Liquorice (*Glycyrrhiza glabra*): a potential salt-tolerant, highly remunerative medicinal crop for remediation of alkali soils

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Alkali lands in India occupy about 3.8 m ha. Due to poor physical properties, excessive exchangeable sodium and high pH, most of these lands support a poor vegetative cover. These lands are reclaimed using costly amendments such as gypsum, phospho-gypsum or press mud. In recent times many of the medicinal plants are in great demand for both internal requirements and export. However, as these crops are non-conventional in nature, farmers are not convinced to cultivate them on fertile lands. The marginal lands, specially those affected by salinity, sodicity and water-logging problems when profitable returns are not possible through routine food or agricultural crops, could be successfully utilized for the cultivation of some high-value stress-tolerant medicinal crops with marginal inputs. Results reported in this study indicate that liquorice (*Glycyrrhiza glabra* Linn.) also known as Mulahatti, which is quite remunerative and high in demand, could successfully be grown on alkali soils. Besides getting (2.4–6.1 tonnes/ha forage per annum), a root biomass of 6.0–7.9 tonnes/ha could be obtained in three years of growth fetching about Rs 6.0 to 8.0 lakhs/ha, i.e. Rs 2–2.65 lakhs/annum/ha. Besides, the sodic lands could also be reclaimed substantially in terms of reducing soil pH and exchangeable sodium percentage by growing this crop.

Keywords: Alkali soils, *Glycyrrhiza glabra*, exchangeable sodium percentage, medicinal crops, secondary salinization.

THE salinity affliction of land constitutes a major threat amongst the various forms of soil degradation. Salt-affected soils, which are of two types – saline and alkali soils, occur under different environmental conditions and have different morphological, physico-chemical and biological properties, but one common feature is the dominating influence of electrolytes on the soil-forming process. These soils are found distributed in almost all the countries covering about 954.8 m ha, which is about 10% of the total surface of dry land[1]. According FAO/UNESCO soil map of the world, the total area of saline soil is 397 m ha and of sodic soil 434 m ha (ref. 2). In India, over 6.75 m ha land is salt-affected, 3.8 m ha being sodic/alkali and rest saline[3]. Due to poor physical properties, excessive exchangeable sodium and high pH, most of the alkali lands support a poor vegetative cover. Many of the medicinal and aromatic plants are in great demand for both internal requirements and export. As most of these crops are non-conventional in nature, they are not preferred on fertile lands which are used for food crops. The marginal lands, especially those affected by salinity or sodicity problems where profitable returns are not feasible from agricultural crops, could be successfully utilized for the cultivation of high-value, salt-tolerant medicinal and aromatic crops with marginal inputs[4–6].

The last three decades have shown substantial growth in the markets of herbal products across the world. Rapidly rising exports of medicinal plants during the past decade attest to worldwide interest in these products as well as traditional health systems. According to the Secretariat of the Convention on Biological Diversity, global sales of herbal products totalled an estimated US$ 60,000 million in 2002 (ref. 7). Trade related to medicinal plants in India is substantial with total turnover of Rs 23,000 million of Ayurvedic and herbal products alone, while major over-the-counter products contribute around Rs 12,000 million (ref. 8).

Based on the data published by the Directorate General of Commercial Intelligence and Statistics (DGCIS), 61 commodities have been enlisted for compiling the information on exports and 40 for import of ‘medicinal plants’ in India[9]. In 2004–05, India exported 57,880 tonnes of these commodities worth Rs 5158 million, while during the same period about 37,483 tonnes of material worth Rs 1732 million was imported[9]. Some of the prioritized medicinal plants listed (in 2004–05) include *Aconitum ferox*, *Aegle mermelos*, *Andrographis paniculata*, *Asparagus racemosus*, *Bacopa monnieri*, *Berberes aristata*, *Cassia angustifolia*, *Cassia tora*, *Chlorophytum arundinaceum*, *Commophora mukul*, *Costus speciosus*, *Emblica officinalis*, *Glycyrrhiza glabra*, *Ocimum sanctum*, *Picrorhiza kurroa*, *Plantago ovata*, *Rauvolfia serpentina*, *Santalum album*, *Saraca asoca*, *Tinospora cordifolia* and *Withania somnifera*. Liquorice (*Glycyrrhiza globra* Linn.), commonly known as Mulahatti and Yashtimadhu, is a potential high-value priority crop which can be successfully cultivated on salt-affected degraded lands. It is a small perennial leguminous herb of the family Fabaceae (Papilionaceae) native to the Mediterranean region and central and southwest Asia, and cultivated in Italy, Russia, France, UK, USA, Germany, Spain, China, Pakistan, Afganistan, Iran, Iraq, Uzbekistan, Turkey, Turkmenistan and north-western India. The herb is one of the oldest and widely used in traditional Ayurvedic and Chinese medicines for its mystic effects to cure numerous diseases such as hepatitis C, ulcers, pulmonary and skin diseases, asthma, bronchitis, abdominal colic and eye problems[10,11]. The rhizomes and roots comprise main active component glycyrrhizin, utilized commercially as a non-nutritional sweetener and flavouring agent in some

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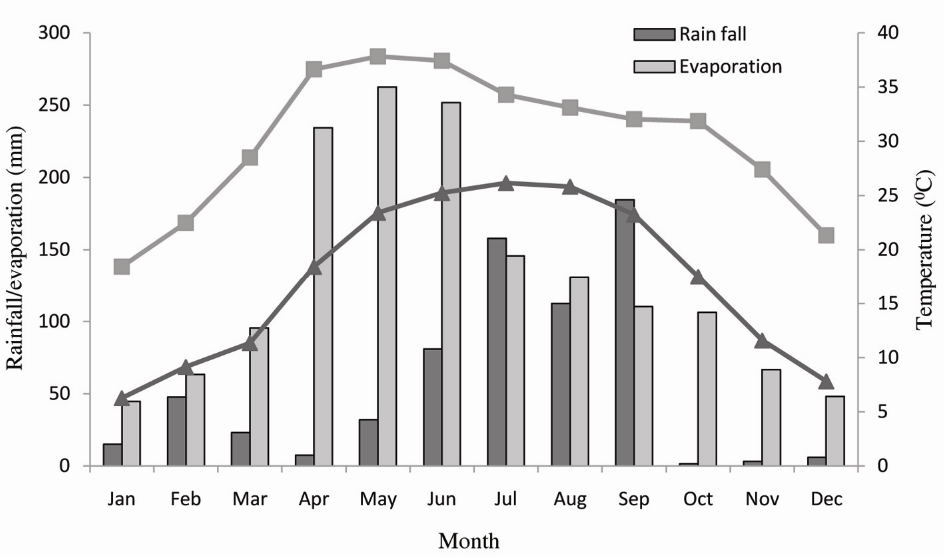

Figure 1. Climatic data at experimental site during the study period (mean of 6 years).

Table 1. Grouping of soils of micro-plots based on pH and ESP

	pH		Exchangeable sodium percentage	
Group	Range	Mean	Range	Mean
A	8.2–8.5	8.39	20–28	26.0
B	9.0–9.2	9.14	30–37	35.0
C	9.3–9.5	9.45	39–44	40.5
D	9.7–9.9	9.84	58–62	59.7

candies and pharmaceuticals including anti-allergy, anti-carcinogenesis, anti-diabetic and anti-inflammatory properties[12–15]. The isoflavene glabrene and isoflavane glabridin, found in the roots of liquorice are exoestrogens[16,17]. Liquorice roots are in great demand and about 1603 tonnes worth about Rs 22 million were imported in 2004–05 (ref. 9). At present, liquorice is cultivated in northwestern India on a limited area. While compiling halophytic vegetation[18,19], it was noticed that Kefu *et al.*[20] had reported *G. glabra* to be one of the halophytes in China. Keeping in view its salt tolerance, planting material of cultivar Haryana Mulhati-1 was procured from Haryana Agriculture University, Hisar and planted in 12 micro-plots already filled for five years, with alkali soil of different pH values brought from the field. The present study shows that liquorice has potential as a future high-value crop for degraded salty soils (including saline, sodic and waterlogged saline).

The present study was carried out at the Central Soil Salinity Research Institute, Karnal (lat. 29°43′N, long. 76°58′E, altitude, 245 m amsl), Haryana, India. The climate of the area is subtropical, semiarid, with little or no water surplus, megathermic and monsoonal. The actual mean annual rainfall measured at the Institute during the study period (2005–2010) was found to be 672 ± 260 mm and open pan evaporation was 1560 ± 171 mm. The maximum rainfall (80%) occurred during June–September. The mean maximum and minimum daily temperatures were 30.1° ± 0.5°C and 17.2° ± 0.6°C, respectively (Figure 1).

The experiment was conducted in 12 micro-plots, each 6 m × 3 m in size and 90 cm deep constructed by bricks and cement. The alkali soils of pH values ranging from 8.2 to 9.9 were transported from the field and filled in the micro-plots. The soil was allowed to settle for at least 5 years. Before bringing the soil from the field, it was analysed so as to get soil of different pH values. The precaution was taken that three workable replications of each range of pH values was available in the micro-plots. During the periods of soil settlement the crops were grown without application of any amendment so that the pH of the entire plot remained almost uniform. The soil profile in all the plots was 90 cm deep. Prior to initiation of this experiment, intensive soil sampling of micro-plots (three places in each plot) was done at 0–15, 15–30, 30–60 and 60–90 cm depths. After careful analysis of soil pH and exchangeable sodium percentage (ESP) of the profile, which are considered the main criteria of alkali soils, the weighted mean of the soil profile of each plot was calculated and all the 12 plots were grouped into 4 categories (3 in each group; Table 1).

After grinding, the air-dried soil samples were passed through a 2 mm sieve and analysed for different soil parameters. The mechanical analysis was done using pipette method[21]. The soil pH and electrical conductivity (ECe) values were measured on the soil saturation extract obtained by subjecting the soil paste to a vacuum pump and using pH meter and micro processer conductivity meter respectively. For determination of ESP, cation exchange capacity (CEC) was determined as described by

Richards[22], and exchangeable sodium was determined using flame photometer as described by Jackson[23]. ESP was calculated as follows

$$\text{ESP} = \text{Exchangeable Na}^+ \text{ (c mol kg}^{-1}\text{)/}$$
$$\text{CEC (c mol kg}^{-1}\text{)} \times 100.$$

Soil samples were again collected and analysed after completing the experiments at the end of two crop rotations – one of two years and another of three years to observe the soil amelioration in terms of reduction in soil pH and ESP, which are indicators of alkalinity. Na^+, K^+, Ca^{++} and Mg^{++} were determined in the plant parts as described by Jackson[23].

The soil was ploughed and mixed with Aldrin (5%) together with 20 kg zinc sulphate/ha at the time of land preparation. A basal dose of N and P at 20 and 40 kg ha^{-1} was applied. Nitrogen dose (20 kg ha^{-1}) was also applied after six months of plantations. The crop was raised from 15 to 20 cm long underground stem cutting (stolons) possessing two or more eye buds after treating with Bavistin (50 WP) for 30 min. The stolons were planted in rows of 30 cm at a distance of 20 cm in 10–15 cm deep furrows in the first week of March. Seed rate of 300 kg ha^{-1} of stem cuttings was sufficient. The planted plots were irrigated with tap water.

The sprouting was started in 15–20 days. Nitrogen (40 kg ha^{-1}) was drilled in rows during February–March annually. About 7–10 irrigations (each of 6 cm) were applied in a year. During October–November, plants were harvested (about 10 cm over the ground) and biomass was observed. This may be used as fodder or green manure. In the first rotation, roots were dug during February–March after two years of growth, while in the second rotation these were harvested after three years. The plant height in each set remained about 1 m (Figure 2), but the number of branches was more during the second and third years. After harvesting the roots were cleaned to remove soil and cut into 15–20 cm long pieces and dried in open sun for 7–10 days when about 85% of the moisture was lost. The dried roots were weighed. The market price was about Rs 60/kg after first harvest and about Rs 90/kg after second harvest (it was Rs 110/kg in February 2014).

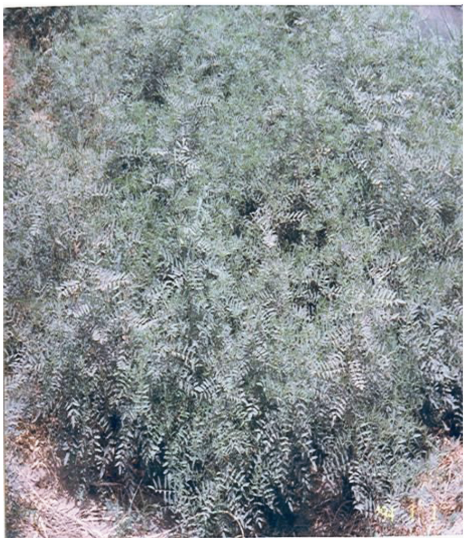

Figure 2. Liquorice on alkali soil.

A subsample of 500 g sun-dried roots was taken from each treatment plot and oven-dried at 70°C till constant weight was attained. The samples were ground and passed through 200 mesh sieve. One gram of dried sample (or equivalent) and 10 ml of concentrated HNO_3 were added to a 100 ml digestion tube. The mixture was heated to 120°C for 12 h, treated with H_2O_2, diluted to 100 ml and analysed for Ca, Mg, Na and K using ICP-OES[24].

The initial physico-chemical characteristic features of the soil in micro-plots are shown in Table 2.

It is evident from the results (Table 3) that during the first rotation the liquorice root yield was 2.54 t ha^{-1} in normal soil (pH ~8.2) and increased with rise in pH, and was 2.82 t ha^{-1} at pH 9.1 and highest (3.25 t ha^{-1}) at pH 9.4. With further increase of pH the yield declined, but it was 18% more than the normal soil, showing halophytic nature of the crop. The forage biomass production was also more at higher pH than normal soil.

During the second rotation also, when the roots were harvested after 3 years, the trend was almost the same, but the yield was 2.4 times more when harvested after two years (Table 3). Very little information is available in the literature regarding the cultivation of liquorice, particularly in salty habitats[25,26]. Recently, Kushiev *et al.*[27] have reported interesting results from the Hungry Steppes of Central Asia, where elevated water tables associated with poor irrigation management and inappropriate drainage infrastructure have resulted in significant secondary salinization of crop lands, resulting in declining cotton and wheat yields and eventually abandonment of lands. In their study the potential use of liquorice cultivation to reclaim abandoned saline areas was assessed over a four-year period before returning to cotton–wheat crop rotation again. During the period high-quality livestock forage (above ground biomass) from liquorice with a protein content of 12% was harvested with dry matter yield ranging from 3.66 to 5.11 t ha^{-1} and root dry matter yields of 5.63–8.55 t ha^{-1} were recorded. At the end of four years, the plots under liquorice were returned to a wheat and cotton crop rotation. This shows potential of the crop for waterlogged saline conditions. In the present study also, besides getting good yield when grown on sodic soil (rather enhanced yield over the normal good fertile land), the crop ameliorated the plots to a greater extent in terms of reducing pH and ESP values.

Roots of all plants in general and legumes in particular exude organic acids, amino acids and phenolic compounds in soil medium. These root exudates have been reported to control N nutrition in symbiotic legumes by

Table 2. Initial soil parameters of alkali soils (mean of three plots in each group)

Group	Soil depth (cm)	Sand (%)	Silt (%)	Clay (%)	pH	Electrical conductivity (dS m^{-1})	Exchangeable sodium percentage
A	0–15	46.5	32.5	21.0	8.43	2.1	26.2
	15–30	46.3	30.8	22.9	8.31	1.6	24.8
	30–60	46.8	30.9	22.3	8.35	1.3	25.4
	60–90	45.7	31.4	22.9	8.45	1.3	27.5
	Mean	46.3	31.4	22.3	8.39	1.6	26.0
B	0–15	48.2	30.0	21.8	9.09	2.7	34.2
	15–30	47.2	30.6	22.2	9.17	2.6	35.6
	30–60	47.0	31.2	21.8	9.12	2.6	34.4
	60–90	46.4	30.9	22.7	9.17	2.9	35.8
	Mean	47.2	30.7	22.1	9.14	2.7	35.0
C	0–15	48.3	31.1	20.6	9.45	3.0	41.1
	15–30	47.9	31.0	21.1	9.53	3.3	42.7
	30–60	47.2	32.1	20.7	9.37	3.1	37.8
	60–90	45.5	32.4	22.1	9.44	3.3	40.5
	Mean	47.2	31.6	21.1	9.45	3.2	40.5
D	0–15	48.5	30.8	20.7	9.82	3.6	60.2
	15–30	47.3	31.1	21.6	9.82	3.8	58.2
	30–60	48.0	30.9	21.1	9.87	3.6	61.0
	60–90	47.5	31.2	21.5	9.85	3.5	59.3
	Mean	47.8	31.0	21.2	9.84	3.6	59.7

Table 3. Liquorice yield (t ha^{-1}) on different alkali soils

			Soil pH group				
	Plant part		A	B	C	D	LSD ($p = 0.05$)
First crop	Shoot biomass	First cut*	2.43	3.33	4.13	3.73	0.61
		Second cut*	3.20	3.63	4.27	4.20	0.43
		Total	5.63	6.96	8.40	7.95	1.04
	Root biomass**		2.54	2.82	3.25	3.00	0.15
Second crop	Shoot biomass	First cut*	2.60	3.20	3.73	3.43	0.49
		Second cut*	3.87	4.23	4.60	4.10	0.54
		Third cut*	4.60	5.47	6.70	6.13	0.60
		Total	11.07	12.90	15.03	13.66	1.63
	Root biomass***		6.11	6.73	7.89	7.57	0.23

*Harvested annually; **Harvested after 2 years of growth; ***Harvested after 3 years of growth.

serving as chemotactic signals and growth promoters of rhizobia. Soils with low availability of nutrients, especially N, stimulate the biosynthesis of isoflavone *nod* gene inducers in symbiotic legumes, thereby enhancing N_2 fixation and nutrition in nodulating legumes[28]. In addition to root exudates, the compounds released from decomposition of organic matter such as dead roots, nodules and fallen leaves have also been found to potentially supplement the maintenance of a steady concentration of flavonoids and mineral nutrients in the rhizosphere. Similar chemical molecules of root exudates also help in establishing the development of plant–fungal (vesicular-arbuscular mycorrhizal fungi) symbiosis by inducing spore germination and increased hyphal growth, thereby increasing root biomass and proliferation, and thus also bringing more volume of soil in contact with plant root system. These factors resulted in improvement in crop growth, and addition of more organic matter in soil, thus production of higher amounts of organic acids and releasing more Ca through dissolution of native $CaCO_3$.

In the present study, the roots were recorded to contain very high contents of Na (1.95 ± 0.06%) in comparison to significantly lower contents of Ca (1.63 ± 0.07%). This helped in tilting the balance in favour of Ca in rhizosphere soil and thus replacing Na by Ca from soil exchange complex, as evidenced from decreased soil pH and ESP. In-turn, lower rhizosphere pH with high root exudation of organic acids has been observed to result in increasing the availability of P (ref. 29) and micronutrients in calcareous soils[30]. Plant uptake of cations in excess of anions is often reported to cause the roots to secrete H^+ in order to maintain electrical neutrality, a process that also leads to lower the rhizosphere pH (ref. 31).

The mean pH of the profile reduced from 9.84, 9.45, 9.14 and 8.39 in the four groups to 9.23, 8.80, 8.36 and 8.07, respectively. The corresponding mean ESP values

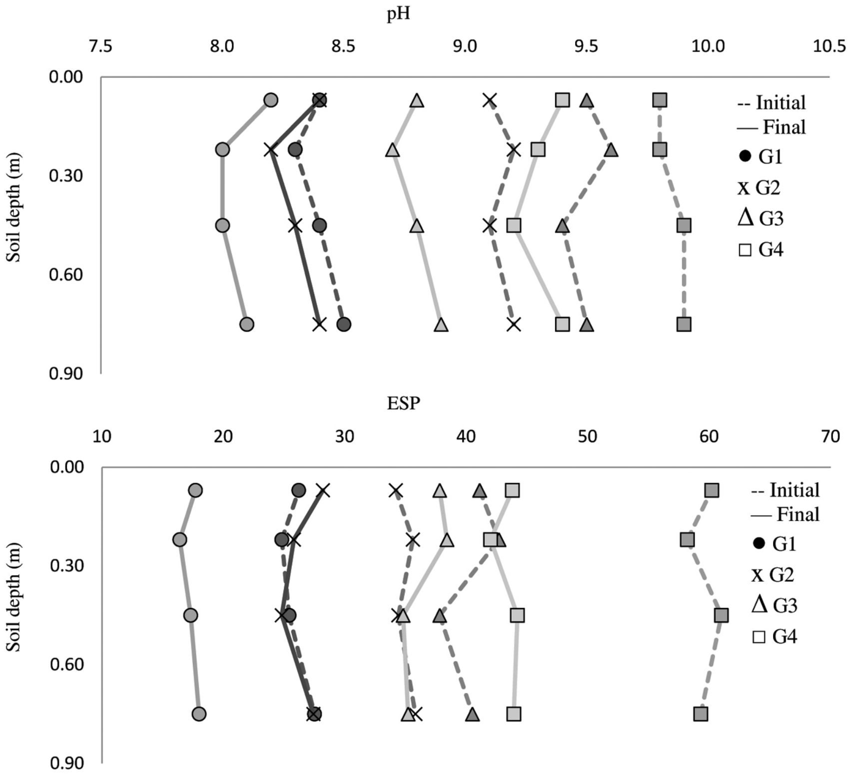

Figure 3. Reclamation of alkali soil in terms of reducing initial pH (above) and exchangeable sodium percentage (below) through liquorice cultivation for 5 years in 4 different groups of alkali soils.

reduced from 59.7, 40.5, 35.0 and 26.0 to 43.5, 36.5, 26.4 and 17.3 respectively. The initial and final values of soil pH and ESP in soil profile are shown in Figure 3.

Thus, the sodic soil was reclaimed considerably during five years in terms of reducing pH and ESP values without applying any amendments. The tolerance of liquorice to sodicity may also be due to presence of a strain of *Mesorhizobium* (CCNWGX 035), which has been isolated from the roots of liquorice by Ge-Hong *et al.*[32], and was found to have high tolerance to NaCl, pH and temperature. This is a significant finding when we are in search of alternatives to amendments for reclamation of large chunks of sodic lands.

The results of the present study have demonstrated the efficacy of liquorice in rehabilitating abandoned sodic soils over a period of 5–6 years and bringing them back to a state where the production of wheat and other arable crops can be undertaken. It has been shown to be a low-cost and highly remunerative option that can be implemented by resource-poor farmers with the potential of increasing their income and diversifying farming enterprises. However, we need to conduct further field experiments on different textural sodic and saline soils and also for waterlogged situations.

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Tree species composition in Koyna Wildlife Sanctuary, Northern Western Ghats of India

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We established belt transects of 1000 m × 5 m in Koyna Wildlife Sanctuary at 12 different localities, to study tree species diversity. A total of 4296 individuals of girth at breast height (GBH) ≥ 15 cm were enumerated belonging to 108 species. A subtype of *Memecylon–Syzygium–Olea* was identified based on dominance from the area previously ascribed to *Memecylon–Syzygium–Actinodaphne* floristic series. Out of 41 families, Melastomataceae, Myrtaceae and Moraceae were found to be dominant families according to the Family Importance Value. Shannon index (*H′*) ranged from 1.5 to 3.03. Taxonomic diversity measured for each sampled locality using normalized simple Avalanche index showed variation between 0.104 and 1.00 and positive correlation with *H′*. Rarity score for identifying unique tree species composition correlated positively with simple avalanche index. Evergreen forest of *Navja* and *Ozarade* together showed highest population of IUCN-listed tree species. This study shall pave the way for the subsequent ecological research in this area which has recently been declared as a World Natural Heritage Site by UNESCO.

Keywords: Koyna Wildlife Sanctuary, *Memecylon–Syzygium–Olea*, rarity score, simple Avalanche index.

WESTERN Ghats (WGs), one of the 34 global biodiversity hotspots[1], shows remarkable variation in rainfall, dry period length, forest cover and temperature which ultimately govern spatial pattern of its biodiversity. Northern parts of Western Ghats of Maharashtra (NWGs) experience dry period up to 6–8 months[2] resulting in a peculiar vegetation from evergreen forest in river valleys to highly endemic herbaceous vegetation on the plateaus. Other than few studies[2–4], there are no attempts to quantitatively assess the diversity and vegetation composition of NWGs. In contrast, Southern Western Ghats (SWGs) are more explored for vegetation composition, structure and

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