

## Spatial variations in soil properties across ecotones: a short review



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Theodore Danso Marfo\*, Klement Resjek, Valerie Vranova

Mendel University in Brno, Czech Republic

\* Correspondence: Department of Geology and Soil Science, Mendel University in Brno, Czech Republic.  
E-mail: xmarfo@mendelu.cz

**Abstract.** Ecotones are considered as unique environments. The concepts of edge effect and ecotone species (flora and fauna) are widely used. Considering the fact that the majority of the species found in ecotones are usually at their physiologically determined limits of distribution, how they react to global climate changes becomes crucial. Ecotones are reputed to be more biologically diverse than areas close to them, and therefore possesses a high conservation value, yet little is known on how soil properties vary across ecotones. In this paper, we firstly highlighted the roles ecotones play in assessing the effect on global climate change, the mediatory role they play in the movement of material (water and nutrients) into and out of the region. Secondly, we reviewed studies on how soil properties change across ecotones and it is worthwhile to note that soil properties tend to differ across various ecotones (e.g. increasing pH and decreasing P & N across forest–glade ecotones, decreasing pH across ancient–recent forest ecotones) in a manner that defines the character of the ecotones existing.

**Key words:**

ecotone,  
soil properties, vegetation,  
climate change,  
soil ecology

### Introduction

The description of an ecotone continues to change with time. In the beginning of the twentieth century an ecotone was described as a stress line that connects points of accumulated or abrupt change (Hufkens et al. 2009). This definition has been in existence longer than the much known ecosystem concept brought forth by (Tansley 1935). However, an ecotone can be loosely defined as the transitional area between two eco-communities (Gosz 1993). This stretch of transitional area exists in several forms and scales and may range from just a few centimetres to kilometres (Scheel et al. 2015). Ecotones are also described as boundaries between

ecosystems (Hansen et al. 1992) and a comparison is made with the semi-permeable membranes of a cell, considering the material movement to and from ecotone regions (Hufkens et al. 2009; Grabs 2010). Ecotones undoubtedly greatly affect the ecosystems they lie between. Ecotones are reputed to be more biologically diverse than areas close to them, and hence possess a high conservation value (Senft 2009; Sheded et al. 2014). Nevertheless, there is a lack of strong evidence either supporting or refuting this claim. Almost all ecotone biodiversity studies have focused on plants, birds, small mammals, and insects and to some extent, soil fauna. Spatial variations in soil properties across ecotones present a key in substantiating (or not) the high biological

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diversity claim attributed to ecotones. That is why, in this paper, we provide a brief literature overview of various approaches to soil diversity in ecotones. Unfortunately, such studies are still rare.

## Global climate change and ecotones

Water balance and cold temperatures during winters are normally the predominant controls of ecotone position (Risser 1995; Kupfer et al. 1996). Since these controls are part of global climate occurrences, ecotones would be relied upon to react to patterns of global climate change (Allen et al. 1998; Parmesan et al. 2003; Gonzalez et al. 2010). A lot of species found in ecotones are usually at their physiologically determined limits of distribution (Traut 2005; Zhang et al. 2009). Accordingly, in light of the fact that as species get to the edge of their ecological resilience, climate changes would have a critical effect on the distribution of species, local ecotones may subsequently be especially responsive (Peters 2002; Kark et al. 2006; Holland 2012). This sensitivity may emerge from direct impacts on physiological procedures as well as indirect impacts such as increased likelihood of pathogens or fire (Weltzin 2000). In general, the reaction of ecotones to climate change relies on: the rate and extent of environmental change; the physiological resilience of the prevailing species; the closeness, aggressive capacities, and dispersal abilities of invading species or pathogens; changes in soil qualities; and the capacity of organisms to withstand diverse ecological conditions (Resler et al. 2009; Goldblum et al. 2010). With the assumption that global warming is followed by higher temperatures and higher concentrations of carbon dioxide, Peters and Darling (1985) made a forecast that lowland species would move to higher altitudes with climate warming. Apparently, increased growth accompanies higher levels of carbon dioxide, and hotter temperatures permit lower-altitude plants to move to higher levels (Hunter et al. 1993). Be that as it may, not all species react with more noteworthy growth under increased carbon dioxide. In the case that climate change is accompanied by water stress, biodiversity in the moving ecotone is probably going to be high as the landscape becomes noticeably divided and

distinctive soils and micro-sites become crucial to the survival and development of numerous organisms (Resler et al. 2008; Tokuoka et al. 2011). Without water stress, there would not be fragmentation of landscape habitats and the ecotone would progressively move through space to another area, as directed by the changed climate (Koepke et al. 2010; Holland 2012). In principle, with climate change, the biodiversity in the ecotonal area would have a different transitional pattern depending upon whether or not there was water stress (Beniston 2003).

## Material movement and ecotones

The movement of materials across ecosystems is governed by a myriad of conditions (Chapin III et al. 2011). In recent times, the roles ecotones play in these activities have become well appreciated. Ecotones may act as areas of habitat that organisms assemble in or migrate through (Robinson et al. 2002). Water and material fluxes moving across ecotones can be changed by adjusting the kinetic energy of wind and water vectors that move materials inside the landscape (Johnston 1993). Additionally, it is not simply the materials that are influenced. Other processes (chemical and biological) happening inside ecotones can influence the concentrations of dissolved and suspended substances found in ecotones or the fluxes that move into and out of ecotones (Johnston 1993). Wetlands are typical example of ecotones that exist between aquatic and terrestrial landscapes and influence a lot of the functional landscape properties, such as flora and fauna distribution (Xiao et al. 2011; Schiemer et al. 2013). Microbe activities, the catching of suspended particulate material and plant growth all enhance the retention of nutrients inside wetland ecotones. In spite of the fact that it is very successful, this act of retaining nutrients varies with wetlands (Casey et al. 2001; Bai et al. 2004; Wang et al. 2008). On the other hand, through the properties of soil surface and profile, ecotones serve to control water and nutrient flows across the terrestrial landscape. There is presently adequate data about ecotones to start to design landscapes in ways that deal with the fluxes of nutrients, such as nitrogen and phosphorous (Triska et al. 1993; Wassen et al. 2006). A generalised sys-

tem could be built, including quantitative consideration of vegetation, soils and hydrology. Presently, there is enough information showing the potential that taking care of ecotones has for helping manage nutrients and water flow and retention.

## Soil properties across various ecotone types

Coastal barrens are moderately open regions comprising inadequate tree cover, and predominately composed of shrubby vegetation, mainly from the Ericaceae family. Coastal barrens are by-and-large found within forest matrix and may have long lived, undisturbed communities or habitats with early successions (Burley 2009; Munro et al. 2014). Along the Atlantic coastline of Nova Scotia and the north-eastern United States, there are non-forested patches called the 'coastal barrens' scattered across territories with uncovered bedrock or little soil cover inside a forested area (Oberndorfer 2006). Burley et al. (2010) conducted a study on vegetation composition, structure and soil properties across a forest-barren ecotone in Nova Scotia. Although the study revealed various noteworthy gradients in the forest structure over the forest-barren ecotone, including diminishing tree age and height, vegetation height and canopy cover, the soil component (soil depth, development, organic matter, pH and nutrients) showed no significant difference across the forest-barren ecotone. This study shows that forest patch-

es are expanding into coastal barrens, because the tree age and height decreases across the forest edges into the barrens. The fact that the study showed uniform soil properties across the gradient means the expansion is not delimited by edaphic factors.

On the other hand, the location and coverage of forest glade openings are mainly known to be determined by edaphic factors, with soil processes influencing management activities, but the link that plant communities in forest glades have with the soil properties underlying them seems to be missing in the literature. Rhoades et al. (2005) made an effort to address this gap in their study of the vegetation and soil characteristics across a glade-forest ecotone in the Knobs Region of Kentucky. The study sought to provide some insight into how stable the plant communities in the glade region are. The study revealed a significantly higher C:N ratio in soils in the glade openings compared to that of the forest. There was also a sharp decline in the level of soil phosphorus and nitrogen and a rapid increase in soil pH and extractable cations across the forest-glade transition. The pH values for the forest region were from 5.5 to 6.5, which is optimum for most tree species. The forest edge recorded pH values from 6.4 to 7.0, which are conducive not just for some tree species but also other kinds of flora, thus to some extent accounting for the diversity attributed to forest edges. Decreasing soil acidity from forested regions to ecotones can also be seen in Karas (2016) research conducted in the Training Forest Enterprise Masaryk Forest Křtiny (Table 1). The decreasing trend of soil acidity was evident in

Table 1. Changes in selected soil parameters along the forest-meadow ecotone in the study plot – Křtiny (Karas 2016)

Sample no.	pH (H <sub>2</sub> O)	pH (KCl)	MCWC (%)	MAC (%)
Z12	6.0	5.1	37.9	9.8
Z11	6.1	5.1	37.7	11.6
Z10	5.9	5.0	35.5	11.1
Z9	5.7	4.7	35.9	15.2
Z8	5.7	4.7	36.3	13.6
E	5.5	4.5	29.9	18.9
L2	6.1	4.1	29.0	21.3
L3	6.0	5.1	34.2	19.5
L4	5.8	5.0	36.7	19.5
L5	5.8	4.9	38.6	17.3
L6	5.6	4.8	42.1	17.8

Symbol explanations: Z8–Z12 – meadow samples, E – ecotone sample, L2–L6 – forest samples, MCWC – maximal capillary water capacity, MAC – minimal air capacity

all the study plots. Maximum capillary water capacity (MCWC) is the ability of soils to retain water for plants. Minimal air capacity (MAC) is the amount of air in the soil when all the capillary pores are filled with water. In the transitional zone between meadow and forest, clear changes in the values of those parameters were recorded.

The pH in the glade region ranged from 7.5 to 8.0. Mineralisation rates in the glade openings declined sharply by 98% compared to soils in the forest and forest-edge regions. Brandon et al. (2006) conducted a study entitled “soil-geomorphic heterogeneity governs patchy vegetation dynamics at an arid ecotone”. In their study, the solid connection between vegetation dynamics and soil properties that was observed does not support a pure self-organisation model (HilleRisLambers et al. 2001; Barbier et al. 2006; Getzin et al. 2015). This suggests that soils alone cannot clarify vegetation pattern. Soil heterogeneity obviously influences the development of vegetation pattern (Lesschen et al. 2008; Zuo et al. 2009). The results raise the likelihood that only a subset of soil patches within a landscape is susceptible to changes over a given period. In their study of the migration of herbaceous plant species across ancient–recent forest ecotones in central Belgium, Bossuyt et al. (1999) found that the differences that exist between ancient and nearby recent forest stands were more qualitative than quantitative. Soil surveys conducted by the researchers revealed much lower pH values (3.1 to 3.3) in the recent forest stands. The lower pH values can be attributed to cultivation activities resulting in the vegetative difference existing between the ancient and recent forest stands. This confirms that forests that were previously cultivated have altered the soil properties, such as having lowered pH. Sjögersten et al. (2003) conducted a study into the chemistry of soil organic carbon (C) in a mountain-birch-forest-tundra ecotone in three areas of the Fennoscandian mountain range. They came to the conclusion that vegetation cover (i.e. mountain birch forest versus tundra heath) hugely impacts the dynamics of soil carbon (higher accumulation in tundra soils as well as contrasting decomposition levels). Clear contrasts between forest and tundra soils were identified, with labile carbon accumulating in the surface layer of tundra soils. The alkyl-to-O-alkyl proportion was likewise lower in tundra soils, demonstrating less

decomposed organic material. Zeithaml et al. (2009) studied earthworm assemblages in an ecotone between forest and arable field and their relations with soil properties. Their research supported Leopold's theory (Guthery et al. 1992), which expresses that organic density and diversity will be higher in ecotones than in adjoining environments. There was a positive link between earthworm density and biomass with distance from the forest edge to the centre and with specific soil properties as content of organic matter, porosity, and moisture as well as infiltration rate. These soil properties were found to be stable in the ecotone region, which presents a suitable environment for microbial life. Zeithaml et al. (2009), concluded their study by stating that “forest edges may play a positive role in the maintenance of earthworm species richness in agroecosystems”. Soil properties are noted to influence vegetation, yet the role of soil heterogeneity in separating the dynamics of vegetation is not well documented.

## Conclusions

This paper draws attention to a gap in the literature that concerns how soil properties change across ecotones. It is commonly known that soil properties have a great influence on vegetation. However, the available literature data shows that there have been very few direct investigations on how soil properties vary spatially across various ecotone types. A lot of the studies have primarily focused on the distinctness of the flora and fauna found in ecotone regions. However, as per this review, it is worth noting that soil properties tend to differ across various ecotones (e.g. increasing pH and decreasing P & N across forest–glade ecotones, decreasing pH across ancient–recent forest ecotones) in a manner that defines the character of the ecotones' existence. This assertion obviously excludes forest-coastal barrens, where, although there are changes in vegetation and structure across the ecotone, the soils properties remained uniform across them, and hence the changes cannot be pinned to edaphic factors. At forest–arable field ecotones, stable soil properties (content of organic matter, porosity, and soil moisture and infiltration rate) favouring microbial life and activities is evident. Although it is clear

that soil properties play a huge role in the vegetation uniqueness of ecotones, more research needs to be conducted targeting the specific soil heterogeneity responsible for various ecotone types.

The authors will follow up with a research article analyzing the pH and water potential of soils across forest–agricultural field ecotones in the Czech Republic.

## References

- ALLEN C.D., BRESHEARS D.D., 1998, Drought-induced shift of a forest–woodland ecotone: rapid landscape response to climate variation. *Proceedings of the National Academy of Sciences*, 95(25): 14839–14842.
- BAI J., DENG W., ZHU Y., WANG Q., 2004, Spatial variability of nitrogen in soils from land/inland water ecotones. *Communications in Soil Science and Plant Analysis*, 35(5–6): 735–749.
- BARBIER N., COUTERON P., LEJOLY J., DEBLAUWE V., LEJEUNE O., 2006, Self-organized vegetation patterning as a fingerprint of climate and human impact on semi-arid ecosystems. *Journal of Ecology*, 94(3): 537–547.
- BENISTON M., 2003, Climatic change in mountain regions: a review of possible impacts. *Climatic Change*, 59(1): 5–31.
- BOSSUYT B., HERMY M., DECKERS J., 1999, Migration of herbaceous plant species across ancient–recent forest ecotones in central Belgium. *Journal of Ecology*, 87(4): 629–638.
- BURLEY S.T., 2009, Forest expansion into coastal barrens in Nova Scotia, Canada. M.Sc. thesis. Saint Mary's University, Halifax, Nova Scotia.
- BURLEY S.T., HARPER K.A., LUNDHOLM J.T., 2010, Vegetation composition, structure and soil properties across coastal forest–barren ecotones. *Plant Ecology*, 211(2): 279–296.
- CASEY R.E., TAYLOR M.D., KLAINE S.J., 2001, Mechanisms of nutrient attenuation in a subsurface flow riparian wetland. *Journal of Environmental Quality*, 30(5): 1732–1737.
- CHAPIN III F.S., MATSON P.A., VITOUSEK P., 2011, *Principles of terrestrial ecosystem ecology*. Springer Science & Business Media.
- GETZIN S., WIEGAND K., WIEGAND T., YIZHAQ H., VON HARDENBERG J., MERON E., 2015, Clarifying misunderstandings regarding vegetation self-organization and spatial patterns of fairy circles in Namibia: a response to recent termite hypotheses. *Ecological Entomology*, 40(6): 669–675.
- GOLDBLUM D., RIGG L.S., 2010, The deciduous forest–boreal forest ecotone. *Geography Compass*, 4(7): 701–717.
- GONZALEZ P., NEILSON R.P., LENIHAN J.M., DRAPEK R.J., 2010, Global patterns in the vulnerability of ecosystems to vegetation shifts due to climate change. *Global Ecology and Biogeography*, 19(6): 755–768.
- GOSZ J.R., 1993, Ecotone hierarchies. *Ecological Applications*, 3(3): 369–376.
- GRABS T., 2010, Water quality modeling based on landscape analysis: Importance of riparian hydrology. Dissertation, Stockholm University, Sweden.
- GUTHERY F.S., BINGHAM R.L., 1992, On Leopold's principle of edge. *Wildlife Society Bulletin (1973–2006)*, 20(3): 340–344.
- HANSEN A.J., RISSER P.G., DI CASTRI F., 1992, *Epilogue: biodiversity and ecological flows across ecotones*. Landscape boundaries Springer, New York: 423–438.
- HILLERISLAMBERS R., RIETKERK M., VAN DEN BOSCH F., PRINS H.H., de Kroon H., 2001, Vegetation pattern formation in semi-arid grazing systems. *Ecology*, 82(1): 50–61.
- HOLLAND M. (ed.), 2012, *Ecotones: the role of landscape boundaries in the management and restoration of changing environments*. Springer Science & Business Media.
- HUFKENS K., SCHEUNDERS P., CEULEMANS R., 2009, Ecotones in vegetation ecology: methodologies and definitions revisited. *Ecological Research*, 24(5): 977–986.
- HUNTER, M.L., YONZON P., 1993, Altitudinal distributions of birds, mammals, people, forests, and parks in Nepal. *Conservation Biology*, 7(2): 420–423.
- JOHNSTON, C.A., 1993, Material fluxes across wetland ecotones in northern landscapes. *Ecological Applications*, 3(3): 424–440.
- KARK S., VAN RENSBURG B.J., 2006, Ecotones: marginal or central areas of transition? *Israel Journal of Ecology and Evolution*, 52(1): 29–53.
- KARAS L., 2016, Forest soils and climatic parameters: The interrelationship between climatic features and chosen soil properties from the viewpoint of changes of air temperatures and precipitations. M.Sc.

- thesis. Mendel University, Brno, Czech Republic. Retrieved from <https://is.mendelu.cz/auth/lide/clovek.pl?id=39009;zalozka=7;zp=51742;studium=81727>
- KOEPKE D.F., KOLB T.E., ADAMS H.D., 2010, Variation in woody plant mortality and dieback from severe drought among soils, plant groups, and species within a northern Arizona ecotone. *Oecologia*, 163(4): 1079–1090.
- KUPFER J.A., & CAIRNS D.M., 1996, The suitability of montane ecotones as indicators of global climatic change. *Progress in Physical Geography*, 20(3): 253–272.
- LESSCHEN J.P., CAMMERAAT L.H., KOOIJMAN A.M., van Wesemael B., 2008, Development of spatial heterogeneity in vegetation and soil properties after land abandonment in a semi-arid ecosystem. *Journal of Arid Environments*, 72(11): 2082–2092.
- MUNRO M.C., NEWELL R.E., HILL N.M., 2014, 3-37 Ericaceae, heath family. Nova Scotia Museum.
- OBERNDORFER E.C., 2006, Plant, macrolichen and moss community structure and species richness in the coastal barrens of Nova Scotia. M.Sc. thesis. Saint Mary's University, Halifax, Nova Scotia.
- PARMESAN C., YOHE G., 2003, A globally coherent fingerprint of climate change impacts across natural systems. *Nature*, 421(6918): 37–42.
- PETERS D.P., 2002, Plant species dominance at a grassland–shrubland ecotone: an individual-based gap dynamics model of herbaceous and woody species. *Ecological Modelling*, 152(1): 5–32.
- PETERS R.L., DARLING J.D.S., 1985, The Greenhouse Effect and Nature Reserves: Global warming would diminish biological diversity by causing extinctions among reserve species. *BioScience*, 35(11): 707–717.
- RESLER L.M., STINE M.B., 2009, Patterns and Processes of Tree Islands in Two Transitional Environments: Alpine Treeline and Bog Forest–Meadow Ecotones. *Geography Compass*, 3(4): 1305–1330.
- RESLER L.M., TOMBACK D.F., 2008, Blister rust prevalence in krummholz whitebark pine: implications for treeline dynamics, northern Rocky Mountains, Montana, USA. *Arctic, Antarctic, and Alpine Research*, 40(1): 161–170.
- RHOADES C.C., MILLER S.P., SKINNER D.L., 2005, Forest vegetation and soil patterns across glade–forest ecotones in the Knobs region of Northeastern Kentucky, USA. *The American midland naturalist*, 154(1): 1–10.
- RISSE P.G., 1995, The status of the science examining ecotones. *BioScience*, 45(5): 318–325.
- ROBINSON C.T., TOCKNER K., WARD J.V., 2002, The fauna of dynamic riverine landscapes. *Freshwater Biology*, 47(4): 661–677.
- SCHEEL B.M., HENKE-VON DER MALSBERG J., GIERTZ P., RAKOTONDRAJARY S.J., HAUSDORF B., GANZHORN J.U., 2015, Testing the Influence of Habitat Structure and Geographic Distance on the Genetic Differentiation of Mouse Lemurs (*Microcebus*) in Madagascar. *International Journal of Primatology*, 36(4): 823–838.
- SCHIEMER F., ZALEWSKI M., THORPE J.E. (Eds), 2013, The importance of aquatic-terrestrial ecotones for freshwater fish. Springer Netherlands, Dordrecht.
- SENFT A.R., 2009, Species diversity patterns at ecotones. Doctoral dissertation, The University of North Carolina at Chapel Hill.
- SHEDED M.G., AHMED M.K., HAMMAD S.A., 2014, Vegetation Analysis in the Red Sea–Eastern Desert Ecotone at the Area between Safaga and South Quseir, Egypt. *Ecologia Balkanica*, 6(2): 7–24.
- SJÖGERSTEN S., TURNER B.L., MAHIEU N., CONDRON L.M., WOOKEY P.A., 2003, Soil organic matter biochemistry and potential susceptibility to climatic change across the forest–tundra ecotone in the Fennoscandian mountains. *Global Change Biology*, 9(5): 759–772.
- TANSLEY A.G., 1935, The use and abuse of vegetational concepts and terms. *Ecology*, 16(3): 284–307.
- TOKUOKA Y., OHIGASHI K., NAKAGOSHI N., 2011, Limitations on tree seedling establishment across ecotones between abandoned fields and adjacent broad-leaved forests in eastern Japan. *Plant Ecology*, 212(6): 923–944.
- TRAUT B.H., 2005, The role of coastal ecotones: a case study of the salt marsh/upland transition zone in California. *Journal of Ecology*, 93(2): 279–290.
- TRISKA F.J., DUFF J.H., AVANZINO R.J., 1993, The role of water exchange between a stream channel and its hyporheic zone in nitrogen cycling at the terrestrial–aquatic interface. *Hydrobiologia*, 251(1): 167–184.
- W.H. FREEDMAN (2010). *The Economy of Nature*, Sixth Edition,
- WANG W., YIN C., 2008, The boundary filtration effect of reed-dominated ecotones under water level fluctuations. *Wetlands Ecology and Management*, 16(1): 65–76.

- WASSEN M.J., OLDEVENTERINK H., 2006, Comparison of nitrogen and phosphorus fluxes in some European fens and floodplains. *Applied Vegetation Science*, 9(2): 213–222.
- WELTZIN J.F., MCPHERSON G.R., 2000, Implications of precipitation redistribution for shifts in temperate savanna ecotones. *Ecology*, 81(7): 1902–1913.
- XIAO R., BAI J., WANG Q., GAO H., HUANG L., LIU X., 2011, Assessment of heavy metal contamination of wetland soils from a typical aquatic–terrestrial ecotone in Haihe River Basin, North China. *CLEAN–Soil, Air, Water*, 39(7): 612–618.
- ZEITHAML J., PIŽL V., SKLENIČKA P., 2009, Earthworm assemblages in an ecotone between forest and arable field and their relations with soil properties. *Pesquisa Agropecuária Brasileira*, 44(8): 922–926.
- ZHANG J., WEI J., CHEN Q., 2009, Mapping the farming–pastoral ecotones in China. *Journal of Mountain Science*, 6(1): 78–87.
- ZUO X., ZHAO X., ZHAO H., ZHANG T., GUO Y., LI Y., HUANG Y., 2009, Spatial heterogeneity of soil properties and vegetation–soil relationships following vegetation restoration of mobile dunes in Horqin Sandy Land, Northern China. *Plant and Soil*, 318(1–2): 153–167.

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