Modelling of forest decluttering technology along with estimation of deadwood amount

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Abstract. A technology has been proposed for cleaning the forest from deadwood along with an evaluation of its total amount on the site (CFD). The basis of the deadwood quantitative evaluation is the linear intersection sampling (LIS). Within the CFD framework technology, the paper considers the technique of harvesting deadwood using a portable winch with a cable length from 40 to 120 m. A mathematical model has been developed of both the technological process and deadwood estimation. In the model, a number of sites were considered accounting for 50 to 150 pcs of deadwood / ha. The results of simulation experiments have showed that the required number of sampling lines decreases in a power-law dependence with an increase in the amount of deadwood on the site and the length of the winch cable (sampling line). For the accuracy index $P = 20\%$, the required number of sampling lines is within the range of 10-70 pcs / ha. Errors between the true values of the deadwood amount on the strip and its estimates did not exceed 7% in absolute value. At the same time, the deviation of the estimates depends neither on the amount of deadwood on the strip nor the length of the winch cable (sampling line). Errors in estimating the mean deadwood length for a sample made from the pieces that crossed sampling lines did not exceed 3%. The estimation procedure impact on the deadwood harvesting productivity proved to be negligible. The drop in performance does not exceed 1%. The impact of the amount of deadwood on the productivity on the site can be considered insignificant. With an increase in the length of the winch cable, a noticeable decrease in productivity is observed. Thus, with an increase in the length of the cable from 40 m to 120 m, productivity drops by 40%. This is due to the fact that the technology in question assumes piece skidding of deadwood. In this case, the time it takes to unwind the cable to a greater distance exceeds the time for the skid relocation. However, should the technology change, for example, in case of using a more powerful winch and skidding several trees at the same time, the situation may change.

1 Introduction

The paper considers the deadwood harvesting in the forest and the technology of its regulation.

Deadwood is understood to mean both tree trunks that have fallen down and lie on the ground in the forest and their parts that, to a greater or lesser extent, have lost their technical qualities and value (Fig. 1). According to the Forestry Committee of Moscow region, 20 million cubic meters of such wood is believed to have been accumulated in the forests of Moscow region alone. Part of the deadwood can be used to produce renewable energy sources - fuel chips or firewood.

In order to rid the forest of deadwood, sanitary and recreational measures are periodically carried out, which are assigned according to the results of forest pathological examinations [1].

A drawback of modern technologies applied to rid the forest of deadwood is their low productivity, since

they are planned in the absence of precise information on the quantity and quality of deadwood (Fig. 2). This causes difficulties in planning its use as a raw material, for example, for processing into fuel chips or other renewable energy sources.

Forest pathology measures include a quantitative evaluation of deadwood, but they are carried out visually [1], and therefore the accuracy of these results can significantly differ from actual values.

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Fig. 1. Deadwood. (Tver region, the author's photo)

Fig. 2. Cleaning the cluttered area in Tishkovskoye forestry of Moscow region

Source: <https://klh.mosreg.ru/sobytiya/novosti-ministerstva/25-04-2019-17-04-58-aprelskiy-gimn-vesne-i-trudu>

Object of the paper. The authors are aimed at proposing and studying the technology of sanitary and recreational measures for decluttering the forest from deadwood, including in-depth forest pathological examinations of the deadwood accumulations in the process of harvesting abbreviated as CFD technology.

In particular, the following tasks were set:

- to establish the accuracy of the way the characteristics of the deadwood (mean length and number of deadwood pieces on the site) were found during an in-depth forest pathological examination along with cleaning the forest from deadwood;
- to determine the impact of an in-depth forest pathological examination on the hourly productivity of the deadwood harvesting using the CFD technology.

2 Methods

To achieve the designated goal, the CFD technology is proposed, which is implemented after the usual activities carried out as part of standard forest pathological surveys [1]. The result of these measures is a visual

determination of cluttered areas in the forest to be cleaned.

Within the CFD technology, for the purposes of harvesting deadwood, the paper considers a technological scheme based on the use of a portable winch [2, 3, 4]. The technological scheme is presented in Fig. 3.

Along with the deadwood harvesting, an in-depth forest pathological examination is carried out, which may include estimating the deadwood total amount on the site and its characteristics, for example, the volume of commercial wood, as well as the percentage of rot damaged wood, etc.

The main idea of the technology considered in the paper (Fig. 3) is that the area of the forest that is to be rid of deadwood is divided into strips with a width equal to or greater than the maximum deadwood length ($b > l_{max}$). At the beginning of each strip, a manual skidding winch is installed on the skidder (road).

Fig. 3. Forest decluttering scheme

1 – winch operator; 2 – winch; 3 – choker setter; 4 – skidding cable; 5 – deadwood

The choker setter then unwinds all the skid cable along the strip. All the deadwood caught on the cable line is taken into account.

After that, the deadwood is skidded towards the skidding track in any order and laid in packs. Later, these packs can be sawn into 1-meter-long shorts and laid in woodpiles to rot, though these activities are not considered in the paper.

After decluttering the strip, the winch is transferred along the skidding track to the next strip and the cycle of evaluation and decluttering is repeated.

The forest decluttering team consists of two workers: a winch operator and a choker setter. Should the winch be remotely controlled, there is no need in employing the winch operator.

To evaluate the characteristics of the deadwood as part of an in-depth forest pathological survey, the method of linear intersections (LIS) was used [4-34].

The effectiveness of the proposed technology was studied on mathematical models using the simulation methods [2-4, 20, 35].

The time to declutter a forested area according to the CFD technology under consideration will be equal to:

$$T_{sum} = \sum_{j=1}^n \left((t_{1j} + t_{2j} + t_{3j}) + \sum_{i=1}^{N_j} t_{4ji} \right), \quad (1)$$

where:

n – a number of strips on the site;

N_j – a number of deadwood pieces on the j strip;

t_{1j} – winch travel cycle time towards the j strip, s;

t_{2j} – winch travel cycle time between the strips, s;

t_{3j} – deadwood evaluation cycle time on the j site, s;

t_{4ji} – skidding cycle time of the i deadwood from the j site, s.

Skidding cycle time of the i deadwood from the j site:

$$t_{4ji} = t_{41ji} + t_{42ji} + t_{43ji} + t_{44ji}, \quad (2)$$

where:

t_{41ji} , t_{42ji} – cable travel time, in the idle and cargo directions, respectively, s.

$$t_{41ji} + t_{42ji} = \frac{l_{winch_ji}}{v_1} + \frac{l_{winch_ji}}{v_2}, \quad (3)$$

where:

v_1, v_2 – winch freight cable speed, without load and with load, respectively, m / s;

l_{winch_ji} – skidding distance of the i deadwood on the j site, m;

t_{43ji} – choking time of the i deadwood on the j site for skidding, s;

t_{44ji} – unchoking time of the i deadwood on the j site after skidding, s.

It should be noted that the entire cycle time is a random variable. In the model, the cycles were also specified as random variables distributed exponentially.

Mean choking time for skidding – 120 s.

Mean unchoking time after skidding – 40 s.

Mean time to account for 1 deadwood piece – 60 s.

Hourly productivity was determined as the sum of the total skidded deadwood per hour:

$$C_{hr} = \frac{3600 \cdot N_{sum}}{T_{sum}}, \quad (4)$$

where:

N_{sum} – the total number of the deadwood pieces on the site.

In the simulation experiments, we used the data of visual and instrumental examination of the forested areas cluttered with deadwood in Moscow and Tver regions (Fig. 1). These sites were characterized as being heavily cluttered (more than 20 m³ / ha). Deadwood was presented by whole fallen trees of different years. There has never been any decluttering in these forests.

Certain measuring procedures (Fig. 4) were carried out to determine the following laws of distribution:

- of deadwood on the site – equal;

- of deadwood orientation angle on the site – equal;

- deadwood piece length – regular.

In the model, each i deadwood piece was specified (Fig. 3) by the coordinate X_{li} , angle f_i and length l_i , which were found according to the above-mentioned laws.

The coordinate X_{li} was specified on the interval:

$$0 < X_{li} \leq b, \quad (5)$$

where:

b – the width of the decluttering strip (equal to 20 m in the model).

The angle f_i was specified on the interval:

$$-\pi/2 < f_i \leq \pi/2, \quad (6)$$

Then the coordinate X_{2i} was specified:

$$X_{2i} = X_{li} + l_i \cdot \cos f_i, \quad (7)$$

The fact that a deadwood piece crossed a sampling line was determined by a condition:

$$X_{li} < b/2 \text{ and } X_{2i} \geq b/2, \quad (8)$$

The coordinate Y_{li} was specified on the interval:

$$0 < Y_{li} \leq l_{winch_max}, \quad (9)$$

where:

l_{winch_max} – maximum winch cable length.

For the j site, the coordinate Y_{li} in the model was specified as equal to l_{winch_ji} .

The deadwood length was specified according to the normal law with a mean value of 8 m and a standard deviation of 1 m.

The characteristics of deadwood in mathematical models were determined using the LIS method [4-34]. This paper provides formulas for evaluating one characteristic only, i.e. the number of deadwood pieces on the site.

According to the theory of the LIS method, evaluation is carried out according to the number of pieces of deadwood that crossed the sampling line. In the CFD technology under consideration, the winch cable line acts as such a line (Fig. 3).

Since the length of the cable is assumed to be constant in each series of experiments, the sampling lines have the same length, respectively.

Fig. 4. Measuring the deadwood length. (Moscow region, the author's photo)

For lines of the same length equal to the length of the winch cable and the uniform law of distribution of the deadwood on a site with a uniform law of orientation of the pieces, the number of pieces of deadwood on a strip of width b using the LIS method can be found by the formula:

$$N_{sum_est} = \frac{\pi \cdot b}{2 \cdot l_{mean_est}} \cdot \frac{1}{n_L} \cdot \sum_{i=1}^{n_L} M_i \quad (10)$$

where:

l_{mean_est} – estimation of the mean length of the deadwood according to the selected intersections of the deadwood pieces with all sampling lines;

M_i – a number of intersections of deadwood pieces with the i sampling line;

n_L – a number of sampling lines.

The estimate obtained in the experiments was compared with the true value and the estimation error was then determined:

$$Beas = \frac{N_{sum} - N_{sum_est}}{N_{sum}} \cdot 100\% \quad (11)$$

The number of sampling lines depends on the number of pieces of deadwood on the site. In practice, as a first approximation, the number of lines is established according to the results of the initial visual forest pathological examination.

In the models, the number of pieces of deadwood on the forested site was specified. The required number of sampling lines was determined by the formula:

$$n_L = \frac{Var^2 \cdot t^2}{P^2}, \quad (12)$$

where:

Var – variation coefficient, %;

P – accuracy index, %;

t – certainty index;

Variation coefficient:

$$Var = \frac{100 \cdot \sigma}{M}, \quad (13)$$

where:

σ – standard deviation;

M – mathematical expectation of the number of deadwood pieces that intersected with the sampling line.

Mathematical expectation of the number of deadwood pieces that intersected with the sampling line:

$$M = p \cdot N_{sum}, \quad (14)$$

where:

p – probability of intersecting a sampling line by a piece of deadwood:

$$p = \frac{2 \cdot l_{mean}}{L_{int} \cdot \pi}, \quad (15)$$

where:

L_{int} – sampling line length, m

l_{mean} – mean length of a piece of deadwood, m.

Standard deviation:

$$\sigma = \sqrt{p \cdot (1 - p) \cdot N_{sum}}, \quad (16)$$

3 Results and Discussion

The simulation experiments planning matrix to estimate the amount of deadwood on the site using the LIS method is presented on Fig. 1.

Some results of the simulation experiments are presented in graphs.

According to the formulas (12-16), the required number of sampling lines decreases in a power-law dependence with an increase in the number of deadwood pieces on the site and the length of the winch cable (sampling line). This was confirmed by the results of the simulation experiments (Fig. 5-6). For the accuracy index $P = 20\%$, the required number of sampling lines is within the range of 10-70 pcs.

Table 1. Simulation experiments planning matrix

Number of deadwood pieces, pcs / ha	Winch cable length, m	Number of deadwood pieces on the strip, pcs
50	40	4
100	40	8
150	40	12
50	80	8
100	80	16
150	80	24
50	120	12
100	120	24
150	120	36

Fig. 5. Dependence of the required number of sampling lines on the number of deadwood pieces

Fig. 6. Dependence of the required number of sampling lines on the winch cable length

The accuracy of determining the amount of deadwood was established by the discrepancy between the true value of deadwood on the strip and its estimate. In a series of experiments, we obtained estimates (Fig. 7-8) of the amount of deadwood on the strip (markers) and their true values (solid lines) depending on the amount of deadwood on the site and the length of the winch cable (sampling line).

The analysis of the results of a series of simulation experiments showed that the errors (11) between the true values of the deadwood amount on the strip and its estimates calculated by the formula (10) did not exceed 7% in absolute value. At the same time, the deviation of the estimates did not depend on the amount of deadwood on the site and the length of the winch cable (sampling line).

Estimating the amount of deadwood on the strip (11) depends on the mean length of the deadwood pieces and the mean number of intersections of the deadwood with the sampling line.

The results of simulation experiments showed that the error in estimating the mean deadwood length for a sample of those pieces that crossed the sampling line did not exceed 3% both for the case of changing the number of deadwood pieces on the site and for the case of changing the length of the sampling line.

An example of estimating the mean length of the deadwood (markers) being relative to the true value (solid line) and depending on the number of deadwood pieces on the site is shown in Fig. 9.

The experiments showed that the error in estimating the mean number of deadwood pieces that intersected with the sampling line did not exceed 8% both for the case of changing the number of deadwood pieces on the site and for the case of changing the length of the sampling line.

An example of estimating the mean number of deadwood pieces that intersected with the sampling line

depending on the number of deadwood pieces on the site is shown in Fig. 10.

Fig. 7. Deadwood estimation on the strip depending on the number of deadwood pieces

Fig. 8. Deadwood estimation on the strip depending on the winch cable length

Fig. 9. Estimating the mean deadwood length on the strip depending on the deadwood amount

Fig. 10. Estimating the number of intersections of deadwood pieces with a sampling line depending on the deadwood amount

The simulation results made it possible to analyze the impact of carrying out the procedure for accounting for deadwood on forest decluttering performance.

The linear intersection method involves accounting for all the deadwood crossed by the sampling line. In practice, estimation procedure is carried out once on each strip. The winch cable is unwound for the entire length along the strip and all the deadwood that crossed the line of the cable is accounted for along with measuring the length of the deadwood. Estimation takes some time. According to the experiment, measuring only the deadwood length takes approximately 60 seconds per piece. This time in the model was assigned as a random variable distributed exponentially.

The calculation of the decluttering productivity was carried out according to the formula (4) for cases that did

not include estimation those that included estimation depending on the length of the winch cable and the number of deadwood pieces on the site.

An example of the dependence of decluttering productivity on the site on the deadwood amount is shown in Fig. 11.

Fig. 11. Decluttering productivity depending on the amount of deadwood

The results analysis showed that the impact of the estimation procedures on the decluttering productivity is negligible. The drop in performance does not exceed 1%.

The impact of the amount of deadwood on the productivity on the site can be considered insignificant.

One can see a noticeable decrease in productivity with an increase in the length of the winch cable. Thus, with an increase in the length of the cable from 40 m to 120 m, productivity drops by 40%. This can be explained by the fact that piece skidding of the deadwood is presupposed in the technology under consideration. In this case, the time to unwind the cable to a greater distance exceeds the time to relocate the skid. However, should the technology change, for example, while using a more powerful winch and skidding several trees at the same time, the situation may change.

4 Conclusions

The simulation experiments that were carried out with the model of forest decluttering along with the deadwood estimation within the framework of the proposed CFD technology made it possible to draw the following conclusions:

1. A technology has been proposed for decluttering the forest from deadwood along with estimating its total amount on the site (CFD). The basis of the quantitative estimation of deadwood is the linear intersection method (LIS).
2. In the framework of the CFD technology, the paper proposes a technology for harvesting deadwood

based on a portable winch with a cable length from 40 to 120 m.

3. A mathematical model of the technological process and deadwood estimation has been developed. In the model, sites with deadwood amount from 50 to 150 pcs / ha were considered.

4. For the accuracy index $P = 20\%$, the required number of sampling lines is in the range of 10-70 pcs / ha.

Errors between the true values of the amount of deadwood on the strip and its estimates did not exceed 7% in absolute value. At the same time, the deviation of the estimates depends neither on the amount of deadwood on the strip nor the length of the winch cable (sampling line).

Errors in estimating the mean length of deadwood pieces that crossed sampling lines did not exceed 3%.

The impact of the estimation procedure on the deadwood harvesting productivity is negligible. The drop in performance does not exceed 1%.

The impact of the amount of deadwood on the productivity on the site can be considered insignificant.

With an increase in the length of the winch cable, a noticeable decrease in productivity is observed. Thus, with an increase in the length of the cable from 40 m to 120 m, productivity drops by 40%.

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