Publication

Functional morphology and productivity of a tussock grassland in the Bolivian Altiplano

Thesis (Dissertationen, Habilitationen)

ID 469467
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Year 2010
Title Functional morphology and productivity of a tussock grassland in the Bolivian Altiplano
Pages 66
Type of Thesis Dissertation;
Start of thesis 01.04.2006
End of thesis 31.07.2010
Name of University University of Basel, Switzerland
Name of Faculty Philosophisch-Naturwissenschaftliche Fakultät;
Supervisor(s) / **Fachvertreter/in** Hiltbrunner, Erika ; Körner, Christian ;
Keywords biomass allocation, Festuca orthophylla, high elevation, in-growth cores , land cover , leaf emergence , leaf longevity , light transmission, semi-arid grassland, subtropical
Tropical and subtropical high elevation grasslands are generally dominated by tall tussock grasses, a life form that seems to dominante in year round cold climates but otherwise quite different soil moisture regimes, from very wet (New Guinea, New Zealand, Ecuador) to rather dry, even semi-arid, as is the case in the NW-Argentinan and Bolivian Altiplano. The biomass production of these vast areas is largely unknown, since the classical harvesting technique cannot be applied in perennial vegetation without affecting growth. Given the steady increase in land use intensity, such information is needed to estimate the carrying capacity of these vast rangelands. In this thesis, I developed the needed non-destructive tools and applied them for a 30-month productivity analysis in the Bolivian Altiplano. The work was conducted in Sajama National Park at 4250 m elevation. The study plant, *Festuca orthophylla*, is a tall (up to 1 m, mostly around 60 cm) tussock forming grass that represents more than 90% of all biomass in many parts of the Altiplano, including the study area. Forming clones of initially compact, but later fragmented shape, persisting many decades, this species is characteristic for the appearance of the semi-arid, Andean landscape over thousands of square kilometers at elevations between 3600 and 4600 m a.s.l. As a first step, I analysed the clonal structure, the morphology and biomass allocation in representative tussocks. The core of the theses is related to the tussock biomass production using a demographic approach and land cover data (Chapter 3), followed by an assessment of seasonal leaf dynamics (Chapter 4).

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In conclusion, our data provide a quantitative characterisation of the architecture and dry matter investment of this dominant Altiplano species, the first year-round productivity estimation for a high-elevation tropical, grassland, and a detailed assessment of leaf dynamics for the rainy and the dry season. In a number of ways the traits exhibited, contrast *Festuca orthophylla* from other, non-woody, high elevation taxa. In particular, the foliage of these tussocks operates at temperature close to that of the free atmosphere, while at the same time, providing shelter to below-ground shoot meristems. The large amount of dead plant material constrains photosynthetic light interception, and reflects slow rates of decomposition, a likely trade-off of generally poor nutrional quality (Patty et al., 2010), which, in turn, relates to the heavy herbivory pressure. The rates of biomass accumulation per unit of tussock area are quite high,

much higher than one would expect in such a semi-arid rangeland. The most plausible explanation is that these tussocks are utilizing a far greater land area for water and nutrient acquisition than represented by their projected canopy area. The space in-between tussocks is, thus, a most likely mechanism explaining these high rates of productivity. The degree of land cover has already been shown to be a most critical mechanism to cope with water shortage in such high elevation grasslands (Geyger, 1985). Given that tussock root spheres do not overlap but rather leave unexplored inter-tussock space, there seems some leeway for increasing tussock density without losing the advantage of wide spacing in terms of water and nutrient relations. It remains to be explored how large the actual root-covered land area is. It seems tussock density could be enhanced by 30 to 50% before root spheres start to overlap. Current grazing pressure prevents tussock recruitment, so natural tussock mortality or man-made mortality by misuse of fire is currently not compensated by natural recruitment. Hence, in addition to llama dung distribution, grazing management with mobile fences seems like an additional management option to retain higher camelid stocks without destructive consequences, From our unquantified observations new tussock establishment occurs already in the first year of fencing. Thus, periodic camelid exclusion could assist in increasing tussock density and, thus, productivity per land area. There is no indication that low temperature *per se* has a major impact on productivity at these high elevations. We observed no compensatory growth in *Festuca orthophylla* in response to foliage removal. Nevertheless, we believe that clipping was a stimulus sensed by the tillers since it delayed the onset of leaf senescence, although not overall longevity. Continuation of leaf elongation during the long dry season is in line with a previous analysis of ramet dynamics and re-growth and underpins the extremely efficient ways of moisture and space utilization in these tussocks. Wide spacing permits greater moisture availability per tussock and, thus, permits year-round production of new foliage (fodder) in this semi-arid high altitude ecosystem.

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