

Coexistence and Vulnerability to Climate Change of Hygrophilous and Non-Hygrophilous Tree Species

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The Mediterranean wetlands are of great importance because they are hot spots of biodiversity, represent the basic land refuges for bird migration, and they contribute to maintain a complex equilibrium with coastal and estuarine ecosystems.

The vegetation in Mediterranean climates is typically sclerophyllous and ever-green, adapted to water stress during the dry summer period, and able to grow on infertile soils. However, the availability of year-round moisture in swamps or near streams areas enables deciduous woody vegetation to occur in the riparian zone of Mediterranean-type streams in the Northern Hemisphere with equivalent species pairs occurring in other Mediterranean regions (e.g. Israel and California). In fact, coexistence of different water-related species in Mediterranean woodlands and riverine floodplain, and in arid or semi-arid wetlands boundaries is documented in the literature.

We have developed a quantitative, dynamic model, that describes the coexistence between two groups of plants, that we name hygrophilous and non-hygrophilous, defined according to their distinct adaptive strategies for water stress. Hygrophilous species, tolerate the submersion of the roots but are drought sensitive, have low water use efficiency, and are not very able control transpiration in response to drought. Non-hygrophilous species are drought resistant but do not tolerate flooding, have higher water use efficiency, and are able to control water lost by transpiration in response to drought. The two types of trees compete for the available soil water and for space (or light).

In abstract form the model reads

$$\begin{aligned}\dot{X} &= (f(W) - m(W)) X - k(X + Y) X \\ \dot{Y} &= (h(W) - n(W)) Y - k(X + Y) Y \\ \dot{W} &= -T_x(W) X - T_y(W) Y + S(W)\end{aligned}$$

where X and Y are the biomass densities

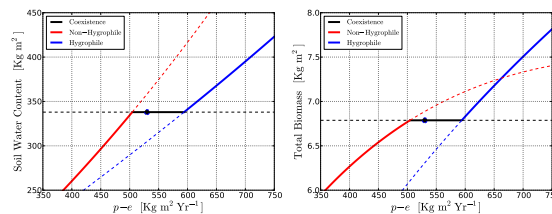


Figure 1. Bifurcation diagrams of coexistence and single-species equilibria. Left panel: soil water content. Right panel: total biomass. Stable equilibria are drawn with solid lines, unstable one with dashed lines.

of, respectively, the hygrophilous and non-hygrophilous species and W is the soil water content. The water-dependent functions f and h are the growth rates of the hygrophilous and non-hygrophilous species, assumed to be monotonic and growing. Analogously m and n are water-induced mortalities. They are assumed to be monotonic, too, but only the second is growing (non-hygrophilous species are subject to root asphyxia in damp soils); the mortality m of hygrophilous species is, instead, a decreasing function of W , which models the vulnerability of these species to drought. The positive constant k tunes the strength of the quadratic terms that model the competition for space. The functions T_x and T_y are the water transpiration rates of the two kind of trees. It is not physiologically inconsistent to take them to be proportional to the growth rates f and h . The function S describes all the biomass-independent sources and sinks of water. In particular we assume that the only important source is the precipitation p and the main sinks are the evaporation e and the percolation of water through the ground down to depths unreachable by the trees' roots.

It is quite remarkable that a rather exhaustive bifurcation analysis of the steady solutions of this

model can be carried out just on the basis of the monotonicity assumptions that we have made on physiological grounds.

We find that a coexistence fixed point exists if (and only if) the net growth rates of the two species may be equal, meaning that there exist a value W_o such that $f(W_o) - m(W_o) = h(W_o) - n(W_o)$. We give necessary and sufficient criteria for the stability of the coexistence fixed point in terms of the derivatives of the growth rates and mortalities, and of the difference of the transpiration rates of the two kind of species. It turns out that these criteria are met by extant hygrophilous and non-hygrophilous species.

As a further step we use data collected at the Castelporziano Presidential Estate and at the Circeo National Park, where coexistence is actually observed, in order to approximate the unknown functions with rational expressions, and to quantify the free parameters of the model.

This, in turns, allowed us to draw the quantitative bifurcation diagrams shown in figure, that use $p - e$ as the control parameter. The actual state of the system (the black dot) is well within the stable coexistence interval (the black segment). But it turns out that the drop in precipitation required to let the system cross the bifurcation that makes the coexistence state unstable and produces the extinction of the hygrophilous species is of a magnitude comparable with the precipitation drop projected by the end of this century by regional climate models.

REFERENCES

1. Di Paola A, Valentini R, Paparella F, PLoS ONE 7(10) (2012).