DIVERSITY OF *JUNIPERUS THURIFERA* L. TREE SHAPES : ORIGINS AND CONSEQUENCES ON BIOMASS ALLOCATIONS

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Summary: In any points of its distribution area, *Juniperus thurifera* presents an important architectural diversity, as a result of interactions between endogenous and exogenous factors. In the case of the Moroccan stands, we identified 4 simple morphological types on the basis of crown length ratio (ratio of crown length to tree height) and number of stems (ranging from 1 to 12). We discriminated single-stemmed trees (SS) from (ii) multi-stemmed trees (MS) in the case of (i) overall crowned trees with the crown length ratio = 1 (OC) and (ii) partially crowned trees (crown length ratio < 1) with a visible trunk (PC). Trees' shape results from a combination of both categories (crown repartition along the trunk x number of trunk; e.g. PC-SS). Altitude induces a higher frequencies of multi-stemmed trees and overall crowned trees while single-stemmed trees are preferentially localized on strong slopes. The determinism of the multi-stemmed trait is probably related to the reduction in apical dominance with altitude. Multi-stemmed trees are larger than single-stemmed trees with a higher biomass allocation in woody parts (trunks and branches) and a higher wood productivity. The overall crowned shape determinism could be related to the low temperatures at high altitude, trees' shape being close to those of xerophytic shrubs and allocating more energy to the photosynthetic organs.
Keywords: *Juniperus thurifera*, Tree architecture, Mountain climate, Biomass allocation

DIVERSIDAD MORFOLÓGICA DE LAS SABINAS Y ENEBRALES: ORIGEN Y CONSECUENCIAS EN LAS ASIGNACIONES DE BIOMASA

Resumen En el conjunto de su área de repartición, la sabina albar presenta una gran diversidad de arquitectura, resultado de la interacción de los factores endógenos y exógenos. En el caso de los pueblos marroquíes, hemos podido identificar cuatro tipos de morfología simple, cimentados en el espesor de copa (ratio entre el espesor de la copa y la altura total) y del nombre de tallos (de 1 a 12). De este modo, hemos discriminado tipos (i) SS (Tronco Único), (ii), MS (Troncos Múltiples), (iii) OC (*Tronco invisible*), (iv) PC (Tronco(s) visible(s)), algunos árboles pueden pertenecer a dos categorías (por ejemplo, PC-SS). La altitud induce una proporción más elevada de individuos multicaules y con copas que llegan al suelo, mientras que los individuos con un tronco único se localizan con mayor frecuencia en fuertes pendientes. En el caso de los árboles multicaules, la determinación de la altitud está en relación probablemente al debilitamiento de la dominante apical. Los individuos son más anchos que los que tienen un tronco único, con una asignación de biomasa para compartir con el tronco y una productividad de tronco más importante. La determinación de las formas de la copa al sol puede estar ligada a las bajas temperaturas de las altas altitudes, donde los árboles adoptan el porte característico de los xerófitos arbustivos, y dando una mayor energía a los órganos fotosintéticos.
Palabras clave : *Juniperus thurifera*, arquitectura de los árboles, clima de montaña, biomasa.

DIVERSITE MORPHOLOGIQUE CHEZ LE GENEVRIER THURIFERE: ORIGINES ET CONSEQUENCES SUR LES ALLOCATIONS DE BIOMASSE

Résumé: Sur l'ensemble de son aire de répartition, *Juniperus thurifera* présente une diversité architecturale importante, résultat de l'interaction entre des facteurs endogènes et exogènes. Dans le cas des populations marocaines, nous avons pu identifier 4 types morphologiques simples sur la base (1) de la répartition du houppier le long du tronc (ratio entre épaisseur du houppier et hauteur totale = EpHp/Ht) et (2) du nombre de troncs (de 1 à 12). Nous avons ainsi discriminé les types à tronc unique (SS) des arbres à troncs multiples (MS), dans deux variantes possibles (i) les types arbustifs avec un houppier partant du sol dont le ratio EpHp/Ht =1 (OC) et (ii) les types arborescents à tronc visible (PC). Les arbres appartiennent alors à une combinaison de ces deux catégories (nombre de tronc x répartition houppier ; exemple : PC-SS). L'altitude induit une plus grande proportion d'individus à troncs multiples et de houppiers descendant jusqu'au sol, tandis que les individus à tronc unique se rencontrent plus fréquemment sur les fortes pentes. Le déterminisme du caractère troncs multiples pourrait être lié à l'affaiblissement de la dominance apicale avec l'altitude. Les individus sont plus gros que ceux à tronc unique, avec une allocation de biomasse pour le compartiment ligneux et une productivité ligneuse plus importante. Le déterminisme des types arbustifs avec un houppier partant du sol peut être lié aux faibles températures à haute altitude, les arbres adoptant le port caractéristique des xérophytes en coussinets, et allouant plus d'énergie aux organes photosynthétiques.
Mots-clés : *Juniperus thurifera*, Architecture des arbres, Climat montagnard, Allocation de biomasse.

INTRODUCTION

Thuriferous juniper is only found in isolated parts of the Western Mediterranean Basin : France (Alps, Pyrenees and Corsican highlands), Spain, Algeria and Morocco (Barbero *et al.*, 1990; Blanco Castro *et al.*, 1997; Chirio and Blanc, 1997). In Morocco, these semi arid mountain stands, where thuriferous juniper trees grow in low-density open woodland, are seriously endangered as a result of the intensive wood removal and livestock activity in these densely populated areas (Gauquelin *et al.*, 1999).

On almost all of its natural range, *Juniperus thurifera* L. is characterized by a large architectural diversity, as a result of an interaction between endogenous and exogenous factors. In France, about 8 architectural types were described (Polidori, 1986; Lathuillière, 1994), most of them in Alps related to the diversity in ecological parameters (climate, slope, altitude, exposure, soil, inter-specific competition). In Spain, some additional morphological types can be found in response to silvicultural and pastoral activities (Blanco Castro *et al.*, 1997). In Morocco, we also found particular shapes due to strong human impact (wood removals and overgrazing) and severe climatic constraints. We will focused in this paper on Moroccan stands, considering only few morphological types that could be objectively discriminated. Other shapes will only be mentioned.

MATERIALS AND METHODS

Thuriferous juniper is a dioecious bush or tree, with scaly leaves (we will employ the word "foliage" for these chlorophyllous organs) and black-bluish cones when mature. In Morocco, Juniper stands are found at the tree line mainly between elevations of 2,000 and 3,000m (Gauquelin, 1988). Isolated specimens may be found above 3,000m (the lowest-level stands are at 1,700m in the western High Atlas).

The site we have studied is the *Juniperus thurifera* woodland of Azzaden valley, in the High Central Atlas, south of Marrakesh (Morocco). In the upper level of this valley, this juniper (which can grow to 18m with a diameter of 5m) is the only arborescent woody species adapted to the severe high mountain Mediterranean climate, and represents the sole wood resource of the local Berber populations . The tree grows in low-density woodlands (about 78 trees.ha^{-1} (Montès, 1999) with fairly old trees (probably more than several hundred years old), which are often scarred, and with a steppic shrub strata (*Bupleurum spinosum* L., *Cytisus purgans* L. Benth. *ssp. balansae* (Boiss.) M., *Alyssum spinosum* L.).

In this study, 102 trees were sampled in a variety of topographic conditions. The slopes ranged from 10 to 37 degrees, and the elevation ranged from 1,915m to 2,350m.

The dendrometric parameters measured were height of the trees, basal circumference, crown projection area, crown length, number of living stems and number of cut stems.

The estimation of tree biomass was obtained in a previous study (Montès *et al.*, 2002). The estimation of biomass of junipers is based on a non destructive method (Montès *et al.*, 2000b; Montès *et al.*, 2000a) very briefly described here: it consists of photographic sampling of trees to reconstruct the different component volumes of the trees (trunks/branches, branchlets (>20mm), and leaves). In view of the axial asymmetry of these junipers, two pictures of each tree were taken with orthogonal views. Then biomass is obtained (after the estimation of the bulk density of each component) by the formula: B = V x d (B: Biomass; V: Volume estimated for each component; d: Estimated density for each component). Similarly, the biomass of cones was measured on female trees.

On the basis of crown length ratio (ratio of crown length to tree height) and number of stems (ranging from 1 to 12). we identified four simple morphological types (fig. 1):

- Single-stemmed trees (SS): this morphological type correspond to trees with only one trunk and possible cut trunk.
- Multi-stemmed trees (MS): trees with two or more trunks.

Independently of the number of trunks, we also discriminated:

- Trees with a crown length ratio = 1, that mean overall crowned trees (OC).
- Trees with a crown length ratio < 1, that mean the trunk(s) is(are) visible(s) (partially crowned trees, PC).

One way analysis of variance (ANOVA) were used to compare tree shapes according to the studied factors (descriptive factors, explicative factors and biomass allocations). Significant level was considered to be 95 %. The software Statview© (version 4.55, Abacus concepts, Inc., Copyright 1992-1996) was used.

RESULTS

Descriptive factors:

Even if the size was not used to discriminate overall crowned trees from partially crowned trees, the results show that partially crowned trees are significantly taller and have a higher basal circumference (Table 1) than overall crowned trees. Despite a low mean height (OC = 3.6 m and PC = 4.3 m), trunk of trees is very large (diameter higher than 0,8 m). The differences between single-stemmed trees and multi-stemmed trees relate not only on the trunk, but also on trees' crown. For all measured variables (crown projection area, crown length, height and basal circumference), overall crowned and multi-stemmed trees (OC-MS) present values significantly higher than single-stemmed trees (OC-SS).

Explicative factors:

Overall crowned trees are located at significantly higher altitudes than partially crowned trees (Table 2). The number of overall crowned trees increases along an altitudinal gradient (altitudinal sections of 125 m) whereas partially crowned trees are completely missing at 2,500 m (fig. 2). The effect of altitude is also significant on the distribution of multi-stemmed trees of which the proportion increases with the altitudinal gradient. The distribution of single-stemmed trees and multi-stemmed trees along the altitudinal gradient is however less regular than it is for overall crowned trees and partially crowned trees (fig. 3), but differences between extreme altitudes are very marked. There is a similar proportion of single-stemmed and of multi-stemmed trees at the lower altitude whereas there are only multi-stemmed trees at the higher altitude. Single-stemmed trees are also located on slopes significantly more pronounced than multi-stemmed trees. This is particularly true for the overall crowned trees. The percentage of cut stems by individual is significantly higher for partially crowned trees than for overall crowned trees. On the other hand, no significant difference between single-stemmed trees and multi-stemmed trees could be highlighted.

Biomass allocation:

Table 3 reveals that biomass of multi-stemmed trees are higher than biomass of single stemmed-trees. However this difference is only significant in the case of the overall crowned trees. No significant difference in the weight of the individuals was evidenced between partially crowned trees and overall crowned trees. For the same cover, partially crowned trees represent, in a very significant way, more biomass than overall crowned trees (respectively 28.1 and 18.4 $kg.m^{-2}$). The observation is similar for multi-stemmed trees with an overall crown.

For all morphological types, the relative importance of the biomass of the various compartments is the same one: Trunk-Branches >> Leaves > Twigs. However, the strategies of biomass allocations between the various compartments of the plant differ according to the number of trunks and the importance of the crown.

The multi-stemmed and overall crowned trees (OC-MS) and partially crowned trees allocate significantly more energy than single-stemmed trees and overall crowned trees to the trunk-branches compartment than to the branches and photosynthetic compartments (Table 3). In the multi-stemmed overall crowned trees (OC-MS), the preferential way of biomass allocation in direction of the ligneous compartment induces a higher productivity. No significant difference between morphological types was evidenced concerning the energy invested in the reproduction (females' cones). Within partially crowned trees, whatever the parameter considered (descriptive factor, explicative factor or biomass allocation), there is a very strong homogeneity in the results (except for basal circumference) between single stemmed trees and multi-stemmed trees.

DISCUSSION-CONCLUSION

The dominance of overall crowned trees at higher altitudes participates to an homogenization of architectural diversity. Trees and xerophytic shrubs present a dense canopy isolating the stem from very low temperatures in winter (Badri *et al.*, 1994). The cambium is thus protected from frost damages.

At high altitude, these overall crowned trees are often multi-stemmed. The presence of multi-stemmed trees seems to be linked to the loss of apical dominance due to frost events on apical buds (Bertaudière *et al.*, 2001). However, if climatic events could be responsible from the growth of secondary shoots developing from adventive buds (Emberger, 1939), the presence of multi-stemmed junipers could also be related to anthropogenic (browsing and cutting) factors.

Even if no significant differences were observed between multi and single stemmed trees concerning the number of dead stems (as a measure of cutting impact), the grazing impact was not quantified but may be an additive factor especially on saplings.

The presence of multi-stemmed junipers (trees but also saplings less than 3 years old) in well preserved areas (French Pyrenees and Alps) where human disturbances (grazing and cutting) are limited, show nevertheless that genetic factors could be involved in multicaulis structure determinism.

The higher percentage of cut stems observed on partially crowned trees reflect a human impact that occured on old trees. Conversely, on overall crowned trees, stems could have been cut on saplings and are not visible today.

The higher total biomass of multi-stemmed trees seems to be related to their architecture: they could be compared to a sum of single-stemmed trees with their own stem and crown. Indeed, both crown projection area and basal circumference of these trees are higher than of single-stemmed. Even if competition for water and nutrient supply between stems of the same tree can occur, these competition phenomenon's appear nevertheless not to be disadvantageous for the radial growth of the trees with a low number of trunks. As shown by Bertaudière *et al.* (2001), the comparison of the radial growth rate between multi- and single-stemmed trees reveals no important differences. Thereby, wood productivity is significantly higher for overall crowned multi-stemmed trees (OC-MS). The multicaulis structure of *Juniperus thurifera* could be considered as an adaptation to severe environment (hard topographical, edaphic and climatic conditions and overgrazing).

The higher biomass allocation to woody compartments (trunk and branches) of partially crowned trees and overall crowned multi-stemmed trees (OC-MS) is expressed by a higher basal circumference. At high altitude, the biomass allocation strategy favours foliage particularly in the case of single-stemmed trees. In spite of the factors affecting architecture of the trees, none of them has affected the biomass allocation strategy concerning reproductive organs.

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TABLES AND FIGURES

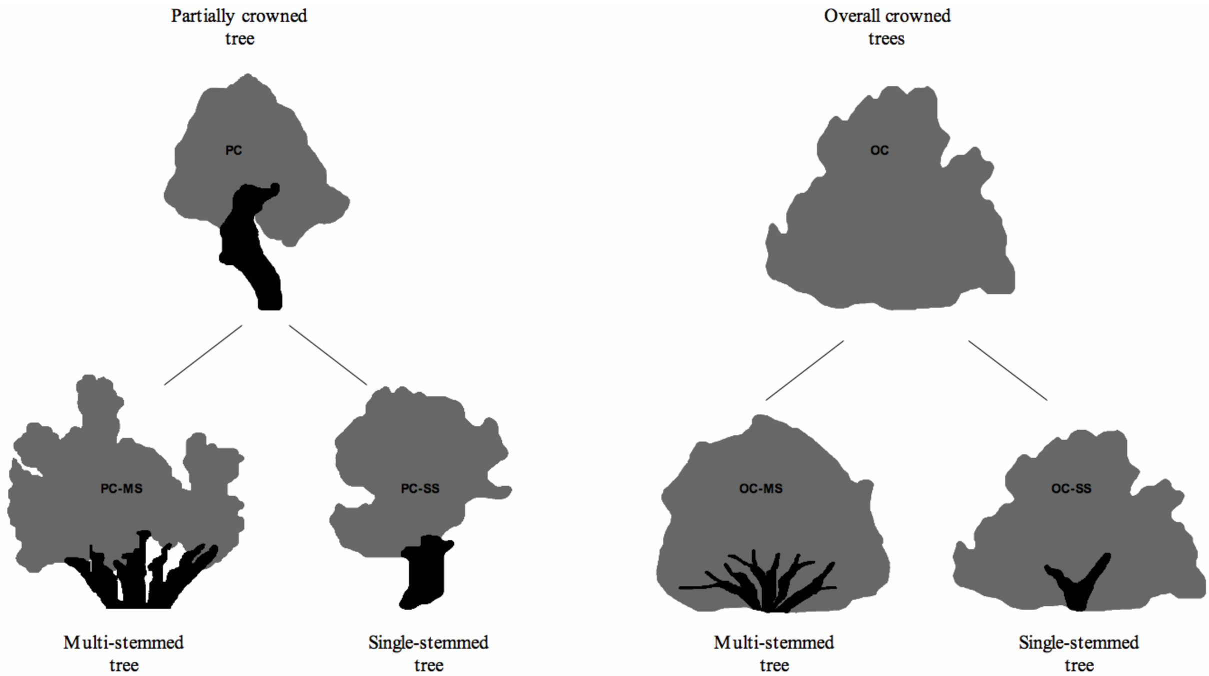


fig. 1 : Morphological types of *Juniperus thurifera*

Shape	Crown projection area (m²)		Crown lenght (m)		Height (m)		Basal Circumference (m)	
	Mean.	*SE*	Mean.	*SE*	Mean.	*SE*	Mean.	*SE*
PC	27,25	*2,68*	3,83	*0,16*	**4,3**	*0,15*	**3,24**	*0,22*
OC	24,33	*2,66*	3,56	*0,21*	3,6	*0,21*	2,47	*0,24*
p	*0,452*		*0,318*		***0,0059***		***0,0246***	
MS	**29,84**	*2,46*	**3,93**	*0,15*	**4,14**	*0,15*	**3,39**	*0,2*
SS	18,64	*2,71*	3,26	*0,25*	3,46	*0,26*	1,54	*0,15*
p	***0,0038***		***0,0151***		***0,0162***		***<0,0001***	
OC-MS	**31,0**	*3,56*	**3,99**	*0,23*	**3,99**	*0,23*	**3,06**	*0,31*
OC-SS	14,6	*3,12*	2,93	*0,35*	2,93	*0,35*	1,38	*0,21*
p	***0,0019***		***0,0102***		***0,0102***		***0,0004***	
PC-MS	28,41	*3,33*	3,86	*0,19*	4,33	*0,19*	**3,8**	*0,22*

PC-SS	25,08	*4,63*	3,78	*0,28*	4,31	*0,24*	1,81	*0,15*
p	*0,5605*		*0,8013*		*0,9353*		***<0,0001***	

Table 1: Descriptive factors (bold means significant)

Shape	Altitude (m)		Slope (D°)		Cut stems %	
	Mean.	*SE*	Mean.	*SE*	Mean.	*SE*
PC	2028	*17,3*	25,86	*1,21*	**0,15**	*0,03*
OC	**2130**	*18,9*	27,48	*0,87*	0,06	*0,02*
p	***0,0002***		*0,2672*		***0,0212***	
MS	**2109**	*17,3*	24,86	*0,98*	0,11	*0,02*
SS	2051	*22,8*	**29,92**	*0,77*	0,07	*0,03*
p	***0,0436***		***0,0004***		*0,2713*	
OC-MS	**2164**	*23,3*	25,4	*1,24*	0,08	*0,03*
OC-SS	2081	*29,6*	**30,5**	*0,83*	0,04	*0,03*
p	***0,0314***		***0,003***		*0,3646*	
PC-MS	2041	*19,8*	24,18	*1,6*	0,16	*0,04*
PC-SS	2003	*33,1*	29	*1,49*	0,12	*0,07*
p	*0,2953*		*0,0561*		*0,5914*	

Table 2 : Explicative factors (bold means significant)

Shape	Wood productivity		Total biomass (kg)		Twigs %		Trunk and branches %		Leaves %		Female cones %	
	Mean.	*SE*	Mean.	*SE*	Mean.	*SE*	Mean.	*SE*	Mean.	*SE*	Mean.	*SE*
PC	29,52	*3,78*	847,71	*97,3*	2,25	*0,13*	**93,05**	*0,4*	4,46	*0,27*	0,51	*0,03*
OC	29,78	*4,2*	653,26	*88,7*	**10,2**	*1,33*	77,15	*4,11*	**15,2**	*2,79*	0,61	*0,07*
p	*0,9643*		*0,147*		***0,0014***		***0,0014***		***0,0015***		*0,2114*	
MS	**34,26**	*3,87*	**851,45**	*86,3*	3,26	*0,5*	**89,94**	*1,56*	6,57	*1,06*	0,51	*0,04*
SS	22,26	*4,04*	547,50	*96,1*	**8,41**	*1,86*	74,03	*5,74*	**17,3**	*3,9*	0,65	*0,09*
p	***0,043***		***0,0246***		***0,0017***		***0,0017***		***0,0018***		*0,0896*	
OC-MS	**38,55**	*6,08*	**844,57**	*127*	4,06	*0,88*	**87,48**	*2,71*	8,21	*1,85*	0,53	*0,06*
OC-SS	17	*4,25*	374,27	*91,1*	**12,3**	*2,75*	62,09	*8,5*	**25,4**	*5,78*	0,76	*0,16*
p	***0,011***		***0,008***		***0,0018***		***0,0018***		***0,0018***		*0,1097*	
PC-MS	28,9	*4,19*	860,05	*114*	2,27	*0,18*	93,01	*0,56*	4,52	*0,39*	0,49	*0,03*
PC-SS	30,67	*7,73*	824,69	*185*	2,22	*0,15*	93,15	*0,47*	4,35	*0,28*	0,54	*0,06*
p	*0,8273*		*0,8649*		*0,8979*		*0,8679*		*0,7598*		*0,3186*	

Table 3 : Biomass allocations (bold means significant)

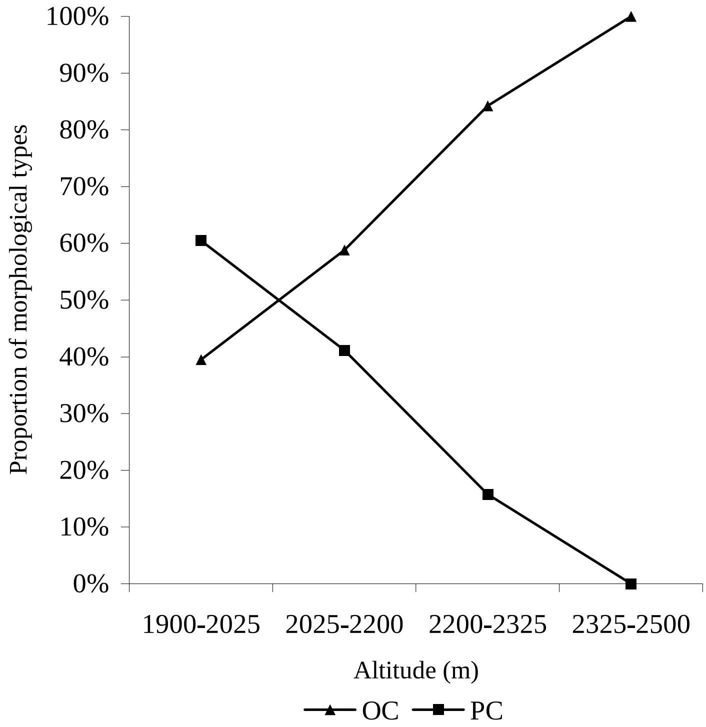
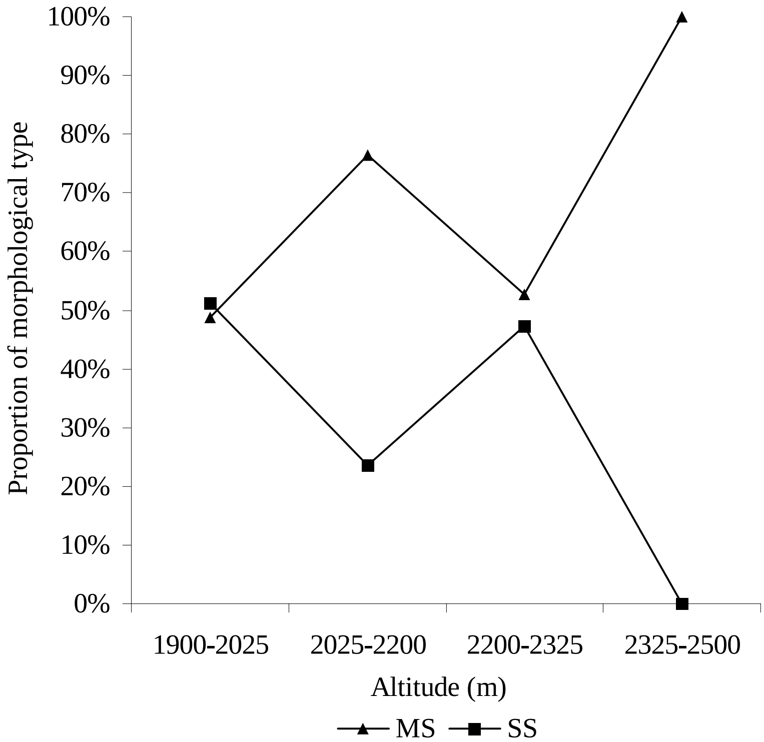


fig. 2 : Distribution of morphological types with altitude



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