Evaluating the shelterwood harvesting system after 25 years in a beech (*Fagus orientalis* Lipsky) forest in Iran

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ABSTRACT: Beech (*Fagus orientalis* Lipsky) is the most industrial commercial tree species among more than 80 broadleaved trees and shrubs in Hyrcanian forests. In this study some of the silvicultural properties of beech were studied under a shelterwood cutting system in a regeneration unit of 25 years old stand in Sangdeh forests of Iran. Tree height, diameter, canopy cover, variety of species, frequency at different stages of growth (seedling, sapling, thicket and pole) and tree density at juvenile phase were recorded in 431 circular 1,000 m^2 sample plots before and after shelterwood cutting. Results indicated that tree density in the diameter at breast height (dbh) class of < 20 cm increased during shelterwood cutting. Canopy cover of regeneration unit was 78.5% in 1957, while in 2000 and after the shelterwood cutting it reached 59%. Growing stages of regeneration were 14% sapling, 21% thicket, 24% small pole and 41% pole. The shelterwood method has not been very successful in our study area due to a number of technical and potential problems.

Keywords: *Fagus orientalis*; shelterwood; regeneration unit; silviculture; Hyrcanian forest

The total forest area of Iran is approximately 12.4 million hectares, which makes only 7.4% of the total land area. Therefore, Iran is categorized under Low Forest Cover Countries (LFCC). However, it is a rich country from the aspect of plant biodiversity with almost 8,000 vascular plant species. The real temperate commercial deciduous forests, with an area of almost 2 million ha, are extended in the north of Iran, in the Caspian Region, the so-called Hyrcanian forest (Rouhi-Moghaddam et al. 2008).

Beech is the most industrial commercial tree species among more than 80 broadleaved trees and shrubs in the Hyrcanian forests. Oriental beech (*Fagus orientalis* Lipsky) belongs to the beech family (Fagaceae) and is closely related to its European counterpart (*F. sylvatica* L.). In mature stage beech reaches dbh of more than 100 cm and height of about 50 m (Bektas, Güler 2001).

During the last four decades, *Fagus orientalis* stands in the Caspian forests have been managed chiefly using the shelterwood system. In most stands, the shelterwood method has been replaced by the selection method due to technical reasons and particularly the regeneration problem in recent years. In the common shelterwood logging system in Iran, preparatory cutting (an optional initial treatment to increase tree vigour and seed production within a mature stand), seeding cutting (a treatment to establish regeneration throughout the stand area) and light felling are carried out before final cutting (Sagheb-Talebi, Schütz 2002).

Currently, the shelterwood system is one of the primary methods used to encourage the regeneration of oak forests (Hannah 1987). To create the shelterwood for oak regeneration, trees are harvested from below (i.e. from the lower diameter classes first) until the desired overstorey stocking is achieved. Nevertheless, the light level alone probably is not the key factor controlling the growth of oak seedlings during the natural regeneration of oak (Brose, Van Lear 1999).

However, abundant research exists on the breeding bird and salamander community response after shelterwood logging (Augenfeld et al. 2008), shelterwood harvesting effects on root diseases (Quesnel, Curran 2000), shelterwood harvesting impact on forest floor nutrient availability and microbial properties (Bradley et al. 2001), shelterwood cutting effects on water, element fluxes and soil surface CO_2 efflux in a tolerant hardwood ecosystem (Scott et al. 2004) and timber production under the shelterwood system (Pastur et al. 2000).

The aim of the present study was to investigate the shelterwood harvesting system after 25 years in Sangdeh beech (*Fagus orientalis* Lipsky) forests of Iran. Our hypotheses were: (1) The main reason of inaccessibility to forest management plan aims is irregular marking, (2) The performed shelterwood system is not similar to management plan aims, (3) Advance regeneration agreement in a marking process causes the propensity of stands to even age and uneven aged stand structure, (4) Intensive harvesting in the unit reduces the species mixture and conducts stands to pure beech type. The results are expected to provide information and guidance to practical forestry for improved silvicultural systems and natural regeneration of beech forest.

MATERIALS AND METHODS

The study was carried out in the first unit (regeneration unit) of the Sangdeh forest management plan, located in the Farim region in the Hyrcanian forest of Iran and watershed number 64 (36°21'30''N latitude and 52°18'00''E longitude). Minimum altitude is about 1,150 m and the maximum is 1,730 m. The slope inclination with the majority of 0–30% ranges from 0% to 100% (Fig. 1). The Sangdeh forest with an area of 3,879 ha has a regeneration unit (886 ha) which includes 17 compartments (Table 1). Other compartments with a total area of 3,013 ha are

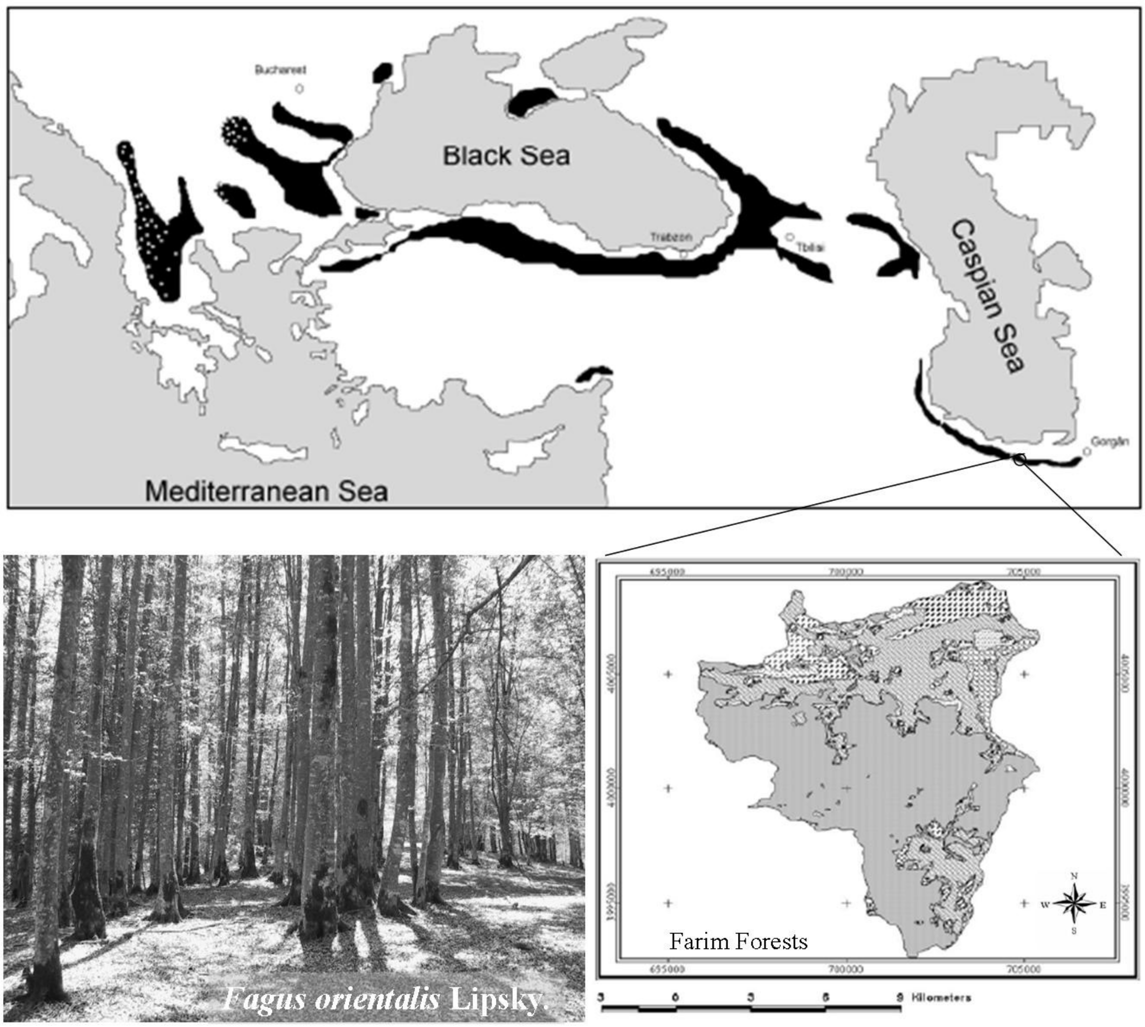

Fig. 1. Ranges of oriental beech and geographical position of the study area

Table 1. Basic information about the compartments of regeneration unit in Sangdeh plan (2000)

No.	Forest area (ha)				Stock growth	
	total	afforestation	protection forest and road	productive	(stem/ha)	(m^3/ha)
30	23.5	5.8	1.0	16.7	281	64.93
31	30.0	6.6	1.0	22.4	355	175.22
32	33.0	9.8	1.5	21.7	172	59.15
33	44.0	19.6	0.5	23.9	183	105.63
34	29.0	20.0	0.5	8.5	195	43.05
35	59.5	13.0	2.0	44.5	223	77.27
36	41.5	8.0	0.5	33.0	173	83.96
37	56.0	12.0	1.0	43.0	249	134.55
38	48.5	27.0	1.0	20.5	194	113.96
39	45.0	19.0	1.0	25.0	105	119.26
40	37.5	2.1	0.5	34.9	140	95.70
41	42.0	–	1.0	41.0	181	113.52
42	35.0	1.1	2.0	31.9	219	135.31
43	40.0	1.0	2.0	37.0	175	92.70
44	61.0	–	3.0	58.0	176	117.44
45	53.0	1.2	4.8	47.0	144	143.14
49	77.0	–	5.0	72.0	222	220.08

improvement units. The region climate is moderate and cold. The mean annual precipitation in this area between 1997 and 2007 is 960 mm and the minimum and maximum temperatures are –6° and 24°C, respectively. The ground is usually snow-covered from late November until late February. Spring migrates from the east side of the Caspian region toward west. Therefore the growth period in eastern parts should be comparably longer. The bedrock type is sandstone, siltstone, claystone and limestone. Soil properties of the study area are shown in Table 2. Forest stands are dominated by *Fagus orientalis* and a shelterwood harvesting system is performed in this site.

Sampling was conducted before and after shelterwood cutting in the regeneration unit according to topographic maps (scale of 1:25,000). The sampling network size was 150 × 200 m and inventory intensity was 3.3%. Also, the distances between sampling strips were 200 m and the distances between circular plots (431 plots) on strips were 150 m according to elevation changes of forest type. The area of plots was 1,000 m^2. Then, start points were randomly selected and the sampling network was systematically located on the map. In each plot all trees with dbh above 12.5 cm and diameter classes of 5 cm were measured with a calliper and the tree coordinates determined. In the sample plots and microplots, tree height, canopy cover, variety of species, frequency at different growth stages (seedling, sapling, thicket and pole) and tree density at juvenile phase were recorded.

Table 2. Mean chemical and physical properties of soil in the regeneration unit of Sangdeh forest

Depth (cm)	Clay (%)	Silt (%)	Gravel (%)	Soil texture	pH	Ec	Organic matter (%)	N (%)	P (%)	K (%)	C/N
0–13	12	30	58	S-L	6.1	0.34	3.43	0.32	5.8	234	11
13–29	23	35	42	L	5.8	0.22	1.19	0.12	1.9	117	10
29–45	28	32	40	C-L	5.8	0.19	0.64	0.06	2.5	130	10
45–80	32	24	44	C-L	6.2	0.24	0.58	0.60	5.2	180	9.5

Table 3. Tree density (n/ha) and volume (m^3/ha) in different compartments of the regeneration unit

No.	Year	Diameter classes (cm)													
		< 20		21–40		41–60		61–80		81–100		> 100		total	
		(n/ha)	(m^3/ha)	(n/ha)	(m^3/ha)	(n/ha)	(m^3/ha)	(n/ha)	(m^3/ha)	(n/ha)	(m^3/ha)	(n/ha)	(m^3/ha)	(n/ha)	(m^3/ha)
30	1975	20	3.1	42	26.4	22	120	24	134	4	44.9	3	36.8	138	366
	2000	245	37.2	34	20.9	1	6.8	–	–	–	–	–	–	281	65
31	1975	2	4.4	48	35.2	59	129	24	135	11	109	4	52.3	148	464
	2000	182	35	162	119	10	21.9	–	–	–	–	–	–	355	176
32	1975	46	6.6	44	35.6	31	78.7	15	85.2	6	66.6	3	31.4	144	304
	2000	145	20.9	23	18.7	2	5.1	–	–	–	–	–	–	172	59
33	1975	60	9.8	91	44.7	37	89.6	14	78.5	14	141	1	21.6	217	335
	2000	106	17.5	62	30.3	13	31.5	–	–	–	–	–	–	183	105
34	1975	18	2.9	115	59.3	26	70.6	22	121	14	146	7	110	202	509
	2000	162	26.3	32	16.7	–	–	–	–	–	–	–	–	195	43
35	1975	97	11.8	98	64.0	37	104	24	134	8	86	2	32.3	266	432
	2000	169	29	49	31.7	5	13.3	1	3.2	–	–	–	–	223	77
36	1975	72	13.6	146	110	47	130	28	155	10	101	4	64.7	307	575
	2000	101	20.4	55	41.4	9	24.9	–	–	–	–	–	–	173	84
37	1975	96	16	87	74.7	31	78.7	23	141	7	75.7	8	131	253	517
	2000	153	25.6	81	68.8	13	33.5	1	6.7	–	–	–	–	249	134
38	1975	36	5.8	54	46.5	40	115	14	114	13	131	8	134	164	546
	2000	137	22.6	47	39.9	8	24	2	13.9	–	–	1	12.6	194	114
39	1975	21	3.5	46	50.8	28	79.5	10	61.2	3	44.3	5	83.6	114	323
	2000	47	7.7	33	36.3	23	65.5	2	9.8	–	–	–	–	105	119
40	1975	47	7.9	50	40.4	29	90.4	25	146	10	102	5	77.2	165	465
	2000	90	15.1	36	28.8	13	38.4	1	4.9	1	8.6	–	–	140	96
41	1975	69	12	152	85.7	73	213	24	158	15	154	4	66.4	337	688
	2000	98	17	69	38.8	13	38.8	1	4.4	–	–	–	–	181	113
42	1975	75	14.9	68	55.6	108	76.3	11	61.2	9	94.8	3	57.2	275	360
	2000	110	21.8	98	80.5	47	32.9	–	–	–	–	–	–	219	135
43	1975	76	13.4	64	50.5	16	137	21	118	3	28.2	1	5.2	181	353
	2000	108	19	58	45.7	3	21.7	–	–	1	10.3	–	–	175	97
44	1975	115	19.6	87	72.7	38	113	3	17.5	12	116	1	7.4	256	346
	2000	100	17	60	49.7	14	42.3	1	8.5	–	–	–	–	176	117
45	1975	77	14.3	67	61.4	40	129	25	174	10	102	1	20.5	220	501
	2000	72	13.4	51	46.6	17	55.1	3	19.7	1	6.4	–	–	144	143
49	1975	59	11.6	110	88.3	54	185	28	188	6	63.6	82	30.2	259	566
	2000	102	20.1	86	69.2	28	97.1	5	33.6	–	–	–	–	222	220
Un.	1975	59	10.1	81	56.8	42	114	20	111	9	94.5	4	56.5	214	450
	2000	116	19.8	25	43.5	13	41.3	4	23.9	1	9.6	1	3.3	189	141

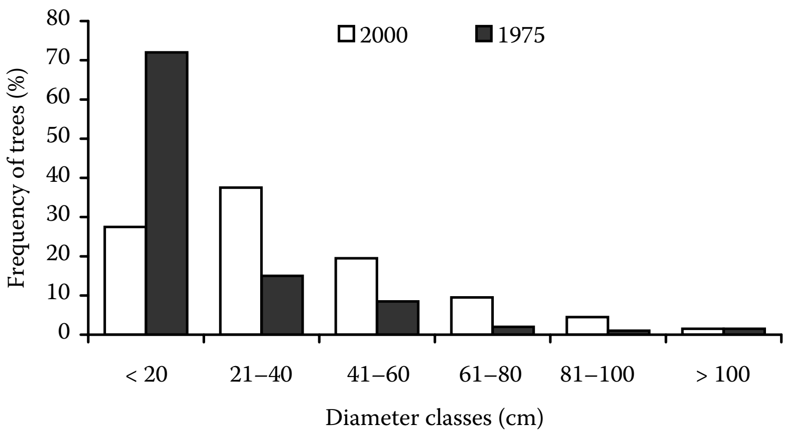

Fig. 2. Frequency distribution of trees in diameter classes before and after shelterwood cutting

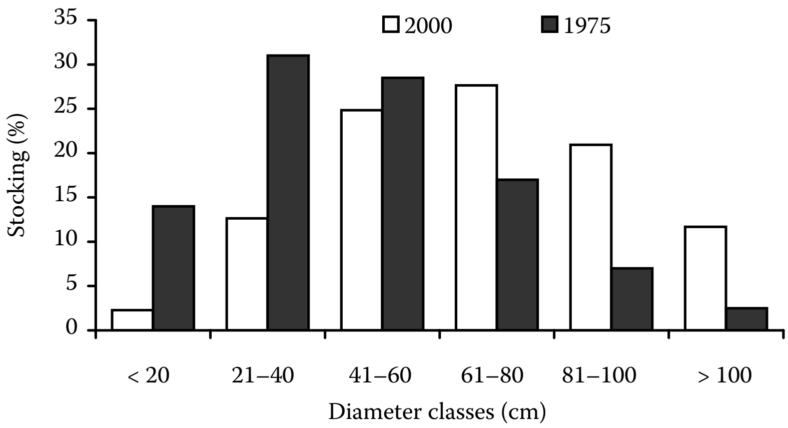

Fig. 3. Stock growth distribution of trees in diameter classes before and after shelterwood cutting

Then, the primary structure and the present structure of forest were compared. Typology and structure of stands created after felling were difference among averages for different parameters were tested at $P < 0.05$ using the least significant difference (LSD) test. SAS software was used for statistical analyses.

RESULTS

The density (number per hectare) of trees in dbh class < 20 cm increased (57 trees/ha) with shelterwood cutting. The density of trees in dbh classes 21–40 cm, 41–60 cm, 61–80 cm, 81–100 cm and > 100 cm decreased during 25 years shelterwood cutting. 11% (25 trees/ha) of tree density in the regeneration unit decreased compared to the primary condition in 1975 (Table 3).

The analysis of tree frequency in diameter classes indicated multi-aged stands. It is obvious that the highest number of trees was distributed in dbh classes < 20 cm, while low numbers of trees were distributed in dbh classes > 100 cm (Fig. 2).

During 25 years, the total volume of stands changed from 450 m^3/ha to 141 m^3/ha. The highest stock growth

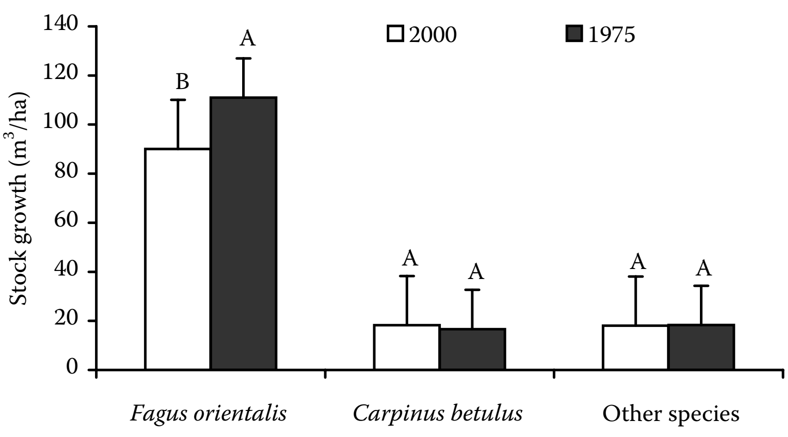

Fig. 4. Mean stock growth of species before and after shelterwood cutting

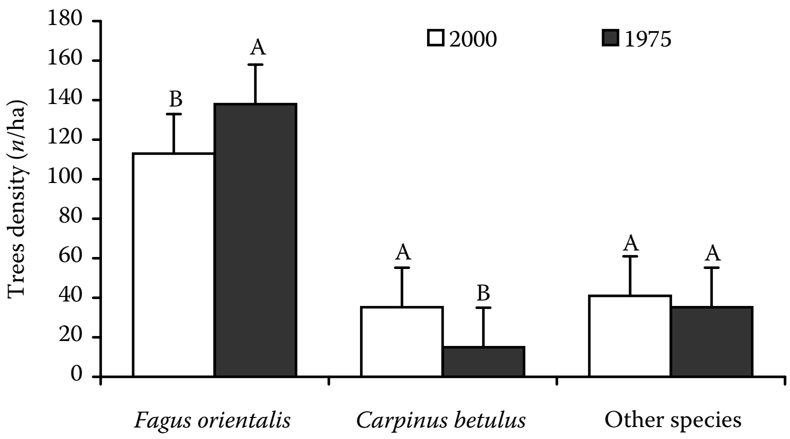

Fig. 5. Species density before and after shelterwood cutting

of trees was distributed in dbh classes 61–80, 41–60 and 81–100 cm after shelterwood cutting, whereas the highest stock growth distribution of trees was in dbh classes 21–40 and 41–60 cm in 1975 (Fig. 3).

The stock growth of *Fagus orientalis* in 1975 was higher than in 2000. The stock growth of *Carpinus betulus* and other species was not changed during 25 years (Fig. 4).

There were significant differences ($P > 0.05$) between *Fagus orientalis* and *Carpinus betulus* density before and after shelterwood cutting (Fig. 5).

Canopy cover was reduced in all the compartments of regeneration unit after shelterwood cutting. The mean canopy cover of regeneration unit was 78.5% in 1957 while it reached 59% after the shelterwood cutting in 2000 (Fig. 6).

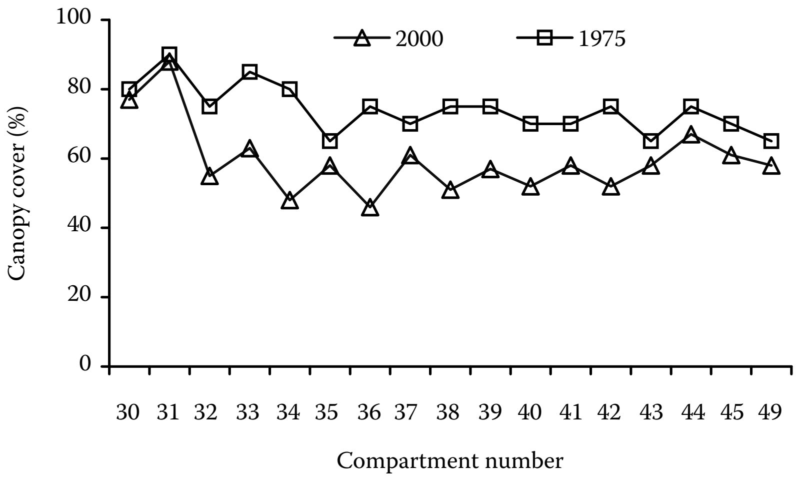

Fig. 6. Canopy cover distribution of trees in compartments before and after shelterwood cutting

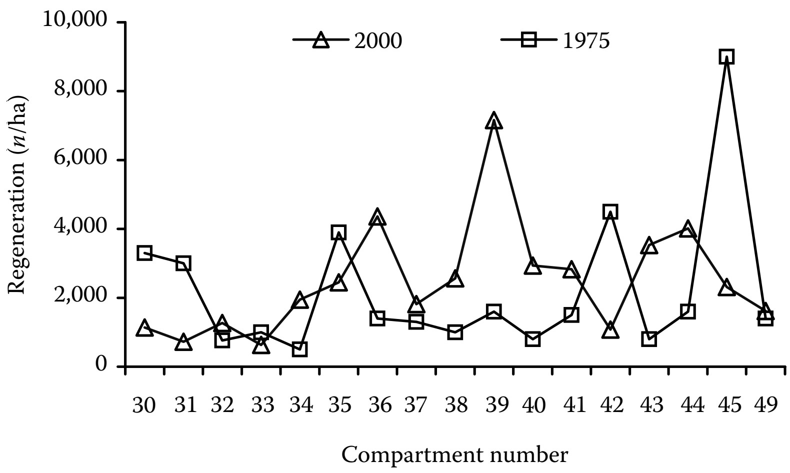

Fig. 7. Regeneration distribution of trees in compartments before and after shelterwood cutting

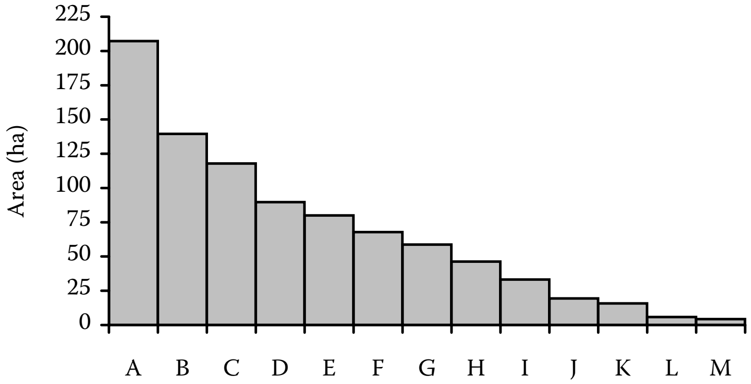

Fig. 8. Land division into the regeneration unit of Sangdeh forest

The regeneration values in most of the compartments increased after a 25-year harvesting period (Fig. 7). Development stages of this regeneration were sapling (14%), thicket (21%), small pole (24%) and pole (41%).

In 2000 the regeneration unit of Sangdeh forests was divided into (A) thicket and small pole area, (B) afforestation, (C) pole, (D) farm land, (E) pole and small pole, (F) sapling, (G) seed trees, (H) intermediate aged stand, (I) afforestation and intermediate aged stand, (J) thicket, (K) afforestation, thicket and sapling, (L) afforestation and seed trees, (M) thicket and sapling (Fig. 8).

DISCUSSION

Both *Fagus orientalis* and *F. sylvatica* L. are widespread and dominant tree species occupying similar ecological habitats. However, each species has a distinct distribution range, *F. orientalis* in Turkey, in the Caucasus Mountains and the Iranian Caspian mountain ranges and *F. sylvatica* in Western Europe reaching from southern Scandinavia southward into the Mediterranean peninsulas (Bektas, Güler 2001). The two distribution ranges overlap in a limited area, mainly in south-east Bulgaria (Pastur et al. 2000).

The results of this study showed that during shelterwood cutting tree density in dbh class of < 20 cm increased. On the contrary, trees density in dbh class of > 21 cm decreased during 25 years (Table 3, Fig. 2). The canopy opening after the shelterwood cut favoured the growth of *Carpinus betulus* seedlings and other light demanding species. From this point, species diversity and mixture in dbh class of < 20 cm increased slowly in the final stages of shelterwood cutting.

After shelterwood cutting, the highest stock growth of trees was distributed in dbh classes of 61–80, 41–60 and 81–100 cm, respectively, whereas dbh classes of 21–40 and 41–60 cm had the higher stock growth in 1975. During 25 years the total volume of the stands changed from 450 m^3/ha to 141 m^3/ha due to the stock growth of *Fagus orientalis* Lipsky. In 1975 it was higher than in 2000 (Figs. 3 and 4). Also, this occurred because at the marking time the age of established regeneration was passed from 25 years old due to advance regeneration and no subsequent interventions. Also, some of the seed trees were protected in clear-cut stage for fear of incomplete regeneration. These factors were repugnant to shelterwood method aims in our study area. In shelterwood logging of a beech forest in Japan, seed trees were left (30 ± 70% by volume) to promote regeneration. Canopy gaps created by this method are usually much larger than those created naturally (Nakashizuka 1984). The seed trees are eventually logged after there has been sufficient regeneration, although few those have actually been harvested in most of the stands managed by this system to date. Shelterwood logging has been reported to make effective beech regeneration more difficult in many Japanese beech forests, but this method might not significantly affect plant species diversity (Nagaike et al. 1999).

Fagus orientalis density (*N*/ha) in 2000 was lower than in 1975, whereas the *Carpinus betulus* and other species density in 2000 was higher than in 1975 (Fig. 5). These conditions show that the shelterwood method has not been very successful in our study area. Canopy cover was reduced in all the compartments of regeneration unit after shelterwood cutting. The mean canopy cover of regeneration unit was 78.5% in 1957 while canopy cover reached 59% in 2000 (Fig. 6). Tabari et al. (2005) reported that most seedlings of *Fagus orientalis* were not discoloured or they were slightly discoloured under gaps of 50, 200 and 600 m^2 and slightly to moderately discoloured in the open. There was a general tendency of higher discoloration in larger openings. It is concluded that small non-regenerated canopy gaps (200 m^2) of beech forests in northern Iran can be restored by planting beech wildings as well as nursery seedlings in small openings, whereas nursery seedlings are preferred in larger gaps (600 m^2).

The regeneration values in most compartments of the unit were increased after a 25-year harvesting period (Fig. 7). Development stages of this regeneration were 14% sapling, 21% thicket, 24% small pole and 41% pole. Infrequent mast years occurring at intervals of five to eight years, closed canopies that rarely produce a fertile seed-crop and a high proportion of infested and predated nuts are natural reasons that add to the regeneration failure in beech forests (Shimano, Masuzawa 1998). This incomplete regeneration is common also in European beech forests which are successfully managed by the shelterwood system and artificial plantation is prescribed to assist natural regeneration (Teissier, Cros 1984).

CONCLUSION

However, the shelterwood method has not been very successful in the North Iranian forests due to a number of technical and potential problems. The presence of livestock in all forests and failure in preventing their entry into the regeneration area, improper felling, incorrect marking, dependence on natural advanced regeneration and improper utilization practices are among the main technical problems. Unfavourable annual regeneration, inappropriate climates such as wet autumns (harmful to ripe seeds on the trees), mild winters with low snowfall (decreasing the shelf time of the seeds), cold springs and late frost (harmful to germination, shooting health and seed tree blooming) could be noted as the main potential problems. Furthermore, frequent droughts, inappropriate beds with acidic humus forms, under-humid or over-humid site conditions, and soil compaction due to the livestock presence, steep slopes unfavourable for seed germination and the naturally irregular structure of the stands and their incompatibility with the even-aged uniform methods also greatly influence the conditions.

Generally, shelterwood is adapted in forests with deep and light soils and slight to moderate inclinations (< 40%). Under these conditions, the ground is favourable for regeneration establishment when shelterwood is applied. As mentioned above, the study site slope ranges between 0 and 100% and the majority of forest area is located on gradient < 30%. The young homogeneous even-aged beech forest which is principally the main goal in the shelterwood method could not be achieved, owing to the above-mentioned conditions, acceptance of the advanced-growth seedlings and saplings and other tree individuals and groups as well as the maintenance of trees on slopes.

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Hodnocení použití metody clonné seče po 25 letech v bukovém (*Fagus orientalis* Lipsky) lese v Íránu

ABSTRAKT: Buk východní (*Fagus orientalis* Lipsky) je nejčastěji průmyslově využívaným druhem z více než 80 druhů listnatých stromů a keřů rostoucích v Hyrkanském pralese. V práci byly studovány některé pěstební vlastnosti buku při použití systému clonné seče. Obnovovanou plochou byla lokalita ve 25 let starém Sangdehském lese v Íránu. Výška a průměr stromu, pokrytí porostem, rozmanitost druhů, četnost výskytu v jednotlivých fázích růstu (semenáček, odrostek, mlazina, tyčovina) a hustota stromů v mladém porostu byly zaznamenány na 431 kruhových zkušebních stanovištích o rozloze 1 000 m^2 před clonnou sečí a po ní. Výsledky naznačují, že hustota třídy stromů s průměrem ve výčetní tloušťce (dbh) < 20 cm se během použití systému clonné seče zvýšila. Vegetační pokryv obnovované plochy v roce 1957 činil 78,5 %, zatímco v roce 2000 a po použití clonné seče dosáhl 59 %. Růstové fáze obnovy byly zastoupeny následovně: 14 % odrostků, 21 % mlaziny, 24 % tyčkoviny a 41 % tyčoviny. Metoda clonné seče nebyla v námi testované lokalitě příliš úspěšná kvůli mnoha technickým i dalším problémům.

Klíčová slova: *Fagus orientalis*; clonná seč; obnovovaná plocha; pěstování lesů; Hyrkanský prales

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