THE OUTSTANDING TRAITS OF THE FUNCTIONING OF THE *POSIDONIA OCEANICA* SEAGRASS ECOSYSTEM

Abstract

The biomass, primary production, nutrient and organic carbon inputs and outputs and food webs of the *Posidonia oceanica* ecosystem are compared with those in other marine and terrestrial ecosystems. It exhibits some striking similarities with terrestrial ecosystems (e.g., forest ecosystems), such as the amount of biomass of the primary producers, the presence of litter and the prominent role of detritus based food webs. Other traits are not uncommon in the marine realm, e.g., the sequestration of organic carbon (sink). In addition, it exhibits two further uncommon features: (i) the juxtaposition of two sets of primary producers, the seagrass, which features material that may require months or years to become degraded and enter the detritus food webs, and the epiphytes, with material which is degraded more easily and which enters the herbivorous food webs; (ii) the occurrence of a relatively high rate of primary production despite low nutrient availability (a LNHC system).

Key-words: *Posidonia oceanica*, ecosystem functioning.

Introduction

The seagrass *Posidonia oceanica* is endemic to the Mediterranean Sea, where it constitutes extensive meadows from the sea level down to 25-40 m depth. Overall, the *P. oceanica* meadow carpets 1-2% of the Mediterranean seabed, which represents a surface area of the order of 37,000 km² (Boudouresque et al., 2006).

The functioning of the *Posidonia oceanica* ecosystem

The average biomass of *Posidonia oceanica* is 501 gDW/m² aboveground and 1,611 gDW/m² belowground (Duarte and Chiscano, 1999). Higher values have been measured: up to 1,640 and 5,500 gDW/m² for leaves and rhizomes, respectively (Boudouresque et al., 2006). No other marine MPO (Multicellular Photosynthetic Organism) key species attains such a high overall biomass. In addition to the seagrass biomass, *P. oceanica* leaves and rhizomes harbour autotrophic epiphytes, belonging to Chlorobionta, Rhodobionta and Stramenopiles; their average biomass ranges between 160 and 420 gDW/m².

The primary production of *P. oceanica* ranges between 400 and 2,500 gDW/m²/y and decreases with depth. Autotrophic epiphytes also contribute to the primary production: up to 500-900 gDW/m²/y (Cebrián and Duarte, 2001; Romero, 2004; Boudouresque et al., 2006). It is the sum of these two compartments, the seagrass and its epiphytes, with values ranging from 2,000 to 3,000 gDW/m²/y, which can approach the highest values of net primary production observed in the terrestrial realm. However, it is worth that such very high values only concern shallow water meadows.

In the context of the very low nutrient (N and P) concentrations which char-
acterize most of the Mediterranean, the very high biomass and the relatively high primary production rate displayed by *P. oceanica* meadows are unexpected. Gobert *et al.* (2002) classify this ecosystem within the category of LNHC ecosystems (Low Nutrient High Chlorophyll). The reasons for this paradox may lie in the functioning of the nutrient machine within the system (Fig. 1): (i) the extraction by roots of nutrients buried within the sediment; (ii) the uptake of nutrients both by roots and by leaves; (iii) the luxury consumption of inorganic nitrogen, taken up in excess with respect to the plant requirements and stored within the rhizomes, for further utilisation (Romero, 2004; Mateo *et al.*, 1997); (iv) the trapping by the canopy of POM (Particulate Organic Matter) from the water column, and its subsequent mineralization (Duarte *et al.*, 1999); (v) the trapping within the canopy water of the nutrients released by the mineralization of POM and *P. oceanica* detritus; the canopy water therefore acts as a nutrient reservoir (Gobert *et al.*, 2002); (vi) the internal recycling of nutrients from senescent leaves towards young leaves; (vii) the possible presence of N₂ fixing bacteria on leaves and/or within the rhizosphere (Béthoux and Copin-Montégut, 1986).

![Diagram of nutrient and carbon fluxes in a *Posidonia oceanica* ecosystem.](image)

**Fig. 1** - Nutrient and carbon fluxes in a *Posidonia oceanica* ecosystem. When not available for *P. oceanica*, some fluxes are extrapolated from other seagrasses. Black circles: N₂ fixing bacteria. Light grey: the belowground compartment. Dark grey: *P. oceanica* (roots, rhizomes, leaves) and leaf epiphytes (both autotrophic and heterotrophic). DIN: dissolved inorganic nitrogen. DOC: dissolved organic carbon. N: nitrogen. P: phosphorus. POM: Particulate organic matter from the water column.

Dissolved Organic Carbon (DOC) can be leached towards the water column and the rhizosphere (Fig. 1), which stimulates the bacterial development (García-Martínez *et al.*, 2005). An interconnected system of gas spaces (aerarium) crosses the whole plant and makes possible the recycling of CO₂ (from photorespiration) and the leaking by the roots of O₂ (from photosynthesis). Carbohydrates derived from the photosynthesis are for a large extent rapidly exported to the rhizomes, then redistributed to the surrounding leaf shoots (Libes and Boudouresque, 1987). This constitutes an insurance mechanism: even if the production rate of a shoot is low, it will receive an amount of carbohydrates corresponding to the needs of the growing leaves. In summer, large amounts of carbohydrates are stored in the rhizomes (Alcoverro *et al.*, 2001).
The *P. oceanica* ecosystem comprises two main organic carbon inputs (Fig. 2): (i) heterotrophic plankton and POM proceeding from the pelagic ecosystem; (ii) teleosts which feed on zooplankton of the pelagic ecosystem in the daytime and shelter at night below the leaf canopy. The ecosystem comprises three main organic carbon outputs: (i) a large part of the leaf production is exported, as dead leaves (outwelling); (ii) adult fishes leave the seagrass nurseries; (iii) organic carbon sequestrated within the matte (sink) for millennia. Within the ecosystem, it is generally considered that a small part (less than 10%) of the leaves are directly consumed by herbivores (Cebrian and Duarte, 2001). However, the paradigm of the low consumption of the leaves by herbivores could be an artefact linked to overfishing (Pergent *et al.*, 1993). The leaves which are not consumed are either exported or accumulate in the litter. The mineralization of the litter is a long-term process, which requires months to years. The detritus based food web is the main mechanism of energy transfer from the leaves towards the higher trophic levels. Contrarily to the *P. oceanica* leaves, autotrophic leaf epiphytes are largely consumed by herbivores and their mineralization is a short-term process (Boudouresque *et al.*, 2006).

For the purposes of our comparison of the functioning of the *P. oceanica* ecosystem with other marine and terrestrial ecosystems (Table 1), (i) we have not taken into consideration lakes and rivers; (ii) we compare this ecosystem with the majority of the ecosystems of a realm, but we are aware that some ecosystems do not fit the general case; (iii) we have set aside the other seagrass ecosystems, which obviously share most of the characteristics of the *P. oceanica* ecosystem.

The *P. oceanica* ecosystem shares several functional characteristics either with many terrestrial (e.g. forests), or marine ecosystems. In addition, it exhibits two more uncommon features: (i) the juxtaposition of two sets of primary producers, the seagrass (Magnoliophyta, Plantae), which features material that requires months or years to be degraded and enter the detritus food webs, and the epiphytes belonging to Chlorobionta, Rhodobionta (Plantae) and Stramenopiles,
whose material is more easily degraded and quickly enters the herbivorous food webs. Most terrestrial ecosystems rely on the first type of primary producers while most benthic photophilous marine ecosystems are based upon the second; (ii) the occurrence of a relatively high rate of primary production despite low nutrient availability (a LNHC system). This characteristic is shared by coral reefs, some pelagic ecosystems and by grasslands based upon the symbiosis between $N_2$ fixing procaryotes and Fabaceae.

None of the characteristics of the functioning of the $P.$ oceanica ecosystem are strictly speaking unique. In fact, what makes it original is the grouping of traits which characterise either terrestrial or marine ecosystems. As far as the marine realm is concerned, $P.$ oceanica beds could be viewed as a terrestrial ecosystem in the wrong place. This is not a surprise as seagrasses are terrestrial plants whose ancestors colonized the sublittoral zone.

Tab. 1 - Some features of the $P.$ oceanica ecosystem which are shared – or not – with marine (ME) and terrestrial ecosystems (TE).

<table>
<thead>
<tr>
<th>Features of the $P.$ oceanica ecosystem</th>
<th>Common in ME</th>
<th>Common in TE</th>
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</thead>
<tbody>
<tr>
<td>Huge primary producers (P1) biomass</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>High belowground P1 biomass</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Relatively high primary production</td>
<td>Yes/No</td>
<td>Yes/No</td>
</tr>
<tr>
<td>Juxtaposition of P1s: hard vs easy to degrade</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>A LNHC system</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Recycling of the nutrients within the ecosystem</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Presence of a litter of dead leaves</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Prominent role of detritus based food webs</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Outwelling of a part of the primary production</td>
<td>Yes/No</td>
<td>No</td>
</tr>
<tr>
<td>A sink for carbon</td>
<td>Yes/No</td>
<td>No</td>
</tr>
<tr>
<td>Low biomass of the secondary producers (P2)</td>
<td>Yes/No</td>
<td>Yes</td>
</tr>
<tr>
<td>Low P2/P1 ratio</td>
<td>Yes/No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Whatever its originality, the $P.$ oceanica ecosystem clearly represents a success story, as it occupies a large part of the Mediterranean sublittoral zone. Two features may account for this success: (i) the traits which characterize the Magnoliophyta, that are the basis for the “nutrient machine”; (ii) the maximization of the biomass, with respect to the energy flow, which constitutes a strategy which enhances the ecosystem’s resilience.

References


