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Abstract In order to protect and understand the regeneration of riparian forests, it is important to understand the environmental conditions that lead to their vegetation differentiation. We evaluated the structure, composition, density and regeneration of woody species in forests along the river Safaroud in Ramsar forest in northern Iran in relation to elevation, soil properties and distance from the river. Using 60 transects located perpendicularly to river and 300 quadrats, we examined forests 0, 50, 100, 150 and 200 m from the stream along an elevation gradient spanning from 350 to 2,400 m a.s.l. We found that total density, regeneration, diameter and basal area of trees were significantly higher in the interior of the forest whereas shrub density was higher close to the river. The uneven-aged forest structure showed no significant differences among gradient from the river to the forest interior. Hydro-geomorphic processes, flooding, the elevation gradient, distance from the river and soil properties were the most important factors that influenced plant community distribution in relation to the river.

Keywords Flooding · Multivariate analysis · Northern Iran · Plant community distribution · Soil properties · Structure

M. N. Adel (✉) · H. Pourbabaei · A. Salehi
Department of Forestry, Faculty of Natural Resources, University of Guilan, Rasht, Islamic Republic of Iran
e-mail: mn.adel87@gmail.com

S. J. Alavi
Department of Forestry, Faculty of Natural Resources and Marine Sciences, Tarbiat Modares University, Noor-Tehran, Islamic Republic of Iran

D. C. Dey
USDA Forest Service, Northern Research Station, 202 Natural Resources Building, Columbia, MO 65211, USA

Introduction

Riparian areas constitute the interface or transition zone between terrestrial and aquatic ecosystems. Also known as shorelines or ecotones, these land/water transitional areas can exert a disproportionate influence over the productivity of aquatic ecosystems (Naiman et al. 2005). Riparian forests have particular influences on this land/water transitional zone and adjacent water bodies. Riparian forests regulate the flow of energy and materials to forest floors and adjacent water bodies, filter nutrients and sediments in runoff, provide canopy to filter out UV radiation, and maintain cool water temperatures, deliver nutrient subsidies to receiving waters in support of aquatic food webs, and riparian-derived woody debris can form critical structural elements of stream beds (Nisbet et al. 2015). Riparian vegetation stabilizes and protects banks against erosion and interacts with hydraulic factors to shape channel morphology (Lecerf et al. 2016). Trees and other woody plants that form the overstorey canopy are recognized as the primary and most valuable components of riparian communities. Tree species must possess morphological, physiological, or reproductive adaptations to persist in the high-energy, disturbance-prone environments of riparian ecosystems (Beschta 1991; Naiman et al. 1998). Riparian forests are also some of the ecosystems that are most sensitive to human influences and most threatened (Schinegger et al. 2012; Greet et al. 2013). Thus, understanding the relationships between the physical features of the environment and vegetation is a great challenge and may help to develop scientific knowledge to enhance riparian restoration projects (Pielech et al. 2015).

Flooding is also a major factor controlling biological community structure, often moderating the interactive relationships among the hydrological regime, soil structure (sediment), flora and fauna (Lee et al. 2014). Many parts of the riverine system are subject to environmental pressures that affect both the chemical and physical environment, including disturbances such as flooding that occur on a somewhat regular basis and vary in extent and duration (Cho and Cho 2005; Capon and Brock 2006). When flooding occurs there is a large flow of water, usually resulting from snow or heavy rain within the upstream catchment, and the effects on river topography can be severe (Pagotto et al. 2011; Stromberg et al. 2011).

The southern limit of the Euro-Siberian region coincides with the southern coastal areas of the Black and Caspian Seas. The western area near the Black Sea is referred to as the Euxinian province whereas the eastern area near the Caspain Sea is known as the Hyrcanian province. The Hyrcanian province is confined here to the coastal surroundings of the Caspian Sea. The most outstanding feature of this area is the broad-leaved deciduous forest (Sagheb Talebi et al. 2014). The Hyrcanian vegetation zone, also called Caspian forest, is a green belt stretching over the northern slopes of the Alborz mountain ranges and covers the southern coasts of the Caspian Sea. The orographic influence of the Alborz Mountains, which are located between the Caspian Sea and the Iranian plateau, contributes to a climate resulting in a distinct vegetation cover (Sagheb Talebi et al. 2014).

There are many rivers in these forests. These rivers provide local communities a large amount of environmental, agricultural, and economic goods and services. Unfortunately, substantial damage to riparian forests has occurred in recent years due to increasing agricultural and industrial uses, tourism, and water and fishery development by government organizations, collectively, natural forests are being transformed into an unnatural state. Despite the seriousness of these problems and their negative impacts to forest resources, a few studies have been done on the riparian forest in the river border areas in Iran. Adel et al. (2014) studied the flora, life form and chorology of riparian forest along the Safaroud riverside in the Ramsar forest. They observed that dominant life forms included hemicryptophytes, geophytes and phanerophytes, respectively. From the chorological point of view, the largest proportion of the flora belongs to the Euro-Siberian, Pluriregional, Euro-Sibirian / Irano-Turanian and Euro-Sibirian / Irano-Turanian / Mediterranean, respectively. In another research, Ejtehadi et al. (2005) studied the Shirinroud riverside in Sari forest. They found that *Alnus subcordata*, *Acer velutinum*, *Fagus orientalis* and *Carpinus betulus* were dominant species in west and east aspects of the river and elevation range of 790 to 1,700 m a.s.l. Management of forest ecosystems requires detailed knowledge of the essential components that define specific ecosystems.

The aim of this study was to evaluate the structure, composition, density and regeneration of woody species in forests along the river Safaroud in Ramsar forest, Mazandaran province, northern Iran in relation to elevation, soil properties and distance from the river. To protect and understand the regeneration of riparian forests, it is important to understand the environmental conditions that lead to vegetation differentiation from rivers to the interior of forests.

Material and methods

Study area

The study area is located in the Safaroud watershed near Ramsar city along the river Safaroud. The area is located on the northern slopes of the Alborz Mountains in western Mazandaran province in northern Iran (north latitude 36°51′7″ to 51°36′45″ and east longitude 50°41′19″ to 50°42′34″). Canopy cover percentage at the 0, 50, 100, 150 and 200 m distances from river was 80, 90, 88, 95 and 95 %, respectively. Soil type is Inceptisols (USDA soil taxonomy). Elevation ranges from 350 to 2,400 m a.s.l.. According to the nearest weather station (Ramsar), the mean annual temperature is 15.9°C, annual precipitation totals 1,330 mm, and mean annual relative humidity is 84.7 %. The mean minimum temperature of 4.4°C occurs in December and the maximum of 30.2°C in July and August. According to the Emberger climate classification, the climate is cold wet (Anonymous 2010). The general direction of the river Safaroud is south western to the northeast over its 21 km to the Caspian Sea. In the study area, management activities such as harvest operations and livestock grazing are not done.

Data collection

Data collection occurred along transects that were run perpendicular to the water flow on both sides of the river (Li et al. 2012). The length of each transect was 200 m (Stokes et al. 2010) and the distance between transects was 200 m (Wei-lei et al. 2010). On each transect, five 400-m^2 quadrats (20 × 20 m; Stokes et al. 2010) were located every 50 m (Wittmann et al. 2008) at the 0, 50, 100, 150 and 200 m marks. At each sampling location the species, number, percent cover and diameter of all trees with a diameter at breast height (DBH) greater than 7.5 cm, as well as the species and number of shrubs were measured. Within each main plot, a smaller (100-m^2 quadrat, 10 × 10 m), nested quadrat was used to study the regeneration). In these quadrats, species and number of regeneration stems less than 7.5 cm in DBH and less than 1.3 m in height were recorded. Three soil samples were taken in each of the nested quadrats, one at plot centre and two on either side of plot centre. Soil samples were taken from the 0–30 cm depth and all three samples from a plot were mixed before being sent to the laboratory for determination of soil physical and chemical properties (Li et al. 2012). A total of 60 transects and 300 quadrats were used to collect species and environmental data.

Data analysis

A two-way indicator species analysis (TWINSPAN) was used to classify the 300 plots into groups with similar species abundance patterns. The cut-off level of 'pseudo-species' followed the software's default. We then used the indicator species analysis (ISA) to extract those significantly associated with each group. TWINSPAN and ISA were performed by PC-ORD software, version 5.10 (McCune and Medford 2006). Multivariate analysis was performed through CANOCO software, version 4.5 to explore the relationship between the elevations, distance from river, width of river, and soil physical and chemical variable factors and the plant community in the riparian and interior forests in the study area in northern Iran. To determine whether to use linear or unimodal based numerical methods, DCA (detrended correspondence analysis) with detrending by segments was first conducted to analyse the vegetation data to evaluate the gradient length of the first axis. A Monte Carlo permutation test based on 499 random permutations (ter Braak and Šmilauer 2002; Yu and Sun 2013) was conducted to test the significance of the eigenvalues of the first canonical axis. Inter-set correlations from the ordination analysis were used to assess the importance of the soil variables (Liu et al. 2012). We used CCA with forward selection of explanatory variables to provide an estimate of the best set of variables for predicting species-environment relation and to provide a ranking of the relative importance of the individual explanatory variables (ter Braak and Šmilauer 2002). The selection procedure was implemented using unrestricted Monte Carlo permutation under the reduced model to test each variable for significance (with 499 random permutations). Soil variables were included in this analysis such as N, P, K, Ca, Mg, pH, total neutral volume (TNV), C, C/N ratio, organic matter, leaf litter, soil texture (clay, sand, silt), bulk density (BD) and electrical conductivity (EC). Kolmogorov–Smirnov tests were used to test normality of all parameters. The significance of difference between variables (tree and shrub density, DBH, basal area, regeneration density) means among five distances along a transect was analysed by the one-way ANOVA, followed by the Tukey test at the 95 % level. All statistical analyses were performed in IBM SPSS version 22.0 (IBM Corp. 2013).

Results

Tree density

In total, 5,580 trees were measured. The results showed that there were significant differences ($P \leq 0.05$) in tree species density between riparian and interior forests. Tree density in the interior forest was greater than in the riparian forest. There was no observed significant differences among four distances in the interior forests. Densities of *Acer cappadocicum*, *Acer velutinum*, *Alnus subcordata* and *Fraxinus excelsior* species were significantly higher in the riparian than the interior forest. Densities of *Carpinus betulus*, *Carpinus orientalis*, *Fagus orientalis*, *Parrotia persica* and *Quercus macranthera* species were significantly greater in the interior forest than in the riparian. *Acer campester*, *Cerasus avium*, *Diospyros lotus*, *Malus orientalis*, *Pyrus communis* and *Taxus baccata* densities were not significantly different between the five transect distances. *Acer platanoides* was present only in riparian forests and at 150 m from the river. *Albizia julibrissin* was found at distances of 150 and 200 m from the river, *Buxus hyrcana* and *Gleditschia caspica* were observed at and near the riverside (50 m), *Ficus carica* and *Morus alba* occurred only at the riverside, *Juglans regia* and *Pterocarya fraxinifolia* occurred at the riverside and at distances of 50 and 200 m from the river, and *Sorbus torminalis* was observed at distances of 50 and 100 m from the river. *Ulmus glabra* and *Tilia platyphyllos* weren not present at the riverside but were present in significantly different densities at other distances (Table 1).

DBH and basal area of trees

The results showed that there was a significant difference in DBH and total basal area of tree species between the riparian and interior forests, whereby trees were larger in diameter and basal area was higher in interior forests compared to riparian forests; however, there was no significant difference in DBH or basal area within interior forests based on an analysis of four distances (50, 100, 150 and 200 m). DBH and basal area of *Acer cappadocicum, Acer velutinum*, *Alnus subcordata* and *Fraxinus excelsior* were significantly higher in the riparian than the interior forest. DBH and basal area of *Carpinus betulus*, *Carpinus orientalis*, *Fagus orientalis*, *Parrotia persica* and *Quercus macranthera* were significantly greater in interior forests than in forests along the margin of the river (Table 2).

Diameter distribution

Diameter distribution of tree species showed that at each of the five distances, the highest density of trees was in the 10 to 40 cm classes. The maximum observed DBH in the riparian forest was 85 cm and 120 cm in the interior forest. At each sampling interval along the transects, tree density in diameter classes greater than 65 cm was less than 10 trees per class. Diameter distribution curves at each interval were consistently reverse J-shaped, which is representative of an uneven-aged forest structure (Fig. 1).

Shrub density

In total, 2,400 shrubs were measured. The results showed that there was a significant difference in the density of shrub species between the riparian and the interior forests (Table 3). Shrub density was significantly greater in the riparian forests than in the interior forest, but there was no significant difference with distance along a transect within the forest. Densities of *Berberis vulgaris*, *Danae racemosa*, *Euonymus latifolia*, *Frangula alnus*, *Ilex spinigera*, *Laurocerasus officinalis*, *Lonicera iberica*, *Mespilus germanica* and *Viburnum lantana* species were significantly higher in riparian than interior forests, but there was no significant difference between the distances in the interior forest. Densities of *Crataegus microphylla* and *Ruscus hyrcanus* species were significantly greater in interior forests than in riparian forests. Densities of *Cornus australis*, *Crataegus pentagyna*, *Frangula grandifolia*, *Juniperus communis*, *Prunus divaricata*, *Rosa pulverulenta*, *Smilax excelsa* and *Vaccinium arctostaphylos* species were nonsignificantly different with intervals along the transect. *Aruncus vulgaris* was found only in riparian forests, *Cornus australis* occurred at the riverside and at 200 m from the river, while *Frangula grandifolia* and *Vaccinium arctostaphylos* were observed at the riverside and at 50 and 200 m from the river. *Smilax excelsa* was present at the riverside and at a distance of 150 m from the riverbank (Table 3).

Regeneration density

In all, 10,980 individuals of regeneration were measured. Regeneration density was significantly higher in riparian than interior forests. There was no significant difference in regeneration density with transect distances in the interior forests. Regeneration of *Acer cappadocicum*, *Acer velutinum*, *Alnus subcordata* and *Fraxinus excelsior* species were significantly higher in the riparian forest than in the interior forest. Regeneration of *Carpinus betulus*, *Fagus orientalis* and *Parrotia persica* species were significantly greater in the interior forests than in the riparian forests. The density of regeneration of *Carpinus orientalis*, *Acer campester*, *Diospyros lotus*, *Malus orientalis*, *Pyrus communis*, *Quercus castaneifolia*, *Quercus macranthera*, *Tilia platyphyllos* and *Ulmus glabra* was similar with distance from the river in riparian forests. *Ficus carica* and *Morus alba* regeneration occurred only in riparian forests. Regeneration of several tree species varied with distance from the river in riparian forests. For example, *Buxus hyrcana* and *Cerasus avium* were present only at 50 m from the river, *Pterocarya fraxinifolia* and *Taxus baccata* occurred at the riverside and at a distance of 50 m, *Albizia julibrissin* was observed at a distance of 100 m, *Gleditschia caspica* at a distance of 200 m, *Acer platanoides* and *Juglans regia*

Table 1 Mean tree species density (*N*/ha) in different distances from the river

Species	Distance from the river [m]				
	0	50	10^{a}	150	200
Acer campester L.	7.82^{a}	8.33^{a}	11.66^{b}	11.66^{a}	9.16^{a}
Acer cappadocicum Gled.	19.16^{a}	11.03^{b}	0	9.07^{b}	9.77^{b}
Acer platanoides L.	1.66^{a}	0	10.04^{b}	4.17^{a}	0
Acer velutinum Boiss.	27.5^{a}	14.16^{b}	0	11.66^{b}	12.5^{b}
Albizia julibrissin Durazz.	0	0	10.93^{b}	1.67^{a}	1.67^{a}
Alnus subcordata C. A. Mey.	40.83^{a}	13.33^{b}	0	10.56^{b}	14.09^{b}
Buxus hyrcana Pojark.	0.83^{a}	2.1^{a}	70^{a}	0	0
Carpinus betulus L.	15.83^{b}	68.33^{a}	15.9^{a}	65.8^{a}	66.66^{a}
Carpinus orientalis Miller	4.5^{b}	17.67^{a}	5.9^{a}	18.78^{a}	16.83^{a}
Cerasus avium (L.) Moench	1.67^{a}	5.54^{a}	7.12^{a}	5.45^{a}	6.67^{a}
Diospyros lotus L.	9.16^{a}	9.05^{a}	202.73^{a}	8.82^{a}	8.43^{a}
Fagus orientalis Lipsky	77.5^{b}	197.93^{a}	0	206.33^{a}	205^{a}
Ficus carica L.	1.66^{a}	0	3.5^{b}	0	0
Fraxinus excelsior L.	22.5^{a}	5.83^{b}	0	4.16^{b}	6.33^{b}
Gleditschia caspica Desf.	2.5^{a}	2.5^{a}	0	0	0
Juglans regia L.	2.5^{a}	5^{a}	4.16^{a}	0	4.5^{a}
Malus orientalis Ugl.	1.66^{a}	5^{a}	0	6.25^{a}	4.83^{a}
Morus alba L.	1.66^{a}	0	63.03^{a}	0	0
Parrotia persica (DC.) C. A. Mey.	13.33^{b}	59.5^{a}	0	66.66^{a}	65.43^{a}
Pterocarya fraxinifolia (Poir.) Spach.	3.33^{a}	2.5^{a}	5^{a}	0	2.5^{a}
Pyrus communis	3.33^{a}	3.33^{a}	0	6.67^{a}	6.25^{a}
Quercus castaneifolia C. A. Mey.	2.5^{a}	1.66^{a}	13.5^{a}	3.33^{a}	2.5^{a}
Quercus macranthera C. A. Mey.	4.16^{b}	15.5^{a}	1.66^{a}	14.95^{a}	16.35^{a}
Sorbus torminalis L. Crantz	0	1.66^{a}	3^{a}	0	0
Taxus baccata L.	1.66^{a}	4.5^{a}	8.33^{a}	3.33^{a}	3.33^{a}
Tilia platyphyllos Scop.	0	6.62^{a}	6.66^{a}	6.5^{a}	7.12^{a}
Ulmus glabra Hudson	0		448.12^{a}	4.72^{a}	5.29^{a}
Total	265.25^{b}			454.54^{a}	465.36^{a}

at 150 and 200 m, and *Sorbus torminalis* only at distances of 50 and 100 m (Table 4).

Developing plant community indicators using TWINSPAN and ISA

Based on TWINSPAN analysis, ten ecological species groups (plant community types) were classified into five groups in the riparian forests and five groups in the interior forests. The majority of the plots (N = 96) belonged to Group 7 that had the indicator species of *Fagus orientalis* and Group 3 (N = 64) with indicator species of *Carpinus betulus* and *Parrotia persica*. The least represented class was Group 1 (N = 8) that were represented by the indicator species *Alnus subcordata* and *Fraxinus excelsior*. Riparian and interior forests were classified into ecological groups (plant communities) using 11 indicator species each. Of the 22 indicator species, 10 trees species and 12 species were shrubs (Table 5).

Analyses of woody species distribution by CCA analysis

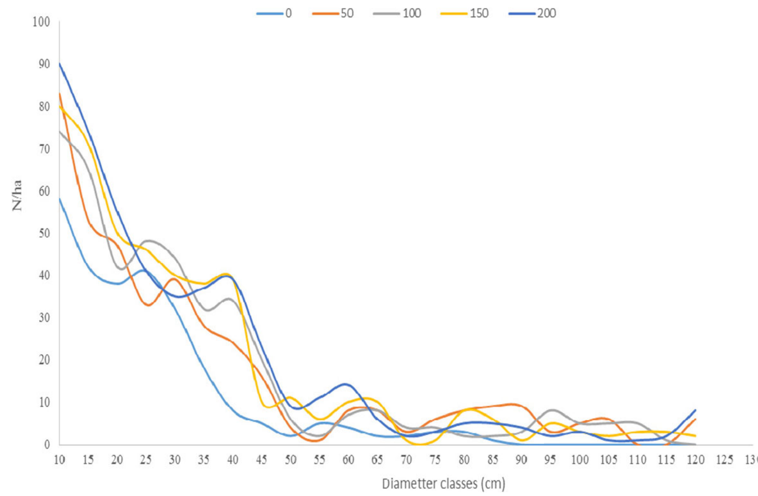
Because the calculated gradient length (11.1) was greater than 4, the CCA ordination was used to assess

Table 2 Mean diameter at breast (DBH) and mean basal area by tree species

Species	DBH [cm]					Basal area [m^2]				
	Distance from the river [m]					Distance from the river [m]				
	0	50	100	150	200	0	50	100	150	200
Acer campester L.	10.13^{a}	10.98^{a}	12.53^{a}	12.89^{a}	11.76^{a}	12.97^{a}	14.49^{a}	14.73^{a}	15.61^{a}	13.21^{a}
Acer cappadocicum Gled.	36.83^{a}	26.9^{b}	21.12 ^{b}	23.37^{b}	25.58^{b}	47.52^{a}	37.13^{b}	33.87^{b}	31.01^{b}	32.65^{b}
Acer platanoides L.	19.25^{a}	0	0	0	21.65^{a}	2.92^{a}	0	0	0	3.05^{a}
Acer velutinum Boiss.	35.53^{a}	28.05^{b}	23.16^{b}	25.25^{b}	26.12^{b}	44.71^{a}	34.85^{b}	29.34^{b}	30.08^{b}	31.55^{b}
Albizia julibrissin Durazz.	0	0	0	15^{a}	17.25^{a}	0	0	0	22.36^{a}	25.96^{a}
Alnus subcordata C. A. Mey.	39.49^{a}	32.55^{b}	29.85^{b}	30.25^{b}	30.83^{b}	48.66^{a}	43.12^{b}	38.11^{b}	41.08^{b}	43.34^{b}
Buxus hyrcana Pojark.	24^{a}	31.5^{a}	0	0	0	14.21^{a}	18.97^{a}	0	0	0
Carpinus betulus L.	20.5 ^{b}	39.41^{a}	40.14^{a}	40.17^{a}	41.66^{a}	29.54^{b}	49.81^{a}	54.11^{a}	54.25^{a}	54.86^{a}
Carpinus orientalis Miller.	8.5 ^{b}	16.31^{a}	13.63^{a}	13.95^{a}	15.71^{a}	14.8^{b}	21.62^{a}	24.09^{a}	22.76^{a}	25.12^{a}
Cerasus avium (L.) Moench	9^{b}	29.75^{a}	27.05^{a}	27.5^{a}	30.85^{a}	1.55^{b}	4.05^{a}	4.62^{a}	5.09^{a}	5.67^{a}
Diospyros lotus L.	11.68^{b}	23.91^{a}	20.05^{a}	19.5^{a}	21.43^{a}	17.82^{b}	28.09^{a}	29.31^{a}	26.77^{a}	29.03^{a}
Fagus orientalis Lipsky	28.78^{b}	41.21^{a}	44.58^{a}	43.23^{a}	44.61^{a}	33.56^{b}	63.12^{a}	65.07^{a}	61.75^{a}	62.92^{a}
Ficus carica L.	18	0	0	0	0	0.63	0	0	0	0
Fraxinus excelsior L.	17.91^{a}	13.5^{b}	12.21^{b}	12.45^{b}	10.11^{b}	28.11^{a}	22.03^{b}	19.11^{b}	20.01^{b}	20.53^{b}
Gleditschia caspica Desf.	12^{a}	16.3^{a}	0	0	0	1.13^{a}	2.2^{a}	0	0	0
Juglans regia L.	15.5^{b}	38.55^{a}	0	0	0	3.75^{b}	7.21^{a}	0	0	0
Malus orientalis Ugl.	8.05^{a}	10.5^{a}	11.33^{a}	9.79^{a}	11.53^{a}	4.9^{a}	6.1^{a}	6.83^{a}	6.22^{a}	7.21^{a}
Morus alba L.	14.5	0	0	0	0	1.05	0	0	0	0
Parrotia persica (DC.) C. A. Mey.	17.33^{b}	29.98^{a}	32.91^{a}	30.5^{a}	34.97^{a}	28.97^{b}	40.12^{a}	42.11^{a}	41.43^{a}	46.07^{a}
Pterocarya fraxinifolia (Poir.) Spach.	11.97^{a}	13.32^{a}	0	0	14.45^{a}	1.71^{a}	1.22^{a}	0	0	1.97^{a}
Pyrus communis	10.7^{a}	11.79^{a}	13.65^{a}	13.45^{a}	12.21^{a}	6.12^{a}	8.54^{a}	7.32^{a}	8.12^{a}	8.76^{a}
Quercus castaneifolia C. A. Mey.	10.63^{b}	32.76^{a}	0	29.11^{a}	29.44^{a}	3.33^{a}	4.76^{a}	0	3.98^{a}	2.38^{a}
Quercus macranthera C. A. Mey.	9.86^{a}	8.45^{a}	12.25^{a}	12.03^{a}	10.38^{a}	12.86^{a}	10.27^{a}	14.04^{a}	13.65^{a}	11.32^{a}
Sorbus torminalis (L.) Crantz	0	40.5^{a}	37^{a}	0	0	0	4.91^{a}	3.23^{a}	0	0
Taxus baccata L.	8.41^{c}	28.56^{a}	18.44^{b}	17.01^{b}	19.23^{b}	6.54^{c}	25.12^{a}	11.5^{b}	8.89^{b}	11.39^{b}
Tilia platyphyllos Scop.	0	41.5^{a}	46.17^{a}	39.54^{a}	43.91^{a}	0	48.76^{a}	51.06^{a}	45.12^{a}	49.19^{a}
Ulmus glabra Hudson	0	9.75^{a}	12.33^{a}	14.5^{a}	13.08^{a}	0	5.51^{a}	7.31^{a}	7.87^{a}	6.67^{a}
Mean	17.33^{b}	25.04^{a}	23.36^{a}	22.61^{a}	23.18^{a}	17.1^{b}	22.73^{a}	25.26^{a}	24.47^{a}	23.43^{a}

environmental influence on species distribution. The first (0.963) and second (0.572) axes having the highest eigenvalues accounted for 84 % of the variation. High correlation between species and environmental factors were observed for the first (0.995) and second (0.925) axes. Forward selection of the variables in the CCA ordinations showed that the woody species composition were primarily affected by elevation, distance from river, N, P, K., Ca, Mg, OC,OM, SP and litter (Table 6). The results of the CCA analysis of woody species indicated that the species with the highest density in the riparian areas, such as *Alnus subcordata*, *Acer velutinum*, *Acer cappadocicum*, *Fraxinus excelsior*, *Laurocerasus officinalis*, *Ilex spinigera*, *Aruncus vulgaris* and *Danae racemosa*, were most correlated with percent soil saturation, clay, silt and litter content, and C/N ratio. Species that had the highest density within the interior forest, such as *Tilia platyphyllos*, *Ulmus glabra*, *Carpinus betulus*, *Parrotia persica*, *Diospyros lotus*, *Fagus orientalis*, *Ruscus hyrcanus* and *Crataegus microphylla*, were most correlated with soil pH, sand content, total neutralizing value (TNV), and concentrations of phosphorus, organic carbon, nitrogen, potassium, calcium, magnesium and organic

Fig. 1 Diameter distribution for all tree species (more than 7.5 cm) in 0, 50, 100, 150 and 200 m distances from the river in the study area



matter and distance from the river. *Acer campester*, *Carpinus orientalis*, *Malus orientalis*, *Pyrus communis*, *Quercus macranthera*, *Berberis vulgaris*, *Crataegus pentagyna*, *Euonymus*, *Juniperus communis*, *Lonicera iberica*, *Prunus divaricata*, *Frangula grandifolia*, *Rosa pulverulenta* and *Viburnum lantana* were correlated with the elevation factor and were located in high elevations (Fig. 2).

Table 3 Mean shrub density (N/ha) by species

Species	Distance from the river [m]				
	0	50	100	150	200
Aruncus vulgaris Raf.	38.16	0	0	0	0
Berberis vulgaris L.	20[a]	13.33[b]	10.67[b]	12.5[b]	10.25[b]
Cornus australis C. A. Mey.	4.16[a]	2.5[a]	0	0	0.83[a]
Crataegus microphylla C. Koch	9.33[b]	52.5[a]	53.5[a]	49.83[a]	47.55[a]
Crataegus pentagyna Waldst. and Kit. ex Willd.	11.83[a]	12.66[a]	12.67[a]	13.33[a]	14.33[a]
Danae racemosa (L.) Moench	20.83[a]	4.67[b]	6.67[b]	8.33[b]	10[b]
Euonymus latifolia	15[a]	5.83[b]	9.16[b]	5.83[b]	8.83[b]
Frangula alnus Miller	14.16[a]	5[b]	8.67[b]	7.5[b]	5.83[b]
Frangula grandifolia Fisch. and Mey.	5.83[a]	0.83[a]	0	0	1.66[a]
Ilex spinigera Loes	20.33[a]	7.5[b]	4.16[b]	4.16[b]	5[b]
Juniperus communis L.	4.33[a]	2.33[a]	1.67[a]	2.5[a]	4.16[a]
Laurocerasus officinalis Roemer	28.33[a]	6.33[b]	3.33[b]	3.33[b]	4.16[b]
Lonicera iberica M. Bieb.	14.45[a]	6.33[b]	9.5[b]	10[b]	8.33[b]
Mespilus germanica L.	14.16[a]	5.16[b]	5[b]	7.5[b]	7.5[b]
Prunus divaricata Ledeb	15[a]	16.66[a]	20[a]	16.66[a]	17.33[a]
Rosa pulverulenta M. Bieb.	9.16[a]	8.83[a]	12.5[a]	9.16[a]	13.33[a]
Ruscus hyrcanus Woron.	1.67[b]	30[a]	28.03[a]	33.83[a]	32.16[a]
Smilax excelsa L.	3.33[a]	0	0	1.67[a]	0
Vaccinium arctostaphylos L.	3.33[a]	3.33[a]	0	0	1.67[a]
Viburnum lantana L.	23.61[a]	6.66[b]	3.33[b]	3.33[b]	5.83[b]
Total	277.39[a]	195.12[b]	188.86[b]	189.46[b]	198.75[b]

Table 4 Mean tree regeneration density (N/ha) by species

Species	Distance from the river [m]				
	0	50	100	150	200
Acer campester L.	5[a]	5[a]	3.33[a]	4.16[a]	3.33[a]
Acer cappadocicum Gled.	132.5[a]	33.55[b]	29.2[b]	35[b]	28.15[b]
Acer platanoides L.	0	0	0	1.67[a]	1.67[a]
Acer velutinum Boiss.	162.5[a]	41.71[b]	42.5[b]	38.86[b]	45[b]
Albizia julibrissin Durazz.	0	0	0.83	0	0
Alnus subcordata C. A. Mey.	75[a]	38.45[b]	37.5[b]	40[b]	36.67[b]
Buxus hyrcana Pojark.	0	4.16	0	0	0
Carpinus betulus L.	15[b]	73.35[a]	72.6[a]	75[a]	78.15[a]
Carpinus orientalis Miller	4.16[a]	3.33[a]	5[a]	7.5[a]	6.11[a]
Cerasus avium (L.) Moench	0	0.83	0	0	0
Diospyros lotus L.	33.36[a]	32.5[a]	34.17[a]	30.83[a]	35[a]
Fagus orientalis Lipsky	89.16[b]	697.75[a]	691.44[a]	694.07[a]	701.5[a]
Ficus carica L.	2.5	0	0	0	0
Fraxinus excelsior L.	44.16[a]	25.83[b]	27.5[b]	26.66[b]	24.16[b]
Gleditschia caspica Desf.	0	0	0	0	1.66
Juglans regia L.	0	0	0	0.83[a]	0.83[a]
Malus orientalis Ugl.	3.33[a]	0	4.16[a]	1.66[a]	1.66[a]
Morus alba L.	0.83	0	0	0	0
Parrotia persica (DC.) C. A. Mey.	37.71[b]	83.87[a]	85[a]	87.83[a]	88.08[a]
Pterocarya fraxinifolia (Poir.) Spach.	3.33[a]	0.83[a]	0	0	0
Pyrus communis	1.66[a]	0	0	4.16[a]	4.16[a]
Quercus castaneifolia C. A. Mey.	5.16[a]	8.33[a]	9.16[a]	8.03[a]	6.33[a]
Quercus macranthera C. A. Mey.	11.16[a]	12.5[a]	13.33[a]	11.16[a]	15[a]
Sorbus torminalis L. Crantz	0	0.83[a]	1.66[a]	0	0
Taxus baccata L.	4.16[a]	7.5[a]	0	0	0
Tilia platyphyllos Scop.	29.88[a]	33.03[a]	31.7[a]	34.13[a]	36.66[a]
Ulmus glabra Hudson	22.65[a]	21.66[a]	24.75[a]	20[a]	22.77[a]
Total	683.21[b]	1,084.48[a]	1,113.33[a]	1,121.55[a]	1,136.89[a]

Discussion

Vegetation composition

In the classification of riparian forest plant communities, two factors – elevation and distance from the river – were important in determining species establishment along an elevational gradient from the river and into the interior forests. Changes in species composition and spatial distribution pattern due to changing elevation is associated with differences in microclimates that affect important regeneration and competition processes (Ajbilou et al. 2006). Oxygen deprivation that occurs during flooding drives selection of species that have adaptive metabolic traits or capabilities in areas near to the river, but disturbance and site conditions change with distance from river to favour the dominance or fidelity of other species to specific site types (Joly 1994). Plants in riparian forests are adapted to two different soil and water environments (i.e. seasonal flooding and drought); however, any changes in flood regime can modify the indicative species of representative plant association even after the establishment of communities (Crawford 1996). Natural disturbances are common in riparian forests and they control the structure and composition and dominance patterns of

Table 5 Classification of riparian and interior forests by indicator species identified using TWINSPAN and ISA analyses of tree and shrub species inventories

Species group	Number of plots	Area	Elevation range [m]	Indicator species
1	8	Riparian	350–600	*Alnus subcordata*, *Fraxinus excelsior*
2	12	Riparian	600–1,000	*Acer velutinum*, *Acer cappadocicum*, *Danae racemosa*
3	64	Interior	350–1,000	*Carpinus betulus*, *Parrotia persica*
4	16	Interior	1,000–1,200	*Tilia platyphyllos*, *Ruscus hyrcanus*, *Crataegus microphylla*
5	14	Riparian	1,000–1,600	*Laurocerasus officinalis*, *Ilex spinigera*
6	10	Riparian	1,600–1,950	*Aruncus vulgaris*
7	96	Interior	1,200–1,950	*Fagus orientalis*
9	24	Interior	1,950–2,150	*Quercus macranthera*, *Carpinus orientalis*
8	16	Interior	2,150–2,400	*Prunus divaricata*, *Crataegus pentagyna*, *Rosa pulverulenta*
10	10	Riparian	1,950–2,400	*Viburnum lantana*, *Berberis vulgaris*, *Lonicera iberica*, *Euonymus latifolia*, *Acer campester*,

these systems by altering the availability of resources or the physical environment (Baker 1992; Naiman and Décamps 1997). In their study of plant communities in Wisconsin, USA riverine systems, Goebel et al. (2006) concluded that physiographic factors especially elevation and hydrogeomorphic processes are important determinants of the composition of plant communities in areas prone to flooding, for example, the valley floor and river edges. Pabst and Spies (1999) in Oregon, USA, Coroi et al. (2004) in the south of Ireland and Goebel et al. (2012) in Michigan, USA found that distance from the stream is one of the most effective factors to determine plant species composition in riparian forest. Goebel et al. (2012) in a research in Michigan, USA and Castillon et al. (2015) in a research in northeastern forests of Mexico found that elevation is the most important factor to determine distribution pattern of plant community. They declared elevation influences precipitation, temperature and soil properties, and these directly affect plant growth.

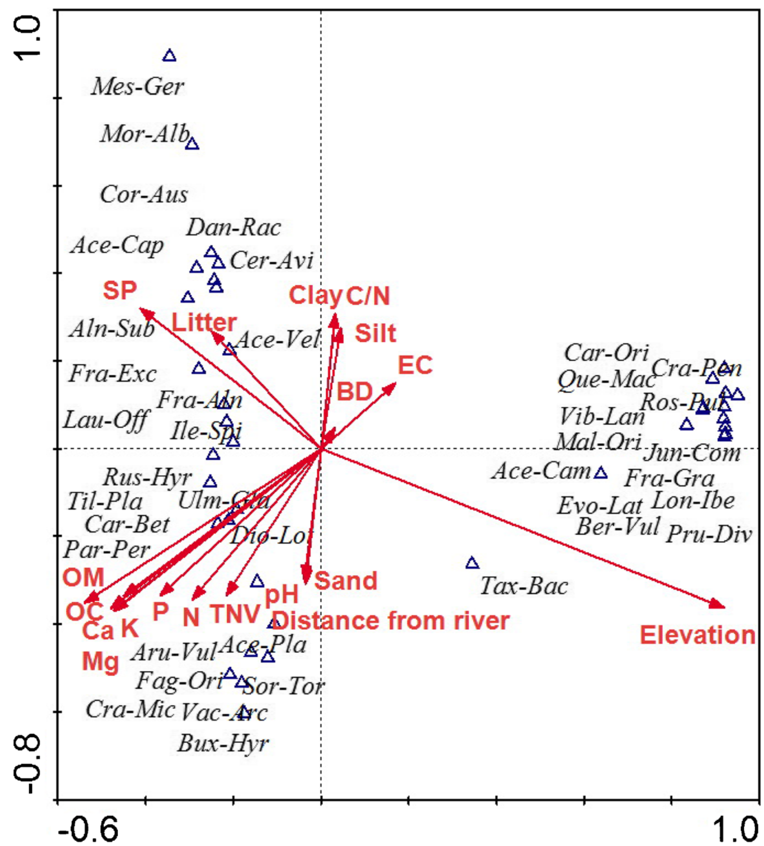
Density

The results showed that density, diameter and basal area in the riparian forest was lower than interior forest, Damasceno-Junior et al. (2005) noted low densities and basal areas in riparian forests in the Pantanal of Brazil. Suzuki et al. (2002) found that tree species density was more in upland stand than riparian stand. Diameter distributions of tree species showed that forest structure is consistently uneven-aged, as indicated by the reverse J-shaped distribution of all species. In fact, proximity to the river did not affect the uneven-aged nature of the forest. Nebel et al. (2001) observed that large diameter trees occurred in low density in natural riparian forests along the river Ucayali in northeastern

Table 6 Marginal and conditional effects obtained from the summary of forward selection in canonical correspondence analysis (CCA)

Variable	Lambda-1	Lambda-A	*P*	*F*
Elevation	0.9	0.9	0.005	10.39
K	0.66	0.6	0.005	7.82
Distance	0.58	0.6	0.005	8.95
P	0.63	0.54	0.005	9.43
N	0.56	0.12	0.025	2.3
SP	0.63	0.1	0.035	1.69
Ca	0.67	0.35	0.05	3.28
C/N	0.57	0.05	0.43	1.01
EC	0.09	0.04	0.57	0.76
Clay	0.56	0.04	0.69	0.73
Mg	0.66	0.45	0.03	1.56
OM	0.68	0.27	0.025	1.42
Silt	0.47	0.02	0.955	0.38
Sand	0.57	0.04	0.72	0.62
OC	0.61	0.3	0.025	1.68
pH	0.57	0.02	0.985	0.28
TNV	0.59	0.01	0.98	0.27
BD	0.05	0.02	0.995	0.22
Litter	0.54	0.01	0.99	0.22

Fig. 2 Canonical correspondence analysis (CCA) ordination of woody species and soil physical and chemical properties of the first two ordination axes in the study area. Full names of species are shown in Tables 1, 2, 3 and 4



Peru resulting in an overall reverse J-shaped diameter distribution and uneven-aged forest structure. For the results in diameter class distribution, similar results were found by other authors (Natta 2003; Wittmann et al. 2008; Sambaré et al. 2011; Adekunle et al. 2013; Šálek et al. 2013).

Patterns in shrub species was quite different than with tree species between riparian and forest interior. Shrub species density was significantly higher in the riparian than interior forests. It appears that shrub species could not compete as well under the higher density and canopy cover of interior forests, and that disturbance regimes in riparian forests that limited tree canopy cover provided more opportunity for shrub development. Villarin et al. (2009) found the largest shrub cover occurred along Cedar River in Washington, USA and concluded that shrub density decreases with distance from the river. Similarly, Šálek et al. (2013) observed that shrub cover decreased with distance from the river in the Czech Republic east.

We found that tree regeneration density in riparian forests was significantly less than that in the interior forests. Successful natural regeneration needs a seed source, favourable seed bed, and adequate light and water, but we did not observe it in the riparian forest. One of the factors that reduces regeneration in riparian forests is the occurrence of frequent flooding over the years, especially in the spring season, which coincides with the beginning of the growing season. Another important determinant of regeneration success is the intensity of interspecific competition among tree-tree seedlings and tree seedlings-shrubs. Because of the significant increase of shrubs in riparian areas, competition for resources such as light and nutrients intensifies between tree seedlings and shrubs. In addition, shading from shrub species of tree regeneration reduces tree seedling density. Hudson et al. (2014) observed that shade by shrubs that invaded the riverbank reduced density and establishment of tree regeneration. Sarr et al. (2011) noted an increase in shrub species in riparian forests that caused increased competition with tree regeneration, resulting in lower tree seedling densities. Another limiting factor of natural regeneration in riparian forests is the reduction in seed supply caused by seed removal by flood waters. Another important factor for regeneration are gaps in riparian forests; if a gap is created in a riparian forest, tree regeneration in the understorey receives more light. This favours species such as *Alnus* sp. because they are shade-intolerant (Marvie Mohadjer 2013). The higher light intensity obtained in forest gaps favours seedling establishment and improves height and diameter growth of seedlings (Collet and Chenost 2006). Collectively, these ecological constraints decrease tree regeneration of the riparian forests in study area. Minore and Weatherly (1994) observed regeneration density was more in the forest interior than at the riverside in Oregon, USA.

Soil properties

Our study of physical and chemical characteristics of the soil showed that there are significant differences between the edge of the river and the interior forest. In Fig. 2, the species that had the highest density at the riverside had positive correlation with soil moisture, clay and silt content, and C/N ratio, and were negatively correlated with the amount of soil acidity, concentrations of nitrogen, phosphorus, potassium, calcium, magnesium, organic carbon, organic matter, TNV and percent sand. High soil moisture content is one of the key factors regulating riparian forests through its influence on many biological processes that become adverse to tree survival and growth when soils are anaerobic. Tree species in riparian forests are affected by physical soil factors and soil moisture (Wei et al. 2010). Clay, silt and C/N ratio were significantly higher and soil pH was lower in the riparian forest than the interior forests.

A problem in riparian forests was the accumulation of litter that occurred because of their location at the bottom of steep slopes. Higher litter amounts reduce microorganism activity, impede air circulation, increase C/N ratios and acidity, and impede decomposition, all which reduces nutrient availability. Stokes et al. (2010) noted that an increase in litter reduce decomposition in riparian forests due to frequency of flooding in riparian areas in east Australia. This is a main reason for lower tree density and impaired regeneration in riparian forests. Soil pH affects species distribution by changing the plant availability of potassium, phosphorus and other nutrients, which affects the occurrence of species in riparian forests (John et al. 2007).

In natural interior forests, the species with the highest densities had the highest positive correlation with soil concentrations of nitrogen, phosphorus, potassium, calcium, magnesium, organic carbon and organic matter, TNV, sand content, and acidity. These species were negatively correlated with moisture, clay and silt content, and C/N ratio. In the interior forest, there is less litter accumulation. This suggests that the lack of flooding disturbances and excessively high soil moisture leads to more adequate conditions for microbial activity, good air flow, lower C/N ratio, favourable rates of decomposition and sufficient amounts of available nutrients that may support greater tree growth than is possible in riparian forests. Although the higher levels of light observed in riparian forests can stimulate decomposition and release of nutrients, flooding, periodic sedimentation and poor drainage can negate these trends in nutrient availability (Everson and Boucher 1998). In a study of Brazilian riparian forests, Budke et al. (2007) stated that local environmental constraints and flooding as regulators of soil chemical and physical properties affected the distribution and abundance of species, reducing the number of species. They reported that nutrients, pH and sand in the riverside had decreased while moisture, clay and silt in riverside was higher.

Conclusion

In this study, we investigated riparian forest attributes and established base-line information in northern Iran. Species composition and community distribution along the river Safaroud are quite different from interior forests. Hydrogeomorphic processes, flooding and elevation were important factors in determining the species composition. These factors may also decrease tree density and regeneration in riparian forests. Because the forests under study are conserved and protected from harvesting, the forest can be used as a good basis for comparing other streamside forests in the north of Iran where have been disturbed. Iran's forest managers can plan for protection of riparian forests through implementation of their conservation programme. First, the riverside forests should be withdrawn and released from government organizations that have promoted uses contrary to sustainable forestry. Since *Alnus subcordata*, *Fraxinus excelsior*, *Acer cappadocicum* and *Acer velutinum* are adapted to these forests, forest managers can use these species for restoration of degraded areas in disturbed riversides in northern Iran that have suffered from high levels of nutrient leaching and soil erosion.

Establishment of native species vegetation can help to maintain biodiversity of riversides.

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