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# Spatio-temporal analysis of alpine ecotones: A spatial explicit model targeting altitudinal vegetation shifts

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ABSTRACT

There is general agreement in literature that Alpine vegetation belt ecotones have shown a trend of upward migration in the last few decades. Despite the potential of such shifts as indicators of global change effects in mountain ecosystems, there are relatively few works focused on their assessment in a systematic and spatially explicit way. In this work our aim is to quantify the altitudinal shifts and analyse the spatial pattern dynamics of mountain ecotones. We developed a novel procedure to delineate the current and former state of three characteristic mountain ecotones, which we formalised as forest, tree and tundra lines. Our approach is based on the recognition of altitudinal extreme outposts identified with ecotone locations at a slope scale. The integration of multi-temporal datasets allows the identification and quantification of altitudinal advances and retreats in the outpost locations for a given period. We tested the method in a section of the Italian Alps for the period 1957–2003. Results show a general trend of an increase in altitude for the three ecotones, despite the occurrence of occasional decreases. We estimate decadal altitude increments of 25 m for forest line, 13 m for treeline and 11 m for tundra line. We also identified changes in ecotone spatial morphology between the two dates, with significant implications in connectivity and colonisation dynamics.



## 1. Introduction

Mountain and boreal ecosystems are among the environments most susceptible to climate change effects (Beniston et al., 1997; Dirnböck et al., 2003; Grabherr et al., 1994; Theurillat and Guisan, 2001). Changes in temperature and rainfall regime may have different effects on mountain vegetation, such as increasing tree growth (Gindl et al., 2000; Motta and Nola, 2001), migrations (Grabherr et al., 1994; Meshinev et al., 2000), changes in species composition (Keller et al., 2000) or, less frequently, genetic adaptations (Huntley, 1991). In this context, transitions between dense upland forest formations to treeless land, often referred to as "kampfzone" ecotone or more in general as "taiga-tundra" ecotone, have been regarded as highly sensitive and potential indicators of environmental change, and particularly climate warming, as most of their species are at their limits of tolerance (Fortin et al., 2000; Holtmeier and Broll, 2005; Kullman, 1997, 2007; Romme and Turner, 1991). These areas have also suffered from intense land cover dynamics due to changes in land uses, and particularly from land abandonment (Didier, 2001; Motta and Nola, 2001). Both phenomena have the general effect of raising the altitude of the ecotone between forest and non-forest, the relative importance of each driver being a matter of discussion (Didier, 2001; Dirnböck et al., 2003; Jobbagy and Jackson, 2000; Körner, 1998, 1999).

The term ecotone (from the Greek "oikos" = house and "tonos" = tension) was originally introduced by Livingston (1903) and Clements (1905, 1907) and was defined as an area of "tension" where species from adjacent communities meet their limits and was further reformulated as "the line that connects the points of accumulated or abrupt change". Modern definitions usually refer to areas of contact between ecosystems and take into consideration spatial and temporal scales as well as functional aspects (Holland, 1988).

The tundra-taiga ecotone definition has been widely discussed in literature and has led basically to three different conceptual schemes. The first scheme considers exclusively the border between tree and treeless land (Dullinger et al., 2004; Gamache and Payette, 2005; Holtmeier and Broll, 2005; Körner, 1999; Kullman,

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