SESSION 1 ***Impacts of groundwater use on the hydrogeological systems***

The climate change influence on the freshwater-saltwater interface: causes and consequences

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Underground natural gas storage in Osso da Baleia

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The storage of natural gas in salt caverns in Carriço is the first project of this kind ever to be realized in Iberia. The aim is to construct storage caverns for two purposes: the storage of strategic reserves, and to balance supply and demand (seasonal and daily fluctuations in demand). The Carriço storage project is located in Pombal in the vicinity of Figueira da Foz which lies on the Portuguese Atlantic coast directly adjacent to a high pressure gas pipeline. The Carriço location was identified as the most suitable site after undertaking detailed investigations and comparisons analyzing technical, economic and environmental criteria. The storage facility is constructed in the Monte Real salt dome. This consists of evaporites deposited during the Triassic / Lower Lias period (i.e. laid down around 200 to 195 million years ago). This salt formations needed to be dissolved to create large underground caverns to store natural gas under pressure. To dissolve the salt, large amounts of water are necessary and a water intake facilities were built near Osso da Baleia close to the sea. In this presentation, an overall view of the project is given, namely the hydrogeological data and the water intake model. It is also presented the monitoring of the water intake established in order to guarantee a sustained exploration of the aquifer.

Modeling of water table level at Osso da Baleia

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To predict the impact f groundwater lowering in plan communities and evaluate individual plant and ecosystem water use under future groundwater change scenarios, it is first necessary to have a spatially model that includes groundwater dynamics. To estimate this scenarios we model the water table level and calculate the distance between ground surface and the water table level. Groundwater modelling was based on the groundwater altitude (height relative to sea level) obtained from each piezometer at Osso da Baleia, and was interpolated monthly for the entire study area. The study was made from 2012 to 2014, and it was considered the mean of the water table level, for each month. Considering that the groundwater table is a plan that tends to the sea, the interpolation methodology used was kriging with external drift. With this approach we obtained a smooth surface representing the water table altitude for the study area. Afterwards was calculated a monthly map showing the distance to groundwater for all the area. This map was calculated as the difference between the water table altitude map and the ground surface altitude, obtained from the digital earth model (DEM). We used a digital earth model of 25 meters resolution that was first corrected with the samples points and piezometers altitude. We conclude that for the four season of measurements the groundwater change weren't significative.

SESSION 2 ***Stable Isotopes as a tool to understand the impact of water dynamics in terrestrial ecosystems***

Stable Isotopes as a reliable tool to investigate plant water sources and relations

Rolf Siegwolf

Paul Scherrer Institute

Stable C and O isotopes have become a well-established tool in plant and ecophysiology for tracing carbon and water fluxes. Both isotopes are strong indicators for analyzing plant carbon and water relations. While the $^{12}C/^{13}C$ isotope ratios represent direct physiological responses by plants to environmental impacts (e.g. drought, low water availability, high irradiation) the oxygen isotope ratios ($^{16}O/^{18}O$) represent both, plant independent (condensation temperature of clouds, origin water sources and of atmospheric water masses) and plant dependent factors (transpiration, stomatal conductance and origin and exploitation of source water). The combination of both isotopes allows for climatic and physiological interpretations and can serve as a proxy for the reconstruction of various climatic and environmental conditions, water relations and plant productivity. Theoretical background information on the fractionation mechanisms of stable isotopes, examples of their applications in ecology, hydrology, ecophysiology and (paleo-) climatology are outlined in the presentation.

Avoider and tolerant strategies coexisting in Mediterranean dune species of Doñana dunes

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Doñana National Park is located in the SW of Spain, facing the Atlantic Ocean and exhibits a Mediterranean climate. The Park includes three main ecological domains: the flood plain filled with silt deposits, the mobile dunes and the stabilized sands. Previous studies (García Novo et al. 1996) have shown that Doñana sands are largely homogeneous and the main environmental factor is the water table depth. More recent studies have confirmed (Muñoz-Reinoso and García Novo, 2005) that the geomorphology and the charge and discharge of the aquifer controls the pattern of vegetation at different scales, mediated by water availability. Dune ridges exhibit xerophytic vegetation, while hygrophytic vegetation and temporal ponds appear on depressions. This mechanism determines that vegetation around the temporary ponds of Doñana is organized in concentring belts, with plants growing around the lower part of the basin largely dependent on the water-table depth, whereas xerophytic vegetation growing on the upper areas depends solely on precipitation (García-Novo, 1979). Therefore, pond vegetation behaves as a dynamic system driven by the interannual rainfall fluctuation typical of the Mediterranean climate, which is also affected by other factors such as pond altitude, location and groundwater abstraction (Zunzunegui et al., 1998). We have monitored groundwater depth in the different ponds for 25 years, and followed the dynamic of these vegetation rings in contrasted dry and wet cycles observing that vegetation rings oscillate associated to water availability. On the other hand the scrub species linked to those rings exhibit different physiological behaviour. On the dune ridges, drought tolerant species as *Rosmarinus officinalis* and *Cistus libanotis* coexist with other species with a marked avoider strategy as *Halimium halimifolium.* Heath species, as *Erica scoparia* occupy the depressions and need water availability for the whole year. The spiny legumes formed an independent group, with little seasonal variation of physiological traits. A plasticity index was calculated to provide an integrated value of species plasticity. In summer, plasticity was higher in the xerophytic sites, while in winter it was higher in the hygrophytic sites (Zunzunegui et al. 2010). In relation to topography and water availability, species combine traits following different strategies according to previous evolutionary story but exhibiting a certain amount of trade among traits, each contributing to alleviate a part of the plant stress. This variation of functional responses allows the remarkable diversity of plant communities coexisting in Doñana dunes.

Water availability and plant location: key factors of water sources for vegetation of coastal dunes

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The aim of this study was to know the water sources used by a coastal plant community, addressing variations in spatial (zonal distribution across the dune from high beach to the inland) and seasonal (spring, summer and winter) patterns. The study was conducted in La Flecha de El Rompido dune system (37º12'N, 7º04'W) in Huelva, SW Spain. Climate is Mediterranean with Atlantic influence, and mean annual rainfall is 583 mm with a marked dry period in summer. $\delta^{18}O$ values of potential water sources (air, rain, soil, ground and ocean water) were measured seasonally, concurrently with stem water of seven representative plant species. Three parallel transects were laid out across the dunes (75, 84 and 76 m length), in which plant samples were taken from 5 habitats determining spatial pattern: 1. Upper beach (proximal to the fore dune); 2. Foredune crest; 3; Foredune slack; 4. Second dune crest; 5. Inland depression. Nine stem samples per species and habitat were collected for xylem water extraction (3 stem replicates x 3 transects = 9 stems per point and species). Results showed isotopic evidence that dune plant species display different use of water sources along their zonal distribution, with a high seasonal influence. The dune vegetation used a mixture of soil and ground water, characterized by the ocean influence spatially and temporally heterogeneous. In seasons with low water availability, spatial patterns arised as plants closest to the ocean were independent of groundwater and standed better ocean influence. Inland plants and species still relied on groundwater and deeper soil layer. Under higher water availability, spatial patterns across the dunes diminished and plant sources relied basically on groundwater. The patterns of water use were also related to the type of radical system of the species: shallow rooted changed the main water source used depending on the season and its water availability, while those species with deepest root systems (present especially in the Inner depression) kept using groundwater the whole year. In conclusion, spatial patterns arised, but highly dependent on the seasonal pattern.

SESSION 3 ***Groundwater use by vegetation - The particular case of coastal forests***

Biota - Functional Gradient – a case study

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Monitoring the impact of groundwater limitations in Osso da Baleia

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In spite of the relative importance of groundwater in coastal dune systems, the number of studies concerning the responsiveness of vegetation to ground water (GW) variability, in particularly in Mediterranean regions, is scarce. In this study, we established 5 study sites within a meso-mediterranean sand dune *Pinus pinaster* forest on the Atlantic coast of Portugal, taking advantage of natural topographic variability and artificial GW exploitation, which resulted in substantial variability in depth to GW between microsites. Here we identify the degree of usage and dependence on GW of different plant functional groups (two deep-rooted trees, a drought adapted shrub, a phreatophyte and a non-native woody invader) and how GW dependence varied seasonally and between the heterogeneous microsites. Our results indicated that the plant species had differential responses to changes in GW depth according to specific functional traits (i.e. rooting depth, leaf morphology, and water use strategy). The species comparison revealed that variability in pre-dawn water potential (Ψpre) and bulk leaf δ13C was related to microsite differences in GW use in deep-rooted (*Pinus pinaster*, *Myrica faya*) and phreatophyte (*Salix repens*) species. However, such variation was more evident during spring rather than during summer drought. The exotic invader, *Acacia longifolia*, which does not possess a very deep root system, presented the largest seasonal variability in Ψpre and bulk leaf δ13C. In contrast, the response of *Corema album*, an endemic understory drought adapted shrub, across seasons and microsites seemed to be independent of water availability. Thus, the susceptibility to changing GW availability in sand dune plant species is variable, being particularly relevant for deep rooted species and phreatophytes, which have typically been less exposed to GW fluctuations.

Analyses of the first results concerning the project “Coastal dune forests under scenarios of groundwater limitation: from Tropics to Mediterranean

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Groundwater alterations, particularly lowering, will affect ecosystems sensitive to water limitation as coastal dune forests. This can produce dramatic changes in plant communities, on physiological performance or survival of plant species. The additional impact of drought due to climatic change on groundwater-dependent ecosystems has become of increasing concern since it aggravates groundwater anthropogenic reduction impacts with consequent uncertainties about how vegetation will respond over the short and long term. Sand dune plant communities encompass a diverse number of species that differ widely in root depth, tolerance to drought and capacity to shift between seasonal varying water sources. Plant functional groups may be affected by water distribution and availability differently. We aim to evaluate in different climatic regions (Tropical, Meso-mediterranean and Thermo-mediterranean) the responses of different coastal woody plants to changing groundwater availability. An ecophysiological approach (leaf δ13C, xylem+water sources δ18O, leaf δ15N, reflectance indices) was used as a tool to assess physiological performance and water strategies, integrated in spatio-temporal water dynamics. This approach provides the possibility of finding patterns of responses, disentangle the influence of Groundwater alterations on plant community and, ultimately, predict effects of water availability changes in coastal dune forests. The first results concerning the project *Costal Dune Forests under Scenarios of Groundwater Limitation: from Tropics to Mediterranean* (FCT Project - PTDC/AAC-CLI/118555/2010) are shown in this presentation.

Kinetics of tracheid development under Mediterranean climate: implications in tree hydraulics

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Since 2010 the Lab. for Mediterranean Dendrochronology (MedDendro) at the Centre for Functional Ecology (CFE) in the University of Coimbra has a field station in the ”Perímetro Florestal Dunas de Cantanhede” nearby Tocha. One of the key aims of the field station is to understand the wood growth dynamics of *Pinus pinaster* and its relation with climatic and physiological data. For that wood samples (microcores) were collected weekly during the growing season for anatomical analysis. The field station is also equipped with a meteorological station, automatic and manual dendrometers, sap flow and soil water sensors. Concerning the xylogenesis of *P. pinaster* we have found that warmer winters trigger an earlier start of xylem differentiation. An earlier stop of wood formation and also the formation of tracheids with smaller lumen area is induced by water stress during the summer. A bimodal pattern of stem radial increment is usually observed, one in spring and another in autumn. The anatomical study suggests that the autumnal increment period corresponds mostly to stem rehydration, since the differentiation of new xylem cells by the cambium was not observed. However, in some years new cells are differentiated during the second growth peak, forming an intra-annual density fluctuation (IADF) characterized by earlywood-like cells within latewood. High-resolution measurements of stem diameter variation can provide valuable information on the growth process as

well as the tree water status. Continuous positive radial increment starts in spring and reaches its maximum by the end of June. A shrinking period is observed in summer, with amplitudes of contraction and recovery 10 times higher than in the other periods. The inability of the trees to recover from the water lost due to transpiration is responsible for stem shrinking and quiescence observed during summer. In autumn, a period of re-hydration and rapid expansion is observed after precipitation. We have also compared the tracheidograms of lumen diameter (LD) and cell wall thickness (CWT) for the years 2010–2013. Our results suggest a close association between LD and soil moisture content along the growing season, reinforcing the role of water availability in determining tracheid size. Compared with CWT, LD shows a higher intra- and inter-annual variability suggesting its strong adjustment value to variations in water availability. The next steps will be to integrate the seasonal dynamics of water conductance, from the ground to the tree canopy and the impact of wood anatomy on tree hydraulics, since it is known that relatively small changes in lumen size of tracheids can have a dramatic effect on xylem conductance. Additionally, we plan to study the frequency and size of bordered pits between adjacent tracheids to understand how these cell features respond to environmental conditions and how they affect total tracheid conductance.

SESSION 4 ***Modeling the impact of groundwater use under climate changes***

Groundwater and Climate Change: an overview

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The EU Water Framework Directive (WFD) and the daughter Groundwater Directive (GWD) require that groundwater status must be assessed, and that good chemical and quantitative status must be achieved in order to protect human health and associated dependent ecosystems. An additional important aspect to be considered in WFD is the definition of ‘‘available groundwater resource’’ as ‘‘the long-term annual average rate of overall recharge of the body of groundwater less the long-term annual rate of flow required to achieve the ecological quality objectives for associated surface waters, to avoid any significant diminution in the ecological status of such waters and to avoid any significant damage to associated terrestrial ecosystems’’. This means that is necessary to stipulate the environmental water requirements based on the best available scientific information and to assess those aspects of the natural water regime that are most important for the persistence of critical ecosystem features (i.e., ecological structure) and processes (i.e., ecological function). Also, habitats and species have to be directly monitoring to determine their response to groundwater levels and quality. In Portugal, there is a lack of knowledge about groundwater dependent ecosystems (GDEs) which is of paramount importance to solve. Nowadays, shallow aquifers are under increasing pressure from human activities such as overexploitation, pollution from point and non-point sources and even climate change, which can pose significant threats to groundwater-related ecosystems. Therefore, it is essential to understand the interactions between aquifers and GDEs. Mediterranean-type ecosystems (MTEs) are located in mid-altitudes on all continents, often on nutrient-poor soils and in coastal regions. MTEs are characterized by wet winters and dry summers with frequent occurrence of droughts. Groundwater plays an integral role in sustaining certain types of aquatic, terrestrial and coastal ecosystems and the associated landscapes such as in MTEs. Groundwater can provide base flow into surface water bodies during droughts and is often the main source of water for vegetation in dry climate. In our days, it is recognized that an increase in groundwater depth can be detrimental to vegetation if the change separates roots from their water source. According to climate change projections, Southern Europe will have less recharge and the region may become more water stressed than at present-day, with any increase in winter recharge unable to compensate for the reduced autumn recharge. Moreover, the largest short term effects of climate change might be due to human actions that react on the actual and predicted changes in precipitation and temperature patterns.

Climate change and drought events in the past decade in Portugal

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