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To cite this article: S A Kabanova *et al* 2018 *IOP Conf. Ser.: Earth Environ. Sci.* **211** 012055

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# Regional risks of artificial forestation in the steppe zone of Kazakhstan (case study of the green belt of Astana)

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**Abstract.** This article deals with results of research on artificial forest in a green zone around the city of Astana. The authors of the article established temporary sample plots where condition, capacity for survival, and growth of trees were observed by standard techniques adapted to conditions of the forest-steppe subzone of Northern Kazakhstan. The reasons for the unsatisfactory condition of the planted forest were found and recommendations on improvement were made. The conclusion was drawn that to establish forest plantations it is necessary to select such species of trees and shrubs that will be resistant in specific conditions to the negative factors of urban lands. A possibility of replanting adult trees to intensify reforestation was also studied. The authors analyzed the dynamics of Silver birch preservation in 2011-2017. The Mann-Whitney-Wilcoxon  $U$  test was used to prove the presence of differences between the types of trees' average preservations. Based on the data thus obtained, it was concluded that the forest plantations created by the different methods differed significantly in terms of the preservation rate, as well as in the heights and diameters of the trees. Forecasts of tree preservations in 2018 were made using moving average and linear regression methods. The best forecasts were chosen in terms of the mean relative absolute error of approximation. The results confirmed an initial hypothesis predicting significant differences between the methods used for artificial reforestation: the non-replanted trees are expected to have the highest rate of preservation, whereas the trees replanted to a low location, the lowest preservation rate. The prediction of the preservation rate of forest plantations of Silver birch created by the different methods will allow reducing the risks when conducting forestry activities on artificial reforestation. Regional features must be taken into account in the development of recommendations for a comprehensive system of measures which are based on the scientific forestry techniques to ensure optimum reforestation.

## 1. Introduction

The creation of green plantings and their handling is a long and difficult process. The economic consequences of using natural versus man-made forests as buffers against environmental deterioration, conserving or protecting forest are discussed by E. Reynolds and P. Wood in [1]. In [2], three main forest management strategies are considered, criteria for choosing a better one are suggested, and the ways of forest adaptation are analyzed. In [3], some aspects of managing forested ecosystems in the face of uncertainty are considered.

In paper [4] Dumroese *et al* discussed some problems of forest management practices, particularly, functional restoration, which helps to reestablish or maintain functions provided by the forest ecosystem. In [5] the forest dynamics was modeled, and it was proved that dynamic protected areas support higher quality home ranges through time than static protected areas.

In [6], risks and losses through reduced forest growth or mortality caused by different factors were considered. It was found that risks are generally less in intensively managed planted forests than in natural forests. The authors found that "the better health of plantations is a reflection of the generally good growing conditions, the proper matching of site to species that is possible in artificial culture."



The testing of new introduced species and their acclimatization is a very complex process that takes place in nature very slowly. However, the acclimatization of wood species in forest cultures is much faster [7, 8]. Therefore, the introduction of trees that are more resistant to the sharply continental climate of northern Kazakhstan and its soil conditions is one of the areas of scientific research [9, 10].

Therefore, the dynamic-managed artificial forestation is a reasonable, more effective, economical, and less-risk way for making city green zones; it also helps to establish forest parks for people to have a better environment for rest. In order to preserve the forest stands of the green zone of the Astana city, it is necessary to undertake a number of forestry measures that will increase their resistance to external anthropogenic factors, adverse climatic conditions, and increase the biodiversity in the region [11,12].

The work on establishing a green zone around the city of Astana was started when transferring the capital of Kazakhstan there. It aimed at decreasing the influence of unfavorable ecological factors, improving the aesthetic situation, and so on. The conditions of Astana are difficult for green construction because of the continental climate, a harsh wind regime, and low-productive soils with low forest vegetation qualities. Forest cover occupies an insignificant part of Akmola region, which supports the need for green plantings around the capital and in the territory of the region [13]. However, it is very difficult to cultivate the greenery because of high complexity of the soil mantle, frank soil alkalinity, salinization, and occurrence of saline soil and salty waters near the surface.

The risks of artificial forestation are connected with the regional soil and climatic conditions, the ways of creation of forest plantations, and financing of the forestry activities. The socio-economic development of the region and the environmental situation depend on the state of the forestry as well. The development of the reforestation scheme is based on the use of various methods of forest culture creation in order to choose the most effective one at the lowest cost. One of the criteria is the evaluation of tree preservation of newly created plantations. The purpose of this paper is to study the possibility of replanting adult trees to intensify reforestation. The green zone around the city of Astana has been created for nearly 20 years. Within this time period about 78 thousand hectares of artificial plantations have been planted. While creating forest plantations, the foresters faced a major problem: almost half of the land allocated for the green zone was unsuitable [14, 15]. The soil conditions are a limiting factor for growing valuable and ornamental conifer and deciduous trees in the green zone of the capital [16]. The right choice of the method of artificial forestation reduces the risk of tree death due to various adverse environmental factors and optimizes financing of the necessary forestry activities [17].

## **2. Description of the green zone of the city of Astana. Applied research methods**

To improve the ecological situation around Astana, establishment of a protective green belt was started in 1997. This was done by creating forest plantations from different species of trees and shrubs. More than 65 thousand hectares of the territory, including 14 thousand hectares in the city, have been planted so far. The annual planting is performed on an area of 5 000 hectares. First of all, strip plantations around Astana were established. These were around 20-25 m wide and had interstrip spaces of the same width similar to windbreak strips. The position of plantings was determined by the complexity of accurate forecasting of the survival capacity, condition, and quality of the future plantings. The latter was caused by the diversity of the soil cover and dissemination of spots of alkaline soil tracts fit for forest. Such soils occupied more than 50% of the area [18].

The lands covered with forests in the green belt make 3.9%, and those uncovered with forests, 1.5%. The largest area of the forest lands is occupied by open-growing forest plantations (39%). The largest area of the lands (55%) intended for establishing the green belt around the capital of Kazakhstan is accounted for by plough-lands, grass swards, and hay-makings, i.e. not forest lands. Thus, the main object of forest management is cultivation and formation of steady forest stands having high aesthetic, sanitary, and hygienic qualities. It was found that 27.4% of the artificial plantings in the green belt of Astana have good condition; 45.1% have satisfactory condition, and 27.5%, unsatisfactory condition. The main reasons for the forestry waste and unsatisfactory condition of the

forest plantations are in the agricultural technique of planting, deficiency of watering, damage by pets, untimely and unsatisfactory silvicultural measures, and wrong selection of species according to the soil conditions.

A project of forest management was studied in the course of work. The amount of forest plantations was determined according to various criteria of aesthetic assessment in the green belt of Astana. The capacity for survival, the growth, and condition of the forest plantations were studied in an area of 200 hectares. More than 10000 trees were surveyed.

The establishment of temporary sample plots was aimed at determining optimum agricultural techniques of creating the green zone and the range of tree and shrub species. These sample plots were used to study the condition, capacity for survival, and the growth of trees by standard techniques adapted for the conditions of the forest-steppe subzone of Northern Kazakhstan [19].

The research was carried out in the plantations of Silver birch of the strip type. In the spring of 2010, 8-year-old trees were replanted ball rooted by the mechanized method. In the strips consisting of 4 rows the lowest trees were selected for replanting in the spaces between the strips. The distance between the replanted trees in the row and between the rows was 3 m. The study of the growth and state of the replanted trees was carried out at the test plots at both low and high locations. In the strips with non-replanted trees, two specimens on the both sides of the dug tree in the row were observed. The inventory indices of these trees were found according to the methodical instructions [20], and the height was measured with a measuring rail; and the diameter, with a caliper. The preservation rate was calculated as the relation between the number of survived plants to the total number of replanted (non-replanted) trees, and was expressed as a percentage. With the help of the Wilcoxon-Mann-Whitney criterion, the hypothesis of existence of statistically significant differences in the tree preservation depending on such factors, as replantation and location was verified; we applied the moving average and linear regression models to predict the preservation for 2018. The best prediction was chosen according to the criterion of minimum average relative the absolute error of the approximation.

### 3. Results and discussion

Table 1 shows the data on the dynamics of the preservation rate of the forest plantations of Silver birch being studied. Their preservation rate dramatically decreased in 2013-2014 at a low location, and further decline of this parameter occurred with no sudden changes. The preservation of the trees replanted to a high location gradually declined and reached 31.9% in 2017. The preservation of non-replanted trees changed slightly: by 1-2% after 2015; the greatest loss of trees was in 2013-2015.

**Table 1.** Preservation of tested artificial plantations of Silver birch.

Considered trees	No. of trial area	Preservation by years (%)						
		2011	2012	2013	2014	2015	2016	2017
non-replanted trees ( $X$ )	1	99.1	96.1	96.1	81.6	79.8	79.8	77.6
	2	100.0	96.0	96.0	95.5	80.5	80.5	80.0
	3	100.0	98.0	98.0	91.0	90.0	88.0	87.0
	average	99.7	96.7	96.7	89.0	83.3	82.8	81.2
trees replanted to a low location ( $Y$ )	1	87.3	81.3	81.3	81.3	79.3	73.4	73.4
	2	72.7	71.3	71.3	69.3	58.7	56.7	50.6
	3	91.7	69.2	69.2	36.7	32.5	32.5	21.7
	average	83.9	83.8	83.8	64.3	58.6	54.2	49.0
trees replanted to a high location ( $Z$ )	1	57.6	51.1	51.1	51.1	49.7	30.5	29.9
	2	66.3	56.0	56.0	41.1	34.8	34.8	34.8
	average	61.5	53.3	53.3	46.7	43.1	32.7	31.9

The statistical hypothesis for the difference between average preservation levels of the trees was checked by means of the Mann-Whitney-Wilcoxon  $U$  test [21], which is based on statistics [22]

$$U = \min\{U_X, U_Y\}, \tag{1}$$

where  $U_{X(Y)} = mn + \frac{1}{2} \cdot m(m+1) - R_{X(Y)}$ ,  $R_{X(Y)} = \sum_{i=1}^m r(X_i)$  is the sum of ranks  $X$  (the average levels of preservation of non-replanted trees) or  $Y$  (the average levels of preservation of trees replanted to a low location),  $m$  is a sample size of  $X$ ,  $n$  is the size of  $Y$ . Here  $m = n = 7$ .

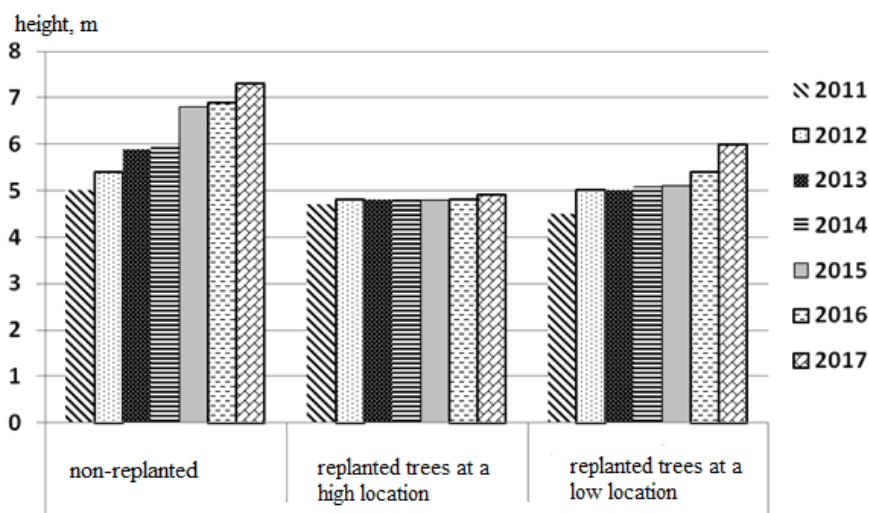
The difference is recognized if  $U$  statistics (1) are small enough. For  $m, n \leq 8$  the decision rule uses the specific tables with critical levels  $U_\alpha$  for different significance levels  $\alpha$ . For  $m = n = 7$  and  $\alpha = 0.05$   $U_{0.05} = 8$ .

As a result, we obtained  $R_X = 50$ ,  $R_Y = 26$ ,  $U_X = 7$ ,  $U_Y = 31$ ,  $U_{XY} = 7 < U_{0.05} = 8$  and, therefore, the statistically significant difference between the average levels of preservation of replanted trees at a low location ( $Y$ ) and non-replanted trees ( $X$ ) is admitted with  $\alpha = 0.05$ .

Similarly, the differences between the average levels of preservation of replanted trees at a low location ( $Y$ ) and high ( $Z$ ) locations, high ( $Z$ ) location and non-replanted trees ( $X$ ) were confirmed in pairs with  $\alpha = 0.05$ , because  $U_{YZ} = 1 < U_{0.05} = 8$  and  $U_{XZ} = 3 < U_{0.05} = 8$ . Note that the difference between the average levels of preservation of replanted trees at low ( $Y$ ) and high ( $Z$ ) locations was higher than for the other pairs, since  $U_{YZ} = 1$  is minimum among  $U_{XY}$ ,  $U_{XZ}$ , and  $U_{YZ}$ .

Thus, it can be argued that the location and the fact that the trees were replanted affected the average preservation rate.

We would like to emphasize that the initial average height of the replanted plants was less than that of non-replanted plants (Fig. 1). During the observation period, the average height of non-replanted plants increased 1.5 times, of those replanted to a low location, 1.3 times; and the height of the birch replanted to a high location hardly increased. The study of the biometric indicators revealed that the trees at a high location significantly lagged in growth in comparison to the trees growing at a low location. Thus, the average height was 4.9 and 6.0 m, respectively, and the diameter was 4.7 and 6.1 cm. Moreover, the average height of the trees at a low location slightly varied (the coefficient of variance  $V=11.7\%$ ), and this parameter in the trees at a high location significantly changed ( $V=22.4\%$ ).



**Figure 1.** Dynamics of changes in the average height of forest plantations of Silver birch.

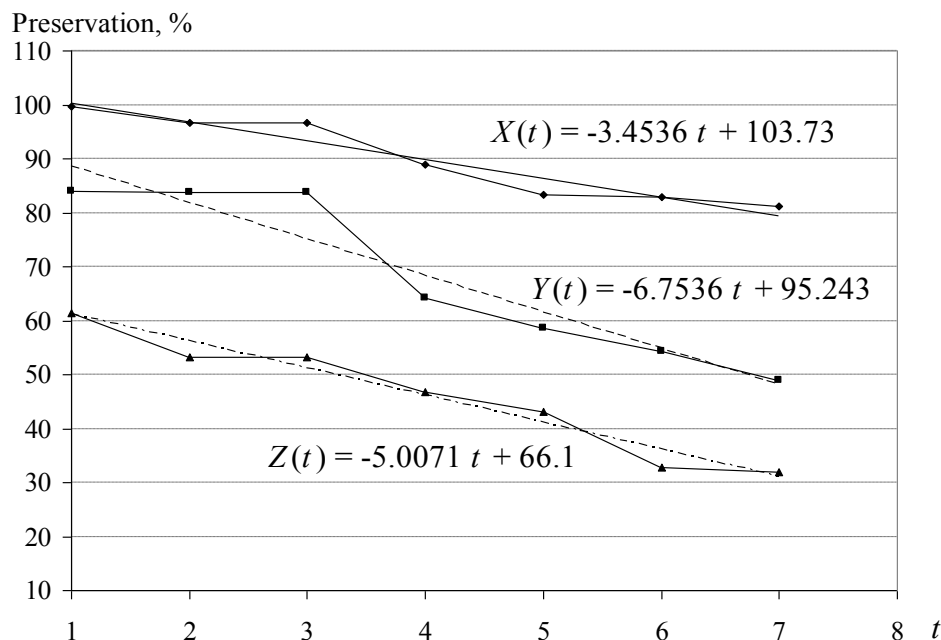
We also predicted the average preservation levels and the average heights for 2018 by using the moving average and linear regression models [23]. The mean relative absolute error of approximation

$$A = \frac{1}{N} \sum_{i=1}^N \frac{|F_i - M_i|}{F_i}$$

was used to choose the best forecast. Here for  $i=1, N$   $F_i$  are the real values,  $M_i$  are the modeling values,  $N = 7$  is the number of years being considered. The results of the forecasting, the error values  $A$  and the achieved significance levels ( $p$ -values) of the Shapiro-Wilk residual normality test [24] are given in Tables 2 and 3 and Figs. 2 and, 3. Since all obtained  $p$ -values are very high, we proved the normality of the residuals, and so used the linear regression models correctly.

**Table 2.** Forecasts of tree preservation for 2018 (%).

Type of the trees	№ of trial area	Forecasts of preservations, %		A		$p$ -value Shapiro-Wilk
		Moving average	Linear regression	Moving average	Linear regression	
non-replanted trees (X)	1	<b>79.1</b>	71.0	<b>0.03002</b>	0.03058	0.877
	2	80.3	<b>74.6</b>	0.03209	<b>0.03153</b>	0.864
	3	88.3	<b>83.6</b>	0.01407	<b>0.01099</b>	0.834
	average	82.4	<b>76.1</b>	0.01630	<b>0.01607</b>	0.763
trees replanted to a low location (Y)	1	<b>75.4</b>	71.1	<b>0.01230</b>	0.01778	0.330
	2	<b>55.3</b>	48.9	<b>0.02652</b>	0.03500	0.414
	3	<b>28.9</b>	4.8	<b>0.14126</b>	0.17451	0.126
	average	<b>53.9</b>	41.2	<b>0.03922</b>	0.04649	0.315
trees replanted to a high location (Z)	1	<b>36.7</b>	27.9	<b>0.04273</b>	0.09721	0.682
	2	<b>34.8</b>	23.7	<b>0.07002</b>	0.08605	0.501
	3	<b>35.9</b>	<b>26.0</b>	0.04164	<b>0.04151</b>	0.124
	average	<b>35.9</b>	<b>26.0</b>	0.04164	<b>0.04151</b>	0.124



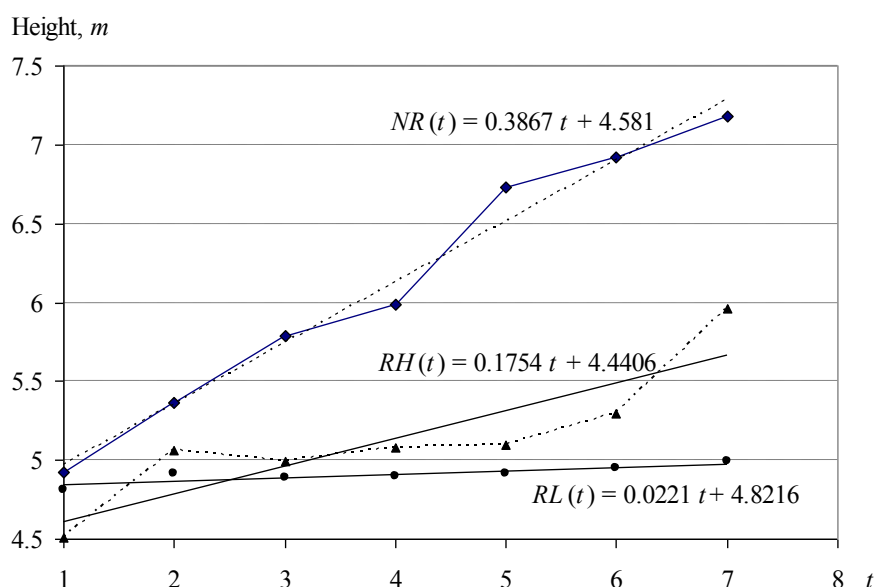
**Figure 2.** Average preservation of trees (%).

It should be noted that, in general, despite the overall decrease in the forest culture preservation index (see Figure 2), the optimistic forecast turned out to be more accurate in most cases. Meanwhile,

the non-replanted trees are expected to have the highest preservation, while those replanted to a high location – the lowest one, which must be taken into consideration when planning forestry work on artificial reforestation.

**Table 3.** Forecasts of tree average height for 2018 (m).

Type of trees	Forecasts of average height, m		A		p-value Shapiro-Wilk
	Moving average	Linear regression	Moving average	Linear regression	
non-replanted trees ( <i>NR</i> )	6.9441	<b>8.0613</b>	0.01523	<b>0.01331</b>	0.695
trees replanted to a low location ( <i>RL</i> )	<b>4.9507</b>	4.9984	<b>0.002647</b>	0.004055	0.539
trees replanted to a high location ( <i>RH</i> )	<b>5.4485</b>	5.8438	<b>0.019853</b>	0.03216	0.224



**Figure 3.** Average height of trees (m).

In Figure 1 we can see that there was an excessive growth in 2015 or a too small one in 2014, which can be explained by the weather factors or a tendency in sampling. Therefore, we involved additional information to improve the data. The information was obtained from the previous long-term observations of non-replanted Silver birch in Astana, and it was the fact that 45% of 10-year old trees are not higher than 6.10 m, i.e., we know the quantile  $x_q = x_{0.45} = 6.10$  m of the  $q = 0.45$  level for the height of 10-year old Silver birches and can use the modified estimate of average height for 2014 by applying the formula [26]

$$\bar{X}^q = \frac{q}{r} \cdot \sum_{i=1}^r X(i) + \frac{1-q}{N-r} \cdot \sum_{i=r+1}^N X(i), \tag{1}$$

where  $X_{(i)}, i = \overline{1, N}$ , are the ordered statistics of the sample,  $X_{(1)} \leq X_{(2)} \leq \dots \leq X_{(N)}$ ,  $N$  is the sample size (in 2014 we measured  $N = 190$  trees),  $F_N(x_q) = \frac{r}{N}$ ,  $F_N(x) = \frac{1}{N} \sum_{i=1}^N C(x - X_{(i)})$  is the empirical distribution function,  $C(y) = \{0: y \leq 0; 1: y > 0\}$ .

Note that the estimate (1) was obtained by substitution of the modified empirical cumulative distribution function using the quantile

$$F_N^q(x) = q \cdot \left( \frac{F_N(x)}{F_N(x_q)} \wedge 1 \right) + (1-q) \cdot \left( \left( \frac{F_N(x) - F_N(x_q)}{1 - F_N(x_q)} \vee 0 \right) \wedge 1 \right)$$

into the integral by which the mean value is given:

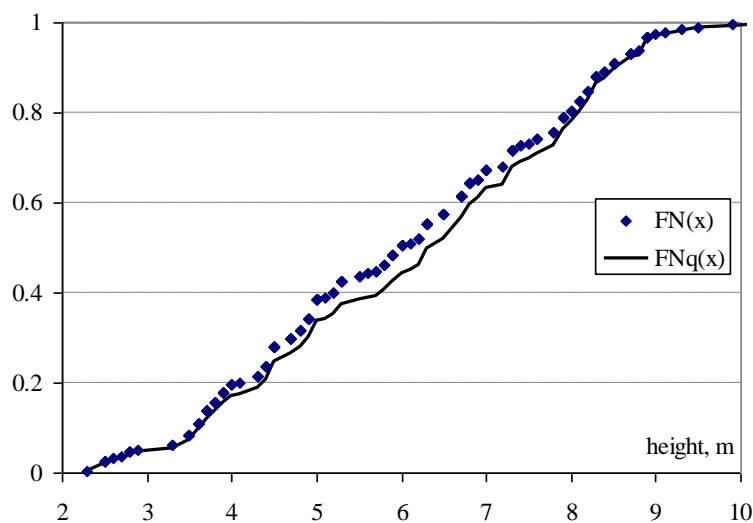
$$\bar{X}^q = \int_{-\infty}^{+\infty} x dF_N^q(x).$$

The estimate (1) is unbiased, its variance asymptotically is less than the variance of the classical estimate  $\bar{X} = \sum_{i=1}^N X_i$ , because [26]

$$\lim_{N \rightarrow \infty} ND\bar{X}^q = ND\bar{X} - \frac{1}{q(1-q)} \cdot \left( \int_{-\infty}^{x_q} x dF(x) - q \cdot EX \right)^2,$$

where  $F(x)$  is the cumulative distribution function of the random value  $X$  – the tree height in 2014. Therefore,  $\bar{X}^q$  is more precise than  $\bar{X}$ .

As a result, we obtained  $\bar{X}^q = 6.229$  m, while the average tree height in 2014 is  $\bar{X} = 5.983$  m. After replacing these amounts in the time series, we found a more precise linear regression for non-replanted trees as  $NRq(t) = 0.3867 \cdot t + 4.6162$  with  $A = 0.0118$  and the Shapiro-Wilk criterion  $p$ -value = 0.937. Finally, we forecasted that the height of non-replanted trees in 2018 will be 7.7098 m instead of 8.0613 m, as it was obtained previously (see Table 3).



**Figure 4.** The empirical cumulative distribution function  $F_N(x)$  and the modified empirical cumulative distribution function using quantile  $F_N^q(x)$ .



We would like to emphasize that the modified estimate of the mean value using quantile was first applied in the practice of artificial forestation. The use of the proposed method allows one to find reliable indicators for planning work in the steppe zone of the Republic of Kazakhstan.

#### 4. Conclusions

In assessing the quality of forest plantations of the green belt of Astana it was found that the greatest percent of their unsatisfactory condition results from two reasons: the deficiency of watering and the use of non-standard planting material. Thus, we suggest increasing the duration of seedlings watering on seasons and years when an establishment of forest plantations is designed. To receive standard seedlings, it is necessary to optimize the agricultural techniques of cultivation of planting material in our own garden nurseries and produce forest plantations with own seeds or seeds collected in other regions according to the seed regional assignment.

An important aspect of establishing sustainable planted forests is the selection of a relevant range of woody plants resistant to the negative factors of urban lands (technogenic pollution, over-consolidation of soil, unfavorable climatic conditions). Note that to establish the plantings it is necessary to consider not only such properties of tree plantations as ecological sustainability, survival, recreational and decorative qualities, but also their functional purpose. Thus, in each specific case it is important to estimate correctly the impact of negative factors of urban environment on the growth and development of plants and select such species that will correspond as much as possible to their purpose in these conditions [25].

During the observation period, the heights of the non-replanted plants increased by 1.5 times, the ones replanted to a low location, by 1.3 times; and the height of the birch replanted to a high location hardly increased. Consequently, the trees replanted to a low location still grow fairly fast; and the growth rate is slightly lagging behind that of the non-replanted plants, although they have a low rate of preservation. Statistically significant differences in the average tree preservation were revealed. Moreover, the differences in the preservation of the non-replanted and the trees replanted to a low location turned out to be most significant. Thus, it may be concluded that the location of the forest plantations and the fact that the trees had been replanted affected the average preservation rates.

The forecast of indicators of preservation of the forest plantations of Silver birch created by the different methods will allow planning forestry actions for artificial reforestation correctly taking into account soil conditions and locations of the forest plantations. Further research will involve the development of recommendations for a comprehensive system of measures based on the use of science-based forestry technologies to ensure optimum reforestation. The reforestation activities should be planned and implemented taking into account the renewable capacity of the different forest plantations.

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