Cu, Fe, Mn and Zn Cycling in Seagrass (*Zostera noltii* Hornemann) Stands from the Arcachon Bay (Atlantic French Coast)

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Abstract - In this paper, an overview of Cu, Fe, Mn and Zn cycling in intertidal banks of the marine phanerogam *Zostera noltii* (Hornnemann) from the Arcachon Bay (Atlantic French Coast) was done. Absorption, distribution and decomposition of the studied metals were subject to individual studies that permitted a better comprehension of the cycle of each metal. An evaluation of the mass budget of the metals present in the *Z. noltii* stand was also done. It is concluded that the pathways by which metals are absorbed, distributed and released can vary significantly as a function of the strategies that these organisms use to stand environmental stress.

Keywords: Metals, Cycling, Phanerogams, Arcachon Bay (France)

Ciclagem de Cu, Fe, Mn e Zn em bancos de fanerógamas marinhas (*Zostera noltii* Hornemann) da Baía de Arcachon (Costa Atlântica Francesa).
Resumo - Este trabalho apresenta uma revisão sobre a ciclagem do Cu, Fe, Mn e Zn em bancos intertidais da fanerógama *Zostera noltii* (Hornnemann) da Baía de Arcachon (Costa Atlântica francesa). Os processos de absorção, distribuição e decomposição dos metais foram estudados individualmente, permitindo uma melhor compreensão do ciclo de cada metal. O balanço de massa dos metais presentes nos bancos de *Z. noltii* foi também realizado. Conclui-se que os caminhos pelos quais os metais são absorvidos, distribuidos em suas parte e posteriormente liberados para o ambiente variam significativamente em função de suas estratégias para sobreviver sob estresse ambiental.

Palavras-chaves: Metais, Ciclagem, Fanerógamas, Baía de Arcachon (França)

Cycle du Cu, du Fe, du Mn et du Zn dans les herbiers à phanérogames marines (*Zostera noltii* Hornemann) du Bassin d'Arcachon (Côte Atlantique Française).
Resumé - Dans cet article nous avons étudié le cyclage du Cu, du Fe, du Mn et du Zn dans des herbiers à phanérogames marines (*Zostera noltii* Hornnemann) du Bassin d'Arcachon (Côte Atlantique

Française). Les processus d'absorption, distribution et décomposition des métaux étudié ont fait l'objet d'études individueles, qui ont permis de mieux comprendre le cycle de chaque élément. Un bilan de la masse des métaux présent dans les Z. noltii a également été fait. Nous avons pu conclure que le parcurs selon lequel chaque métal est absorbé, distribué et relargué peut varier significativement selon les stratégies que les organismes utilisent pour supporter le stress environnemental.

Mots-clés: Métaux, Cyclage, Phanérogames, Bassin d'Arcachon (France)

1. INTRODUCTION

In the coastal environments the plant biomass is quantitatively the most important biological compartment for metals cycling. While in the tropical coastal environments, the biomass is dominated by mangrove vegetation, in temperate areas, the dominant species are marine phanerogams, frequently in almost monospecific stands. In the northern hemisphere, as stated by Den Hartog (1970), phanerogams can reach productivities of up to 18.7 g C m^{-2} day^{-1} (for *Cymodocea nodosa* in the Mediterranean; (Gessner and Hammer, 1960). The most widespread species in the northern hemisphere is *Zostera marina* L. (Jacobs, 1984), accounting for productions reaching more than 10 g C m^{-2} day^{-1} (Thorne-Miller and Harlin, 1984).

Drifmeyer *et al.* (1980) studied the cycles of Mn, Fe, Cu and Zn in a coastal marine environment and observed that the *Zostera marina* stands were a significant reservoir of metals, exceeding the contribution of *Spartina alterniflora* stands. In this case, the role of *Z. marina* in the metals cycle was beyond a merely quantitative importance, it also represented an important biological link of the food chain.

Mobility and availability of metals were shown to be directly affected by the biological component of the cycle. A number of authors (e.g. Kenworthy and Thayer, 1984) observed that phanerogam plants (*Thalassia testudinum* and *Z. marina*) presented a very slow decomposition rate, remaining buried in the sediment for as long as many years. In this case, at least part of the metals present in the plant tissue would also remain trapped. On the other hand, phanerogams present chemical characteristics that limit grazing, thereby reducing metals transfer to the food chain. Nonetheless, many aspects concerning decomposition rates and metals release are still obscure, like the role of the environmental conditions or the differences between the various species of phanerogams.

Z. noltii is a marine phanerogam that presents a narrower leaf than *Z. marina*, that yields a greater resistance to desiccation during low tide. That is the reason *Z. noltii* covers large intertidal flats of the Arcachon bay (French Atlantic coast) while Z. marina stands only grow in the submerged channels. Subjected to desiccation during low tide, *Z. noltii* is also a plant that is submitted to a

considerable stress, that is expected to change the process of absorption, translocation and release of metals and therefore, changing the cycling rates of metals within the plant stand.

The aim of this work was to develop a box model that would describe metal cycling within a *Z. noltii* stand. These models described the processes of metal absorption, translocation and release, based on literature data. The quantitative importance of the *Z. noltii* stands was established based on a mass balance of the metals present in the plants, debris, water and sediments (Wasserman, 1990; Wasserman *et al.*, 1991; Wasserman *et al.*, 1992). The absorption processes in the Z. noltii were studied by Wasserman (1990) and Wasserman and Lavaux (1991). The translocation processes are inferred based on the data of metal distribution in plant tissues (Wasserman, 1989; Wasserman, 1990). The decomposition processes with consequent release of metals were studied by Wasserman and Dumon (1995) and Wasserman *et al.* (1997). Finally, it was established a design for the cycling of Cu, Fe, Mn and Zn in *Z. noltii* stands from the Arcachon Bay.

2.   METALS BUDGETS WITHIN *Z noltii* STANDS

Wasserman *et al.* (1991), based on the results of metallic concentrations in plants and sediments from the Arcachon Bay, established mass balances for Zn, Cu, Fe and Mn. The data they were based on are presented in table 1. Surface informations like area covered by eelgrasses, area of the tidal flats and area of the channels were obtained by the treatment of an aerial photography of the Bay (Figure 1). In this photograph channels, bare tidal flats and tidal flats covered by eelgrasses were perfectly distinguishable.

Table 1: Sizes of the compartments in the Arcachon Bay

| |
|---|
| **Surfaces, volumes and masses of the bay** |
| Surface of the bay: 156, 1 Km^2 ? |
| Surface covered by *Zostera* stands: 61.5 Km^2 |
| Volume of the sediments in the tidal flats (upper 2 cm): 2.1 ? $10^6 \, m^3$ |
| Mass of the sediment (fraction <63μ): 1.6 ? 10^{12} g |
| Water volume (high tide): 459 ? 10^9 L |
| **Biomasses of *Zostera noltii*** |
| Whole plant: 327.8 $g.m^{-2}$ or 20160 ton |
| Root: 223 $g.m^{-2}$ or 13715 ton |
| Young leaves: 145 $g.m^{-2}$ or 8918 ton |
| Senescent leaves (appear only in winter): 72 $g.m^{-2}$ or 4428 ton |
| Epiphytes (appear only in winter): 70 $g.m^{-2}$ or 4305 ton |
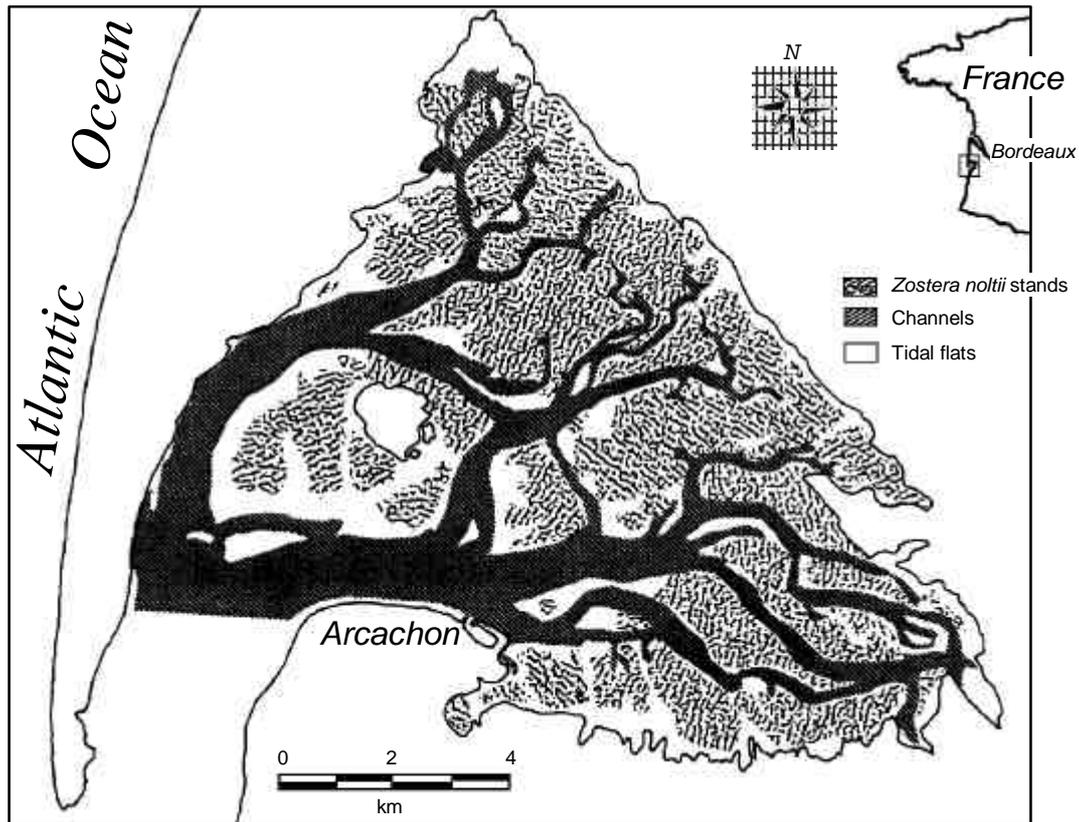
Figure 1: The Arcachon Bay with its *Zostera noltii* stands.

The budget is presented in table 2. In this work, some compartments that do not appear in Wasserman *et al.* (1991) were included, based on the concentrations of water (Wasserman and Dumon, 1995) and in the eelgrass debris (Wasserman *et al.*, 1997).

Although it can be observed that the sediment compartment is quantitatively the far most important, it has to be considered that in the biological compartment, metals are more readily available for the organisms and will recycle faster than sediment metals. Faraday and Churchill (1979) highlighted that the accumulation of metals in *Z. marina* leaves can modify the residence time of these elements in the estuarine environment. After the absorption of Cd through leaves directly from the water, these authors observed significant translocation to the roots, where it remains trapped for quite long periods.

Compared to the water compartment, eelgrass constitute a large pool of Fe and Mn, while Zn and Cu masses are in the same order of magnitude. Epiphytes that appear only during winter (in senescent plants) do not constitute an important pool, although apparently they have important roles in the absorption and translocation processes. Finaly, the budget of the debris could not be calculated because it was not possible to establish a reliable mass balance of this biomass.

Table 2: Average concentrations of metals (mg kg^{-1}) in each compartment (standard deviation) and total stock of each metal in the compartments in the Arcachon Bay.

	Cu	Fe	Mn	Zn
Sediments (n=18)	3.8 (2.3) 6080 Kg (91%)	3622 (1594) 5795 ton (98%)	52.2 (33.5) 83 ton (91%)	59 (21) 95 ton (96%)
Water (μg.L^{-1}) (n=10)	0.9 (1.17) 403 Kg (6%)	15.2 (3.8) 6977 Kg (0.1%)	< 1,0 ( ) < 459 Kg (< 0.5%)	4.3 (1.7) 1974 Kg (2%)
Whole plants (n=18)	8.3 (4.7) 167 Kg (3%)	5191 (3410) 105 ton (1.8%)	355 (220) 7157 Kg (8%)	75 (37) 1512 Kg (2 %)
Roots (n=13)	7.6 (5.1) 104 Kg (1.6%)	8135 (3307) 115 ton (1.9%)	129 (75) 1769 Kg (1.9%)	50 (25) 686 Kg (0.7%)
Young leaves (n=10)	4.9 (3.8) 44 Kg (0.7%)	2133 (1006) 19 ton (0.3%)	713 (564) 6358 Kg (7.0%)	70 (36) 624 Kg (0.6%)
Senescent leaves (n=3)	10.0 (3.0) 44 Kg (0.7%)	3339 (775) 15 ton (0.3%)	218 (112) 965 Kg (1.1%)	115 (33) 509 Kg (0.5%)
Epiphytes (n=3)	12.7 (5.9) 55 Kg (0.8%)	19136 (5104) 82 ton (1.4%)	193 (45) 830 Kg (0.9%)	108 (21) 465 Kg (0.5%)
Debris (n=2)	8.4 (0.11) -	5324 (1054) -	115 (185) -	150 (13) -
Stock *	6650 Kg	5907 ton	91 ton	99 ton

*Total stock was calculated based on the sum of sediment + water + whole plant stocks

3. ABSORPTION RATES

In terrestrial plants, batch experiences like those performed by Wasserman (1998) can establish absorption rates from soil to roots, leaves or fruits. On the other hand direct leaf absorption from atmospheric sprays has been observed for a number of plants and a number of elements. Although metal absorption in marine phanerogams can occurs through leaves and through roots, the rates vary with the considered metal. For *Z. marina* McRoy and Barsdate (1970) developed a simple two-chamber batch experience to study phosphorus absorption rates through roots, through leaves and basipetal or acropetal transport. The same concept was used by Brinkhuis *et al.* (1980) to study other metals absorption.

Yet most of the results obtained with *Z. marina* can be applied to *Z. noltii*, in the case of metal absorption processes these two species can behave differently, since while the former is permanently submerged, the second is submitted to daily tidal desiccation. For that reason (Wasserman, 1990) decided to establish absorption rates determining concentrations in roots/rhizomes, leaves, overlying water and sediments that were collected in seven sampling sites during winter and summer. In table 3 calculated enrichment factors are presented.

Table 3: Average concentrations (Av), standard deviation (SD) and Enrichment Factors of Zostera noltii tissues as related to sediments (EF$_{sediment}$) and water (EF$_{water}$) concentrations. All concentration values given in mg kg^{-1} except water, given in μg L^{-1}.

	Sediments (n=13)	Water* (n=10)	Roots/Rhizome (n=13)	Leaves (n=13)	Epiphytes (n=3)
Cu					
Av(SD)	3.13(2.05)	0,9(1.17)	7.75(5.11)	6.09(4.05)	12.73(2.97)
$EF_{sediment}$	-	-	2.4	1.9	2.7
EF_{water}	-	-		6,767	14,148
Fe					
Av(SD)	3,396(1,532)	15(4)	8,135(3,307)	2,411(1,032)	19,136(2,650)
$EF_{sediment}$	-	-	2.4	0.7	5.8
EF_{water}	-	-		158,608	1,258,947
Mn					
Av(SD)	52.2(36.0)	< 1.0	128.5(74.7)	599.0(535.5)	192,7(22.4)
$EF_{sediment}$	-	-	2.5	11.5	5.8
EF_{water}	-	-		> 599,039	> 192,667
Zn					
Av(SD)	58.9(21.7)	4.3(1.7)	50.4(24.5)	77.5(40.1)	107.5(10.3)
$EF_{sediment}$	-	-	0.9	1.3	1.8
EF_{water}	-	-		18,023	25,008

* given in $\mu g\ L^{-1}$

The first figure that can be drawn from Table 3 is the extremely high enrichment factors from overlying water (EF_{water}) in leaves and epiphytes that probably indicate that the absorption of metals from this compartment is metabolically expensive. As a consequence, translocation from roots is probably a more reliable path for metal enrichment in leaves. On the other hand, leaves and to a greater extent epiphytes probably pump metals directly from sediments during low tides, when the leaves are lying on the sediment.

Before talking about enrichment factors from the sediments it has to be clarified that metal concentrations in this compartment were obtained by partial extraction with HCl 0.1N, corresponding to the so called bioavailable phase. Although, total concentrations are also available in the work of Wasserman (1990), the partial concentrations were chosen for only available metals for absorption are accounted.

Enrichment factors from sediment ($EF_{sediment}$) are considerably lower (closer to the unit) indicating that the main source of metals for the accumulations in *Z. noltii* is this compartment. It is interesting to note that $EF_{sediment}$ in the roots for Cu, Fe and Mn are quite similar, that should be explained by the formation of iron plaques (Armstrong, 1967; Tanizaky, 1994). Zn was expected to be present in this group because, like Cu, it is also known to be trapped in the iron oxide plaques, however the $EF_{sediment}$ for this element is lower showing that in the studied environment this trapping is less effective for that element. Furthermore, Zn seems not to be metabolically necessary, for its $EF_{sediment}$ in the leaves are also reduced. This is not the case for Mn that can be enriched in the leaves at a rate of

11.5, indicating that the plant need important amounts of this element that are not easily available in the studied environment. Considerable amounts of energy are probably expent during absorption of this element.

4.   METALS DISTRIBUTION WITHIN *Z. noltii* TISSUES

The type of metal and its chemical form are important in determining the pathway it will enter the plant compartment (Ernst, 1987), after being absorbed, the phanerogams are able to transport the metals through their tissues, metabolically placing it where the plant mostly need it (Schroeder and Thorhaug, 1980). For example, Bond *et al.* (1985) show a very fast absorption of lead (^{210}Pb). In this phase, adsorption to the more available exchange sites of the plant occurs. If just after this phase the plant is drowned in an EDTA solution, strong release is observed. These authors state that this phase seems to exist for all metals. Pickering and Puia (1969) observed this same rapid absorption phase for other fresh water plants. After this first absorption phase, slower processes take place, frequently metabolicaly mediated. Brinkhuis *et al.* (1980), observed that Cd and Mn absorptions are quite different. In a two chambers experiment, using isotopes they have shown for *Z. marina*, that cadmium is absorbed by underground parts, as well as by leaves. They have also observed more important basipetal transfer (leaves to underground parts) than acropetal transfer (underground parts to leaves) for this element. On the other hand, manganese is preferably absorbed by the leaves and no basipetal transport was observed at all. Faraday and Churchill (1979) and latter, Brix and Lyngby (1982) stated that roots function as a sink for cadmium, a very toxic element.

Metabolic concentration processes play an important role for manganese, since *Z. noltii* seem to need important amounts of this element, mainly during the growing phase (Wasserman and Lavaux , 1991). Wasserman (1990), observed that the concentrations of Mn in the leaves are frequently higher than in the roots and sediments, therefore stocks in the leaves are more important than for other elements (see table 2) confirming metabolicaly mediated absorption. Although to a lesser extent than manganese, zinc also shows low mobility in the plant and higher concentrations in the leaves (Lyngby *et al.*, 1982).

Yet, a number of studies concerning the absorption of metals by eelgrasses have been done, most of them are laboratory studies ("in vitro") where environmental variations are frequently very far from that observed in the natural environment, furthermore, these studies concern mostly *Z. marina*, what is justified by the large distribution of this species. In order to understand environmental variation effects on the absorption of metals, Brinkhuis *et al.* (1980) applied a salinity gradient between the root environment and leaves environment and observed important effects on the absorption rates of metals.

Faraday and Churchill (1979) varied light intensity incident on the leaves to identify photosynthetically mediated absorption of metals. Although no effect was observed when cadmium was considered, manganese and zinc are clearly affected by this factor. In an "in situ" study, Lyngby and Brix (1982) observed considerable seasonal and environmental induced variations of metal concentrations in *Z. marina*. At the end of the growing season the plants accumulate larger amounts of Zn.

Although, as shown above, a considerable set of data is available on the absorption processes of *Zostera*, generalizations based on the results of *Z. marina* are not always applicable. Thus, the study of different species, subjected to varying environmental conditions consists of an important lag in the knowledge.

In the Arcachon Bay (France), although *Z. marina* is present, *Z. noltii* is largely dominant. The study of the ecology of these two plants (Parriaud, 1975) show important differences. *Z noltii* is widespread in the tidal flat areas (comprising 70% of the surface of the bay) while *Z. marina* appears only in the channels. This is due to the ability of the former plant to stand tidal periods in the dryness. Its narrower leaf is less subjected to loss of water and desiccation. This has a large range of implications on the processes of absorption of metals. For example, Wasserman (1990) observed that during low tide, the plants stay lying on the sediments (that never happens to *Z. marina*) and important leaf absorption of metals from the direct contact with sediment may occur. This process was observef for Fe in senescent leaves, when epiphytes (not identified, but possibly diatoms in a mucilage mass) function as a true metal pump.

5.   DECOMPOSITION PROCESSES AFFECTING METAL CONTENT

The behavior of metals during plant decomposition is a much more complicated and less studied process than absorption. On a first approach, one should think that during decomposition of organic matter mineralization would yield metals to the environment. Actually, this process occur, but simultaneously there is adsorption of metals to the exchange sites formed during organic matter decomposition. When considering eelgrasses, mineralization processes are so slow that almost intact leaves of *Zostera* sp. were found in the open ocean, at about 4000 meters depth, off North Carolina (Menzies *et al.*, 1967). Therefore, dynamics of metals in the debris can be a very long term process where loss and enrichment will be always occurring.

In order to understand the decomposition processes in eelgrasses, it is necessary to define the moment the plant decomposition starts. Biebl and McRoy (1971) consider this starting point when the leaf becomes brown. Thus, yet the plant is still fixed to its roots, it is photosynthetically inactive and is considered dead plant. Notwithstanding this somewhat arbitrary definition, decomposition takes place

when the plant is still senescent. Fenchel (1970) studied bacterial development in *Thalassia testudinum* leaf surface and observed that they play an important role in decomposition of this plant. The presence of other bacteria feeding organisms like flagellates and ciliates can increase decomposition by increasing leaf surface available for new bacterial attack.

Z. marina decomposition have been studied in laboratory experiments. Harrison and Mann (1975) observed that bacterial decomposition is not as important as Fenchel (1970) stated for *T. testudinum*. They observed a rapid loss of weight (25%) during the very first moments of the experience, due to the release of dissolved organic matter. This fast process was responsible for 82% of the weight loss during the whole experience (102 days). After this release, an increasing bacterial community developed, probably based on the dissolved organic matter released by the plant to the milieu of the experience, and maintained the plant weight constant for some time. Actually, biomass substitution occurred as shown by the increasing C/N ratio of plant samples (Harrison and Mann, 1975).

Godshalk and Wetzel (1978) also studied *Z. marina* decomposition using laboratory experiments, but for a longer period (180 days) and established a three step decomposition process: a) the first step was characterized by a rapid weight loss in the form of dissolved organic matter (the velocity of this process depends on the oxygen concentration and on the temperature in the experience milieu), followed by bacterial development (corroborating data from Harrison and Mann, 1975); b) during the second step of decomposition, bacterial biomass substitution was observed by ATP analysis, although very little weight loss occurs. In this second step, the presence of amphipodes and isopodes have shown to increase decomposition, because while they eat parts already colonized by bacteria, they leave clear substract for further colonization. On the other hand, yet these macroscopic animals are not able to digest plant debris, they clean surface for new bacterial attack; c) the third step is characterized by very slow decomposition rates. Although some bacterial development can be achieved by changing physico-chemical variables like temperature and nutrient concentrations, this bacterial activity in the leaves themselves is seriously reduced by very refractive leaf tissue. After 180 days of experiment, Godshalk and Wetzel (1978) did not observe further decomposition.

Wasserman (1990) studied these decomposition steps by working out "in situ" experiences. The first used an adapted "bell jar" where *Z. noltii* leaves were placed on the sediment and water was sampled from it in order to estimate the fluxes of organic matter issued from the plants (Wasserman and Dumon, 1995). They observed important organic matter release during the first 2 days and no release at all until the fifth day, when this experience was finished. They also studied heavy metal concentrations in the water, in order to observe how they were affected by dissolved organic matter release. In the levels of concentrations of this experiment, reliable data are quite difficult to obtain, however they

observed that very little Cu release occurs during the whole experience. For Fe, a rapid release during the very first minutes of the experience is observed, followed by slow release until the third day, when consumption of the metal present in the water seem to occur. Zn showed the same behavior as Fe during the first two days of the experience. During the third day, strong release is again observed. In this experience, very little should be said about the behavior of metals, however, it can be stated that metal loss is occurring, probably associated with the dissolved organic matter.

The second experience (Wasserman *et al.*, 1997) was also "in situ" and consisted of placing *Z. noltii* on the sediment, covered by a nylon net (1mm internal diameter). The experience lasted 6 months and monthly, 50 cm cores were taken from the site. Particulate Organic Carbon analyses showed strong decomposition during the third and fourth months, and by the end of the experience leaves were macroscopically still intact. Cu, Fe and Zn showed the same peak concentrations in the top layers apparently associated with POC during the third and fourth months. Fe continued showing high concentrations in the top layers after the fourth month. Finally, manganese did not show any enrichment in the sediment during all samplings, showing that it is probably strongly bound to refractive organic matter.

Very little work was done concerning metal behavior during the decomposition of eelgrass, and considering the importance of these plants for the marine environment, as stated above, new research programs should be started. Kenworthy and Thayer (1984) consider that eelgrasses are an important ecological stock of organic matter, since its decomposition rates are very slow, and they persist in the ecosystem for very long periods. In this case, metals (like Mn) and other pollutants can be trapped in this refractive organic matter. This would strongly affect the global geochemical cycle of these elements.

6.   METAL CYCLING MODELS FOR THE ARCACHON BAY

The models for Cu, Fe, Mn and Zn (figures 2, 3, 4 and 5) were established, based on the above statements and data of *Z. noltii* stands from the Arcachon bay. The observation of the models lead us to the fact that few quantitative data is available and although compartments can be roughly quantified, fluxes can not.
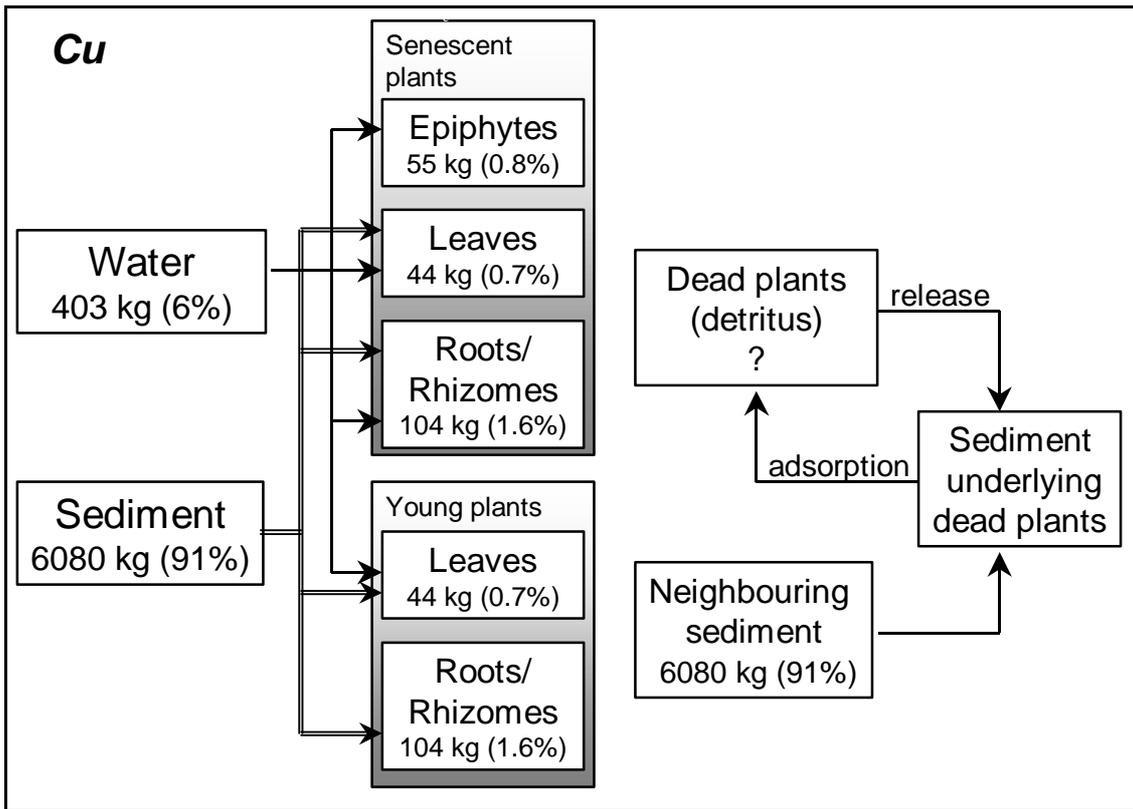
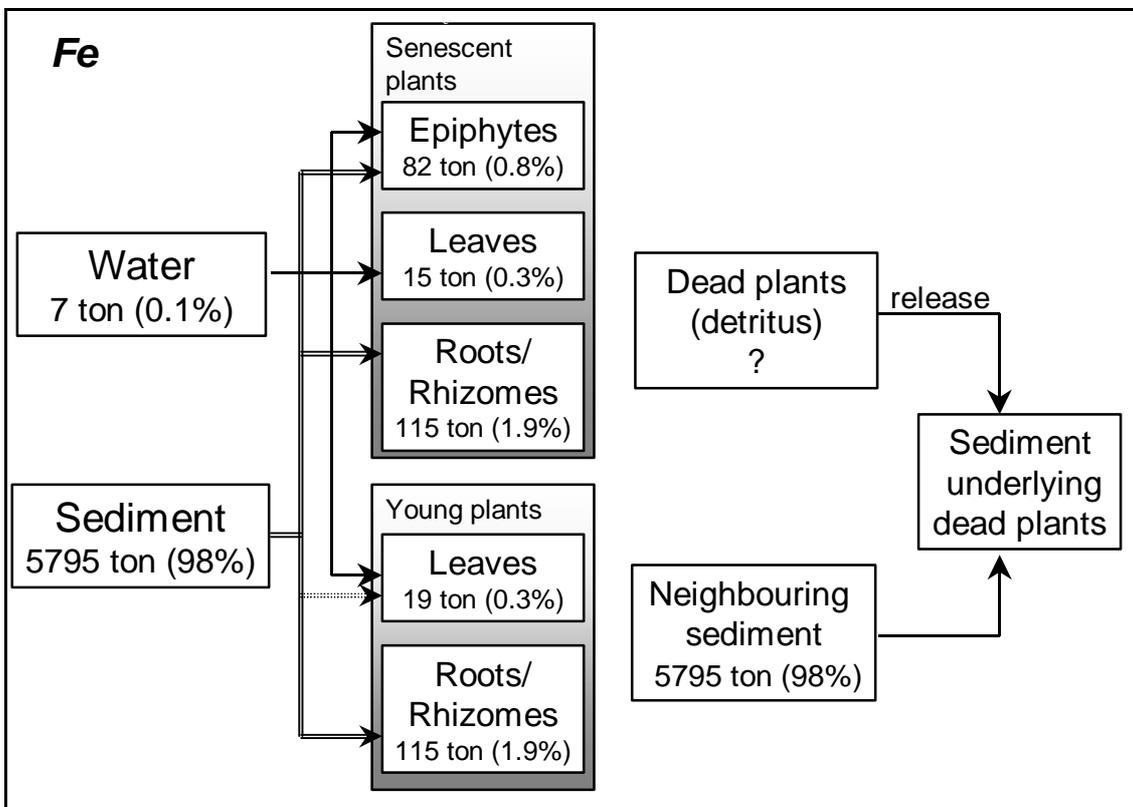**Figure 2**: Cycle of Cu in *Zostera noltii* stands from Arcachon Bay

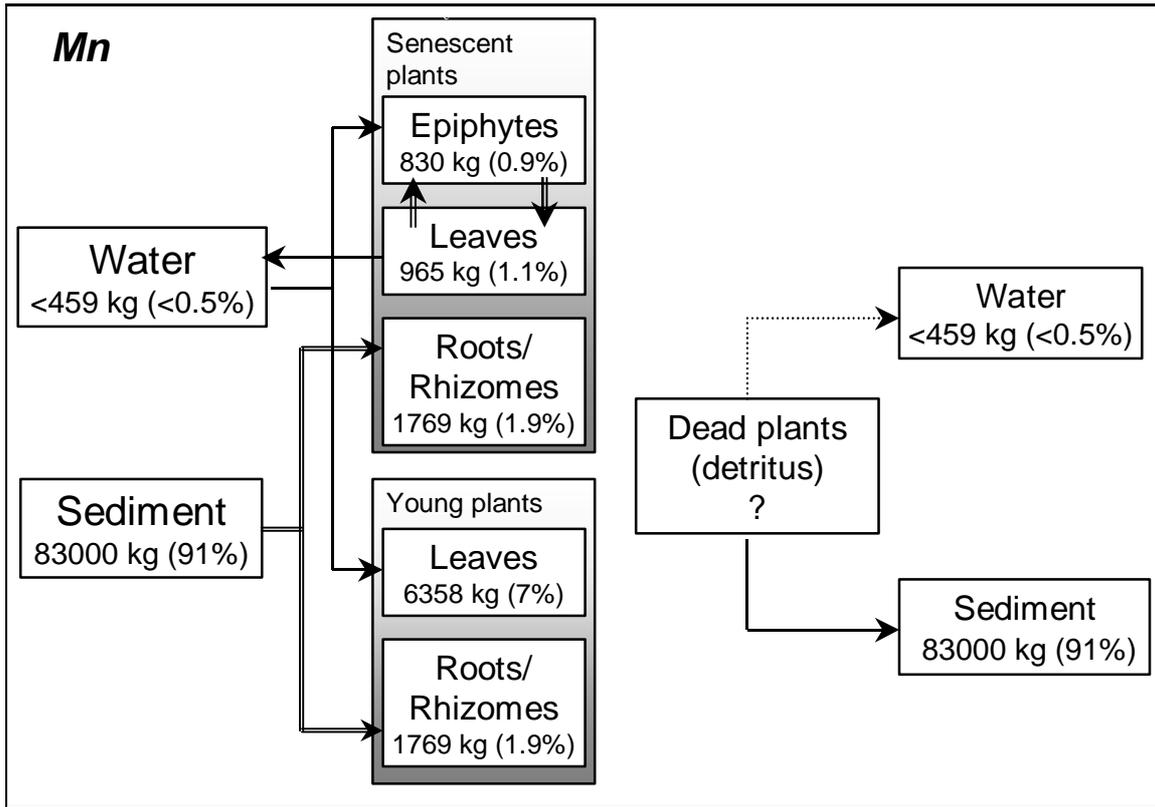**Figure 3**: Cycle of Fe in *Zostera noltii* stands from Arcachon Bay

Figure 4: Cycle of Mn in *Zostera noltii* stands from Arcachon Bay
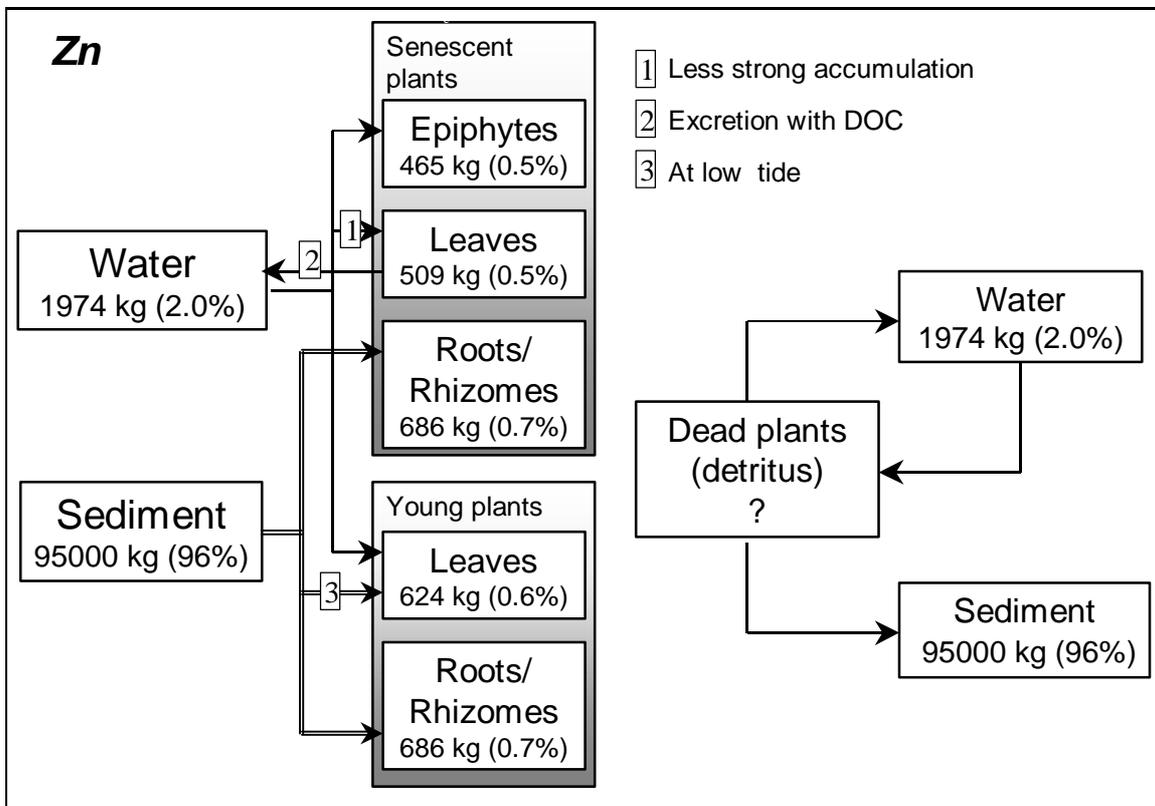

Figure 5: Cycle of Zn in *Zostera noltii* stands from Arcachon Bay

Some of the aspects of the cycling of metals in *Z. noltii* stands, shown in the models are to be underlined. In senescent plants, the presence of epiphytes covering the whole plant surface seems to be an important feature. For Zn and Mn epiphytes function as a sort of filter and very small amounts of these metals are directly absorbed by the leaves. During low tide, when the leaves lie over the sediment, strong absorption directly from this sediment seems to occur (mainly for Fe). It is a particular process only observed in *Z. noltii*, due to the fact that this plant can stand low tide periods of immersion. Another important feature on the models is the absorption of metals directly by leaves in young/adult plants. This seem even more important for essential metals that are present in low concentrations in the environment (Mn).

Concerning decomposition processes, the behavior of metals is quite more complicated and lot more studies are needed. Wasserman (1990) observed loss of Fe at long term process suggesting that the decomposition of plant would increase sediment stock, and although the plant compartment is almost insignificant, this contributed Fe seem to be bonded in organic matter. Farther, bonding sites seem to be added to the system and enrichment of metal in the sediment is to be expected. Although the Mn loss for the water could not be observed, clear loss for the sediment must occur, since when the plant is alive, this metal is largely metabolic concentrated and the concentrations of the debris are almost 10 fold higher than sediment's

7.   CONCLUSIONS

Z. noltii is an stressed plant. It is submitted to tidal range, stays long periods out of the water environment subjected to dissication. The plant stress is expressed by its production, quite lower than that of *Z. marina*. The behavior and cycling of metals in *Z. noltii* is consequently different of that observed for other plants and also the toxicity of these metals is different. Odum (1985) discussed environmental changes as affecting organisms and stated that even very small changes can be devastating upon stressed organisms. It is to be expected that *Z. noltii* would not have enough energy for defense strategies against high pollution levels.

The impact of human activities on seagrasses was reviewed by Thayer *et al.* (1975). Although the seagrasses are not considered an important link in the food chain (due to its low nutritive value), this author suggest that the low decomposition rates of these plants have an important role in the maintenance of the standing stock of organic matter in the coastal environment and even in deep sea environment (Wolff, 1976). Accidents like the wasting disease, reported in Cotton (1933, in Short *et al.*, 1988) can render the environment quite more fragile and subjected to ecological upset.

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