A Comparison of Pampas Grass (*Cortaderia jubata)*, Coyote Bush (*Bacharis pillularis*), and Poison Oak (*Toxicondendron diversilobum*) on Soil Cohesion in Big Sur, California

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Abstract An infestation of pampas grass along the California coast has displaced native plants. This change in vegetation has dramatically effected the local soil's stability and cohesive properties. Previous studies in the Oregon Coast Range show sharp declines in soil stability after the introduction of new species. If soil cohesion is weakened by the invasion of pampas grass, land sliding may occur more frequently. Root tensile forces, rooting depth, and root morphology of pampas grass, coyote bush, and poison oak were measured to establish each species' contribution to soil stability.

The roots of native coyote bush and poison oak have penetration depths of 3-5 meters, root diameters of 2-4 cm, and nodular rooting morphologies. The roots of invasive pampas grass have an average penetrance of 1.3 meters, an average diameter of 0.3 cm, and a radially symmetric rooting morphology.

Roots act as fibers to reinforce the soil, and as such are important to soil stability. The number of roots per unit area for coyote bush is on average 4 roots/m^2. Poison oak has an average 15 roots/m^2. Pampas grass has 60 roots/ m^2.

To adequately compare cohesion added by each species, a slope stability model was applied to the data gathered. This model predicts cohesion values for soils based on three main parameters: root tensile strength, root diameter, and number of roots per unit area. Based on this model coyote bush contributes 0.82 Kpa, poison oak contributes 0.78 Kpa, pampas contributes 1.34 Kpa cohesion.

Introduction

Pampas grass, *Cortaderia jubata*, has infested the California coast from San Diego to north of Mendocino (Lambrinos, 2001). *C jubata* is a major pest along the Big Sur Coastline where it has colonized the steep ocean-side cliffs and road cuts. Native vegetation has evolved to live in the rapidly uplifting and frequently sliding terrain of Big Sur. Pampas grass invasions displace native vegetation (D'antonio, 1991), possibly changing the stability of these slopes. *C jubata's* shallow roots may not penetrate deeply enough to add the soil strength a deep-rooted native would.

Landscapers in Big Sur use *C jubata* to stabilize steep or loose slopes (La Loma Landscaping). No scientific study has been performed to assess the merits of such practices. Steep cliffs along the Big Sur Coast roads may become unstable when infested with *C jubata*, endangering motorists.

The purpose of this study is to determine how pampas grass affects soil cohesion in Big Sur. The working hypothesis is that pampas grass contributes less soil cohesion than the native species it displaces. Native species such as coyote bush, *Baccharis pillularis*, and poison oak, *Toxicodendron diversilobum* are found growing within and around pampas infested areas on steep slopes in Big Sur. Until now, no data has been published about their impact on soil cohesion. A major paper by Schmidt et. al (2000) documented a significant loss of soil cohesion as a consequence of clear cutting forests in Oregon.

Soil-root interactions affect slope stability (Wu, 1976). According to the Mohr-Coulomb slope failure criteria (Selby, 1983),

$$[1] \quad \mathbf{S_{sr} = c_s' + c_r + (\sigma - \mu)\tan \phi'}$$

In this equation, S_{sr} is the soil-root shear strength, c_s' is effective soil cohesion, c_r is the cohesion added by roots, σ is the normal stress from the weight of soil and water, μ is the soil pore-water pressure, and ϕ' is the effective internal friction angle of the soil.

Soil-root shear strength is directly proportional to root cohesion. This means a soil with high root cohesion will increase the soil-shear strength, adding to slope stability. Roots of plants increase soil cohesion by binding to soil particles (Waldron, 1982). The number, depth, size, and growth patterns of roots affect the soil cohesion (Wu, 1976).

A few models quantify the cohesion added to soils from roots. Schmidt et al (2000) employ the model

[2] $\mathbf{c_r = 1.2 \Sigma T_{ri}(A_{ri}/A_s)}$

where $\mathbf{c_r}$ is the cohesion added to soil, T_{ri} is the root-breaking (tensile) strength, and the root-area ratio, (A_{ri}/A_s), is root cross-sectional divided by area of exposed soil. The root-area ratio is included in this model to address the variation in number, size and distribution of roots for each species.

The focus of this research is on that of $\mathbf{c_r}$, the strength added to soil from roots. To address this, tensile strength, root diameter and root density were measured for various species.

Materials and Methods

Site Description The study site is located 10 miles south of Monterey in a steep, south-facing swale two miles up Palo Colorado Canyon, Big Sur. The colluvium in the hollow is a loose aggregate of small (<1-20mm) xenolithic angular rocks covered with half a meter of rich topsoil.

Native vegetation dominated the landscape until 8 years ago when a landscaping company planted *C jubata* to stabilize the slope below a residential driveway. Down slope of the initial planting a dense population of *C jubata* now exists.

Procedure A large flat shovel, a potting shovel, two meter-sticks, pruning shears, a Piesola tensiometer (0-40 kg), vice grips, wire, calipers (0-10 cm), and a cotton towel were all used to perform the following procedures.

On November 17, 2002 eight cross-sections of soil 1m wide and 1m deep were excavated perpendicular to the slope face and centered on the plant of study. Excavations were done on previously exposed landslide scarps. All exposed roots >1mm were tested. Each root was clamped with vice grips and pulled on with the Piesola scale. Tensile strength sampling procedures were performed according to Schmidt et. al. 2000. However, to prevent root breakage from the vice compression and better simulate the soil's pull, a small towel was wrapped around the root at the place of vice grip attachment, thereby distributing the clamping force over a larger surface area. Root breakage was generally near the soil-root interface.

The maximum force reached before breakage was recorded. Diameter of root at the point of breakage was measured using calipers. Fifteen individual root measurements were taken on two plants of each species.

All roots from each cross section were identified. Rooting depth was then measured perpendicular to the soil surface with a flexible metal measuring tape. Root morphologies were sketched, photographed, and then classified according to branching pattern and symmetry.

Results

	Mean Root Strength	Mean Root Diameter	Mean Root Density	Cohesion Added
Pampas Grass	6 Kn	0.3 cm	62 roots/m^2	1.34 Kpa
Poison Oak	13 Kn	1.2 cm	15 roots/m^2	0.78 Kpa
Coyote Bush	18 Kn	3.5 cm	4 roots/m^2	0.82 Kpa

The average measurements above provide the basis for all cohesion values determined. Total cohesion added to the soil, $\mathbf{c_r}$, from *C jubata* is 1.34 Kpa. Cohesion added from *B pillularis* is 0.78 Kpa. *T diversilobum* contributes 0.82 Kpa.

	Root Morphology	Average Rooting Depth
Pampas Grass	Radial symmetric	1.3 m
Poison Oak	Wandering lateral branches	3-4 m
Coyote Bush	Distichously Orthogonal	4-6 m

Rooting depth is also a key factor to the slope's stability. *C jubata's* roots penetrate to a depth of < 1.3 m while roots of *B pillularis* and *T diversilobium* penetrate much deeper into the colluvium, >3m.

Discussion

Critical tensile (breaking) forces for individual root threads are indicative of the plant's total root strength. However, the soil cohesion added from these roots can only be determined by normalizing this strength per-root to the area of soil. The root area ratio (Ar/As) from equation [2] is therefore used.

The root area ratio greatly affects the outcome of root-cohesion values. The cohesion values of *C jubata* are greater than *B pillularis* and *T diversilobum* because *C jubata* has so many more roots-per unit soil area.

The number of roots a plant has is related to its root morphology. Pampas grass, like other grasses, has a radial, fibrous rooting structure. Each root that goes out remains in the top meter of soil, is not particularly large in diameter, and does not branch significantly. However, the sheer number of roots adds significant strength to the upper layer of soil. Coyote bush has a main taproot which travels deep into the lower colluvial soil horizon and branches distichously, alternating branch nodes from one side of the taproot to the other along its length. Poison oak has a wandering node-dominated morphology. It's Latin suffix, *diversilobium,* means "many forms." The root morphology is in accord with this definition.

These differences in rooting structure invariably have impacts on the types of stability they impart on the overall soil architecture. Further studies of root-morphology and its mechanical impacts on soil stability should be undertaken.

Interestingly, the root cambium of pampas, analogous to the bark on a tree, expands to accommodate seasonal root growth. On trees, the bark generally expands and cracks, but remains attached to the shoot or root. The root cambium of pampas completely detaches itself from the root each growing season, creating a void space between the cambium and the root. During times of cambial shedding the soil appears to cohere only to the loose cambium. This residual cambium is present at least until November, just prior to the rainy season. If land sliding occurs during cambial shedding the soil cohesion may be better represented by the tensile force and diameter of the root cambium than that of the root.

Investigation of pampas roots exposed along a fresh scarp at the study site in February, after the rainy season, showed no residual cambium present. This method of cambial shedding or disintegration, homologous to a lizard loosing it's tail, may facilitate greater plant survival in areas of frequently sliding terrain.

Conclusion

Experimentally determined tensile values for invasive pampas grass indicate a contribution of 1.34 Kpa to soil cohesion. This cohesion contribution is greater than its native neighbors, poison oak and coyote bush. However, the deeper root penetrance is not taken into consideration by the applied model when evaluating values of 0.78 Kpa and 0.82 Kpa for poison oak and coyote bush.

The higher cohesive properties of pampas grass's roots are restricted to the upper 1.3 meters of soil. The cohesion added by native coyote bush and poison oak affects at least 4 meters of regolith. The slides studied in Big Sur are greater than two meters in depth. Any cohesion imparted by the roots of pampas grass will therefore provide only surface support. While cohesion added from coyote bush and poison oak will be present at depths of up to 4 meters.

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