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Assessing Site Disturbance Using Two Ground Survey Methods in a Mountain Forest

Akbar Najafi, Ahmad Solgi

Abstract – Nacrtak

Assessment of disturbance can provide forest managers with information to make appropriate decisions on site rehabilitation and monitoring. This paper evaluates the accuracy of successive estimates of site disturbance using two ground survey methods. The results from the point transect and grid point transect and grid point intercept methods were compared with the results from an intensive 1x1 m grid survey over a 4 ha study area. The point transect method, using a transect spacing of 30 m, provided the most accurate and consistent estimate of disturbance in the study area. Following the harvest, approximately half of all treated area was disturbed to varying levels. Intact forest floor (undisturbed) and light slash were the dominant surface conditions, covering an average of 70% of harvested area. The results indicate that shallow disturbances (litter left in place or removed) were more frequent than deep disturbances (topsoil removed, subsoil exposed, or rut exposed).

Key words: site disturbance, timber harvesting, survey methods, point transect, grid point intercept

1. Introduction – *Uvod*

In forestry operations, the use of ground-based heavy machinery for harvesting is common practice around the world. Forests are known to be the ecosystems that best protect soils and watercourses (Horswell and Quinn 2003). In forest harvesting, there is an ongoing trend to increase almost constantly the size, power and load of logging machines, with weights that generally amount up to 12–16 tones in unloaded state (Ampoorter et al. 2007). This may cause soil degradation in forest ecosystems as the passes of harvesting machines modify important soil structural characteristics (Greacen and Sands 1980, Corns 1988, Jurgensen et al. 1997, Kozlowski 1999, Grigal 2000, Startsev and McNabb 2000, Makineci et al. 2007). Nevertheless, in commercially managed forests where stands are clear-cut and heavy machinery is used for harvesting and site preparation, the maintenance of forest soil sustainability is greatly questioned because plant cover is disturbed and the risk of erosion intensifies (Aust et al. 1995c, Aust et al. 1997b, Hartanto et al. 2003). Site disturbance may result in degradation of soil properties (increase soil compaction and decrease soil macroporosity, infiltration), and may cause a decline in site productivity (McMahon 1995). The most significant changes have been shown to occur in soil surface layers (Rab 2004, Pennington and Laffan 2004, Yavuzcan et al. 2005); this can restrict the movement of air and water into soil layers (Rab 1994). Soil disturbance is defined as an alteration in the properties of a soil (dry bulk density, porosity, infiltration) (Quesnel and Curran 2000) and can be used as an index of the environmental impacts of logging (Miller and Sirois 1986, Rab 1999a).

It is important to develop a quick and easy procedure to measure the disturbance of the soil caused by forest practices during harvesting and site preparation in order to asses the effects of the use of heavy machinery and to evaluate forest practices. Assessment of disturbance can provide forest managers with information to make appropriate decisions on site rehabilitation and monitoring. In addition, disturbance assessment may also be required by regulatory bodies to assess compliance (McMahon 1995).

However, the assessment recording of a whole area is a complex and time-consuming procedure. It is also evident that there are major problems in having the surveys carried out in a reliable and consistent fashion.

This study was conducted to evaluate the relative accuracy and consistency of two ground survey methods compared to the intensive 1 by 1 m grid survey method and provides an overview of several ground survey methods in a mountainous forest, and also determines the level of impact by visual classification of soil disturbance in comparison with McMahon (1995).

2. Materials and methods – *Materijal i metode*

2.1 The study site – *Mjesto istraživanja*

The study area – Tarbiat Modares University Forestry Experiment Station, located in a temperate forest in North of Iran, between 36° 31' 56'' N and 36° 32' 11'' N latitudes and 51° 47' 49'' E and 51° 47' 56'' longitudes is dominantly covered with *Fagus orientalis* and *Carpinus betulus* stands. Canopy cover has been estimated as 80%, average diameter: 29.72 cm, average height: 22.94 m, maximum extraction distance: 400 m and stand density: 170 trees/ha. Records show that 1500 m^3 of timber was skidded by Timberjack 450C in May 2007 and immediately thereafter the current study was conducted.

2.2 Ground survey methods – *Terenske metode opažanja*

Three ground survey methods have been used by researchers to assess site disturbance (McMahon 1995):

Point transect (PT) method

In this method, disturbance is classified at predetermined points along the survey transect. Intersects are laid generally parallel to the site contours or perpendicular to the contours. Bloomberg et al. (1980) (cited in McMahon 1995) developed a random method of starting point location, which permitted a more statistically valid assessment of variation and sampling intensity. To locate sampling points, a rod is dropped on to the ground surface using the specific chain mark as guide. The coverage (%) of each disturbance class is determined from the number of points in each class and the total number of points sampled.

Line transect (LT) method

Similarly as with the PT method, disturbance along surveyed transects is classified. As disturbances are encountered along the line, their beginning and end points are recorded as shown in Table 1. The lengths of each of the disturbance classes are summed to determine the relative coverage (%) of the net forested area. Transects are evenly located over a site, parallel to the site contours or a combination of two orientations perpendicular to each other. In a variation on these, Turcotte et al. (1991) used randomly oriented transects to define the disturbance within 10x15 m plots. The minimum length that was recorded (0.1 m) was less than that of the minimum width of disturbance (0.5 m). This ensured that all disturbance features could be recognized.

Grid point intercept (GPI) method

In this system, the sampling points are determined based on layout of a randomly systematic square grid. The dimensions of the grid are determined by the size of the area being sampled and an estimated sample size (Rab 1999b).The first transect is orientated randomly, and subsequent transects are orientated at 90°, 180° and 270° from the original.

The study area and the skidding directions are shown schematically in Fig. 1. Disturbance was intensively assessed over the area using a 1x1 m spacing between observation points (Fig. 2a). To satisfy the degree of soil disturbance in harvest coupes, various soil surface disturbance categories have been used (e.g. Bukhiem et al., 1975, Murphy 1982, McMahon 1995, Rab 1999a). The classification scheme used for this study was adapted from that of McMahon (1995). Field observations of the soil were categorized on the basis of visible evidence of disturbance (Table 1). At each point, the predominant disturbance class within a 0.3 m radius was classified according to the scheme shown in Table 1.

The disturbance was then assessed using the PT and GPI methods. The LT method was excluded from the method evaluation as it was considered that identification of boundaries among disturbance classes could be too subjective, introducing excessive variation into the assessment results (McMahon 1995).

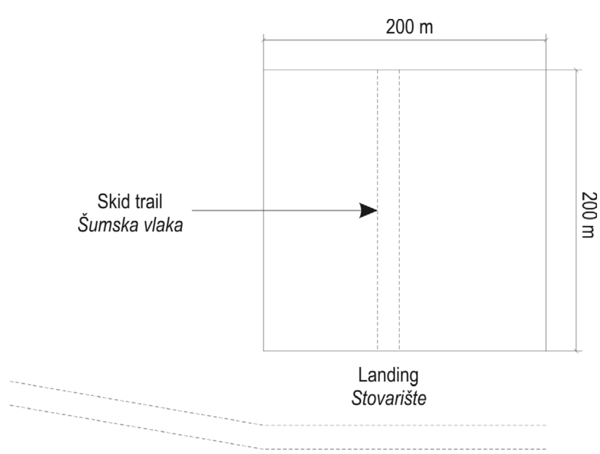

Fig. 1 Study area layout

Slika 1. *Shema mjesta istraživanja*

For the PT method, transect spacing of 30 m (PT30), 50 m (PT50) and 80 m (PT80) were used. Transects were orientated perpendicular to the skidding direction (Fig. 2b).

The first transect was located at a randomly assigned distance from the landing, not exceeding the spacing between subsequent transects. For each transect spacing, the method was repeated three times, each with differently located transects.

In the GPI method, 12 grid points were located within the study area at 60x60 m spacing. The disturbance was classified at 1-m intervals along four 30-m-long transects originating from the grid point. The orientation for the first transect was random, with the second being 180º from the first. The third and fourth transects were orientated at 90º degrees to the first two (Fig. 2c). Where transect crossed outside of the study area, the grid point was adjusted for the affected orientation. The disturbance at the grid point was excluded from the data set (McMahon 1995). The GPI method was applied three times using different grid points and transects orientations each time.

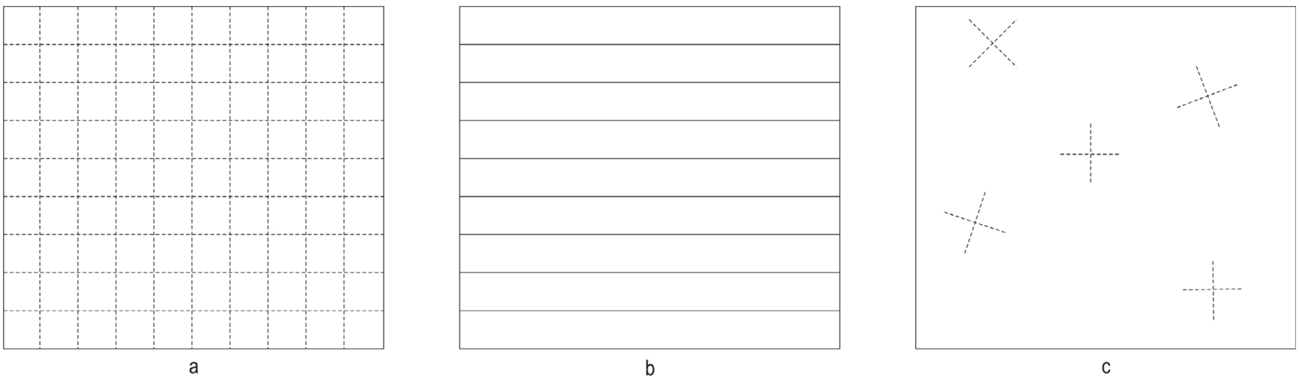

Fig. 2 Illustration of the three survey methods used in the study

Slika 2. *Prikaz triju metoda opažanja primijenjenih u istraživanju*

Table 1 Visual disturbance classification system (McMahon 1995)

Tablica 1. *Vizualni sustav razvrstavanja oštećenja (McMahon 1995)*

Soil disturbance type *Vrsta oštećenja tla*	Description *Opis*		Code *Oznaka*
Undisturbed soil – *Neoštećeno tlo*	No evidence of machine or log passage, litter and understorey intact *Bez traga prolaska stroja ili trupca, listinac i biljni pokrov nedirnuti*		1
Shallow disturbance – *Površinska oštećenja*	Litter still in place, evidence of minor disruption – *Listinac nepomaknut, uočljiv manji poremećaj*		2
	Litter removed, topsoil exposed – *Listinac uklonjen, tlo vidljivo*		3
	Litter and topsoil mixed – *Listinac i tlo pomiješani*		4
	>5 cm topsoil on litter – *> 5 cm tla na listincu*		5
Deep disturbance – *Velika oštećenja*	Topsoil removed – *Premještanje tla*		6
	Erosion feature – *Erozija tla*		7
	Topsoil puddled – *Žitko tlo*		8
	Rut depth – *Dubina kolotraga*	5–15 cm	9
		16–30 cm	10
		>30 cm	11
	Unconsolidated subsoil or base rock deposit – *Nekonsolidarano tlo ili matični supstrat izložen*		12
Slash/understorey residue – *Drvni ostaci, granjevina*	10–30 cm		13
	>30 cm		14
Non-soil (stumps, rocks) – *Panjevi, stijenje*			15
Compacted soil – *Zbijeno tlo*	Evidence of tire, track and/or log passage – *Očitost prolaska gume, gusjenice i/ili trupca*		16

Table 2 Soil disturbance assessment results
Tablica 2. *Rezultati procjene oštećenja tla*

Survey method *Metoda opažanja*	Number of observation *Broj opažanja*	Soil disturbance – *Oštećenje tla*, %		
		Undisturbed and shallow disturbances *Neoštećeno tlo i površinska oštećenja*	Deep disturbances *Velika oštećenja*	Compacted soil *Zbijeno tlo*
		%		
1x1 m	40,000	89.09	1.22	10.91
GPI	1440	90.42	0.78	9.58
PT30	1400	88.68	1.22	11.32
PT50	800	89.13	1.16	10.87
PT80	600	89.78	1.09	10.22

2.3 Data analysis – *Obrada podataka*

For the data sets collected during the 1x1 m PT and GPI surveys, frequency distributions were produced including all 15 disturbance classes (Table 1), as well as the occurrence of compaction. The results for 15 individual classes were combined to represent three types of disturbance: (1) undisturbed and shallow disturbance, (2) deep disturbance, and (3) compaction (McMahon 1995).

The accuracy of the method was defined as »the ability of a measurement to match the actual value of the quantity being measured«. For example, if the outside temperature is 34.0 F and a temperature sensor reads 34.0 F, then the sensor is accurate. The precision was defined as »(1) the ability of a measurement to be consistently reproduced« and »(2) the number of significant digits to which a value has been reliably measured«. If in several tests the temperature sensor matches the actual temperature while the actual temperature is held constant, then the temperature sensor is precise. By the second definition, the number 3.1415 is more precise than the number 3.14.

The accuracy of the PT and GPI methods was assessed by ANOVA, and mean disturbance estimates were compared to intensive 1x1 m grid survey using a Student *t*-test procedure (McMahon 1995). Method consistency was assessed from the magnitude of 95% confidence, which reflected the range of survey results produced when the method was repeated.

3. Results – *Rezultati*

The results of the 1x1 m grid survey were assumed to represent the absolute disturbance within the study area, and thus were considered the standard by which the other methods would be assessed. Using this method, a total of 40,000 observations were made in the study area compared to 1440, 1400, 800, 600 observations for the GPI, PT30, PT50 and PT80 surveys (Table 2). The potential for sampling error within this absolute measure was recognized.

The estimate percentages for slash cover and non-soil area or points have been omitted. Percentages of undisturbed, shallow disturbance, deep disturbance (presented), slash and non-soil (not presented) add up to 100. All results are expressed as a percentage of the total number of observations made for each individual assessment.

Results from each of the methods are shown graphically in Fig. 3 and summarized in Table 2.

Estimate variations in PT and GPI methods are evident in Fig. 3. Comparing the mean estimates with those of 1x1 m survey, it appeared that the PT30

Table 3 Consistency of survey methods
Tablica 3. *Pouzdanost metoda opažanja*

Survey method *Metoda opažanja*	Consistency, % – *Pouzdanost*, %		
	Undisturbed and shallow disturbances *Neoštećeno tlo i površinska oštećenja*	Deep disturbances *Velika oštećenja*	Compacted soil *Zbijeno tlo*
GPI	98.6	33.8	86.5
PT30	99.6	80.1	97.0
PT50	94.4	72.8	54.4
PT80	95.4	73.2	59.6

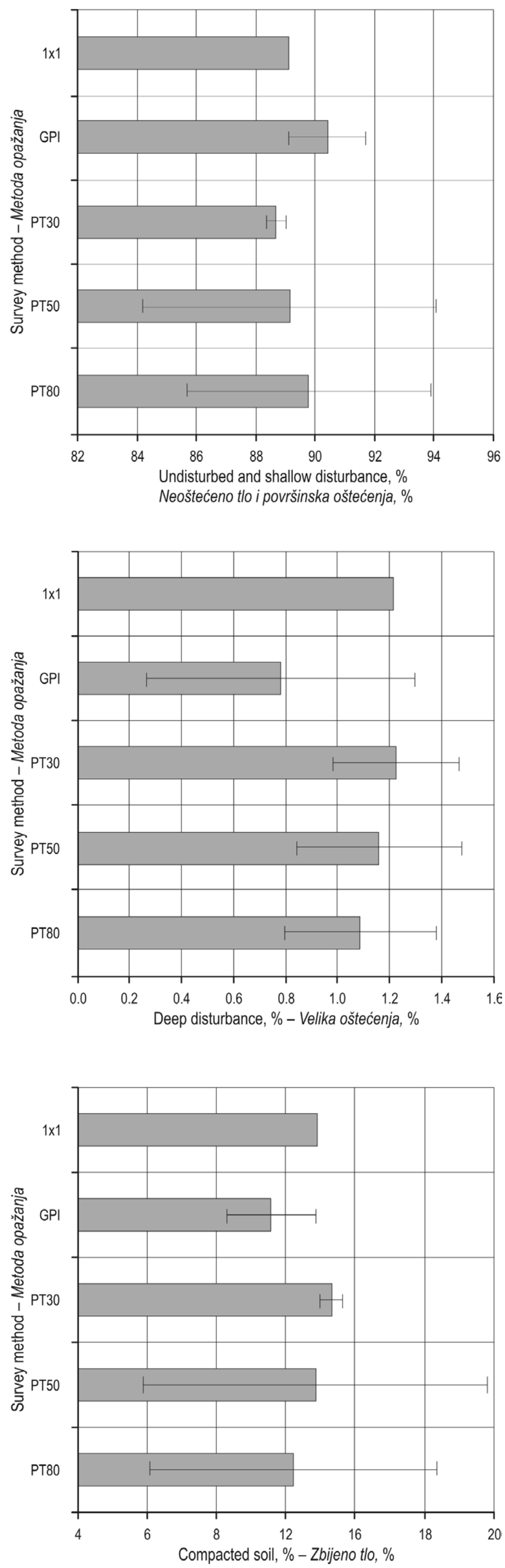

Fig. 3 Selected disturbance results using the 1x1 m survey, mean results and 95% confidence intervals for the PT and GPI methods

Slika 3. *Rezultati opaženih oštećivanja primjenom 1x1 m metodom opažanja i srednje vrijednosti rezultata s 95 % intervalom pouzdanosti primjenom metode pravca točaka i sjecišta mreže točaka*

method consistently provided the most accurate estimates of disturbance.

The consistency of the PT and GPI methods was indicated with the magnitude of 95% confidence intervals attached to the respective mean estimates shown in Fig. 3. For the three types of disturbance, the most consistent method was the PT30.

For three disturbance types, the level of consistency of PT methods decreased as the transect spacing increased from 30 m to 50 m (Table 3).

Results show that most observations (70%) were slash cover (9%) and undisturbed soils (61%). Disturbed soils accounted for nearly 30% of observations with the most comprising shallow (20%) and compacted (8.9%) disturbed classes. Deep disturbed soils accounted for only just over 1.1% of observations. Rutting affected 81% of the deep disturbance classes. Slash residual classes were distributed as 91% Class I (10–30 cm), 9% Class II (>30 cm).

4. Discussion – *Diskusija*

The results showed that accuracy did not always reflect sample sizes. Although there were no significant differences among the mean estimates provided by the three transect spacing for the PT method, there was variation among them (Table 2). The accuracy was not decreased with increasing the transect spacing from 30 m to 80 m and decreasing the sample size. The large sample size of the PT30 method did appear to provide the most accurate estimate relative to other PT methods.

The mean estimates of both PT30 and GPI methods were based on similar sample sizes (1400 and 1440, respectively). However, the GPI method was less accurate than the PT method (Table 2).

The method consistency was not affected by sample size. From three disturbance types, PT30 provided a more consistent estimate than PT50 and PT80 methods. Similar to accuracy, the PT30 method provided more consistent estimates than the GPI, which had a similar sample size.

The differences in the accuracy and consistency of PT and GPI methods could not be explained by sample size. It is possible that the differences in sampling strategies may also have contributed to method performances (McMahon 1995). Both PT and GPI methods involved contrasting approaches to the location of the observation or sampling points but a systematic approach was used for the PT method, based on transects orientated perpendicular to the dominant extraction direction. In contrast, the GPI method involved the random location of grid point pattern and random orientation of transects. The

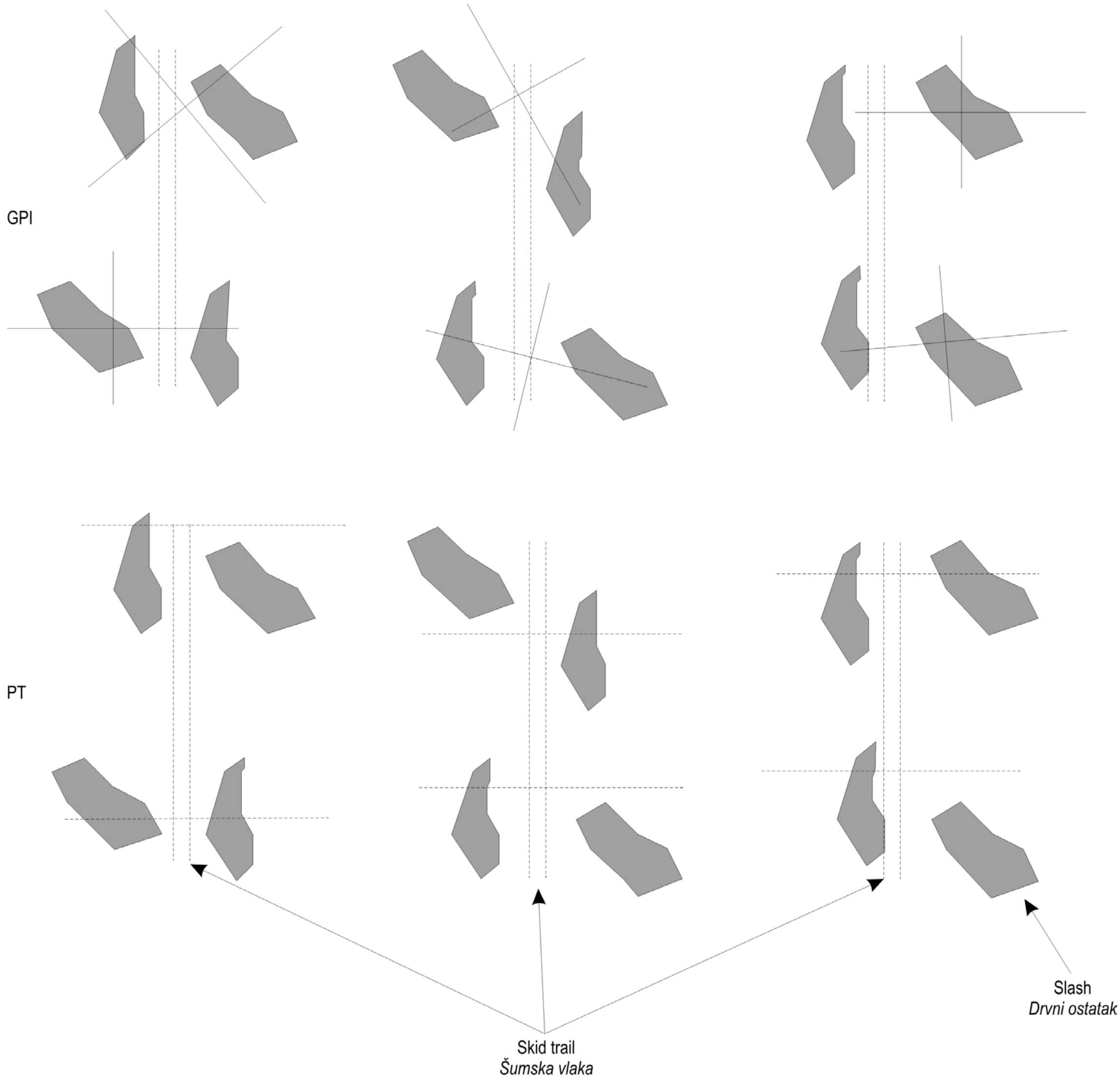

Fig. 4 Examples of causes in variation in estimates between three successive applications of GPI and PT methods

Slika 4. *Primjer razlike u procjeni između triju uzastopnih primjena metode pravca točaka i sjecišta mreže točaka*

random approach employed by GPI method is likely to result in less consistent estimates of disturbance types which were systematically orientated, parallel to extraction direction (Fig. 4). At bigger transect spacing, disturbance features may be missed in the systematic approach of the PT method relative to the GPI method. In the three successive surveys shown in Fig. 4, it could be expected that the consistency of deep disturbance estimates would be lower for the GPI method. This was the case of the results of this study shown in Fig. 3. This study has highlighted that there are no considerable differences among three methods from consistency and accuracy point of view in a mountainous forest compared to flat area. Disturbance assessment only provides an estimate of actual disturbance levels.

The results show that the PT30 method was the most consistent for the three types of disturbance. This is similar to the results of McMahon (1995). In comparison with our study McMahon (1995) found 71% undisturbed and shallow disturbance, 4% deep disturbance, and 37% compacted, when rubber-tired skidders were used. Rab (1996b) reported that following logging and slash burning, on average 11% of the coupe area remained undisturbed, 11% litter disturbed, and 78% had mineral soil exposed. The snig tracks, log landings and disturbed general logging area occupied about 19%, 3% and 66% of the coupe area, respectively. Laffan et al. (2001) indicated that after logging by conventional ground-based skidding from steep slopes, most observations (>70%) were slash cover (47%) and undisturbed soils

(25%). Disturbed soils accounted for nearly 30% of observations mostly comprising slightly (17%) and moderately (10%) disturbed classes. Severely disturbed (subsoil exposed) soils accounted for only just over 1% nearly all attributable to tree uprooting during logging operations. Heninger et al. (2002) found that soils with a thin topsoil (A and A–B horizons), therefore, are more likely to be classified as severely disturbed than soils with a thick topsoil. Gondard et al. (2003) found 52% undisturbed and shallow disturbance, 3% deep disturbance, and 37% slash residue, when skidder and terraces were used, and also found 27% undisturbed and shallow disturbance, 0% deep disturbance, and 58% slash residue, when forwarder and terraces were used. Eisenbies et al. (2005) reported that rutting and churning affected 72% of heavy disturbance category. Helvey et al. (1985) compared five different log retrieval systems (after hand felling) with respect to soil disturbance and erosion: tractor skidding over bare ground (<30% slope), tractor skidding over snow (<40% slope), cable skidding over bare ground, skyline (Wyssen skycrane), and helicopter. They found that tractor skidding over bare ground caused the greatest percentage of area with severe soil disturbance (36%), followed by cable skidding (32%), tractor skidding over snow (9.9%), skyline (2.8%), and helicopter (0.7%).

These reveal that the logging tractor used for skidding is a very important factor, but that the presence of shallow or deep disturbances, and their intensity, also depends on environmental characteristics. McIver and Starr (2001) reported that the type of logging system and the time used for logging relative to soil moisture are both important in determining soil disturbance and sediment transport.

Ground-based systems have a broad range of machinery configurations. Rubber-tired skidders are capable of producing more severe damage than tracked machines due to their ability to continue skidding under more severe terrain. Steel-tracked machinery is also generally considered to have a lower impact on soil than rubber-tired machinery due to lower static ground pressures (Horn et al. 2004). Murphy (1982) has studied the effect of various types of machinery on severity of soil disturbance. He found that a Clark 66 RTS with its high ground pressure and fast speeds caused more severe soil disturbance than an FMC 100 STS. He also found that the Timbermaster TM70 (RTS) caused less severe disturbance than the Bombardier Muskeg (STS), although the Timbermaster exerted slightly higher ground pressures than the Bombardier Muskeg. This was probably because the Timbermaster had articulated steering while the Bombardier had controlled differential steering (Murphy 1982).

5. Conclusions – *Zaključci*

The two methods were applied to a 4 ha harvest area, which was harvested recently and logs were removed by a crawler tractor. An intensive 1x1 m grid survey was made over the study area and a field evaluation of two methods of site disturbance assessment was conducted to determine the accuracy and consistency of two ground survey methods, and then the accuracy of the two methods was assessed by comparing mean disturbance estimates with the results of the survey. The two methods were the point transect method, using three different transect spacing, and the grid point intercept method. Method consistency was determined by independently applying the assessment methods three times to the same area. We found that the most accurate estimate of disturbance was provided by the point transect method, with 30 m spacing transects. In contrast, the grid point intercept method provided the least accurate estimates of the disturbance. The point transect method, with 30 m spacing transects, appeared to be more consistent than the other methods.

Feature studies must continue to improve the understanding of the relationship between visual evidence of damage and actual impacts, particularly in relation to compaction related to ecosystem regeneration, soil recovery and ecosystem health and vitality. The present system of defining soil damage on the basis of soil disturbance is based on a well recognized process of visual features. However, it does not incorporate any direct measure or description of compaction, one of the most significant aspects of soil damage. This aspect must presently be inferred on the basis of evidence of traffic (i.e. snig tracks).

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Sažetak

Procjena oštećenja staništa primjenom dviju terenskih metoda opažanja u planinskim šumama

Smjernice razvoja šumskih vozila, koja se upotrebljavaju pri pridobivanju drva, upućuju na njihovo povećanje mase i nosivosti. Izvođenje radova šumskim vozilima može uzrokovati oštećenja staništa i tla. Pri tome se najčešće zbog prolaska šumskih vozila mijenjaju strukturna svojstva šumskoga tla (povećava se prirodna gustoća i smanjuje poroznost tla), premještaju slojevi tla te nastaje kolotrag. Ujedno se narušavaju uvjeti za rast biljaka te se povećava opasnost od erozijskih procesa na strmim staništima.

Cilj je ovoga rada razvoj brzoga i lakoga postupka za procjenu oštećenja staništa i šumskoga tla koja nastaju pri radovima na pridobivanju drva. U radu je prikazana procjena oštećenja staništa primjenom dviju metoda *opažanja, a rezultati su uspoređeni s procjenom oštećenja provedenom detaljnom metodom opažanja u mreži točaka razmaka 1x1 m. Za ispitivane metode opažanja oštećenja staništa određena je točnost i pouzdanost izmjere.*

Istraživanje je provedeno u planinskim šumama sjevernoga Irana, u odjelu nakon završetka privlačenja drva skiderom Timberjack 450C. Ukupno je privučeno 1500 m^3 drva pri srednjoj udaljenosti privlačenja od 400 m. Mjesto istraživanja s naznačenim pravcem privlačenja drva prikazano je na slici 1.

Na početku su uočena i razvrstana sva oštećenja šumskoga tla u mreži točaka razmaka 1 x 1 m. Oštećenja staništa i šumskoga tla razvrstana su prema sustavu prikazanom u tablici 1. Postotni je udio pojedine vrste oštećenja tla određen iz broja točaka (stajališta) na kojem je uočeno oštećenje u odnosu na ukupan broj točaka (stajališta). U rezultatima je 15 vrsta oštećenja tla raspodijeljeno u tri grupe:

⇒ *neoštećeno tlo i površinska oštećenja*

⇒ *velika oštećenja i*

⇒ *zbijeno tlo.*

Zatim je procijenjeno oštećenje primjenom metoda pravca točaka (PT – point transect) i sjecišta mreže točaka (GPI – grid point intersect).

Prema metodi pravca točaka (PT) oštećenja se uočavaju i razvrstavaju na određenim točkama/stajalištima u pravcu. Pravac se postavlja paralelno s granicama odjela i okomito na pravac privlačenja drva. Koristeći mjerni lanac na određenim se udaljenostima po pravcu određuju stajališta (slika 2b). U istraživanju se u primjeni ove metode koristila udaljenost između stajališta u pravcu od 30 m, 50 m i 80 m.

Primjenom metode sjecišta mreže točaka (GPI) na površini su istraživanoga odjela određene mreže točaka veličine 60 x 60 m. Na pravcima duljine 60 m određena su stajališta za procjenu oštećenja u razmaku od 1 m. Položaj je prve mreže točaka određen nasumično, druge pod kutem 180^o, a treće i četvrte mreže točaka pod kutem od 90^o u odnosu na prve dvije (slika 2c).

Točnost je izmjere određena statističkim programom ANOVA, a procjena je srednje oštećenosti staništa uspoređena s rezultatima opažanja u mreži točaka 1 x 1 m primjenom Student t-testa. Pouzdanost je pojedine metode opažanja određena njezinim trostrukim ponavljanjem na istraživanoj površini.

Rezultati su istraživanja prikazani u tablici 2 i na slici 3. Usporedbom rezulata pojednih metoda vidljivo je da primjena metode pravca točaka s razmakom stajališta od 30 m (PT30) daje najtočnije rezultate, odnosno najbliže vrijednosti u odnosu na rezultate opažanja s detaljnom izmjerom oštećenja u razmaku stajališta 1x1 m. Isto tako metoda pravca točaka s razmakom stajališta od 30 m ima najveću pouzdanost izmjere (tablica 3).

Rezultati pokazuju da točnost metode ne ovisi mnogo o veličini uzorka. Povećanje razmaka između stajališta na pravcu je neznatno smanjilo točnost i pouzdanost. Razlike u opažanju oštećenja primjenom ispitivanih metoda ne mogu se obrazložiti veličinom uzorka (slika 4). Metoda je sjecišta mreže točaka (GPI) zasnovana na slučajnom položaju točaka stajališta, što može rezultirati manjom pozdanošću od metode pravca točaka (PT) koja je sustavno postavljena s obzirom na pravac privlačenja drva. S druge strane veći razmaci između točka na pravcu (PT) mogu prouzročiti propust u uočavanju oštećenja u odnosu na metodu sjecišta mreže točaka (GPI).

Ključne riječi: oštećenje staništa, pridobivanje drva, metode opažanja, pravac točaka, sjecište mreže točaka

Authors' address – *Adresa autorâ:*

Asst. Prof. Akbar Najafi, PhD.
e-mail: a.najafi@moadres.ac.ir
Ahmad Solgi, MSc.
e-mail: solgi_ahmad231@yahoo.com
Tarbiat Modares University
Faculty of Natural Resources
P.O.Box 46414-356
Noor, Mazandaran Province
IRAN

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