Available online at www.sciencedirect.com
ScienceDirect
Estuarine, Coastal and Shelf Science 73 (2007) 299–315
ESTUARINE COASTAL AND SHELF SCIENCE
www.elsevier.com/locate/ecss

# A seasonal survey of the food web in the Lapalme Lagoon (northwestern Mediterranean) assessed by carbon and nitrogen stable isotope analysis

Antoine Carlier [a,*], Pascal Riera [b], Jean-Michel Amouroux [a], Jean-Yves Bodiou [a], Karine Escoubeyrou [a], Martin Desmalades [a], Jocelyne Caparros [a], Antoine Grémare [a]

[a] Université Pierre et Marie Curie-Paris 6 and CNRS, UMR 7621, F-66650 Banyuls-sur-Mer, France
[b] UMR 7144 CNRS, Adaptation et Diversité en Milieu Marin, Station Biologique de Roscoff, Université Pierre et Marie Curie-Paris 6, CNRS-INSUE, Place Georges Teissier, BP 74, 29682 Roscoff Cedex, France

Received 11 October 2006; accepted 22 January 2007
Available online 23 March 2007

**Abstract**

We used carbon and nitrogen stable isotope analysis to describe the food web of the Lapalme Lagoon, one of the best preserved coastal lagoons along the French Mediterranean coast. Three surveys, corresponding to contrasting situations both in terms of continental inputs and of connection between the lagoon and the open sea, were conducted in June and September 2004 and in February 2005. There were significant spatio-temporal changes in the isotopic ratios of both primary producers and consumers. Temporal changes were mostly linked to important $^{13}$C-depleted continental inputs caused by the long period of heavy rainfall before the June survey. Conversely, isotopic ratios were rather similar in September and February despite the opening of the connection of the lagoon with the sea between these two surveys. The interpretation of the results in terms of the structure of the trophic network differed between the June period and the two other ones. In September 2004 and February 2005, the food web was mostly based on SOM and lagoon POM pools with only a few consumers departing from this general trend. In June 2004, a significant proportion of consumers were conversely $^{13}$C-depleted probably due to the assimilation of significant amounts of continental inputs by grazers and filter-feeders. This stresses the necessity of carrying out seasonal surveys to get a sound idea of the structure of the food web in highly variable ecosystems such as coastal lagoons. Spatial changes in isotopic ratios were likely linked to: (1) the salinity/confinement gradient with a trend toward lower $\delta^{13}$C and $\delta^{15}$N values (i.e., higher continental influence) in the inner part of the main lagoon; and (2) the high $\delta^{15}$N values of primary producers and discretely motile consumers in a semi-confined site located downstream a vineyard receiving large amounts of fertilizers. We hypothesised that these inputs are quickly $^{15}$N-enriched through denitrification and ammonia volatilisation processes and then contribute to the $^{15}$N-enrichment of salt marsh plants and seagrass at this site. This interpretation is supported by the fact that such a $^{15}$N-enrichment of primary producers only occurred in February (i.e., after the dispersion of the fertilizers). Conversely, discretely motile consumers were $^{15}$N-enriched all year round, which suggests that they were mostly exploiting the detritic pool derived from $^{15}$N-enriched salt marsh plants.


*Keywords:* food webs; $\delta^{13}$C; $\delta^{15}$N; coastal lagoons; spatio-temporal changes; food sources; northwestern Mediterranean

## 1. Introduction

In spite of their small surface coastal lagoons are key zones in the life history of many organisms (Boutière, 1980). These ecosystems are used by marine fishes and migratory birds as nursery and/or feeding grounds because they constitute sheltered and highly productive areas (Nixon, 1981). Due to continental inputs of nutrients and organic matter, primary production in coastal lagoons is typically between 200 and 400 gC m$^{-2}$ yr$^{-1}$ (Nixon, 1981). In Mediterranean lagoons, phytoplanktonic production can reach up to 300 gC m$^{-2}$ yr$^{-1}$ (Vaulot and Frisoni, 1986). Consequently, fish landings represent up to 150 kg ha$^{-1}$ year$^{-1}$ (Amanieu and Lasserre, 1981), which is 20 times higher than in

* Corresponding author.
*E-mail address:* antoine.carlier@obs-banyuls.fr (A. Carlier).

0272-7714/$ - see front matter © 2007 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ecss.2007.01.012

open Mediterranean (Margalef, 1985). Coastal lagoons are submitted to strong seasonal changes in main environmental parameters. The increase of temperature, the lack of wind and the degradation of organic matter typically reduce oxygen availability during summertime eventually leading to dystrophic crises (Boutière et al., 1982; Bachelet et al., 2000). Coastal lagoons thus constitute extreme environments, where only a restricted number of species is usually present. The diversity of benthic macrofauna is typically low whereas both its abundance and biomass are high (Guelorget and Perthuisot, 1983), which may facilitate the assessment of the architecture of benthic food webs. However, the diversity of potential food sources (e.g., continental inputs, salt marsh plants, seagrasses, macroalgae and phytoplankton) makes coastal lagoons complex ecosystems and the description of their trophic relationships challenging. This explains why, there is currently no paradigm stating, which main source of organic matter fuels the food web of coastal lagoons, and how relative contributions may shift spatially and/or temporally (Fry, 1984; Sprung, 1994; Kwak and Zedler, 1997).

Analysis of the natural abundance of stable isotopes of carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) had proved to be a useful tool for the study of coastal marine food webs (Peterson and Fry, 1987; Kwak and Zedler, 1997). Many studies have dealt with the assessment of trophic relationships in ecosystems featuring strong salinity gradients. However, coastal lagoons have been much less studied than estuaries (Peterson et al., 1985; Deegan and Garritt, 1997; Bardonnet and Riera, 2005), and salt marshes (Peterson and Howarth, 1987; Riera et al., 1999) in this particular context. Stable isotope data on food webs of Mediterranean coastal lagoons are still scarce. The Stagnone di Marsala (Western Sicily) was the subject of frequent investigations on: (1) suspended particulate organic matter (Sarà et al., 1998); (2) seagrasses as a food source for higher trophic levels (Vizzini et al., 2002); and (3) the diets of *Atherina boyeri* (Vizzini and Mazzola, 2005) and *Syngnathus* spp. (Vizzini and Mazzola, 2004). The food web of the Lake of Sabaudia (central Italy), was investigated seasonally but without any assessment of spatial changes (Vizzini and Mazzola, 2003). To our knowledge, the Vaccarès and the Mauguio Lagoons are the only French Mediterranean lagoons, whose food web have been studied through the use of stable isotopes (Persic et al., 2004; Vizzini et al., 2005). However, although these large lagoons are both characterised by a salinity gradient, their investigations were based on one single and two sampling sites only, respectively.

Besides stable isotope analysis, the assessment of the amino acid composition of potential food sources may also help in assessing their relative contributions to a food web. Bioavailable amino acids can be quantified by mimicking digestion through an enzymatic hydrolysis (Mayer et al., 1995). The relative contribution of enzymatically hydrolysable amino acids (EHAA) to the total hydrolysable amino acids (THAA) pool can then be used as an index of nutritive value (Grémare et al., 1997; Dauwe et al., 1999).

The Lapalme Lagoon is a small coastal lagoon located on the French Mediterranean coast. Its small catchment area is only slightly disturbed by anthropogenic pressure. Consequently, its water is of good quality and dystrophic crises are nearly absent (Wilke and Boutière, 2000; Ifremer, 2006). Moreover, its only connection with the open sea has not been modified by human activities and is thus still functioning naturally with a succession between periods of opening and closure depending on meteorological conditions. This characteristic is important since the free circulation of water plays an essential role in the functioning of Mediterranean lagoons (Petit, 1953). Overall, the Lapalme Lagoon is one of the most genuine along the French Mediterranean coast and can therefore be considered as a comprehensive example of undisturbed Mediterranean coastal lagoons.

The aims of the present study were to assess: (1) spatio-temporal changes in the $\delta^{13}C$ and the $\delta^{15}N$ of primary producers and consumers in the Lapalme Lagoon; and (2) how these changes are linked to the relative importance of continental and marine inputs, and to anthropogenic effects.

## 2. Materials and methods

### 2.1. Study area

The study was conducted in the Lapalme Lagoon (Languedoc-Roussillon), which is located 60 km north of the French-Spanish Mediterranean border. Its surface is about 600 ha, and its mean water depth 60 cm. The lagoon is divided in 3 basins, which are connected by narrow channels (Fig. 1). It has a unique temporary connection with the open sea, which is usually closed during summer, opens in fall and then remains open until spring.

The Lapalme Lagoon shows marked seasonal changes in salinity (i.e., between 3.6 and 76.8 with a mean annual salinity of 28), because of seasonal rainfall (500 mm per year), and intense sunshine during summertime (Wilke and Boutière, 2000). It is submitted to strong ($>16\ m\ s^{-1}$) winds (150 days per year) with maximum speed up to $56\ m\ s^{-1}$. Northwesterly winds dominate and southeast winds are less frequent. They both play a major role in the hydrodynamism of the lagoon (especially in the opening of the connection with the open sea) and generate strong resuspension events.

The Lapalme Lagoon receives freshwater from a small catchment area (about 65 $km^2$), which is almost not affected by human activities. Several karstic springs, which flow almost constantly all year round (about $0.6\ m^3\ s^{-1}$), constitute the main freshwater inputs. The peripheric channel bordering the salt pans north of the lagoon is a second significant input of freshwater with an annual mean flow of $0.24\ m^3\ s^{-1}$. A few small streams (the most important being the Rieu River) contribute for sporadic (annual mean of $0.03\ m^3\ s^{-1}$) inputs of freshwater. They are almost dry in summer, but their flow can reach up to $3\ m^3\ s^{-1}$ in fall and winter after strong rainfall. There are only 2 potential sources of pollution around the lagoon: (1) the waste waters from the La Palme village (about 1000 inhabitants) which are processed in a sewage treatment plant and then injected in the main karstic springs in the north of the lagoon; and (2) inputs of fertilizers in association with