POPULATION STRUCTURE AND ECOLOGY OF A HIGH ANDEAN FOREST: *POLYLEPIS RUGULOSA* (ROSACEAE) FROM PERU

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Abstract

Thirteen plots of 500m^2 were established in the forest of quenoa at Muylaque, district of San Cristóbal (Moquegua), southern of Peru. The population structure showed a predominance of saplings (239 individuals), followed by adults (217 individuals), and seedlings (164 individuals). The average of individuals per plot was higher for the seedlings (18.4 ± 3.6), followed by adults (16.7 ± 4.3) and saplings (12.6 ± 4.5). It was estimated 334 adult individuals per hectare. *P. rugulosa* yielded floral buds during the wet season (December to February), while in the dry season (July to September) individuals in a vegetative stage predominate. The fruiting stage predominated at the end of the wet season (February to April). The plants affected by anthropogenic activities were accounted up to 13% of the plants evaluated. The associated flora to the *P. rugulosa* forest is composed of 72 species of herbaceous and shrubby plants distributed in 28 families.

Key words: Anthropogenic influence; associated flora; phenology; plant growth

Introduction

Quenoa (genus *Polylepis*, Rosales: Rosaceae) forests are recognized as centers of endemism and biological diversity (Sevillano-Ríos and Rodewald 2017). These forests with quenoa as dominant species are scarce and occupy small areas (patches) mainly due to human activities and the effects of climate change (Renison et al. 2004; Kessler 2006; Peng et al. 2015). The distribution of these forests is restricted to rocky or broken slopes (Kessler 2006; Trinidad and Cano 2016; Segovia-Salcedo et al. 2018; Morales-Araníbar et al. 2019) and their ecological importance lies in providing habitat for the development of high Andean avifauna, endemic plants, mammals, hydric regulation, and carbon sequestration (Servat et al. 2002; Patterson 2004; Mendoza y León 2006; Morales-Araníbar 2015; Trinidad and Cano 2016; Sevillano-Ríos et al. 2011, 2018; Poca et al. 2018; Aquino et al. 2018; Samata et al. 2019). In *Polylepis* forests, the observed associated flora and fauna are unique for these ecosystems due to the presence of particular niches that favor the formation and coexistence of many species (Kessler 1995; Servat et al. 2002; Sevillano-Ríos and Rodewald 2017). Despite the importance of these forests as biodiversity hotspot and its ecosystem services, phytosociological studies are still scarce in the Andes, particularly in southern Peru and northwestern Bolivia (Montesinos-Tubée et al. 2015; Cuykens and Renison 2018; Segovia-Salcedo et al. 2018; Morales-Araníbar et al. 2019).

The fragmentary distribution of these high Andean forests has provoked discussion about the relative importance of the anthropogenic and climatic causes of this pattern, which vary with topography and climate (Toivonen et al. 2017). Some studies proposed that the loss of high Andean forests could increase during the Inca Empire and the colonial era due to the intensification of agriculture and a greater demand for firewood and charcoal as fuel (Kessler 2002; Hensen et al. 2012; Domic et al. 2017). The biomass of high Andean forests is used as fuel and in the construction of rural buildings of the Puno region in Peru and Bolivia (Collahuasi 2011). Across the Andes, these forests suffer accelerated processes of erosion, landslides of slopes by the implementation of roads and rural roads, especially in connection to mining and logging activities (Collahuasi 2011; Morales-Araníbar et al. 2019) to promote grazing lands and wood extraction (Renison et al. 2004;

Ciertjacks et al. 2008). These anthropogenic activities have caused the loss of extensive forest areas and have reduced the regeneration capacity of the Polylepis forests (Domic et al. 2013).

The quenoa forest of Muylaque (Moquegua) is recognized as a priority area for conservation according to Regional Ordinance No. 29-2012-CR/GRM of the Moquegua Regional Government, with the main objective of conserving its biological diversity. The Muylaque forest is characterized for the dominance of *Polylepis rugulosa* Bitter. Currently, this forest is intended for conservation and ecotourism practices although rural populations still practice economic traditional activities (e.g., agriculture, grazing, and wood extraction). This study could contribute to gather primary information on the current situation of quenoa population at Muylaque forest. This information could be used to promote its management and conservation. The objectives of this study were: 1) to evaluate the population structure by development stages of *P. rugulosa*, 2) to estimate the abundance of *Polylepis*, 3) to observe their phenology in the wet and dry season, 4) to evaluate the effects of anthropogenic activities on *Polylepis* forest, and 5) to identify the associated flora of the *Polylepis* forests.

Materials and methods

2.1. The study area

The study area is located in the northeast of the Muylaque Little Town, San Cristóbal district, Mariscal Nieto province, Moquegua region, Perú. We evaluated the quenoa forest (7.96 km^2) composed mainly by *Polylepis rugulosa* Bitter, located between the coordinates 16° 39´ - 16° 37´ N and 70° 43´ - 70° 39´ W. The altitudinal range spans from 3250 masl to 4350 masl. The annual average temperature ranges between 4 °C to 6 °C, and the annual average rainfall ranges between 450 mm and 550 mm (Chancayauri 2008). It is recognized as a priority area for the conservation of the Moquegua region in the Tambo river basin by the Regional Ordinance No. 29-2012-CR/GRM of Moquegua Regional Government. According to the Holdridge life zones classification, the Muylaque quenoa forest belongs to the humid paramo - Subalpine Subtropical (ph-SaS) (Chancayauri 2008; GORE Moguegua 2015).

2.2. Field survey

Thirteen plots (20m X 25m) were set for analyzing the different demographic stages of *P. rugulosa*. The population structure was selected into three development stages: a) seedling, <0.30m, b) sapling, between 0.30m to 1m, and c) adults, >1m. The stem density was estimated by counting individuals for each plot, and these values were expressed as individual per hectare (1 hectare = 0.01 Km^2).

We monitored the phenology of *P. rugulosa* in 40 marked individuals from January to December 2016. The phenological stages correspond to: vegetative (V), flowering (Fl), and fructification (Fr). In each marked individual four branches of 40 cm long were selected, based on the representativeness of reproductive structures compared to the entire canopy of the individual.

The anthropogenic effects in the populations of *P. rugulosa* were determined with direct observations in three different levels: a) Unaffected (good visual appearance, vigorous leaves and no anthropogenic impact), b) Middle affected (slightly damaged, signal of cutting, dried branches, there are a few dry leaves), and c) Affected (broken, cut, dry, burned, and/or dead individuals), following the levels of anthropogenic effects proposed by the Tacna Regional Government (GORE Tacna 2015).

Plant specimens were collected in the dry and wet season to identify all the vegetation associated to *P. rugulosa*. The collections were made inside and outside of the plots. The collected botanical specimens were treated according to the method proposed by Gutierrez-Salazar and Garcia-Mendoza (1999). The taxonomic identity was determined using the CUZ Herbarium collections from the Universidad Nacional de San Antonio del Cusco (UNSAAC).

For statistical analysis, we used the Past software v 3.2 (Hammer *et al.*, 2001). The performed analyzes were descriptive statistics (average ± standard error), and normal distribution (Shapiro-Wilk normal distribution test).

Results

3.1 Population structure and density of P. rugulosa

We registered a total of 620 individuals in all thirteen plots. The highest number of individuals was for saplings stage (239 individuals), followed by the adults (217 individuals), and seedlings (164 individuals). The evaluated plots showed a heterogeneous population structure, with the predominance of the sapling stage. In three of these plots, only the adults and saplings were recorded; in other four plots, the number of saplings was higher than the number of adults.

The evaluated plots did not show a normal distribution (Shapiro-Wilk test, $W = 0.772$, $p = 0.003$), the same happened in the case of the adult individuals ($W = 0.679$, $p < 0.001$). The average of individuals per plot was higher for the saplings (average ± standard error: 18.4 ± 3.6) followed by adults (16.7 ± 4.3) and saplings (12.6 ± 4.5) (Figure 1).

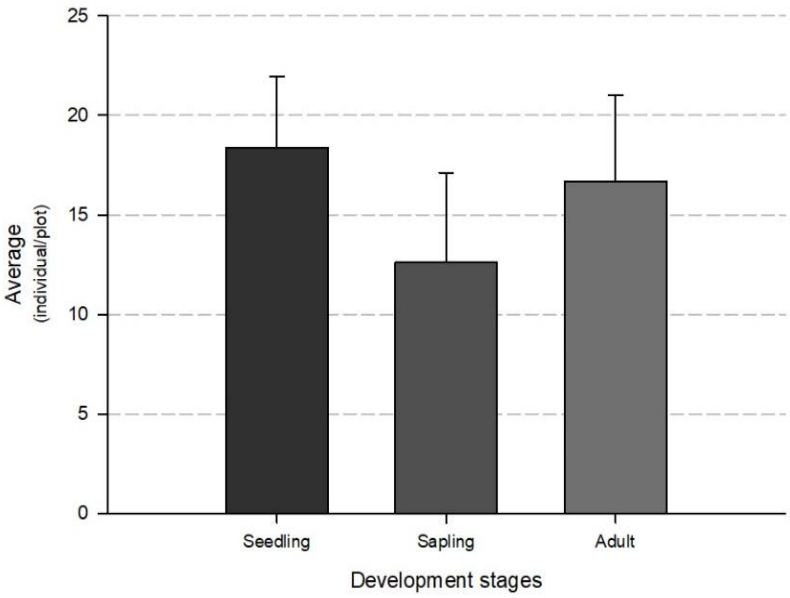

Figure 1. Population structure of Polylepis rugulosa (mean ± standard error)

The total density of individuals per plot varied from 0.03 individuals/m2 to 0.23 individuals/m2. The density of adult individuals per plot did not exceed 0.15 individuals/m2 and for the entire evaluated area the density of adults did not exceed 0.05 individuals/m2. We estimated 333.8 adult individuals per hectare in the Muylaque quenoa forest.

3.2. Phenology

We observed floral buds (Fl) of P. rugulosa from December to March, while the individuals were more abundant in the vegetative stage (V) from July to September. The fruiting stage (Fr) predominated from February to April, and reached the peak in February (Figure 2). There were individuals that showed different phenological stages simultaneously

3.3. Anthropogenic factors affecting the plants

From the total registered plants (n = 620) the affected plants were only 1% (n = 6) across all the plots, the middle-affected plants were 12% (n = 75), and the unaffected¸87% (n = 539). These results show that the quenoa forest of Mulayque has a low anthropogenic intervention.

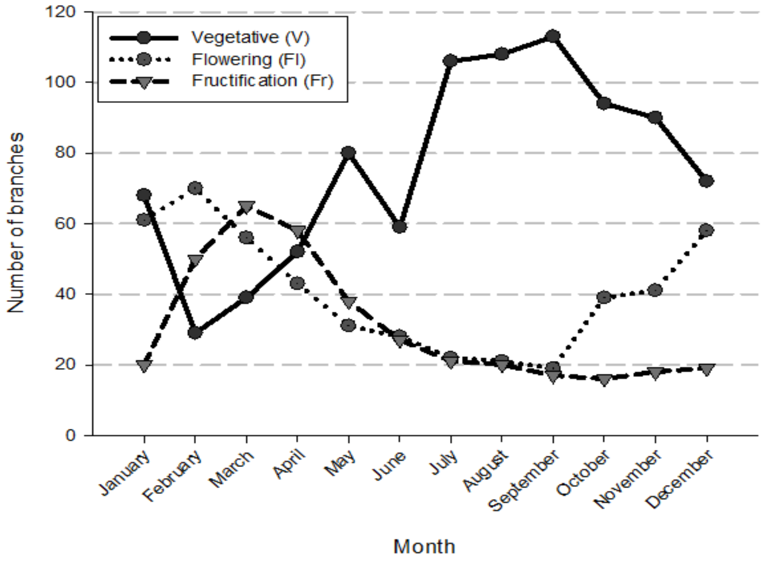

Figure 2. Phenology of sampled branches per month

3.4. Associated flora

72 species of plants associated to the quenoa forest were registered, distributed in 28 families. The richest families were Asteraceae (Asterales) and Poaceae (Poales) with 24 and six species respectively, followed by Cactaceae (Caryophyllales), Calceolariaceae (Lamiales) and Fabaceae (Fabales) with four species, respectively (Table 1). The most common associated plants to P. rugulosa were: Parastrephia lucida (Meyen) Cabrera, Adesmia spinosissima Meyen ex Vogel, Bacharis tricuneata (L.f.) Pers., Gynoxys longistyla (Greenm. & Cuatrec.) Cuatrec., Senecio adenophylloides Sch. Bip., S. boliviensis Sch. Bip., S. neoviscosus Cuatrec., Festuca orthophylla Pilg., Poa annua L., Stipa obtusa (Nees & Meyen) Hitchc., S. rigidiseta (Pilg.) Hitchc., S. ichu (Ruiz & Pav.) Kunth, Bromus berterianus Colla. Also, there are epiphytic and climbing plants (Cantua candelilla Brand, Mutisia acuminata Ruiz & Pavón, Mutisia lanigera Wedd).

Discussion

It is known that adult trees are used for several human activities (fuel wood, building, making tools for agriculture); protecting these trees, they would contribute to the generation of new individuals (seedlings). In this sense, it must be assumed that the Muylaque forest is in the process of regeneration, since more saplings were observed. Dendrochronological studies that could explain the size of the trees, maturity and the age of these forests were not performed in Moquegua. Argollo et al. (2004) mentioned that the maturity of Polylepis tarapacana Phil is reached between 73 and 90 years, and Tacna Regional Government (GORE Tacna 2015) stablished the maturity average age is 80 years in forests adjacent to Moquegua region. Performing dendrochronological studies would facilitate the diagnosis of the historical evolution of these forests, contributing to the integration in management and restoration plans.

Understanding the structure and composition of forests is the key to achieving an adequate management and restoration of these ecosystems, including the associated flora. There is still limited information about the factors that shaped the structure and the actual species composition of the quenoa forests, and how the species response to environmental stress, particularly in the early stages of development, which may be the key to understanding their dynamics and response to environmental changes (Toivonen et al. 2017; Mejía et al. 2018).

One of the fundamental bases of the sustainable management of Polylepis forests is the maintenance of natural regeneration, that is not the result solely of anthropogenic use since it can be strongly influenced by the interaction of the biotic and abiotic components of the forest ecosystem, such as geomorphological, temperature and rainfall factors (Kessler 2006; Rada et al. 2009; Leigue 2011; Mejía et al. 2018). The sustainable management requires that species regenerate naturally to maintain their populations and ensuring the future productivity of the forest (Bawa and Seidler 1998). The density of adult individuals of quenoa (Polylepis reticulata Hieron and P. sericea Wedd.) was studied in the north of Peru and was reported from 0.06 up to 0.21 individuals/m2 (Castro and Flores 2015), higher than the current record in Moquegua (maximum of 0.15 individuals/m2) but within the registered density range. The number of individuals of Polylepis per hectare varies among species and locations across Los Andes. For example, the highest number of individuals/hectare was reported for P. reticulata (4095 individuals/hectare) and P. tarapacana, (from 400 to 1420 individuals/hectare) in Colombia and Tacna (Peru) respectively (Pacheco 2015; Morales-Araníbar et al. 2019). In northern Peru, Polylepis weberbaueri Pilger showed also a high density of individuals per area (698 individuals/hectare) (Cuya 2015). Likewise, studies showed a high variation in individuals/hectare for P. rugulosa, with densities ranging from 389 up to 2420 individuals/hectare in the forests of Arequipa and Tacna (Rodríguez 2018; Morales-Araníbar et al. 2019). The density of adults of quenoa differs between species and between sites of evaluation. The natural regeneration, and consequently the density, is closely related to the biotic factors (including human exploitation) and abiotic factors that interact in the ecosystem (Leigue 2011). In that sense, the density of adults, saplings and seedlings will depend on the intrinsic and extrinsic conditions that interact in each forest. The results showed low values of individuals/hectare for P. rugulosa (334 individuals) suggesting that the quenoa forest of Mulayque may be recovering from past forest extraction and degradation.

The phenology stages are associated mainly to abiotic and intrinsic factors of the plants (Lobo et al. 2003; Domic et al. 2013; Carnwath and Nelson 2017; Basnett et al. 2019). Hensen (2011) mentions that the Polylepis species show phenological patterns similar to Polylepis tomentella Wedd., where the maturity of the fruits occurs at the end of the dry season until the middle of the wet season. P. rugulosa flourished mostly during the months of December, January and February, and fructified from February to early April. In San Cristobal City, the climatic station nearest to Muylaque forest registered January as the rainiest month during 2018, the remaining months had very scarce precipitation (SENAMHI, 2018; climatic data no available for 2016). According to the peak recorded for flowering and fruiting stages from January to April, it would be favored by higher rainfall in prior months. In that sense, the rainfall will affect flowers production, fruiting and subsequent seed production (Domic et al. 2013; Basnett et al. 2019). The synchronization of this process, would favor the recruitment and the viability of seedlings for natural regeneration.

In Muylaque, the plants affected by human activities were less notorious, the quenoa plants showed good external appearance. Although cows, lambs, donkeys, and other wild herbivorous that often feed on seedlings and saplings were observed, the evaluated plots showed minimal impact on seedlings and saplings by feeding or mechanical damage. With the introduction of domestic animals into forests, the grazing was intensified, being one of the causes of forest reduction and the increase of grass areas (Urrego et al. 2011; Valencia et al. 2016), mostly by reducing the capacity of survival of the seedlings and saplings. On the other hand, the physiography and topography of the land (little canyons, rocky areas, abrupt slopes) protect to plants against the wind, variation of temperatures, decreasing or increasing of soil moisture, fire or herbivores browsing (Kessler 2002; Rada et al. 2009; Renison et al. 2018).

Across time, the quenoa species has an economically value and all parts of the plant has been used. For instance, the wood is used in house construction, for making tools (e.g., shovels and peaks) and for furniture. But more importantly, the wood is used as fuel to heat the houses and for cooking. The leaves, roots and bark are also used and mainly to cure diseases and to dye wool. Currently, in Muylaque forest, there is an afforestation program (with eucalyptus, Eucalyptus globulus Labill. and molle, Schinus molle L.) promoted by regional authorities for decreasing the demand for quenoa wood.

This study recorded 72 plant species overcome the number of species registered in previous studies on floristic diversity in quenoa forests from Peruvian Andes, for example: Mendoza (2000) recorded 43 species in four forests, INRENA (2006) recorded 48 species from five forests; Servat et al. (2002) recorded 144 species from four forests, and Trinidad and Cano (2016) registered 282 species from two forests. In general, the quenoa forests house a high floristic richness, containing several endemic and threatened species (Mendoza y León 2006). However, the number of species can be comparatively lower or higher depending on the sampled area, effort for sampling, and the extent of the forest. In Muylaque and other places, at certain times of the year, pastures are burned with the intention of improving soil fertility (Yallico 1992) affecting the endemic flora and fauna of quenoa forests (Kessler and Dreisch 1993).

Conclusions

According to our results, the seedling stage is highest than adults and sapling stages. The density of adult individuals of P. rugulosa was lower than other species in the quenoa forests in Peru and Colombia. P. rugulosa produces floral buds during several months, mainly from December to February. The fruiting stage reaches the peak in March, and remaining months predominate the vegetative stage (from April to November). The affected plants by anthropogenic activities are low (13%). Additionally, the species of associated flora represent an intermediate richness comparatively to other quenoa forests.

Conflict of interest

All authors declare that there is no conflict of interest in this paper.

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Supplementary

Table 1. Associated flora of the quenoa forest at Muylaque.

Order	Family	Species
Polypodiales	Cystopteridaceae	*Cystopteris fragalis* (L.) Bernh.
Apiales	Apiaceae	*Azorella compacta* Phil. *Bowlesia lobata* Ruiz & Pav.
Asterales	Asteraceae	*Aequatorium* sp. *Baccharis boliviensis* (Wedd.) Cabrera *Baccharis genistelloides* (Lam.) Pers. *Baccharis salicifolia* (Ruiz & Pav.) Pers. *Baccharis tola* Phil. *Baccharis tricuneata* (L.f.) Pers. *Chersodoma jodopapa* Phil. *Chuquiraga rotundifolia* Wedd. *Erigeron pazensis* Sch.Bip.ex Rusby *Gamochaeta purpurea* (L.) Cabrera *Gynoxys longistyla* (Greenm. &Cuatrec.) Cuatrec. *Hieracium pilosela* L. *Luciliocline longifolia* (Cuatrec. & Aristeg.) M. O. Dillon & Sagást. *Mutisia lanígera* Wedd. *Mutisia acuminata* Ruiz & Pav. *Parastrephia lucida* (Meyen) Cabrera *Proustia berberidifolia* (Cabrera) Ferreyra *Raoulia rubra* Buchanan *Senecio adenophylloides* Sch. Bip. *Senecio boliviensis* Sch. Bip. *Senecio neoviscosus* Cuatrec. *Senecio nutans* Sch. Bip. *Stevia ovata* Willd. *Werneria* sp.
Brassicales	Brassicaceae	*Cremolobus chilensis* (Lag. ex DC.) DC. *Descurainia myriophylla* (Willd. ex DC.) R. E. Fr.
Caryophyllales	Cactaceae	*Corryocactus brevistylus* (K. Schum. ex Vaupel) Britton & Rose *Cumulopuntia corotilla* (K.Schum. ex Vaupel) E. F. Anderson *Opuntia ignescens* Vaupel *Opuntia soehrensii* (Britton & Rose) D. R. Hunt & Iliff
	Caryophyllaceae	*Drymaria ovata* Humb. & Bonpl. ex Schult. *Pycnophyllum molle* Rusby *Silene* sp.
Cornales	Loasaceae	*Caiophora sepiaria* (Ruiz & Pav. ex G. Don) J. F. Macbr.
Dipsacales	Caprifoliaceae	*Valeriana nivalis* Wedd.
Ericales	Polemoniaceae	*Cantua candelilla* Brand *Phlox gracilis* (Hook.) Greene
Fabales	Fabaceae	*Adesmia spinosissima* Meyen ex Vogel

		Lupinus ballianus CP Sm. *Lupinus misticola* Ulbr. *Lupinus aff. Toratensis*
Gentianales	Rubiaceae	*Galium hypocarpium* (L.) Endl. ex Griseb. *Galium weberbaueri* K. Krause
Geraniales	Geraniaceae	*Erodium cicutarium* (L.) L'Hér. ex Aiton
Gnetales	Ephedraceae	*Ephedra rupestris* Benth.
Lamiales	Boraginaceae	*Heliotropium curassavicum* L.
	Calceolariaceae	*Calceolaria inamoena* Kraenzl *Calceolaria lobata* Cav. *Calceolaria parvifolia* Wedd. *Calceolaria sclerophylla* Molau
	Orobanchaceae	*Barstsia bartsioides* (Hook.) Edwin
	Plantaginaceae	*Plantago linearis* Kunth
Liliales	Alstroemeriaceae	*Bomarea dulcis* (Tussac) Herb.
Malvales	Malvaceae	*Fuertesimalva chilensis* (A. Braun & C.D. Bouché) Fryxell *Nototriche turritela* A. W. Hill
Myrtales	Onagraceae	*Oenothera elongata* Rusby
Poales	Poaceae	*Bromus berterianus* Colla *Festuca ortophylla* Pilg. *Poa annua* L. *Stipa ichu* (Ruiz & Pav.) Kunth *Stipa obtusa* (Nees & Meyen) Hitchc. *Stipa rigidiseta* (Pilg.) Hitchc.
Ranunculales	Ranunculaceae	*Clematis millefoliata* Eichl.
Rosales	Rhamnaceae	*Colletia spinosissima* J.F.Gmel.
	Rosaceae	*Tetraglochin cristatum* (Britton) Rothm.
	Urticaceae	*Urtica leptophylla* Kunth
Santalales	Schoepfiaceae	*Quinchamalium procumbens* Ruiz & Pav.
Saxifragales	Crassulaceae	*Crassula connata* (Ruiz & Pav.) A. Berger
Solanales	Solanaceae	*Solanum corymbosum* Jacq.