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GROWTH ATTRIBUTES AND DISTRIBUTIONAL PATTERN OF HALOPHYTIC *CYPERUS LAEVIGATUS* L. ALONG SALINITY AND ALTITUDE GRADIENTS

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Abstract

To examine the growth response and distributional pattern of a potential hydro-halophyte, *Cyperus laevigatus* L., a detailed survey of Punjab province was conducted. Sixteen habitats possessing different salinity and altitude levels were explored and different soil and eco-morphological parameters were assessed. *C. laevigatus* growing at Pakka Anna with heavily sat-affected sandy loam soil and low altitude showed the maximum growth, however, many other habitats with higher salinity and low altitude showed reduced growth like Sangla Hill and Sargodha as compared to Pakka Anna. Therefore, it was concluded that distribution and growth of *C. laevigatus* was not due to either salinity or altitude, but depends on the combined effect of many environmental factors like soil texture, ECe, altitude etc. however, the degree of tolerance of this species was extremely high not only along salinity but also with altitude.

Key words: Altitude; *Cyperus laevigatus*; Salinity, Growth, Ecology.

Introduction

Wetlands are the water bodies which are formed due the accumulation of stagnant or flowing, fresh as well as salt water. Wetlands are rare and unique ecosystems that are important part of global ecosystem (Koull & Chehma, 2016). These ecosystems provide a wide range of services related to biodiversity, water regulation and tourism by supporting many endemic plants and animal species (Gill *et al*., 2012). Wetlands create considerable impact on different economic and social aspects of any country such as tourism, industry and agriculture. Wetlands not only support rare plant species but are also main breeding centers for waterfowls (Khan & Arshad, 2014). Natural wetlands are declining throughout the world due to anthropogenic activities like population pressure, construction work, industrial effluents and use of pesticides etc. in agriculture (Prasad, 2010).

The vegetation zones in salt marsh are very specific and dominated by unique plants. Examples are the complete dominance of *Spartina alterniflora* and *Salicornia virginica* in low elevation marshy habitats of New England (Bertness, 1991). Similarly, terrestrial and seaward borders are occupied by *Juncus gerardi* and *Spartina patens* (Pennings & Callaway, 1992). Disturbed marshy habitat in California are occupied by *Distichlis spicata* and *Salicornia europaea* (Bertness, 1991). The distribution of these plants depends upon the plant tolerance to the harsh environment of the zone and other physical characteristics associated with tidal inundation (Bertness & Ellison, 1987). Most plants that grow in wetlands and salt marshes possess adventitious root system at the sediment surface to facilitate the exchange of gases like *Spartina alterniflora* roots penetrate in the uppermost 3 cm zone of the sediment (Anderson & Treshow, 1980). Some plants possess well-developed aerenchyma formation in roots for transfer of oxygen from atmosphere to submerged roots (Armstrong, 1979; Silliman, 2014.).

Salinity is an important soil feature due to which crop production and environmental quality have been severely affected (Ashraf & McNeilly, 2004). A salinity indicator is a sign or symptom that recommends the soil is under the influence of salinity (Tuna *et al*., 2007; Lin & Bañuelos, 2015). In Pakistan, salt-affected habitats like salt marshes and dryland salinities are characterized by salt indicator species including *Cyperus lavigatus* (Khan & Qaiser, 2006). All over the world, the most common salinity indicator species are *Sonneratia apetala, Allenrolfea occidentalis, Sporobolus virginicus, Atriplex* spp., *Aegiceras corniculatum, Avicennia marina, Bruguiera gymnorrhiza, Mesembryanthemum crystallinum, Crambe maritima, , Sesuvium portulacastrum, Casuarina* spp., *Chenopodium album, Distichlis spicata, Hordeum marinum, Glycyrrhiza glabra, Juncus acutus, Rhizophora mucronata, Salsola vermiculata, Portulaca oleracea, Salicornia europaea, Plantago media, Suaeda maritime, Suaeda australis, Tetragonia tetragonioides* and *Sarcocornia quinqueflora* (Aslam *et al*., 2011).

Cyperus laevigatus L., commonly called smooth flat sedge, is perennial sedge that is distributed in subtropical areas of the world with hot and arid climatic conditions. It grows mostly in aquatic habitats, particularly mud flats, flood plains and sandy coastal places, where brackish water and waterlogged soils are dominant (Piwpuan *et al*., 2013). *C. laevigatus* is used for making mats and for the treatment of wetland systems, in which NH_4^+ concentrations are high (Jampeetong *et al*., 2012). It was hypothesized that differential salinity and altitudinal gradients may significantly influence growth and distributional pattern of this species in the Punjab region. *C. laevigatus* is an important component of salt marshes supporting a number of wildlife species, and this study will help to investigate degree of tolerance in *C. laevigatus*, which is important to re-vegetate disturbed habitats throughout the province due to anthropogenic activities.

Materials and Methods

Cyperus laevigatus populations were explored in the Punjab province to investigate growth response and distributional pattern along salinity gradient. The populations were collected from Rasul Headworks, Bhurban, Treemu Headworks, Dape Sharif, Domeli, Ucchkera, Baloki, Motorway 3, Kirana Hills, Khanki, Sargodha, Jahlar Lake, Sangla Hill, Pakka Anna, Kalar Kahar Lake and Sahianwala (details are presented in Tables 1 & 2, Figs. 1-3).

Soil that adhere the roots was taken from each habitat at 10 cm depth (root-zone) to analyze the physicochemical characteristics. For saturation percentage, pH and electrical conductivity of soil, 200g of dried soil was taken for the preparation of saturation paste. Saturation percentage was determined by subtracting the weight of saturated paste from dry weight of soil. The soil extract was used to determine the pH and ECe using pH/ECe meter (WTW series InoLab pH/Cond 720). The soil extract was used to determine the pH and ECe using pH/EC meter (WTW series InoLab pH/Cond 720). The protocol followed by Moodie *et al*. (1959) was used to determine soil texture. Sodium (Na^+) content was determined with a flame photometer (Jenway, PFP-7), whereas Cl^- content was determined with a digital chloride ion meter (Jenway, PCLM 3).

The plants were carefully uprooted from their natural habitats without damaging their root for measuring morphological characteristics like plant height, and fresh and dry weights of plants. For ecological studies, density per unit area (1x1 m^2) was calculated from 6 different sites within each habitat using quadrat method. Percent cover within 1x1 m^2 quadrat was estimated by visual observation. Associated species within *C. laevigatus* population were also observed.

The Principal Correspondence Analysis (PCA) technique was applied on different morpho-ecological parameters to determine the degree of association between habitats and soil parameters and plant eco-morphological characteristics using XLSTAT software. Correlation among different parameters was assessed using Microsoft Excel.

Results

Soil characteristics: A wide range of variation was observed in soil physicochemical characteristics. Sandy loam soil texture was recorded in most of the habitats from where *Cyperus laevigatus* was collected. Loamy soils were observed in Baloki, Sangla Hill and Motorway 3, but clayey loam in Kirana Hills and Khanki. Saline sodic soil was recorded in Sahinwala habitat (Table 1). There was no clear-cut picture about relationship between salinity gradient and soil texture. Salinity level in the present investigation seems to be due to natural processes or anthropogenic activities on individual site rather than any geographical factor or soil characteristics (Shrivastava & Kumar, 2015).

Soil pH was slightly alkaline at most of the sites (7.1-9.1), however, acidic pH (6.7-6.9) was observed in only three habitats (Treemu, Sangla Hill and Motorway 3) (Table 1). Soil formation from original source by weathering of rocks is responsible for the soil pH, when rocks are rich in silica etc., becomes acidic and when contains large amount of limestone or calcium carbonates, it will be more alkaline (Schoonover & Crim, 2015). The Salt Range (and other mountainous habitats) in Pakistan mainly composed of sandstone or limestone (Abu Bakar *et al*., 2013), and this might be a reason of dominance of basic soils throughout.

Saturation percentage ranged from 24.1-41.1, the higher values of saturation percentage was recorded in soils from saline waterlogged areas like Sahianwala and Sargodha, but Treemu and Motorway 3 showed the lower values (Table 1). Soil saturation percentage can be related to textural class (Aali *et al*., 2009), and salinity gradient may not influence this characteristic.

A huge variation was observed in electrical conductivity (ECe) of habitats, it varied from 1.2-47.8. The minimum ECe was recorded at Rasul, while the maximum was at Sahianwala. Habitats like saline waterlogged areas, salt marshes and saline fish ponds showed exceptionally high ECe (Table 1). Source of salinity in salt marshes of the Salt Range is due to runoff water that contains salts from exposed rocks and also by brine springs, resulting in an accumulation of large quantities of salts (Hameed *et al*., 2008). Lands at Sahianwala and Pakka Anna are heavily salt-infested resulting in large non-cultivable areas (Batool & Hameed, 2013).

Ecological characteristics: The minimum density and percent cover was recorded from Rasul where vegetation was very sparse and scattered (Table 3). The population was collected from the river bank, and this habitat might not be suitable for growth and propagation of *C. laevigatus*, which is a halophytic sedge (Khan & Qaiser, 2006). In spite of a halophyte, it showed some growth over there, indicating its wide range of degree of tolerance to a variety of habitats. The maximum density was observed at Sahianwala which was followed by Pakka Anna, however, maximum cover was noted at Pakka Anna followed by Sahianwala (Table 3). These habitats were heavily salt-affected where salinities ranged between 30-50 dS m^{-1}. The high salinities seemed to be quite suitable for this species, which showed dense and compact populations at both sites.

Density and percent cover was also high at sub-mountainous saltmarshes, at Jahlar Lake, cover and density was relatively high than that recorded at Kalar Kahar Lake (Table 3). Density and cover at sub-mountainous water bodies at lower elevations (Domeli and Kirana Hills) were quite low. At higher elevation (Dape Sharif), however, density and percent cover was about two-folds than that recorded at other sub-mountainous bodies. All these site are slightly salt-affected with salinities ranges between 3-6 dS m^{-1}. Among polluted areas, Khanki had dense population of *C. laevigatus* than Ucchkera, which is a disturbed area due to anthropogenic activities. This indicated that toxic metal ions may hamper the growth and propagation of *C. laevigatus.* There are some earlier reports on adverse effect of toxic metal on some other halophytes e.g., Chai *et al*. (2013) in *Spartina alterniflora* and Mnasri *et al*. (2015) in *Sesuvium portulacastrum*, but no work till has been reported on *C. laevigatus.*

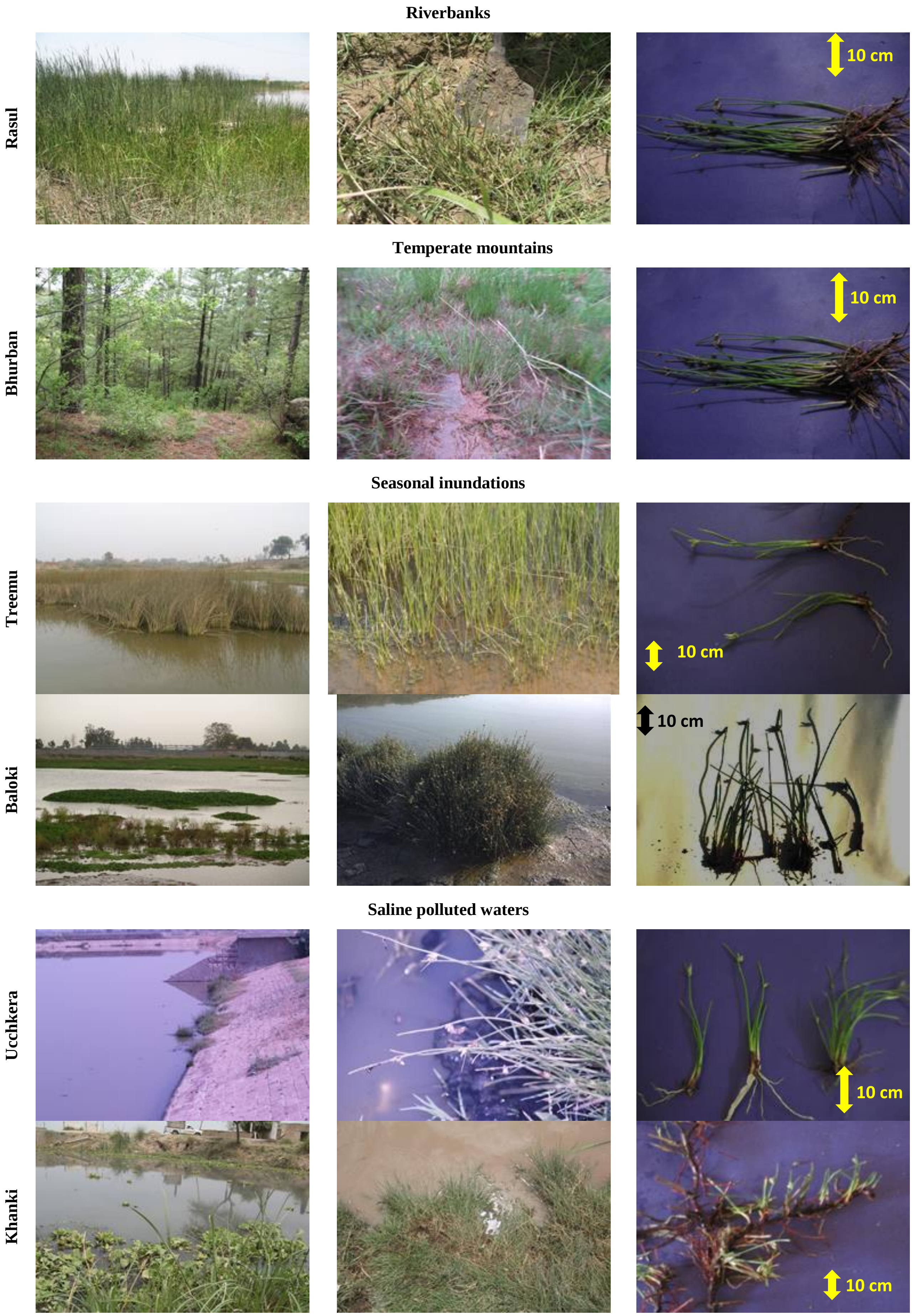

Fig. 1. *Cyperus laevigatus* collection sites from riverbanks, temperate mountains, seasonal inundations and saline polluted waters.

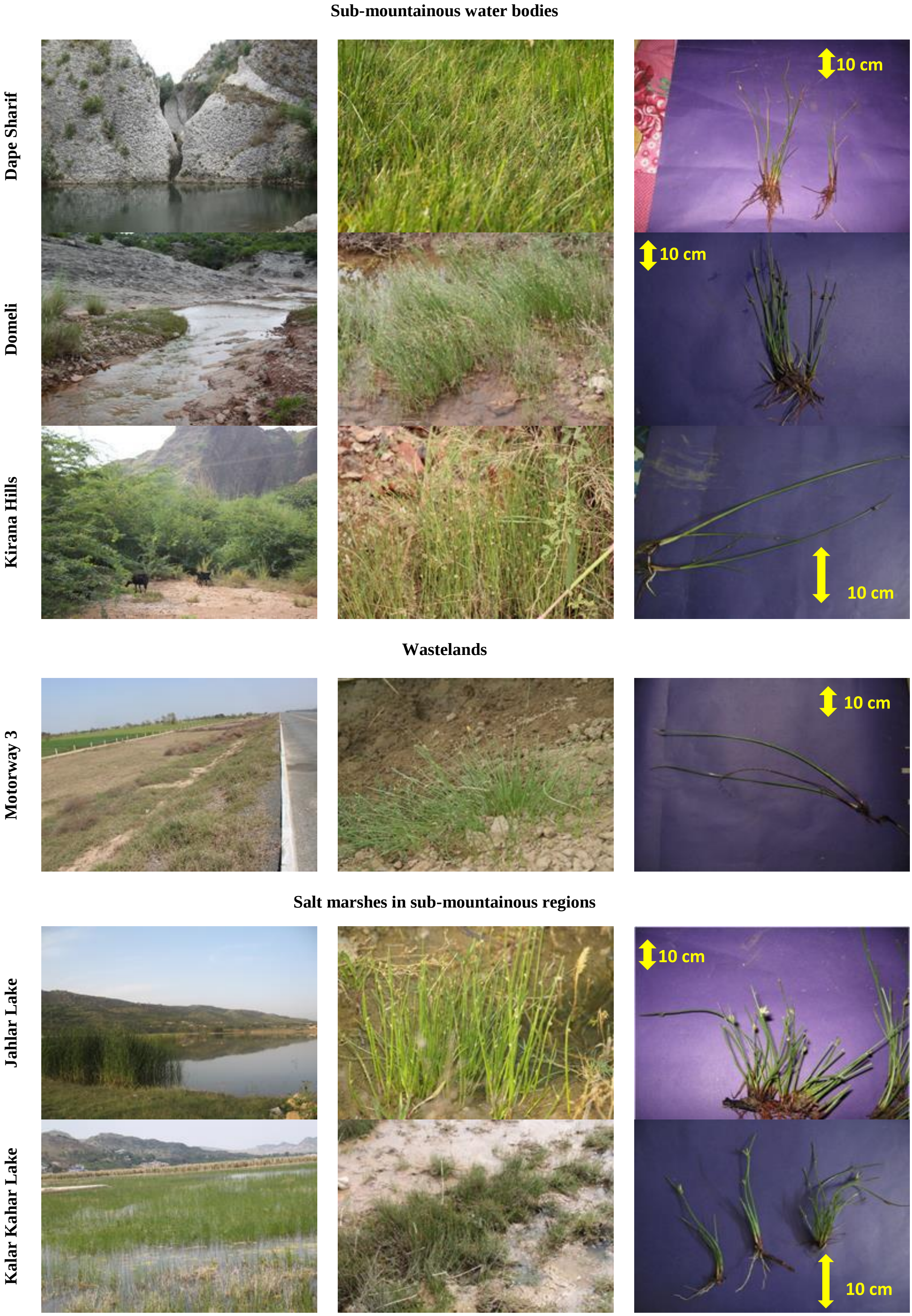

Fig. 2. *Cyperus laevigatus* collection sites from sub-mountainous water bodies, wastelands and salt marshes in sub-mountainous regions.

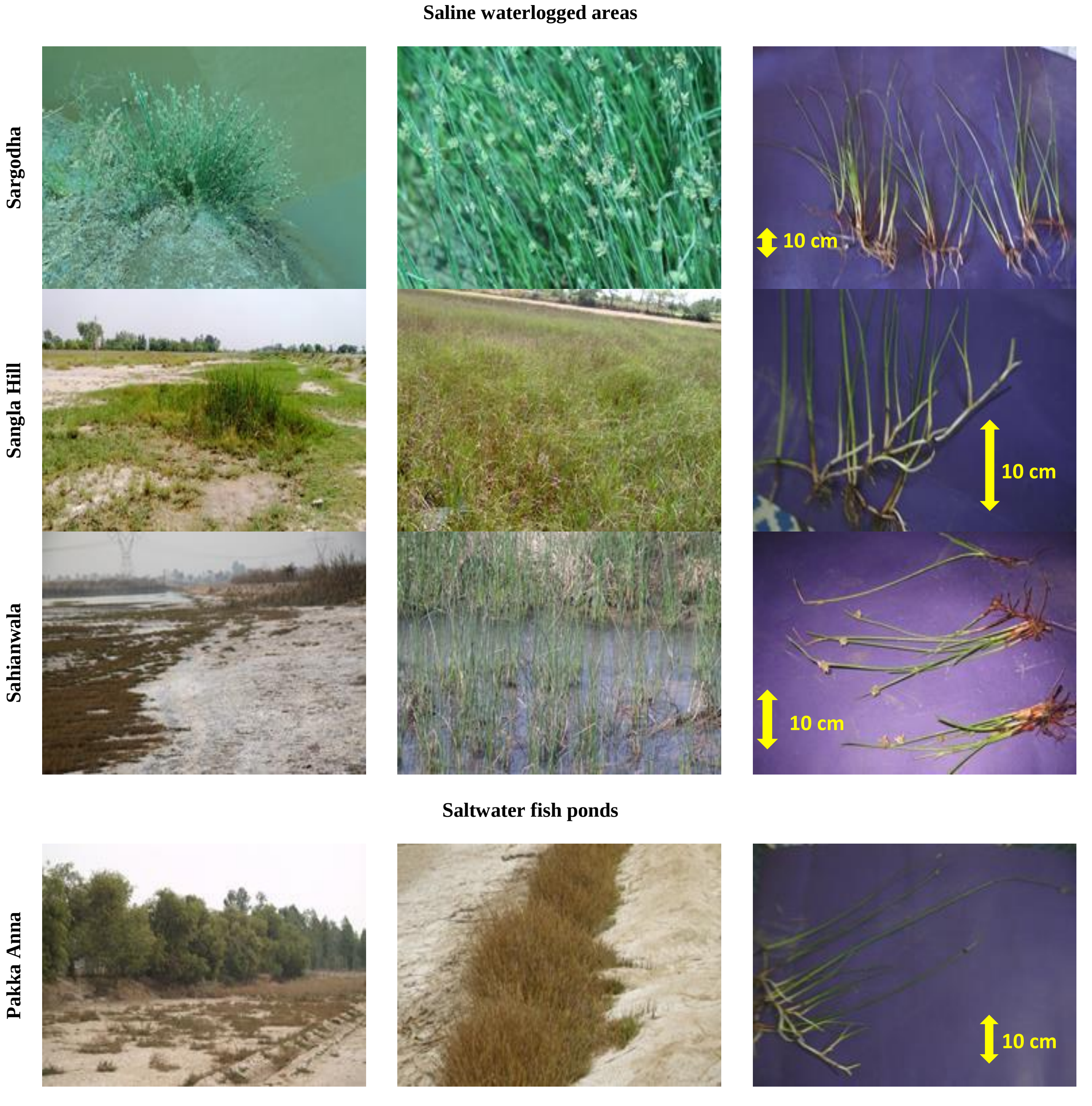

Fig. 3. *Cyperus laevigatus* collection sites from saline waterlogged areas and saltwater fish ponds.

Associated species at each study site apparently altered not only with salinity gradient but also with altitudinal gradient (Table 3). Associated species at riverbanks (Rasul) mainly dominated by the member of family Cyperacea, mostly *Fimbristylis* spp. However, the most dominating component of vegetation was *Schoenoplectus corymbosus*, and that was followed by *Typha domingensis*. Both *Schoenoplectus* spp. (*S. lacustris*, *S. juncoides* and *S. triqueter*) and *Typha* spp. (*T. domingensis*, *T. elephantina* and *T. latifolia*) are the dominant component of wetlands all over the Punjab (Sardar *et al*., 2013) that provide food, shelter and breeding site to a number of aquatic wildlife species (Bilal *et al*., 2013). Temperate mountains (Bhurban) depicted association of *C. laevigatus* with high altitude grasses, *Oplismenus undulatifolius* and *Arthraxon lancifolius*. These grasses are found above 1500 m altitude and are dominant component of moisture habitats like hill torrents, mountains springs and marshy areas (Hussain *et al*., 2016). At Treemu site, *C. laevigatus* was associated with two sedge species along with *Typha domingensis*. This habitat was moderately salt affected supporting more salt tolerant monocot species like *Typha* and *Schoenoplectus* (Akhtar *et al*., 2016). Baloki dominated mainly by sedges like (*Fimbristylis bisumbellata*, *Cyperus compressus* and *Schoenoplectus corymbosus*), but the most dominant component at this habitat was *Cynodon dactylon*. This species is capable of tolerating a variety of habitats including wetlands and complete dominance can be expected at low salinities all over the Punjab (Hameed *et al*., 2013).

Table 1. Soil physico-chemical characteristics of *Cyperus laevigatus* L. populations collected from different regions of Punjab.

Site	Soil texture	ECe (dS m^{-1})	pH	SP	Na^+ (mg kg^{-1})	Cl^- (mg kg^{-1})
Riverbanks						
Rasul	Sandy loam	1.2	7.3	27.3	90.2	182.17
Temperate mountains						
Bhurban	Sandy loam	1.8	8.2	31.2	103.4	200.7
Seasonal inundations						
Treemu	Loamy sand	5.5	6.9	24.1	337.71	341.57
Baloki	Loam	1.7	7.6	29.8	178.3	440.4
Saline polluted waters						
Ucchkera	Loamy sand	3.6	7.2	25.0	175.5	437.45
Khanki	Clayey loam	6.0	7.7	32.3	357.6	557.2
Sub-mountainous water bodies						
Dape Sharif	Sandy loam	3.2	8.7	35.0	151.6	410.4
Domeli	Sandy loam	3.5	9.1	32.6	172.7	435.8
Kirana Hills	Clayey loam	5.3	8.4	36.5	300.8	501.6
Wastelands						
Motorway 3	Loam	4.2	6.8	25.6	301.7	482.3
Salt marshes in sub-mountainous regions						
Jahlar Lake	Sandy loam	16.7	7.49	35.6	2848.7	1629.18
Kalar Kahar Lake	Loam	37.4	7.7	34.9	4046.2	2159.4
Saline waterlogged areas						
Sargodha	Loam to clayey Loam	4.8	7.1	40.7	3217.5	1394.7
Sangla Hill	Loam	19.5	6.7	33.5	3411.9	1718.6
Sahianwala	Saline-sodic	47.8	8.2	41.1	5856.4	2753.8
Saltwater fish ponds						
Pakka Anna	Sandy loam	32.6	8.6	38.4	3749.6	1926.1
Pearson's correlation coefficient with ECe			$0.122^{N.S.}$	0.666**	0.958***	0.972***

N.S.: Not-significant, **: Significant at p>0.01, ***: Significant at p>0.001

In Ucchkera, *C. laevigatus* was associated with *Cyperus compressus* and *Desmostachya bipinnata*, where the main source of pollution was industrial effluents containing large quantities of metal ions like Cd^{2+} and Ni^{2+} (Ashraf *et al*., 2012). Pollution at Khanki was by sewage disposal containing pollutants like detergents, soaps and nutrients (Altaf *et al*., 2013) and *C. laevigatus* was associated with floating hydrophytes like *Pistia stratiotes* and *Eichornea crassipes* along with tall submerged species like *Cyperus alopecuroides* and *Typha domingensis* (Table 3). Among sub-mountainous water bodies, Dape Sharif is situated at the highest altitude, therefore, associated species are much different from the other sub-mountainous water bodies. At Dape Sharif, dominant species were *Carex fedia* and *Typha elephantina*. *Carex fedia* was only reported from Dape Sharif in the Salt Range and like other *Carex* species it is restricted to high altitudes (Öztürk *et al*., 2015). In Domeli, *C. laevigatus* was associated with grasses like *Saccharum spontaneum* and *Cynodon dactylon* and a sedge *Fimbristylis dichotoma*. *C laevigatus* was associated with *Cynodon dactylon* and *Phragmites karka* along with one weedy dicot species *Convolvlus arvensis*. The later species dominates the whole Kirana Hills as was reported by Iqbal *et al*. (2016).

The wasteland along Motorway 3 was dominated by some noxious weeds like *Ranunculus muricatus, Cyperus rotundus* and *Cynodon dactylon* (Table 3), and all these species are wide spread throughout the Punjab (Riaz *et al*., 2009; Hanif *et al*., 2012. Salt lakes in the Salt Range are characterized by hyper-saline waters (Hameed *et al*., 2008) that support very specific species. The Jahlar Lake is situated at the highest point in Salt Range among all lakes or lakes of Ucchali complex (Ali *et al*., 2011), where *C. laevigatus* showed association with *Typha domingensis* and *Fimbristylis dichotoma*. The Kalar Kahar Lake, in contrast, is dominated by some tolerant species like *Typha domingensis* and *Phragmites karka* along with spreading *Cynodon dactylon* and *Polypogon monspeliensis*. The most dominant, however, was *Schoenoplectus lacustris* that completely invade shallow waters in the lake along with *C. laevigatus.*

Saline waterlogged areas in the vicinity of Faisalabad district was completely dominated by *Typha domingensis* (Table 3), however, other associated species with *C. laevigatus* were site specific. At Sargodha *Cynodon dactylon* dominated the area, at Sangla Hill *Ochthocloa compressa*, *Desmostachya bipinnata* and *Phragmites karka* were the dominant species. *Fimbristylis dichotoma* and *Leptochloa fusca* were associated with *C. laevigatus* at Sahianwala. Saltwater fish ponds were constructed in vast saline wasteland at Pakka Anna where there grasses *Ochthocloa compressa*, *Aeluropus alopecuroides* and *Leptochloa fusca* dominated the area. All these species are salt indicator that colonize salt-affected lands all over the Punjab.

Table 2. Details of collection sites of *Cyperus laevigatus* L. populations along with their habitat ecology.

Site of collection	Coordinates	Elevation (m asl)	Habitat description
			Riverbanks
Rasul	32º42’23.4”N 73º32’49.2”E	211.23	Rasul Headworks was constructed on River Jhelum near Mandi Bahauddin city. The population was collected along river bank
			Temperate mountains
Bhurban	33º57’32.6”N 73º27’12.4”E	1817.22	The highest altitude in the Punjab province with cool, temperate climatic conditions. Plants established their along freshwater pond are in sparse patches, but taller than those from many other locations
			Seasonal inundations
Treemu	31’09’01.7”N 72’07’30.8”E	149.05	River Jhelum and Chenab meet at Treemu Headworks. The population was collected from seasonal inundations on a road towards Layyah, and moderately salt-affected
Baloki	31º14’19.1”N 73º52’11.5”E	192.94	Baloki Headworks was constructed in River Ravi. The population was established near seasonal inundations, where soil was not affected by salts
			Saline polluted waters
Ucchkera	31º27’25.1”N 73º00’33.7”E	180.44	Brackish and metal-polluted water from sewage and industries are treated at Ucchkera by water treatment plants. The population of *C. leavigatus* was collected along waste water ponds
Khanki	32º24’20.4”N 74º00’53.1”E	218.54	Khanki Headworks was constructed on River Chenab. The population was collected from saline polluted water drain containing industrial wastes, and this water is disposed off in the river
			Sub-mountainous water bodies
Dape Sharif	32º31’49.9”N 72º00’25.0”E	831.79	A beautiful point in the Soone Valley (Salt Range) with relatively mild summers and cool winters. Plants are along brine mountain spring with low salinity
Domeli	33º01’48.5”N 73º20’04.9”E	378.56	Domeli is a game reserve, but heavily disturbed area by livestock grazing. Population of *C. laevigatus* was established along freshwater permanent mountain spring in foothill zone near Sohawa City on northeastern side of the Salt Range
Kirana Hills	32º56’55.1”N 72º43’06.5”E	185.92	Kirana Hills are the small group of stony hills near Sargodha city, which is heavily disturbed by stone crushing activity. The vegetation is facing severe dust pollution. The population was collected from a small marshy pond, slightly saline in nature
			Wastelands
Motorway 3	31º20’53.6”N 72º47’53.6”E	177.39	Motorways-3 was constructed about 3 years ago by completely clearing vegetation, and all species that established along this road are new colonizers. *Cyperus laevigatus* established afterwards on damp, waterlogged patches along water channels nearby agricultural fields
			Salt marshes in sub-mountainous regions
Jahlar Lake	32º29’49.5”N 72º05’06.6”E	830.27	Jahlar Lake is relatively smaller lake of the Ucchali Complex (the Ramsar site). The water is hypersaline supporting only few halophytic species like *C. alopecuroides*
Kalar Kahar Lake	32º46’21.1”N 72º42’52.1”E	644.04	A saltmarsh and a beautiful recreational point in the Salt Range. The lake is dominated by two species, *Schoenoplects lacustris* and *Phragmites karka*. The population of *C. laevigatus* was collected along the bank, plants were relatively short-structured
			Saline waterlogged areas
Sargodha	32’00’29.8”N 73’01’07.6”E	187.45	The population was from waterlogged areas along general traffic road near Sial-mor interchange on a way towards Sargodha. The habitat was slightly salt-affected
Sangla Hill	31’42’56.3”N 73’22’24.3”E	197.81	Heavily salt-affected waterlogged area along roadside. The population was dense but much smaller in length
Sahianwala	31º39’46.6”N 73º13’25.7”E	190.80	The area is heavily saline and waterlogged. The population was relatively small but in very dense patches along hyper-saline wetland
			Saltwater fish ponds
Pakka Anna	31º14’58.8”N 72º47’54.7”E	175.26	The area is severely affected by high dryland salinity, where Nuclear Institute for Agriculture and Biology (NIAB) started their effort to reclaim the soil by cultivation of many succulents and salt excretory halophytes. The population was collected from the bank of brackish fish ponds, used for raising saltwater fish species. Population was quite dense and taller in length
Pearson’s correlation coefficient with ECe		$-0.124^{N.S.}$	

asl: Above sea level

N.S.: Not-significant

Table 3. Ecological characteristics of *Cyperus laevigatus* L. populations collected from different regions of Punjab.

Site of collection	Density	% Cover	Associated species
Riverbanks			
Rasul	52	15.9	*Fimbristylis miliacea, Fimbristylis dichotoma, Fimbristylis bisumbellata, Typha domingensis, Schoenoplectus corymbosus*
Temperate mountains			
Bhurban	83	20.0	*Oplismenus undulatifolius, Arthraxon lancifolius*
Seasonal inundations			
Treemu	197	47.6	*Kyllinga triceps, Typha domingensis, Schoenoplectus juncoides*
Baloki	86	22.5	*Cynodon dactylon, Fimbristylis bisumbellata, Cyperus compressus, Schoenoplectus corymbosus*
Saline polluted waters			
Ucchkera	150	33.2	*Cyperus compressus, Desmostachya bipinnata*
Khanki	257	60.1	*Cyperus alopecuroides, Eichornea crassipes, Pistia stratiotes, Typha domingensis*
Sub-mountainous water bodies			
Dape Sharif	215	54.8	*Eleocharis palustris, Carex fedia, Juncus* sp., *Typha elephantina*
Domeli	120	32.9	*Saccharum spontaneum, Cynodon dactylon, Fimbristylis dichotoma*
Kirana Hills	101	29.0	*Cynodon dactylon, Phragmites karka, Convolvulus arvensis*
Wastelands			
Motorway 3	162	47.2	*Ranunculus muricatus, Cyperus rotundus, Cynodon dactylon*
Salt marshes in sub-mountainous regions			
Jahlar Lake	340	77.3	*Typha domingensis, Fimbristylis dichotoma*
Kalar Kahar Lake	254	58.3	*Typha domingensis, Cynodon dactylon, Phragmites karka, Schoenoplectus lacustris, Polypogon monspeliensis*
Saline waterlogged areas			
Sargodha	61	19.5	*Cynodon dactylon, Typha domingensis*
Sangla Hill	388	86.4	*Ochthocloa compressa, Desmostachya bipinnata, Typha domingensis, Phragmites karka*
Sahianwala	472	89.1	*Fimbristylis dichotoma, Leptochloa fusca, Typha domingensis*
Saltwater fish ponds			
Pakka Anna	421	96.1	*Ochthocloa compressa, Aeluropus alopecuroides, Leptochloa fusca*
Pearson's correlation coefficient with ECe	0.771***	0.714**	

: Significant at p>0.01, *: Significant at p>0.001

Table 4. Growth characteristics of *Cyperus laevigatus* L. populations collected from different regions of Punjab.

Site of collection	Plant height (cm)	Fresh weight (Plant^{-1})	Dry weight (Plant^{-1})
Riverbanks			
Rasul	47	14.34	3.08
Temperate mountains			
Bhurban	51	15.28	1.89
Seasonal inundations			
Treemu	55	16.32	1.65
Baloki	45	16.93	1.43
Saline polluted waters			
Ucchkera	22	7.98	1.63
Khanki	12	6.49	0.13
Sub-mountainous water bodies			
Dape Sharif	39	16.78	1.76
Domeli	38	18.05	1.74
Kirana Hills	40	15.36	1.23
Wastelands			
Motorway 3	67	15.23	2.01
Salt marshes in sub-mountainous regions			
Jahlar Lake	54	20.84	1.83
Kalar Kahar Lake	18	7.08	1.51
Saline waterlogged areas			
Sargodha	52	15.75	1.77
Sangla Hill	19	7.49	1.55
Sahianwala	33	11.34	2.08
Saltwater fish ponds			
Pakka Anna	72	22.98	4.51
Pearson's correlation coefficient with ECe	-0.170$^{N.S.}$	-0.200$^{N.S.}$	-0.280$^{N.S.}$

N.S.: Not significant

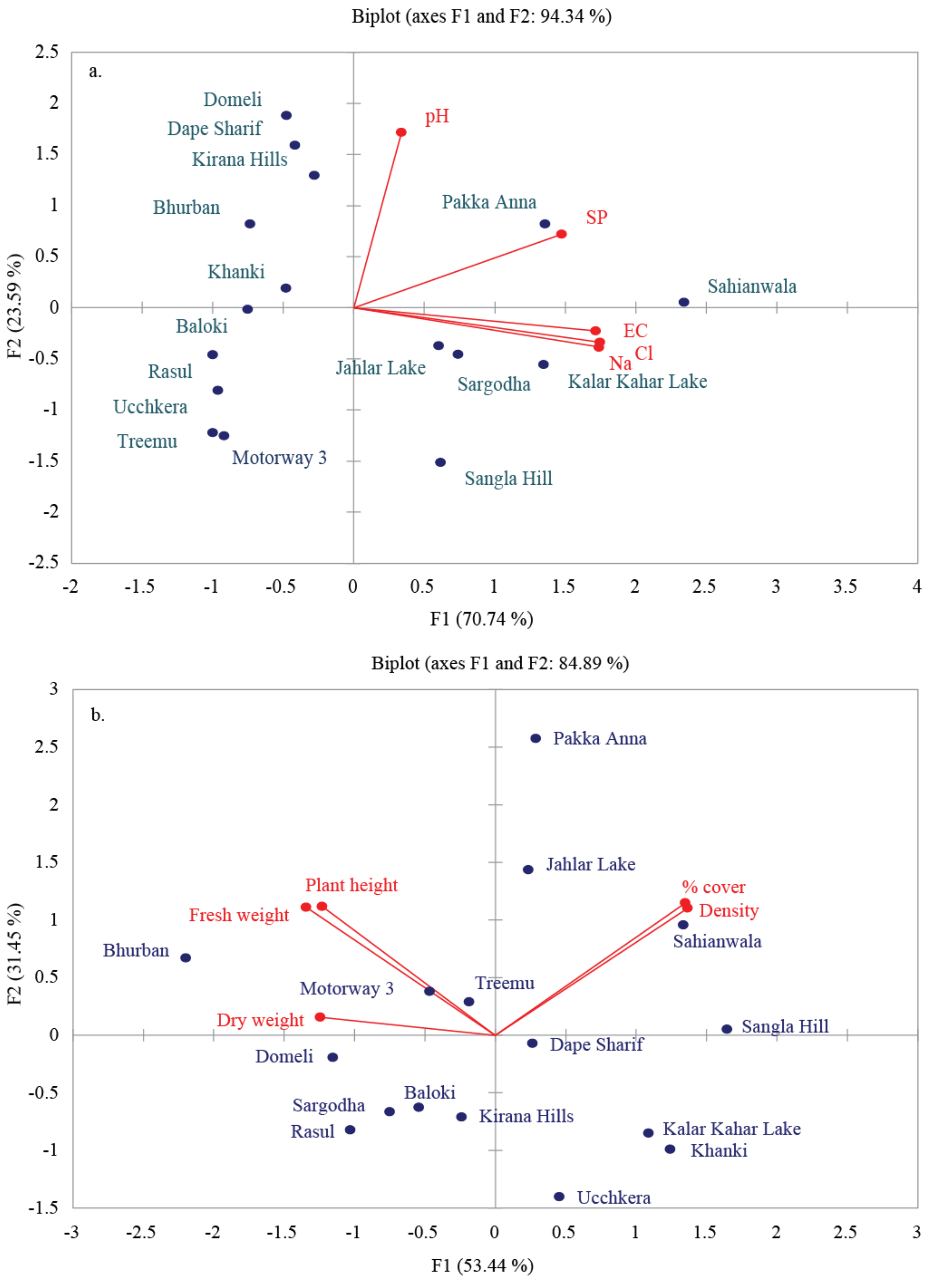

Fig. 4. PCA (Principal Correspondence Analysis) showing biplot of a. collection sites versus soil physicochemical characteristics and b. collection sites versus eco-morphological characteristics.

Morphological characteristics: The maximum growth (plant height, fresh and dry weights) was recorded at Pakka Anna (Table 4) which is heavily salt-affected but the soil texture is relatively soft. This kind of habitat seems to be most suitable for growth and germination of *C. laevigatus* as was also reported for other hydro-halophytes like (Qadir *et al*., 2008; Hasanuzzaman *et al*., 2014). Soil compactness apparently directly related to growth and propagation of this species as most of the habitats with more compact soils possessed shorter plants e.g., Sangla Hill, Sahianwala, Kalar Kahar Lake. Similar findings have been also observed by Hamza & Anderson (2005) who reported restricted growth in compact soils.

Another important factor for restricted growth and development in this species was the pollutants, either from industrial sources or from sewerage. Plants collected from Ucchkera and Khanki were very short structured. Adverse effect of industrial or sewerage pollutants has earlier been reported by Fonkou *et al*. (2005) in *Cyperus papyrus*, however, many members of this family possess phytoremediation potential as reported in *Cyperus articulatus* and *Cyperus exaltatus* by Mganga *et al*. (2011) and in *Cyperus rotundus* by El-Nakhlawy (2017). There was no significant difference in plant height and fresh and dry weights of plants collected from sub-mountainous water bodies like Dape Sharif, Domeli and Kirana Hills. However, among salt marshes Jahlar Lake population was much taller than that recorded from Kalar Kahar Lake. Here soil compactness seemed to be recessive factor for controlling growth and propagation of this species.

Correlation studies: Pearson's correlation coefficients (*r*) of EC was calculated with soil chemical, ecological and plant morphological characteristics (Tables 1, 2, 3 & 4). Soil ECe significantly correlated with Saturation percentage and percent cover at p>0.01 and with Na^+, Cl^- and density at p>0.001. In contrast, it showed no correlation with morphological characteristics, elevations and soil pH.

Principal correspondence analysis: Pakka Anna showed a strong association with soil saturation percentage. Sahianwala, Kalar Kahar Lake, and Jahlar Lake showed weak association with ECe, Na^+ and Cl^- contents. Motorway 3 and Treemu showed a strong association with plant height and fresh weights whereas percent cover and density was strongly associated with Sahianwala. A weak association of dry weight was recorded with Domeli (Fig. 4).

It was concluded that growth and distribution of C. *laevigatus* was not controlled by a single factor or environmental gradients like salinity, altitude or soil structure. Soil ECe apparently was the strongest factor for distributional pattern whereas soil compactness may control growth and propagation. The tolerance range of species was extremely high for either salinity level or elevation gradient.

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