to 56% in the flow of particulate matter passing a mussel raft in Galicia. Nevertheless, in a mussel park where the density of ropes is high, such as are found in the Thau lagoon, current velocities can be reduced by half (Grenz, 1989), thereby reducing food availability. In the middle of an intensive culture zone Tournier and Pichot (1987) have observed a fall of chlorophyll content (Grenz, 1989), thereby reducing food availability. In those conditions, according to the gyres’ direction of rotation. This can be considered as an advantage for the distribution of nutrients into different production units.

The fact that all currents are wind induced has three major consequences:

1. Because of variability in the direction of currents, the nutrient flow is not unidirectional, as in high tidal range estuaries of fjords (Larsson, 1985), but varies according to the gyres’ direction of rotation. This can be considered as an advantage for the distribution of nutrients into different production units.

2. Due to frequency of strong winds, the mean current velocity is high (4.84 cm s$^{-1}$) for a nearly tideless sea. Observed values in our case are comparable to those estimated in the Skagerrak (Rosenberg and Loo, 1983).

3. The existence of gyres can be considered as an advantage, on the one hand, for recruitment by trapping the planktonic larvae until settlement on the ropes, and on the other hand for enhancing the development of a primary production base on regenerated nutrients from molluscs’ excreta and mineralization of bio-nutrients on the bottom (Baudinet et al., 1989).

References


