Estimating stand density and condition with the use of picture histograms and visual interpretation of digital orthophotos

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Prethodno priopćenje

ESTIMATING STAND DENSITY AND CONDITION WITH THE USE OF PICTURE HISTOGRAMS AND VISUAL INTERPRETATION OF DIGITAL ORTHOPHOTOS

PROCJENA OBRASTA I STANJA SASTOJINE UPORABOM HISTOGRAMA SLIKE I VIZUALNOM INTERPRETACIJOM DIGITALNOG ORTOFOTA

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The paper presents the possibilities of using histograms of a stand scene and visual interpretation of a digital orthophoto to estimate stand density and condition. Black-and-white aerial photographs with an approximate scale M ≈ 1:20,000 and 60% overlap, obtained during cyclical survey of the Republic of Croatia, were used for this purpose.

According to research results, there are three basic forms of histograms which may be associated with the corresponding density categories. They may also purposefully be used to estimate the density and condition of a stand. Furthermore, the form of histograms of stand scenes corresponds to stand descriptions.

Stands with normal and poor density may be defined with digital value classes, while stands with density between 0.50 and 0.80 cannot be specified accurately.

Ocular assessment of density based on stand canopy was also made, and firm correlation with concrete density was established, i.e. it was found that canopy may be used as a measure of density.

Key words: cyclical survey, digital orthophoto, picture histogram, density, canopy, stand description

INTRODUCTION
UVOD

The highest benefit is achieved with the least costly data which nevertheless provide information of acceptable accuracy (Oluić, 2001).

Such information has been collected for a relatively long time with remote sensing methods, that is, with visual or computer analyses of aerial or satellite images.

Aerial photographs obtained in the cyclical survey of the Republic of Croatia are available on the Croatian market at a very reasonable price.

These are black-and-white aerial photographs at an approximate scale M ≈ 1:20,000 and a 60%-overlap. It is useful to determine the purposefulness of these photographs in assessing stand density and stand condition.

Density is the most frequently used parameter in quantitative descriptions of stands. Density is one of the most important and the most useful stand parameters which indicate the general condition of a stand. Density by tree species indicates past management but also future planning and implementation of management guidelines.

Stand density may be expressed with the number of trees, the basal area and the stand volume in absolute and relative units. The number of trees is the absolute measure of stand density expressed by the number of trees per hectare. Relative density represents the relation of absolute parameters of a stand (number of trees, basal area, volume) and standard (normal, ideal) parameters (Pranjić and Lukić, 1997).

Canopy is the degree of ground cover and mutual spatial relations of tree crowns in a forest. This is the relation of the crown projection towards the total ground surface, and is expressed in percentages or tens of units. When crown projections cover, for example, 80% of the ground surface, the canopy is 80% or 0.8.

In terms of mutual spatial crown relations, the canopy is assessed ocularly and is subjective as such.

There may be extensive differences between canopy and density. Canopy shows the mutual spatial ratio of trees in a stand and the degree of ground cover. Density gives a reliable measure in terms of basal area - wood mass ratio in a stand. In normally developed stands, canopy and density are identical. In stands developed with a small number of trees from youth, abundant light has allowed the growth of very large crowns and the canopy may be complete or normal, while density may be low (Dekanić, 1983).

In even-aged high forests, complete canopy is almost identical to complete density. This does not mean that a decrease in density is parallel to an equal decrease in canopy. The differences are bigger or smaller according to biological properties of species (so, for example, a beech stand aged 120 years with highly developed crowns may have density of 0.8, whereas the canopy is almost complete). Age may also play a decisive role, together with a relatively significant role of the health status (dry-topped trees), as well as the composition mix of varying species (Klepac, 1983).

As experience shows, terrestrial canopy identification is predominantly related to negative errors, because an assessor is often misled by the space below the crowns and thus estimates a smaller canopy. Identifying canopy with aerial photo appraisal may be linked with positive errors, if small darker gaps among the crowns are interpreted wrongly (Tomašegović, 1986).

Research conducted in this respect (Neumann, 1933, Klier, 1974, Križanec, 1987, Kušan, 1991, Klobučar, 2002) has confirmed firm correlation between canopy and density; in other words, it has been confirmed that canopy may be used as a measure of density.

RESEARCH GOAL
CILJ ISTRAŽIVANJA

The paper is aimed at presenting the possibilities of using a digital orthophoto in the estimation of stand density and stand condition by applying image processing software and visual interpretation.

To achieve the set goal successfully, it is necessary to:

- Delineate subcompartments (stands) in an orthophoto,
- Construct a scene histogram for each subcompartment (stand),
- Define digital classes and complement them with relevant density categories,
- Describe (descriptive key) the basic histogram form for each density category,
- Correlate stand histograms with stand descriptions (O-2 form),
- Recommend the content, functionality and need to describe a stand,
- Establish correlation between the canopy and density,
- Establish correlation between the concrete and the estimated density.

METHOD OF WORK
METODA RADA

Research was conducted in the management unit "Jamaričko Brdo", which belongs to Lipovljani Forest Administration.

To do the research, it was necessary to first construct a digital orthophoto and to vectorize management division.

The procedure of making an orthophoto map is faster and therefore more economical compared to the production of a classical or digital map. In this case, a user assumes the role of a decipherer or interpreter and interprets the presented image from his or her experience. Such maps are exceptionally suitable for various kinds of spatial planning in urbanism, road construction, forestry and water management. An orthophoto is based on an oriented digital photogrammetric image and a digital terrain model. Once constructed, the digital terrain model need not be made again; therefore, the process of creating a map with new images is very fast, which enables continuous monitoring of spatial phenomena and events. The user receives an analogous orthophoto map (paper) and a digital, orthorectified picture which they may use in their GIS or CAD applications. A digital orthophoto is made in the black-and-white technique (greyscale) or in colour (RGB).

The applicability and suitability of both a photo plan and an orthophoto plan depends to a large extent on photographic quality. This quality is crucial not only for the accuracy derived from such a plan, but also for the readability and richness of detail and nuances that can be easily observed and defined with certainty (Braum, 1982).

Since cyclical surveys are conducted with standardised methodologies and means, the quality of photographic material is determined in advance; therefore, the original photograph quality cannot be influenced upon.

Cyclical surveys are done in the winter, when the ground is covered with the least quantity of ground vegetation and the trees are leafless, at the time of the day when the shadows are small and the weather calm.

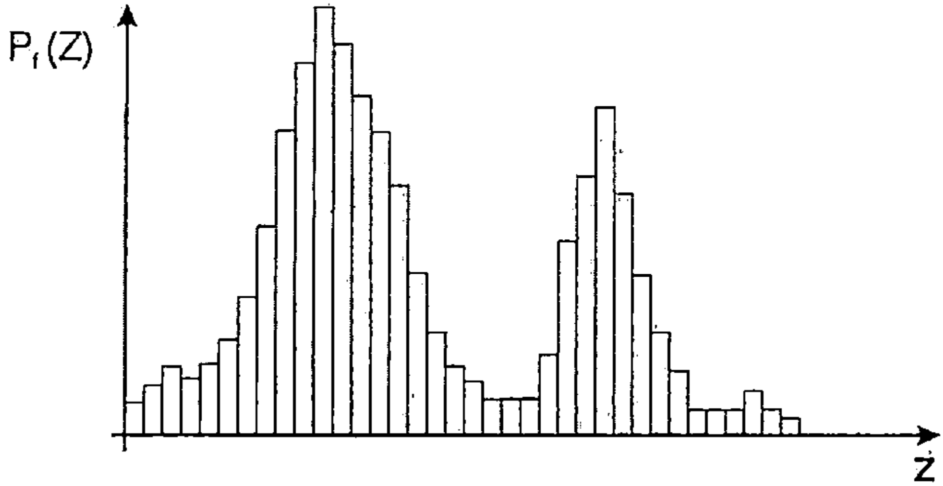
Forest areas not covered with ground vegetation, shrubs and forest trees are reflected in photographs in white or light grey colours, while areas covered with forest trees are reflected in darker tones of grey or in black. In a digital orthophoto, they are pixels in these same colours, or in the corresponding digital values.

A photograph from an individual spectral canal shows reflected electromagnetic energy from the area of the recorded terrain, as well as its distribution in two-dimensional space. Energy is shown with digital numbers that represent varying tones of grey (Oluić, 2001).

A photograph is scanned to be disseminated into a series of rectangular units, so called pixels. A digital datum that is described by a given pixel is the intensity of grey hues ranging from 0 to 255. The value 0 stands for colour black and 255 for colour white. This procedure refers to black-and-white photographs.

A histogram is a graphic representation of numerically expressed values of gray (colour) in the pixels of a scanned photo (Figure 1).

Figure 1. Example of picture histogram
Slika 1. Primjer histograma slike



On the horizontal axis of a histogram, gray values range from 0 to 225 and on the vertical axis there is the total number of pixels with these gray values. Relative relations by separate parts of a histogram are important. Histogram analysis provides reliable data on the quality of a photograph.

To analyse a histogram, attention should be paid to three important rules:

- A histogram should be filled in its entire width, that is, it should incorporate all values from 0 to 225. Gaps in the histogram, like a comb, mean that some tones are absent and that the quality of a photograph is consequently poorer.
- Account should be taken of undesirable accumulation of points with extreme values 0 and 225 (so called black and white point). This does not refer to cases in which the original contains both white and black background, which should be retained as such.
- A histogram should be as smooth as possible, with no sudden oscillations and distinct accumulations in all other values (Vlašić, 1995).

The three rules above are not so important for our research. What is important is to be able to discriminate covered areas (darker colours - lower pixel values) from bare areas (lighter colours - higher pixel values). In the next part of the text we will explain the basic forms of the most common histograms (already drawn), which will clarify the above statement.

a) In the first case (rule), if a histogram contains almost all values from 0 to 225, it means that the histogram has a shape of a longer or a shorter comb, and that stand density is not uniform over the whole area, but that it has a relatively broad valence. In other words, a stand consists of larger or smaller coherent and less coherent groups and clusters of trees interspersed with bare land and failed patches.

Therefore, gaps in the histogram indicate thinned stands of reduced density, which is numerically represented with the mean pixel value that belongs to the right side of the histogram (Figure 2).

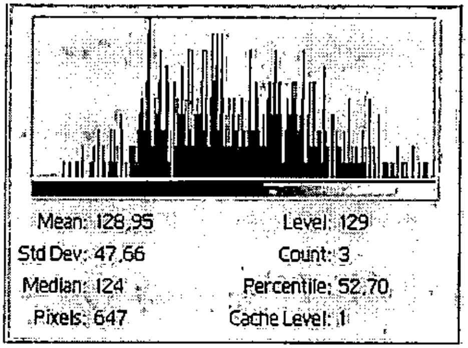


Figure 2. Histogram of 64c compartment
Slika 2. Histogram 64c odsjeka

In our concrete example in subcompartment 64c, the calculated stand density is 0.38 and the canopy is patched.

This histogram analysis, that is, its value distribution, corresponds to the descriptive part, the so-called stand description (O-2 form).

... the stand was damaged by snowbreak over a larger part of the area. The central part of the compartment is almost completely bare, while the edges are covered with thinned groups and clusters. The stand is slightly denser (hornbeam) in the southern part of the compartment, towards the oil well (O-2, 64c).

b) Undesirable accumulations of pixels in extreme values approaching the so-called black or white point in the given histograms are very rare or almost non-

Figure 3. Histogram of 22d compartment
Slika 3. Histogram 22d odsjeka

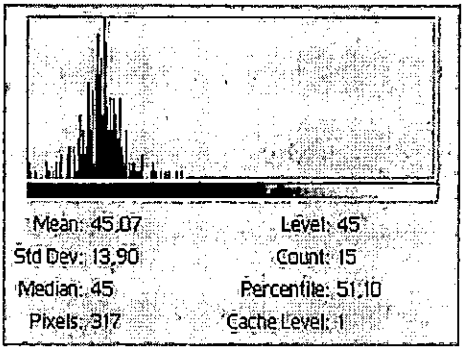
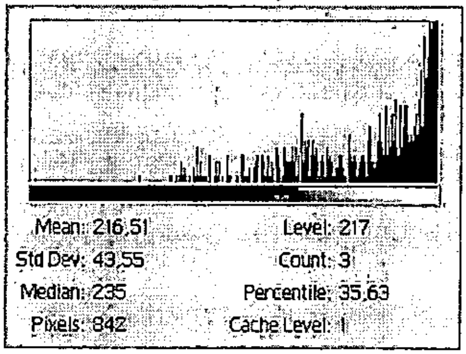


Figure 4. Histogram of 27c compartment
Slika 4. Histogram 27c odsjeka



existent. A histogram with more extreme values relates to the area covered with conifers (Figure 3), and to a bare area (Figure 4).

In cases in which pixel accumulation was closer to the white point, such a histogram would indicate reduced density (Figure 2) or an almost complete absence of forest trees (Figure 4), with which the stand description also corresponds.

A histogram represents a bare productive hunting area covered with grass vegetation and with individual alders on the edges (O-2, 27c).

c) The most frequently produced histograms are those contrasting the third rule. Extreme accumulations of points with a high participation of individual pixel values or levels of grey in the left part of the histogram indicate uniformity of density in a positive sense (Figures 5 - 14), while a histogram with a higher pixel participation in its right part relates to the previously described histograms that indicate reduced density.

Naturally, these histograms correspond to relevant stand descriptions. What is most important, the form of a histogram with the highest number of pixels in its left part, whose digital values are marked with darker colours, corresponds to closed stands with normal density.

This interaction between histograms and stands and normal density has also been confirmed with recent terrestrial measurement and with an equivalent dendrometric list.

These observations have also been confirmed by general histogram analyses.

A scene with a homogeneous area and low contrast will produce a histogram in the form of a simple maximum. A broad simple maximum indicates homogeneity, but with a wide range of contrasts. However, pictures containing several different types of surfaces will have histograms with several maximums (Oluić, 2001).

To carry out this work, a digital orthophoto was constructed. Stand descriptions (Klobučar, 2001) and terrestrial measurement data were used. These data relate to density values obtained from comparing the measured basal areas per hectare with tabular (normal) basal area from Špiranec's yield tables.

Stands in the 1st age class were precluded from this analysis, as well as stands in the management class of black alder, which are unsuitable for this analysis. A total of 83 compartments were analysed.

Since the human eye does not discriminate all 256 levels of the grey tone, or pixel values (0-225), but only some twenty (Oluić, 2001), pixels were grouped into 16 classes with 16 digital values (Table 1).

A histogram was produced for every subcompartment (stand) in the programme Photoshop 6.0, in which, apart from visual perception, it is possible to read mean pixel values (mean), standard deviation (Std Dev) and median (median).

After a histogram has been constructed, and on the basis of the read mean pixel value, arelevant class was associated to the subcompartment. Also, subcompartments were previously grouped according to density categories (NN 11/97):

Table 1. Digital values grouped in classes
Tablica 1. Digitalne vrijednosti grupirane u klase

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
0	16	32	48	64	80	96	112	128	144	160	176	192	208	224	240
1	17	33	49	65	81	97	113	129	145	161	177	193	209	225	241
2	18	34	50	66	82	98	114	130	146	162	178	194	210	226	242
3	19	35	51	67	83	99	115	131	147	163	179	195	211	227	243
4	20	36	52	68	84	100	116	132	148	164	180	196	212	228	244
5	21	37	53	69	85	101	117	133	149	165	181	197	213	229	245
6	22	38	54	70	86	102	118	134	150	166	182	198	214	230	246
7	23	39	55	71	87	103	119	135	151	167	183	199	215	231	247
8	24	40	56	72	88	104	120	136	152	168	184	200	216	232	248
9	25	41	57	73	89	105	121	137	153	169	185	201	217	233	249
10	26	42	58	74	90	106	122	138	154	170	186	202	218	234	250
11	27	43	59	75	91	107	123	139	155	171	187	203	219	235	251
12	28	44	60	76	92	108	124	140	156	172	188	204	220	236	252
13	29	45	61	77	93	109	125	141	157	173	189	205	221	237	253
14	30	46	62	78	94	110	126	142	158	174	190	206	222	238	254
15	31	47	63	79	95	111	127	143	159	175	191	207	223	239	255

- normal density, above 0.80;
- less than normal, from 0.50 to 0.80;
- poor, up to 0.50.

RESEARCH RESULTS AND DISCUSSION
REZULTATI ISTRAŽIVANJA I RASPRAVA

Grouping subcompartments into categories yielded the following results (Tables 2-4):

- Stands with normal density above 0.80 (n=59), table 2.

From the analysis of the above table it ensures that:

1 subcompartment belongs to class 5 (66b)

11 subcompartments belong to class 6 (22a, 22b, 23a, 23e, 35a, 36a, 41a, 55a, 65a, 66a, 67b),

16 subcompartments belong to class 7 (13b, 17a, 21a, 23d, 26a, 27a, 31b, 33a, 34a, 42a, 49a, 54a, 64a, 67a, 68b, 69b),

Table 2. Normal density compartments with relevant classes and statistical values
Tablica 2. Odsjeci normalnog obrasta sa pripadajućim klasama i statističkim vrijednostima

Compartment *Odjel*	Subcomp. *Odsjek*	Density *Obrast*	Mean *Aritm. sred.*	Std. dev.	Median *Medijana*	Class *Klasa*
13	,b	0.94	108.85	27.16	107	7
14	a	0.87	113.91	35.12	111	8
15	a	1.02	114.06	36.94	111	8
16	a	0.86	111.61	31.82	111	8
17	a	0.96	108.74	31.47	106	7
18	a	1.00	130.61	42.44	131	9
19	a	1.11	112.93	35.49	113	8
20	a	1.08	112.01	31.09	110	8
21	a	1.01	111.43	31.46	110	7
22	a	0.89	87.47	17.27	85	6
22	b	0.94	86.96	23.26	88	6
23	a	0.93	93.86	21.90	91	6
23	b	0.85	112.08	25.33	110	8
23	d	0.94	100.36	28.50	99	7
23	e	0.91	95.27	23.15	94	6
24	a	0.94	117.70	34.10	113	8
24	b	0.81	130.09	35.91	128	9
25	a	1.00	117.15	36.84	114	8
26	a	0.85	100.44	22.64	98	7
27	a	0.83	102.38	30.89	98	7
28	a	0.97	119.68	28.01	117	8
29	a	0.89	125.85	41.60	123	8
29	b	0.86	118.84	32.08	121	8
30	a	0.90	134.33	35.69	133	9
31	a	1.01	118.12	30.45	116	8
31	b	0.98	102.53	38.89	101	7
32	a	0.85	124.46	44.11	124	8
33	a	0.89	108.25	33.04	106	7
34	a	0.96	103.87	37.99	100	7
35	a	1.02	84.73	25.12	83	6
36	a	1.03	88.25	18.28	87	6
37	a	0.86	119.99	31.56	118	8
38	a	1.04	137.24	37.38	136	9
39	a	0.97	147.47	38.74	147	10

Nastavak tablice 2.

40	a	0.95	118.84	49.69	118	8
41	a	1.01	83.32	26.66	82	6
42	a	1.02	95.66	26.99	93	7
45	a	0.94	116.81	47.76	113	8
45	c	0.88	175.68	35.46	176	12
49	a	0.83	111.09	34.17	109	7
50	a	0.95	119.75	38.81	117	8
54	a	0.91	110.79	31.70	110	7
55	a	0.91	92.26	29.42	89	6
56	a	0.86	113.37	38.67	110	8
58	a	0.84	129.34	41.45	130	9
59	a	0.95	120.88	33.38	119	8
60	a	0.94	120.51	25.58	119	8
61	a	0.88	111.46	39.39	105	8
62	a	0.85	129.85	28.51	128	9
64	a	0.83	107.64	35.51	103	7
64	b	0.84	125.33	39.61	122	8
65	a	0.96	91.79	28.58	89	6
66	a	0.84	82.90	20.86	82	6
66	b	0.99	76.60	16.19	77	5
67	a	1.01	102.19	25.46	100	7
67	b	0.82	85.85	19.99	85	6
68	b	0.83	98.62	30.25	95	7
69	b	0.94	98.54	33.22	93	7

23 subcompartments belong to class 8 (13a, 14a, 15a, 16a, 19a, 20a, 23b, 24a, 25a, 28a, 29a, 29b, 31a, 32a, 37a, 40a, 45a, 50a, 56a, 59a, 60a, 61a, 64b),
6 subcompartments belong to class 9 (18a, 24b, 30a, 38a, 58a, 62a).
1 subcompartment belongs to class 10 (39a)
1 subcompartment belongs to class 12 (45c).

Stands with normal density are predominant and the majority are found in class 8 or in lower classes (5, 6, 7). Therefore, stands with normal density are associated (defined) with these classes.

The arithmetic mean of mean pixel values is 110.75 and is on the border between class 7 and 8. The highest mean pixel value is 175.68 in subcompartment 45c, while the lowest value is 76.60 in subcompartment 66b.

The analysis of the descriptive part in Table 2 shows that 51 subcompartments or 87% belong to the above classes, whereas only 8 subcompartments or 13% belong to classes higher than 8.

Figure 5. Histogram of 15a compartment
Slika 5. Histogram 15a odsjeka

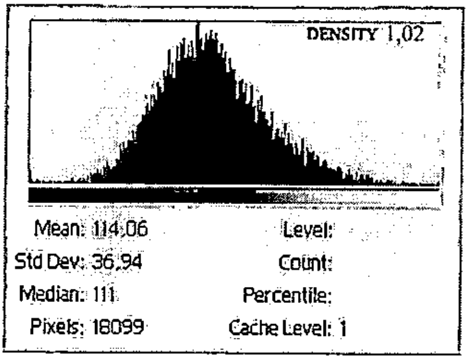


Figure 6. Histogram of 55a compartment
Slika 6. Histogram 55a odsjeka

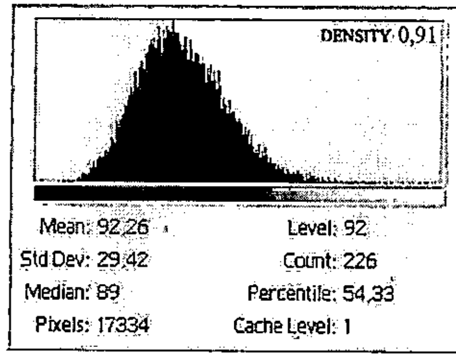


Figure 7. Histogram of 13a compartment
Slika 7. Histogram 13a odsjek

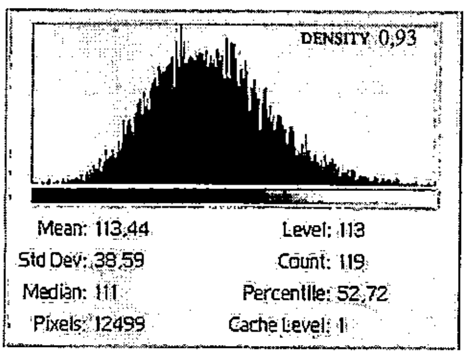


Figure 8. Histogram of 14a compartment
Slika 8. Histogram 14a odsjeka

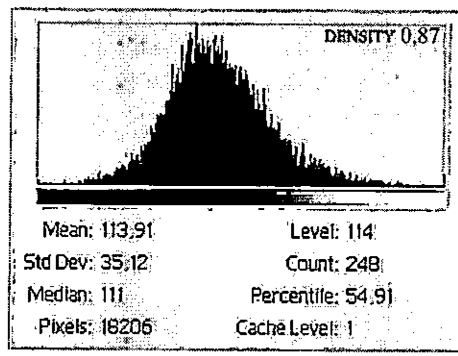


Figure 9. Histogram of 23e compartment
Slika 9. Histogram 23e odsjeka

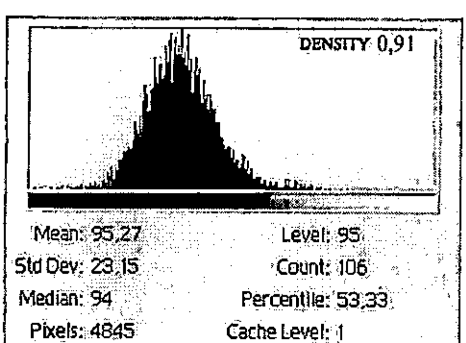


Figure 10. Histogram of 25a compartment
Slika 10. Histogram 25a odsjeka

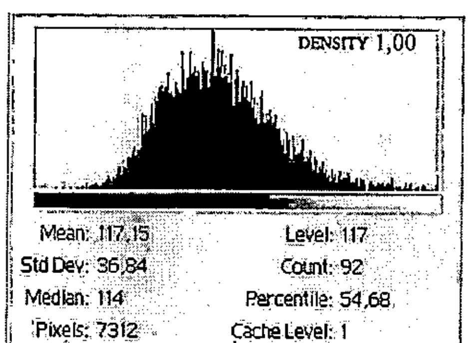


Figure 11. Histogram of 27a compartment
Slika 11. Histogram 27a odsjeka

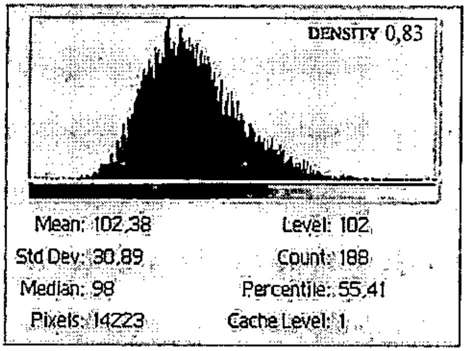


Figure 12. Histogram of 67a compartment
Slika 12. Histogram 67a odsjeka

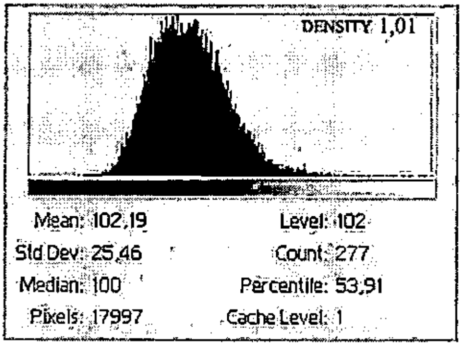


Figure 13. Histogram of 68b compartment
Slika 13. Histogram 68b odsjeka

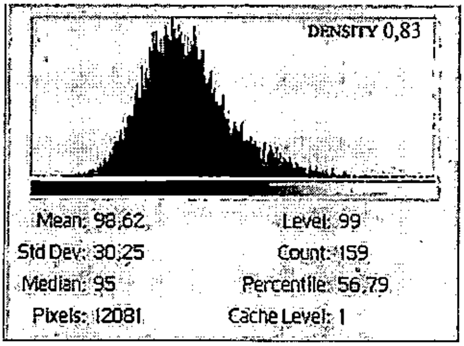
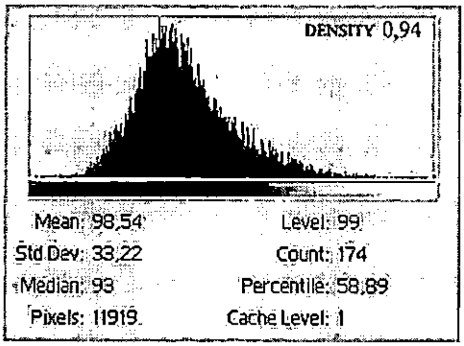


Figure 14. Histogram of 69b compartment
Slika 14. Histogram 69b odsjeka



However, it should be pointed out, (and this fact was already partly discussed (rule c)), that histograms showing scenes of stands with normal density are mostly uniform in appearance and that in form they resemble the normal distribution with a stronger or weaker slant and flatness.

These are simple histograms with one maximum, whose mean pixel values are mostly in the above classes (5, 6, 7, 8) and in which the largest number of pixels belongs to the left side of the histogram, but closer to the centre of the abscissa (Figures 5 - 14).

As seen in the preceding pictures, each histogram has a definite number of pixels which represent lighter values or bare areas. This fact is justified by the fact that density in the majority of Croatian regular commercial forests is lower than 1.0 (0.8 is the statistically average density in regular forests, and the same is valid for the sample management unit). This is considered to be the reason that histograms contain these pixels.

Naturally, there are several histograms with an atypical form (Figures 15-17) with mean values in the quoted classes, which define stands with normal density. Such a histogram form is not accidental; it can be explained with the structure, canopy and tree distribution in a stand, and will indicate to an informant the stand's specific feature and possible exclusions. Such histograms require specific interpretative knowledge, and the explanation of their forms may be read from stand descriptions:

... the stand canopy is complete, sporadically incomplete, less frequently bare (O-2, 32a)

... the stand canopy and density are disrupted by several failed patches and bare land (a slightly larger bare area of about 0.4 ha with a sporadic tree is located among oil-wells) resulting from snowbreak (O-2, 45a).

Since only 13% of the stands do not correspond to the defined classes for normal density, these compartments will be analysed in the next part.

Subcompartment 45c belongs to a high class 12 with regard to the density value of 0.88. This can be explained with the fact that the subcompartment borders with subcompartment 45b (density 0.51), whose structure is disturbed and which belongs to class 11. The border part between these two subcompartments is almost bare and the light pixels (which belong to subcompartment 45c) have affected the increased mean pixel value of subcompartment 45c. Also, the stand in subcompartment 45c has an in-

Figure 15. Histogram of 32a compartment
Slika 15. Histogram 32a odsjeka

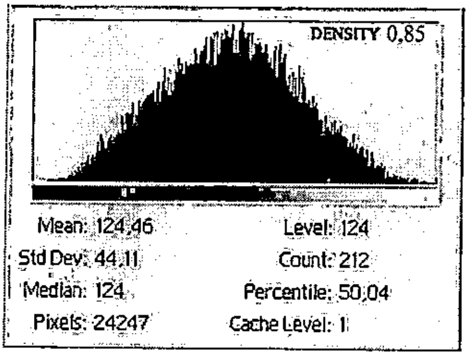


Figure 16. Histogram of 40a compartment
Slika 16. Histogram 40a odsjeka

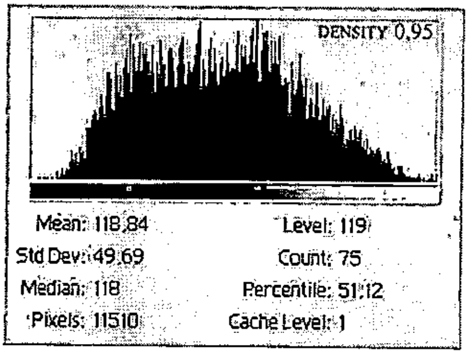
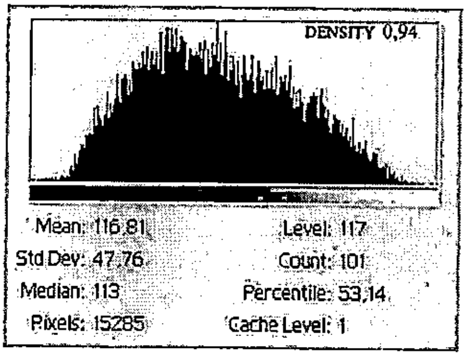


Figure 17. Histogram of 45a compartment
Slika 17. Histogram 45a odsjeka



complete canopy, of medium density and sporadic rare places, a well developed layer of ground vegetation and rare shrubs (O-2), which is an additional indicator of an increased mean pixel value.

Subcompartment 39a has normal density and is in the inappropriate class 10, which defines stands with poor density. One of the reasons for an increased mean pixel value in this subcompartment can be read in the O-2 form, which states that: "due to icebreak on the border with compartment 34, there are several smaller bare areas."

There are reasons why the three compartments of the remaining six are in class 9 (inappropriate), which defines stands of poorer density.

Thus, the stand canopy in subcompartment 18a ranges from incomplete to complete, medium thick and sporadically thin. In subcompartment 38a there are several smaller bare areas, identical to subcompartment 58a, which has affected the increase in mean pixel values. However, the mean pixel value for all three subcompartments is relatively close to the upper boundary of class 8.

There is no adequate explanation for the tree remaining subcompartments (24b, 30a, 62a). It can only be pointed out that the areas of these subcompartments in photographs, or in the digital orthophoto, are seen as a mosaic of lighter and darker variations of grey (Figure 18). Therefore, the lighter tones have affected the increased value of mean pixel.

Figure 18. Histogram of 30a compartment
Slika18. Histogram 30a odsjeka

- Stands with density from 0.50 to 0.80 (n=15)

From the analysis of Table 3, it is clear that:

5 subcompartments belong to class 7 (46a, 47a, 48a, 52a, 57a),

4 subcompartments belong to class 8 (51a, 68a, 69a, 70a),

2 subcompartments belong to class 9 (43a, 53a),

2 subcompartments belong to class 11 (45b, 61b).

Stands with density from 0.5 to 0.8 are found in classes ranging from 7 to 11. Therefore, these are classes that define stands with normal density (class 7 and 8) and classes (9, 10 and 11) that define stands with poor density.

The arithmetic mean of mean pixel values is 129.09 and belongs to class 9. The highest mean pixel value is 170.54 in subcompartment 45b, while the lowest pixel value is 96.44 in compartment 52a.

This is understandable, because stands with such densities, or their scenes, consist of light pixels that represent poorer density and of darker pixels that represent

Table 3. Compartments with density from 0.50 to 0.80 with relevant classes and statistical values

Tablica 3. Odsjeci obrasta od 0.50 do 0.80 sa pripadajućim klasama i statističkim

Compartment *Odjel*	Subcomp. *Odsjek*	Density *Obrast*	Mean *Aritm. sred.*	Std. dev.	Median *Medijana*	Class *Klasa*
44	b	0.70	144.84	43.15	146	10
45	b	0.51	170.54	43.41	176	11
46	a	0.77	110.55	37.62	107	7
47	a	0.71	102.79	44.77	97	7
48	a	0.72	107.38	42.34	102	7
51	a	0.76	117.90	35.36	112	8
52	a	0.77	96.44	28.23	93	7
53	a	0.73	142.87	39.11	142	9
57	a	0.75	107.25	44.06	104	7
61	b	0.64	168.34	43.60	172	11
63	a	0.75	155.07	37.35	156	10
68	a	0.66	124.32	37.18	119	8
69	a	0.75	127.26	35.41	124	8
70	a	0.78	120.30	27.49	118	8

normal density. Depending on the larger number of one or the other pixel group, the compartment is defined with a given class which denotes stands with normal or poorer density.

Thus, stands within this group cannot be specified with certain classes, but reduced density or unfavourable stand structure will be indicated in the form of the histogram.

Figure 19. Histogram of 44b compartment
Slika 19. Histogram 44b odsjeka

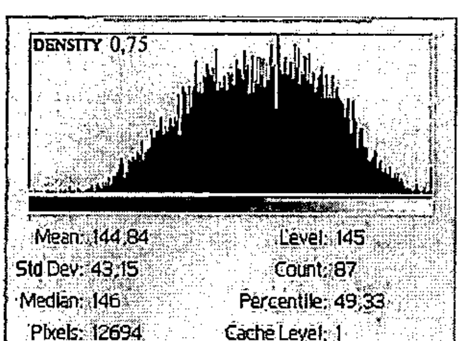
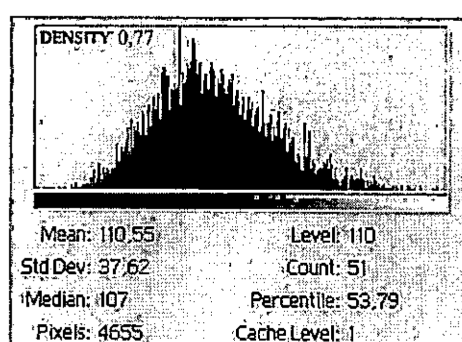


Figure 20. Histogram of 46a compartment
Slika 20. Histogram 46a odsjeka



Stands with density insignificantly lower than normal, whose histograms (Figures 19-29) resemble histograms of stands with normal density but with a higher pixel participation in the right part of the histogram, will belong to the first part of this group.

The second part of this group encompasses stands with significantly reduced density and a disturbed stand structure, which is seen in their histograms (Figures 30-33) of incomplete comb-like forms.

Figure 21. Histogram of 47a compartment
Slika 21. Histogram 47a odsjeka

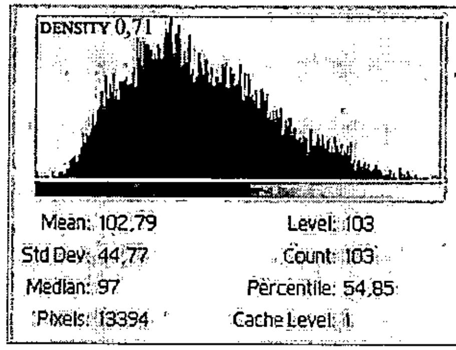


Figure 22. Histogram of 48a compartment
Slika 22. Histogram 48a odsjeka

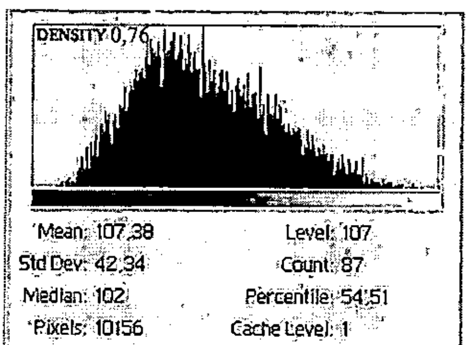


Figure 23. Histogram of 51a compartment
Slika 23. Histogram 51a odsjeka

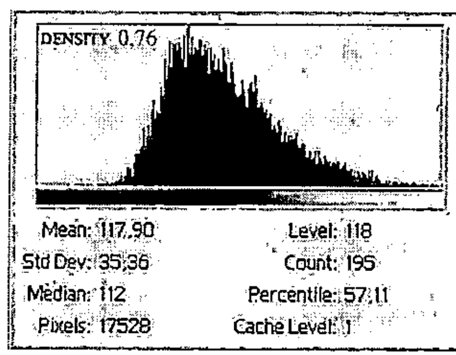


Figure 24. Histogram of 52a compartment
Slika 24. Histogram 52a odsjeka

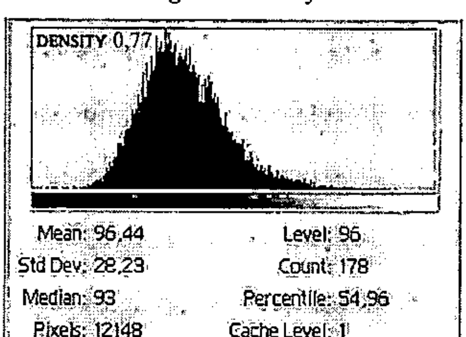


Figure 25. Histogram of 53a compartment
Slika 25. Histogram 53a odsjeka

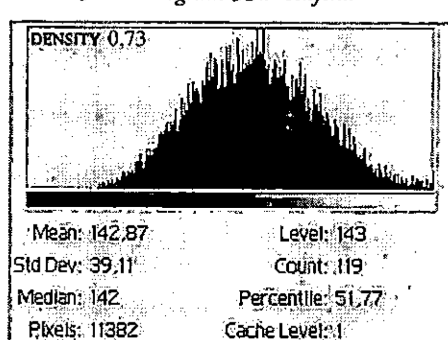


Figure 26. Histogram of 57a compartment
Slika 26. Histogram 57a odsjeka

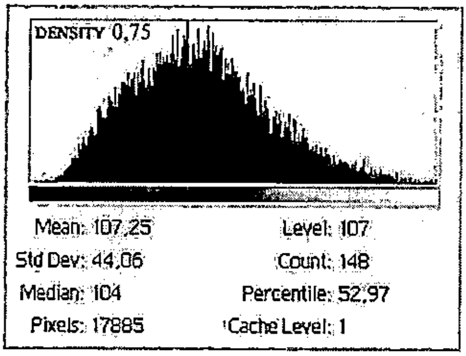


Figure 27. Histogram of 63a compartment
Slika 27. Histogram 63a odsjeka

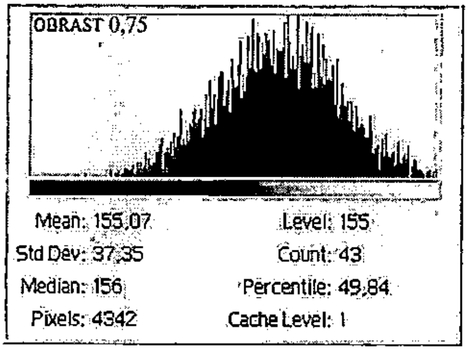


Figure 28. Histogram of 69a compartment
Slika 28. Histogram 69a odsjeka

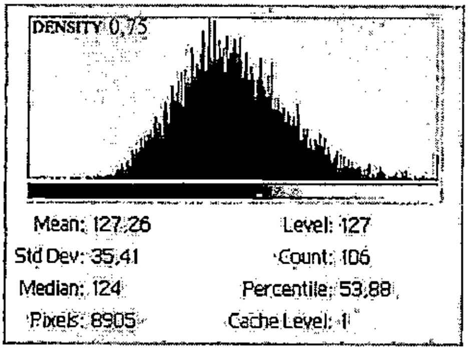


Figure 29. Histogram of 70a compartment
Slika 29. Histogram 70a odsjeka

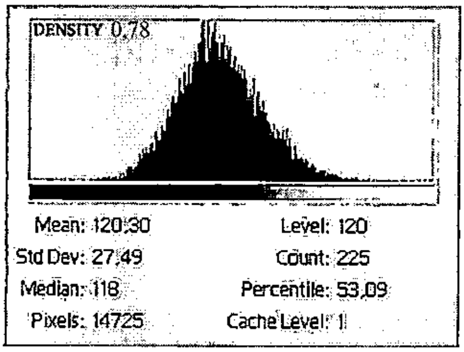


Figure 30. Histogram of 43a compartment
Slika 30. Histogram 43a odsjeka

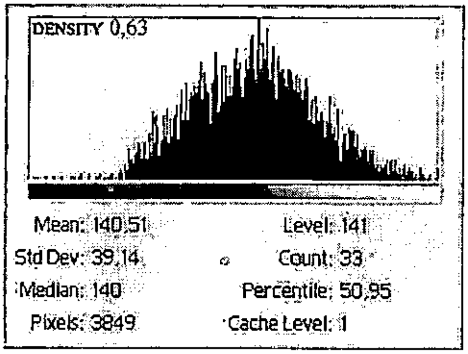


Figure 31. Histogram of 45b compartment
Slika 31. Histogram 45b odsjeka

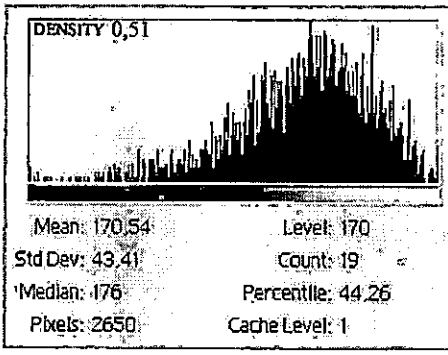


Figure 32. Histogram of 61b compartment
Slika 32. Histogram 61b odsjeka

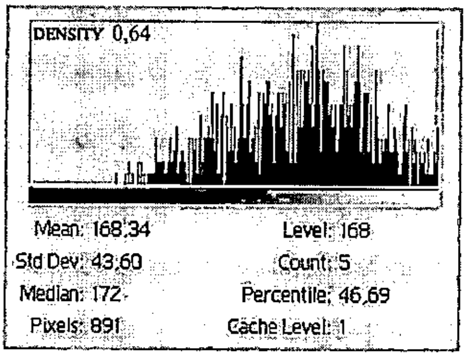
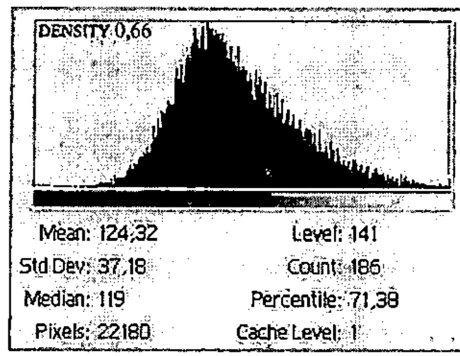


Figure 33. Histogram of 68a compartment
Slika 33. Histogram 68a odsjeka



Naturally, the presented histograms correspond to stand descriptions:

... the stand was damaged across the entire area during snowbreak. Considerable damage was inflicted to the eastern part of the compartment, where a sporadic stocked group or a smaller cluster occurs in several smaller clearings. In the western part of the compartment, there is a succession of bare areas and failed patches with infrequent groups and clusters (O-2, 43a).

... the stand has an incomplete canopy. Some consequences of snowbreak are visible over a smaller area (below "c"). In other words, the canopy is sporadically gapped and there are still some remaining damaged trees (O-2, 44b).

... during snowbreak (on several occasions), the stand structure was disturbed. Barea areas, failed patches and smaller clearings with stocked groups and clusters alternate over a larger part of the area. More coherent and slightly larger stocked areas are found along the openings as well as below the boundary of compartments 46 and 47, while a visually distinct, strip-like, unstocked area extends along the whole compartment. There are still some remaining damaged (bent, dry-topped, rotten, broken etc.) trees (O-2, 45b).

... the stand is medium thick over a larger part of the area. There are some sporadic less dense parts resulting from snowbreak. Damage caused by snowbreak can be seen on hornbeams (to some extent), and the trees are bent (O-2, 46a).

... stand coherence is partially disturbed in the upper part of the compartment (towards compartment 49), since there are several failed patches and smaller clearings resulting from snowbreak (O-2, 48a).

... the stand is medium thick and closed, with an incomplete canopy and with several failed patches occurring during snowbreak (O-2, 51a).

... on the whole, the stand is medium thick and closed; however, there are several failed patches and smaller bare areas brought about by snowbreak from several successive years (O-2, 52a).

... it should be pointed out that the stand is medium thick to thin over its larger part due to snowbreak, with incomplete canopy (O-2, 53a).

... the stand is medium thick, mainly closed (O-2, 57a).

... snowbreaks have led to a disturbed stand structure. Larger or smaller, thinly stocked groups alternate with bare areas in the form of gaps and patches over the whole compartment. The stocked groups are not fully vital, because some trees within these groups are damaged (O-2, 61b).

... the stand is uniform in the sense that the canopy oscillates over the whole compartment and is incomplete on average (O-2, 63a).

..., larger or smaller bare areas and failed patches, less frequently smaller clearings, with stocked (thin to medium thick) groups and clusters, alternate over a larger part of the area (O-2, 68a).

... larger or smaller bare areas and failed patches, and less frequently smaller clearings, with stocked (thin to medium thick) groups and clusters, alternate over a larger part of the area (O-2, 69a).

... there is a smaller clearing (about 0.3 ha) resulting from snowbreak on the boundary with subcompartment 69b (O-2, 70a).

Table 4. Poor density compartments with relevant classes and statistical values
Tablica 4. Odsjeci slabog obrasta sa pripadajućim klasama i statističkim vrijednostima

Compartment *Odjel*	Subcomp. *Odsjek*	Density *Obrast*	Mean *Aritm. sred.*	Std. dev.	Median *Medijana*	Class *Klasa*
44	a	0.49	144.42	49.43	145	10
44	c	0.25	171.18	46.79	169	11
46	c	0.26	108.84	49.87	103	7
48	c	0.22	80.80	38.54	77	6
50	b	0.24	138.28	33.17	135	9
50	c	0.31	132.30	43.10	120	9
51	b	0.26	181.13	33.82	183	12
64	c	0.38	128.95	47.66	124	9

- Stands with poor density up to 0.50 (n=9):
From the analysis of Table 4, it ensures that:
1 subcompartment belongs to class 6 (48c).
1 subcompartment belongs to class 7 (46c)
1 subcompartment belongs to class 8 (22c)
3 subcompartments belong to class 9 (50b, 50c, 64c),
1 subcompartment belongs to class 10 (44a),
1 subcompartment belongs to class 11 (44c),
1 subcompartment belongs to class 12 (51b).

Stands with poor density are defined by classes 9, 10, 11 and 12. It can be noted that not all subcompartments in this group belong to these classes, but that one subcompartment each belongs to class 6, 7 and 8, which define normal density.

The arithmetic mean of mean pixel values is 133.43 and belongs to class 9. The highest mean pixel value is 181.13 in subcompartment 51b, while the lowest mean pixel value is 80.80 in subcompartment 48c.

Subcompartments 48c and 46c belong to classes 6 and 7. These subcompartments have small areas (1.00 ha and 0.67 ha) which are not clearly visible in a digital orthophoto. The boundary of the compartments (which overlaps across the digital orthophoto) depends on the accuracy of mapping and on the accuracy of digital orthophoto geocoding (Klobučar, 2003). It can be concluded, therefore, that small area subcompartments are not suitable for such analyses. For the same reason, compartments in the management class of black alder that take up small narrow areas along streams were also excluded from the analyses.

With regard to the calculated density of 0.48, subcompartment 22e also belongs to a lower class, which does not correspond to the defined class scope of 9-12. This stand is a good example illustrating that there may be big differences between the canopy and density in cases in which stands have developed with a small number of trees, while crowns have developed under abundant quantities of light.

In the concrete example, it is an old, thin beech stand (aged 111 years) with an incomplete to broken canopy and large, branchy crowns. It is these large and branchy crowns that have caused the average pixel value to drop into a lower (8) class than expected. However, the histogram indicates a disturbed stand structure in this subcompartment, too.

The histograms of all these stands also indicate disturbed stand structures and considerable decrease in density. These histograms have the form of a longer or shorter comb (rule a), (Figures 2, 34-41).

Figure 34. Histogram of 22e compartment
Slika 34. Histogram 22e odsjeka

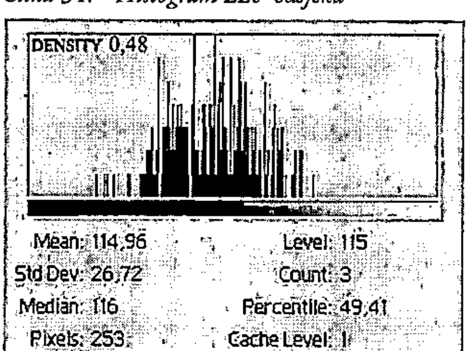


Figure 35. Histogram of 44a compartment
Slika 35. Histogram 44a odsjeka

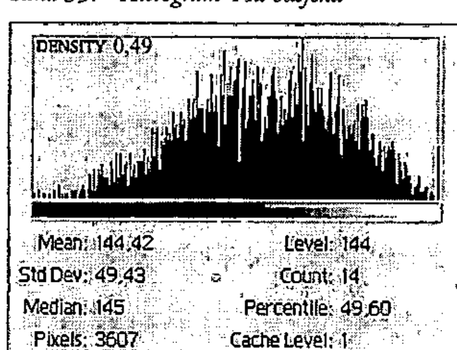


Figure 36. Histogram of 44c compartment
Slika 36. Histogram 44c odsjeka

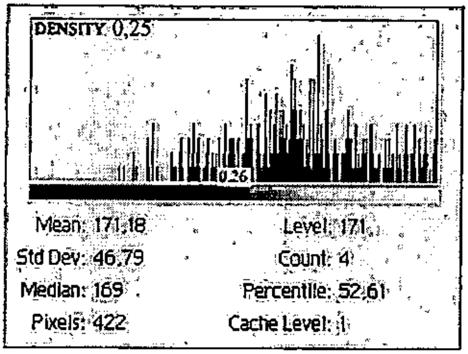


Figure 37. Histogram of 46c compartment
Slika 37. Histogram 46c odsjeka

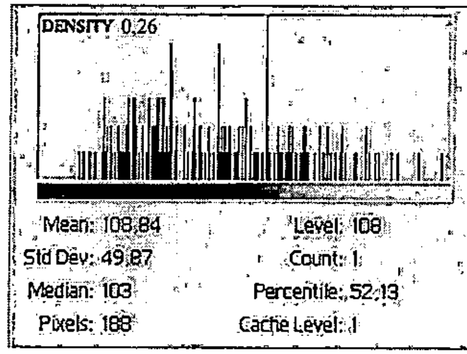


Figure 38. Histogram of 48c compartment
Slika 38. Histogram 48c odsjeka

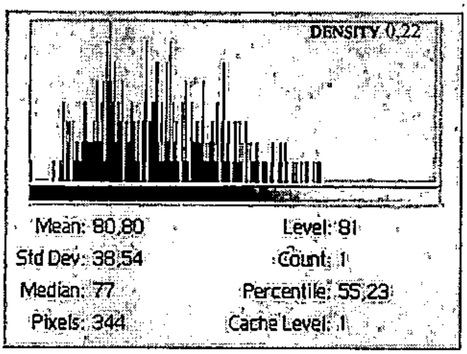


Figure 39. Histogram of 50b compartment
Slika 39. Histogram 50b odsjeka

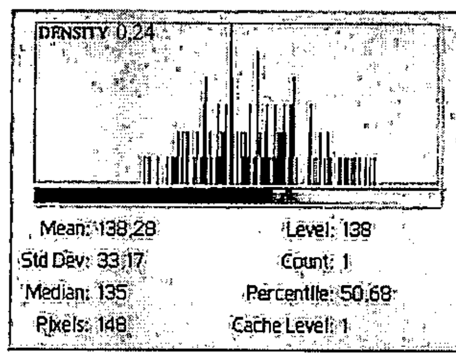


Figure 40. Histogram of 50c compartment
Slika 40. Histogram 50c odsjeka

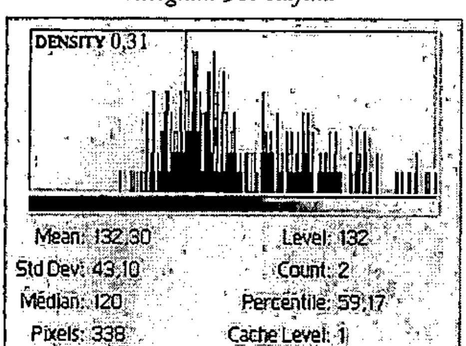
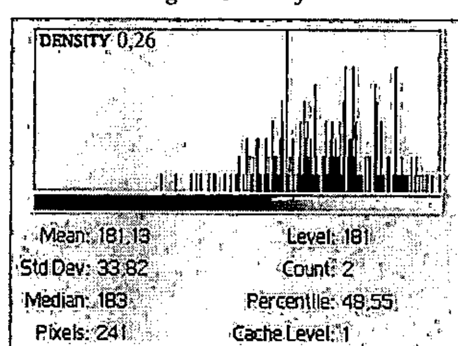


Figure 41. Histogram of 51b compartment
Slika 41. Histogram 51b odsjeka



As in the two preceding groups, the histograms of stands with poor density correspond with stand descriptions and dendrometric lists.

... in the past period, the stand suffered snowbreak on several occasions, which has led to a significant disturbance of its structure. In this sense, the least damage occurred along the very ridge (an opening towards compartment 46), where sessile oaks and beeches with some hornbeams form a more coherent (about 0.4 ha) structure. Snowbreak affected the central part of the compartment most. As a result, in this part of the compartment there is a bare area in the form of a wider or narrower strip containing a sporadic tree or groups of trees. The edge part towards the "b" compartment along the ditch, where hornbeams arranged in thinner or thicker groups have the largest participation, is in the middle between the two above situations (O-2, 44a).

... the stand has been considerably damaged by snowbreak, and is today a thin stand with individual trees or groups of trees (O-2, 44c).

... the stand structure is disturbed, and smaller and mostly sporadic groups dominated by hornbeam with some individual sessile oaks alternate in a mosaic-like pattern (O-2, 46c).

... today, this stand consists only of several smaller remaining groups of hornbeams or individual sessile oaks or beeches (O-2, 48c).

... today, this is a structurally destroyed stand with only two smaller remaining groups of beech and hornbeam trees (O-2, 50b).

... the stand structure is disturbed over the whole area. There are only some sporadic remaining trees towards the "a" compartment and a larger group along the opening with subcompartment 51a (O-2, 50c).

... the stand structure is disturbed over the whole area. There are only some smaller groups or the trees are dispersed individually over the whole area (O-2, 51b).

Dendrometric data themselves, if they are not accompanied with good stand descriptions, do not give a comprehensive insight into the stand condition and do not guarantee the establishment of a functional GIS model, the so called descriptive or attributive part

Apart from general stand features, a stand description should also contain:

- the composition mix and silvicultural form,
- spatial distribution of species in the horizontal and vertical sense,
- the quality and appearance of trees (stems and crowns), the condition of the canopy, density and health status,
- age and diameter structure by species,
- regeneration status,
- a description of the ground layer, etc.

It is clear from the above that a stand description should provide a descriptive interpretation of a dendrometrical list.

The recommended content of a stand description may be used by a forestry expert in prescribing and implementing management guidelines.

The above histograms and descriptive explanations of their forms show that darker pixels, or their digital values, represent tree crowns, and that lighter pixels and their digital values refer to bare areas.

Furthermore, the stands (compartments) grouped according to digital classes and density categories, based on average pixel values and concrete density, provide a very transparent illustration of correlation between digital classes and density categories.

Therefore, individual digital classes or digital pixel values in fact represent the reflected electromagnetic energy from the surface of tree crowns, which are defined by specified density.

These facts were used to do an ocular estimate of stand canopy from the stereomodel and digital orthophoto. As the reasons for possible correlation between density and canopy have been described above, the estimated degree of ground coverage with crowns or crown coverage in fact represents the ocularly estimated stand density.

Thus, all darker colours, in other words, dark grey and black pixels, denote (define) the areas stocked with forest trees; the density of a compartment or a subcompartment whose entire area is darker was 1.0. Of the total compartment or subcompartment area, darker areas representing density are assessed in percentages or hundreds of units; therefore, the compartment or subcompartment is proportionally decreased by the amount of lighter areas.

This estimation method has a drawback; it is not possible to assess density values above 1.00 because this value is held by a stand with a completely dark scene, which is the upper differentiation boundary.

In the concrete management unit, density was estimated according to the described methodology (Table 5, Figures 42, 43).

CONCRETE DENSITY
KONKRETNI OBRAST

$\bar{O}$	0.82	F – test		
Std	0.21	F – cal.		1.44
var	0.04	F – test	(α = 0.01)	1.70
Cv	25.36	F – test	(α = 0.05)	1.45

ESTIMATED DENSITY
PROCIJENJENI OBRAST

$\bar{S}$	0.81	U – test		
Std	0.17	U – cal.		0.32
var	0.03	U – test	($\alpha = 0.01$)	2.56
Cv	21.40	U – test	($\alpha = 0.05$)	1.96
R	0.91			
cov	0.03			

Table 5. The relationship between concrete and estimated density with determined differences
Tablica 5. Odnos konkretnog i procijenjenog obrasta sa utvrđenim razlikama

Compartment *Odjel*	Subcomp. *Odsjek*	Concrete density *Konkretni obrast (O)*	Estimated density *Procijenjeni obrast (S)*	Difference of density *Razlika obrasta*
13	a	0.93	0.85	-0.08
13	b	0.94	0.90	-0.04
14	a	0.87	0.95	0.08
15	a	1.02	0.95	-0.07
16	a	0.86	0.85	-0.01
17	a	0.96	0.85	-0.11
18	a	1.00	0.90	-0.10
19	a	1.11	0.95	-0.16
20	a	1.08	1.00	-0.08
21	a	1.01	0.95	-0.06
22	a	0.89	1.00	0.11
22	b	0.94	0.95	0.01
22	e	0.48	0.60	0.12
23	a	0.93	0.95	0.02
23	b	0.85	0.90	0.05
23	d	0.94	1.00	0.06
23	e	0.91	1.00	0.09
24	a	0.94	0.85	-0.09
24	b	0.81	0.90	0.09

Nastavak tablice 5

25	a	1.00	0.85	-0.15
26	a	0.85	0.90	0.05
27	a	0.83	0.90	0.07
28	a	0.97	0.90	-0.07
29	a	0.89	0.85	-0.04
29	b	0.86	0.90	0.04
30	a	0.90	0.90	0.00
31	a	1.01	0.95	-0.06
31	b	0.98	0.95	-0.03
32	a	0.85	0.80	-0.05
33	a	0.89	0.90	0.01
34	a	0.96	0.90	-0.06
35	a	1.02	1.00	-0.02
36	a	1.03	1.00	-0.03
37	a	0.86	0.85	-0.01
38	a	1.04	0.80	-0.24
39	a	0.97	0.80	-0.17
40	a	0.95	0.75	-0.20
41	a	1.01	0.90	-0.11
42	a	1.02	0.95	-0.07
43	a	0.63	0.60	-0.03
44	a	0.49	0.55	0.06
44	b	0.70	0.65	-0.05
44	c	0.25	0.35	0.10
45	a	0.94	0.80	-0.14
45	b	0.51	0.35	-0.16
45	c	0.88	0.75	-0.13
46	a	0.77	0.85	0.08
46	c	0.26	0.40	0.14
47	a	0.71	0.80	0.09
48	a	0.72	0.75	0.03
48	c	0.22	0.35	0.13
49	a	0.83	0.85	0.02
50	a	0.95	0.80	-0.15

Nastavak tablice 5

50	b	0.24	0.35	0.11
50	c	0.31	0.35	0.04
51	a	0.76	0.75	-0.01
51	b	0.26	0.40	0.14
52	a	0.77	0.85	0.08
53	a	0.73	0.75	0.02
54	a	0.91	0.90	-0.01
55	a	0.91	0.90	-0.01
56	a	0.86	0.90	0.04
57	a	0.75	0.75	0.00
58	a	0.84	0.85	0.01
59	a	0.95	0.90	-0.05
60	a	0.94	0.95	0.01
61	a	0.88	0.90	0.02
61	b	0.64	0.50	-0.14
62	a	0.85	0.90	0.05
63	a	0.75	0.75	0.00
64	a	0.83	0.90	0.07
64	b	0.84	0.75	-0.09
64	c	0.38	0.5	0.12
65	a	0.96	0.85	-0.11
66	a	0.84	0.95	0.11
66	b	0.99	1.00	0.01
67	a	1.01	0.90	-0.11
67	b	0.82	0.90	0.08
68	a	0.66	0.75	0.09
68	b	0.83	0.90	0.07
69	a	0.75	0.75	0.00
69	b	0.94	0.85	-0.09
70	a	0.78	0.90	0.12

Since there is no statistically significant difference between the estimated and concrete density, it can be concluded that canopy can be justifiably used as a measure of density.

Figure 42. Graphic presentation of estimated and concrete density
Slika 42. Grafički prikaz odnosa procijenjenog i konkretnog obrasta

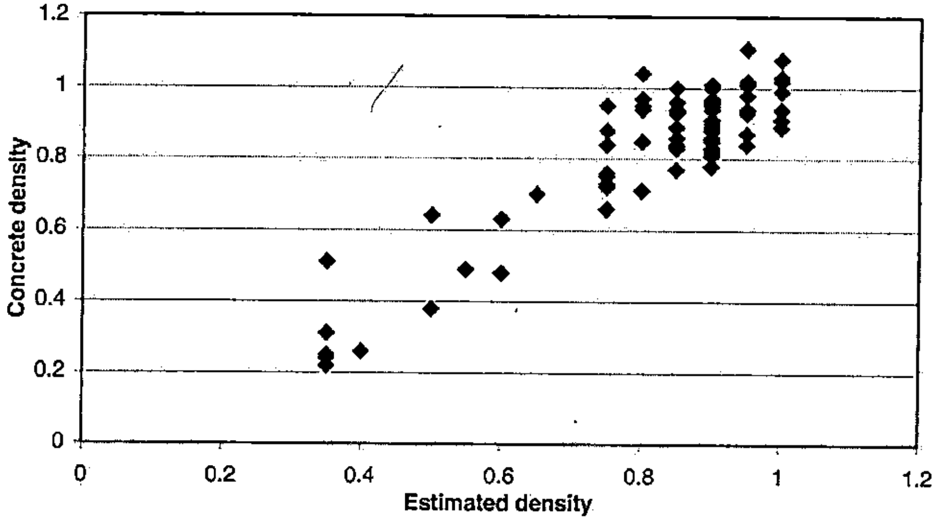
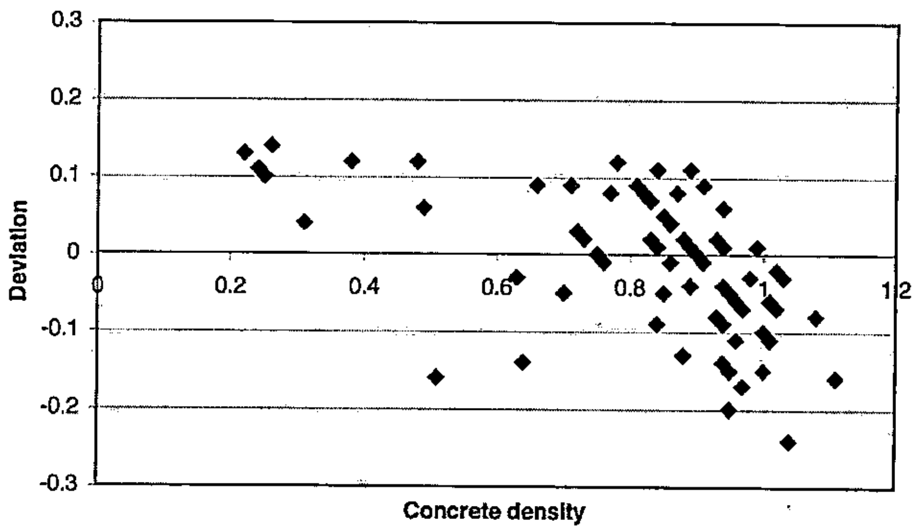


Figure 43. Graphic presentation of concrete density and deviation
Slika 43. Grafički prikaz odstupanja procijenjenog od konkretnog obrasta



CONCLUSIONS
ZAKLJUČCI

Research into estimating stand density and condition with picture histograms and visual interpretation of digital orthophotos was carried out on the example of the management unit "Jamaričko Brdo" in the Lipovac Forest Administration.

Based on the conducted research and the obtained results, the following conclusions may be drawn:

1) A histogram of a stand scene may be used purposefully in evaluating a stand condition and stand density,

2) Stands with normal density are defined with digital value classes 5, 6, 7 and 8, while stands with poor density are defined with classes 9, 10, 11 and 12. Stands with densities from 0.50 to 0.80 cannot be specified with any defined digital value classes,

3) Three basic histogram forms have been constructed which can be associated with adequate density categories,

4) The histograms of stands with normal density are simple, uniform in appearance and have one maximum, in which the largest number of pixels is found in the left part of the histogram closer to the middle of the abscissa.

5) The histograms of stands with densities lower than normal are dual in appearance. Stands in which density is slightly lower than normal have histograms resembling those of stands with normal density, but with a larger number of pixels in the right part of the histogram. Stands in which density is considerably reduced, but not so much as to be poor, have histograms with an incomplete comb-like form.

6) The histograms of stands with poor density have longer or shorter comb-like, easily recognisable forms.

7) The form of histograms of stand scenes corresponds to stand descriptions.

8) Stand descriptions should be informative; in other words, they should interpret and complement dendrometrical data in a descriptive way.

9) There are no statistically significant differences between the estimated and concrete density in the studied example. The calculated correlation coefficient is high (0.91), which indicates firm correlation between the estimated canopy (density) in aerial photographs and concrete density found in the field. It also confirms that canopy may be used as a measure of density.

10) The construction of a digital orthophoto, preferably with a large scale, is recommended for forest management and other forest activities, because it provides the user with a large number of information.

11) This paper illustrates yet another possibility of applying computer technology and remote sensing methods to forestry and to forest management in particular.

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PROCJENA OBRASTA I STANJA SASTOJINE UPORABOM HISTOGRAMA SLIKE I VIZUALNOM INTERPRETACIJOM DIGITALNOG ORTOFOTA

SAŽETAK

U radu su prikazane mogućnosti primjene histograma sastojinske scene i vizualne interpretacije digitalnog ortofota u procjeni obrasta i stanja sastojine, na primjeru gospodarske jedinice "Jamaričko brdo", šumarije Lipovljani.

U tu svrhu korištene su crno-bijele aerofotosnimke približnog mjerila M ≈ 1: 20 000, sa 60% prijeklopom, pridobivene tijekom cikličkog snimanja Republike Hrvatske.

Prilikom kvantitativnog opisivanja sastojine najčešće korištena veličina je obrast. Obrast je jedan od najznačajnijih i najkorisnijih parametara sastojine, koji šumarskom stručnjaku ukazuje na opće stanje sastojine, dok obrast po vrstama drveća ukazuje na dosadašnje gospodarenje, ali i na buduće propisivanje i provođenje smjernica gospodarenja.

Za svaki odsjek (sastojinu) izrađen je histogram u programu Photoshop 6.0, u kojem je pored vizualne percepcije istog, moguće očitati srednje vrijednosti piksela (mean), standardnu devijaciju (Std Dev) i medijanu (median).

Budući da ljudske oči ne razlikuju svih 256 razina sivog tona, odnosno vrijednosti piksela (0-255), nego samo njih dvadesetak, pikseli su grupirani u 16 klasa, po 16 digitalnih vrijednosti.

Nakon izrađenog histograma, te na osnovi očitane srednje vrijednosti piksela, odsjeku je pridružena odgovarajuća klasa. Također, odsjeci su prethodno grupirani prema kategorijama obrasta: normalni obrast, iznad 0,80; manji od normalnog, od 0,50 do 0,80; slab, do 0,50.

Rezultati provedenog istraživanja ukazuju da postoje tri osnovna oblika histograma koji se mogu pridružiti odgovarajućim kategorijama obrasta, te da isti svrsishodno mogu poslužiti u procjeni obrasta i stanja sastojine. Također, izgledi histograma sastojinskih scena korespondiraju s opisima sastojina.

Sastojine normalnog i slabog obrasta mogu se definirati određenim klasama digitalnih vrijednosti, dok se sastojine obrasta 0,50 do 0,80 ne mogu specificirati određenim klasama digitalnih vrijednosti.

Histogrami sastojina normalnog obrasta su jednostavni, jednoličnog izgleda, s jednim maksimumom, kod koji najveći broj piksela pripada lijevom dijelu histograma, bliže sredini apscise.

Histogrami sastojina čiji su obrasti manji od normalnog, po izgledu su dvojaki. Sastojine kod kojih je obrast tek neznatno manji od normalnog, imaju histograme

slične sastojinama normalnog obrasta, ali s većim brojem piksela u desnom dijelu histograma. Sastojine kod kojih je obrast značajnije smanjen, ali ne u tolikoj mjeri da bi bio slab, imaju histograme nepotpunog češljastog oblika.

Histogrami sastojina slabog obrasta imaju duži ili kraći češljasti, lako prepoznatljiv oblik.

Ujedno izvršena je okularna procjena obrasta na osnovi sklopa sastojine, te je utvrđena čvrsta veza sa konkretnim obrastom, odnosno da se sklop može upotrebljavati kao mjera obrasta.

Prilikom uređivanja šuma i drugih šumarskih radova preporučuje se izrada digitalnog ortofota, jer isti korisniku pruža razmjerno dosta informacija, ali po mogućnosti sa snimkama krupnijeg mjerila.

Ključne riječi: histogram slike, digitalni ortofoto, obrast, sklop, opis sastojine, cikličko snimanje.