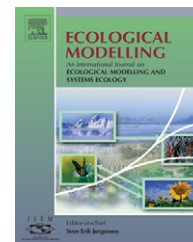


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A first step towards modelling confinement of paralic ecosystems

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ABSTRACT

This paper deals with the concept of *confinement* of paralic ecosystems. It presents a modelling procedure in order to compute the *confinement* field of a lagoon without tide. Then it realizes an improvement in this concept allowing it to be used for tide-influenced lagoons. This improvement consists essentially in including the tide wave into the *confinement* computation. Finally, using a simplified model of benthic population dynamics, this improved version shows that *confinement* may explain benthic population distribution even in paralic ecosystems with strong tide.

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1. Introduction

The concept of *confinement* was introduced by Guélorget and Perthuisot (1983) as the pertinent parameter controlling the features of living macrobenthic populations in paralic ecosystems which are ecosystems encountered in estuaries, lagoons or closed bays.

A wide comparative study (Perthuisot, 1975; Guélorget and Perthuisot, 1982, 1983, 1984; Guélorget et al., 1983; Perthuisot and Guélorget, 1987, 1992, 1983) on zonal qualitative and quantitative biological organisation in habitats along the Mediterranean coasts showed that species distribution is not mainly

related to salinity. Instead, the presence of a given species in a given place of a paralic ecosystem is related to the time for the sea water to reach this place. Indeed, this amount of time is relevant to decreasing availability of nutrients coming from the sea and it is therefore considered as a measure of *confinement*.

Confinement cannot be measured *in situ*. Guélorget and Perthuisot (1983) proposed biological indicators of *confinement*. More precisely, they proposed a division of paralic ecosystems into a series of six zones, each one corresponding to a level in a *confinement* scale, and dominated by specific species.

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Confinement has been widely tested throughout numerous regions: The Red Sea (Ibrahim et al., 1985), The Persian Gulf (Perthuisot and Jauzein, 1978), Guadeloupe (Guélorget et al., 1990), The Baltic and Belt seas (Muus, 1967), and tested for the microfauna of foraminifers in Mediterranean regions (Guélorget et al., 1983), in African coasts (Debenay et al., 1993) and in South Brittany, France (Redois and Debenay, 1996).

Indisputably, *Confinement* is regarded as the right parameter explaining the distribution of species in paralic ecosystems which are not influenced by tide or if the characteristic size of the considered ecosystem is large compared with tide-influenced zones.

On the other hand, *Confinement* seems to be regarded as incompatible with paralic ecosystems in regions where tide is strong. The key argument leading to such a conclusion is that the zonal organisation of species in a strong-tide context is very different from the zonal organisation in a low-tide context. For instance, when it came to macrobenthic species, Barnes (1994) showed that this difference was very clear. This author appraises the “application of Guélorget and Perthuisot’s concept to the paralic ecosystem and confinement to macrotidal Europe”: “it is concluded that confinement is only marginally applicable to brackish-water systems in macrotidal region”. Concerning foraminifers, the comparison of the distribution in Mediterranean paralic ecosystems (see the review in Murray, 1991; Favry et al., 1997, 1998; Guélorget et al., 1999) and in paralic ecosystems located on Eastern Atlantic coasts, (see the review in Murray, 1991; Debenay, 1995, 2000; Redois and Debenay, 1996; Debenay et al., 2006, 2000; Debenay and Guillou, 2002) shows that two species can be separated in a strong-tide context and co-exist in the absence of tide.

From our point of view, those sensible remarks on zonal organisation do not call into question the pertinence of *confinement* for describing living organisation even in strong-tide regions. They rather brought to light that the *confinement* measurement tool, based on biological indicators built by Guélorget and Perthuisot (1983) for Mediterranean paralic ecosystems, is not an ad-hoc tool to measure *confinement* in tide-influenced paralic ecosystems.

Modelling is certainly a good way to go further in this debate and more generally to understand the precise role of *confinement* in the living organisation of paralic ecosystems. Indeed, as *confinement* cannot be measured *in situ*, having software on disposal would be nice in order to have access to the *confinement* value in any place of a given paralic ecosystem. In the future, such software could contribute to the explanation of the different biological zonations occurring in paralic ecosystems or to predict new biological zonation after the construction of harbour, sea wall, dredging, . . . Modelling *confinement*, as a first step in that direction, is then clever.

Modelling also allows one to enter the tide wave into the *confinement* computation. Hence, it is a good way to improve the *confinement* framework to be used to explain species repartition in paralic ecosystems influenced by tide.

The influence of tide on living organisation has already been modelled in other contexts. For instance Focardi et al. (1989), Dejak et al. (1987), Carreras and Menéndez (1990) and more recently Perriñez (1998) used tidal hydrodynamic simulations in order to deduce pollutant diffusion in marine and paralic ecosystems. The effort in modelling the response of

paralic ecosystem to physical forcings like tide was first led by Melaku Canu et al. (2004) and continued by Bendoricchio and De Boni (2005), Ferrarin and Umgiesser (2005), Cucco and Umgiesser (2006) and Marinov et al. (2006). In those references, heavy finite element simulations are led to deduce hydrodynamic fields. From those, parameters having ecological meaning are deduced. The most common parameters computed are residence time, temperature or salinity. But none of those references led any investigation concerning *confinement*.

The aim of this work is to introduce the modelling and computation of *confinement*. More precisely, we produce a modelling procedure to compute *confinement* in a parallelepipedal lagoon without tide. Then, we improve this *confinement* computation procedure in order to use it in the same parallelepipedal lagoon but influenced by tide. More precisely, we present a way to compute what we call *instantaneous confinement* which, in a given place and at a given time, gives the amount of time the water which is presently there has spent in the lagoon water mass. We also compute *effective confinement* that we define as the mean time for the sea water to reach a given point of the lagoon. Finally, we explore a way to explain, using *confinement*, benthic population organisation in tide-influenced paralic ecosystems. For this, we build a very simplified ecological model. It consists in considering that, in a lagoon, the growth rate of benthic species depends on *instantaneous confinement*. Then by entering the tide wave in this model, we compute what we call *specific confinement effective sensitivity* indicator. Then using a simplified criterion involving this indicator, we locate places of the lagoon where a given species may grow. Using this model, in a lagoon with tide and in a lagoon without tide, we get different zonal organisation. This backs up our point of view that *confinement* is pertinent even in a tide-influenced paralic ecosystem.

2. Computation of the *confinement* in a lagoon without tide

We establish the formulas allowing the computation of the *confinement* field in a lagoon which is not tide-influenced. By definition, the *confinement* value in any point of the lagoon is the time for the sea water to reach this point. We consider a lagoon which is a parallelepiped with length l , from the lagoon entrance to the lagoon far end and with depth h . We assume that it is of unit width and we consider x , $0 \leq x \leq l$ as the distance of a given point of the lagoon from the lagoon entrance (see Fig. 1).

We suppose that the water displacements inside the lagoon are solely governed by evaporation. To describe this process we let the constant η be the hydric deficit which is defined as the water volume that evaporates through a surface unit during a time unit. We consider that evaporated water is immediately replaced by surrounded water.

We assume that water velocity is constant along vertical lines and that it decreases proportionally to the distance x , from a maximum in $x = 0$ to 0 in $x = l$.

The water volume that evaporates from the lagoon during a time unit is given, under above assumptions, by the product of the lagoon surface area by η that is $l\eta$. From this, we obtain

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