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To cite this article: A A Egorov *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **263** 012002

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# Long-term biodiversity monitoring of the spontaneous successions for the assessment of the artificial restoration progress on the quarries in Russian Arctic

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**Abstract.** The results of long-term monitoring observations of natural recovery successions in the tundra and forest-tundra zones in various sectors of the Russian Arctic are analyzed. Efficiency of works on accelerated nature restoration is evaluated. Particular attention is paid to the analysis of mistakes made in the quarries reclamation projects. The combined review of the accumulated experience in natural and artificial vegetation restoration allows us to offer some recommendations for effective restoration of nature. Key words: natural recovery, spontaneous succession, anthropogenic vegetation, disturbed sites, biodiversity monitoring, artificial restoration

## 1. Introduction

The Northern regions of Russia have been involved in the process of active industrial development of mineral and hydrocarbon raw materials in the second half of the XX century, which resulted in a serious change of terrestrial ecosystems up to their complete destruction. Strategies for the development of natural resources of the North as well as new industry technologies and standards are being adopted in the current economic conditions in the Russian Federation. One of the main tasks of the optimization strategy of nature use in the regions of the Far North is the reconstruction of natural ecosystems through intensive (cultural) measures that accelerate the recovery process. It is already well known that the natural restoration of disturbed systems can last for many tens or even hundreds of years especially in extreme environmental conditions [1,2,3,4]. The search for a solution to the problem of disturbed lands restoration in the Northern regions has been actively conducted since the 1990s. Some practical experience has already been summarized in the review publications [5,6,7].

In the last few decades, attention has been paid to the recultivation of quarries. A mandatory section on the restoration of soil and vegetation was introduced into the projects of their development. Currently, the state policy of the Russian Federation in the field of recultivation of disturbed lands is



aimed at restoring the physical, chemical and biological properties of the soil [8], which is impossible without science-based measures for biological recultivation of disturbed lands.

The purpose of our study is working out measures for land recultivation in the Russian Arctic on the basis of monitoring of natural restoration processes and vegetation development in artificially restored areas of quarries.

## 2. Materials and Methods

### 2.1. Study methods of natural recovery

Observations of the vegetation biodiversity restoration have been carried out for over 25 years in various sectors of the Russian Arctic, such as the North-East of European part of Russia, the North of Western Siberia, the Yamal Peninsula, Chukchi Peninsula). Primary successions of vegetation were studied in quarries using both direct methods (the permanent geobotanical plots) and proxy data (the extrapolation of spatial patterns in time series in similar environmental conditions). In total, the data of more than 1000 geobotanical relevés were analyzed. The size of the study plot was 25 m<sup>2</sup>. The methods of regular large-scale mapping of the quarry vegetation were also used. The data were analyzed statistically with priority use of modern nonparametric criteria.

### 2.2. Study methods of artificial restoration

The study of vegetation on disturbed lands resulting from the extraction of sand, the creation of a technological site or sand mound, the development of the deposit, etc., allows us to get an idea of the time of overgrowing of disturbed lands and of the used reclamation technology effectiveness. The dynamic series of vegetation recovering can be obtained from the following studies:

1. having studied similar habitats with different terms of disturbance;
2. having studied for a long time on permanent geobotanical plots.

The first approach allows to study the long-term dynamics of vegetation restoring during one field season. The second one requires long-term observations of vegetation restoration. Both methods were used in combination in this work.

Our research was carried out on the disturbed lands of the North of Western Siberia:

1. grass-recultivated open sandy areas of the Arctic tundra in the village of Sabetta and its surroundings (Yamal Peninsula) in 2016-2018;
2. recultivated quarries in the forest-tundra subzone in the vicinity of Aksarka village (the first survey in 2013, repeated in 2016 on permanent geobotanical plots);
3. temporary geobotanical test plots at quarries in the vicinity of Aksarka village examined in 2016;
4. recultivated quarries in the North of a forest zone in the surroundings of Nadym (surveyed in 2014).

### 2.3. Method of experiment on willow planting using stimulants and rooting systems

It is known that willows show rather high ecological plasticity in the conditions of moderate and cold zones. So we carried out an experiment on quarries restoration with the cuttings of local willow tree *Salix gmelinii* Pall. (= *S. dasyclados* Wimm.). To select an effective method, we conducted experimental planting with different variants of stimulants and rooting systems.

Planting was carried out by cuttings of the same length (20 cm) and at the same depth (10 cm) in June 2014 at a quarry in the vicinity of Gornoknyazevsk village.

The following specimen planting options were carried out:

1. Growth-regulating powder E (Indole-3-butyric acid – 0,68%, 4-Aminobenzoic acid – 1,95%, talc powder – 97,37%);
2. Badivir (the complex biological drug created on the basis of the drug Diprin [9] consists of predatory nematode, pseudomonad bacterium, Ectomaactorin fungus and Virin virus; they

operate in a complex, living in symbiosis; the drug was given by the developer Kostina L.Ya.);

3. Laser irradiation (green laser, distance to the irradiated object 10-15 cm, frequency 532 nm, power 38 mW, exposure time 3 min).

A control planting was also performed. In each version of the experiment 100 specimens of willow cuttings collected in the vicinity of Salekhard and Gornoknyazevsk were used.

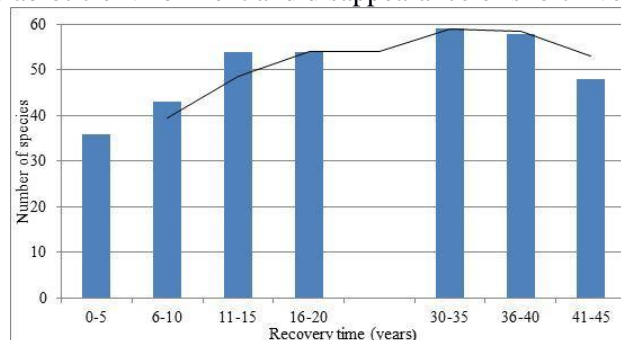
### 3. Results

#### 3.1. Basic features of natural recovery

The factors determining the speed and success of primary succession have been identified, including geographical location, spatial heterogeneity of the territory, soil moisture, granulometric composition of the soil, etc.

Our research revealed that the natural recovery of quarries is due to the resources of the local flora. The attraction of species with a more southern geographic range to disturbed sites was not revealed. So, the phyto-remediation should be focused primarily on local-adapted species of plants, which often come from intrazonal habitats or sites with natural erosion. Apophytes coming from zonal tundra communities may also be successful during the initial stages of the recovery in contrast with the dominant species of zonal vegetation. However, the testing of plant species from the other regions with similar environmental conditions is also possible for restoration tasks. The knowledge of biology and ecology peculiarities of successful colonist plants obtained in our study will help to select promising species for phyto-restoration. In any case, there is a need to develop the local seed plant industry.

The species diversity of the quarry vegetation changes non-linearly. This is confirmed by both direct and proxy data (fig. 1). Species diversity increases rapidly in the initial stage of succession during the first 10 years. In the next 10-20 years, this parameter increases more slowly and practically does not change in the next decade. Afterwards, species diversity reduce due to competitive exclusion or selective action of the abiotic environment and disappearance of short-lived weeds.

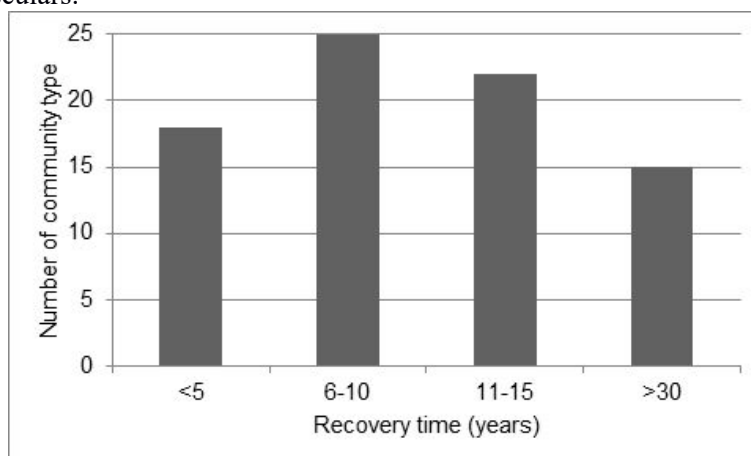


**Figure. 1.** The average number of vascular plant species in the quarries with different time of natural recovery. No quarry with the age of 20-30 years was found. The trend is shown by black solid line.

Most plants-colonists have secondary strategies combined two or three primary ones. Species with R and RS strategies are typical for the initial stage. Plant species with RS and RCS strategies are more successful in the next ("graminoids") stage, for the more advanced ("shrubs") stage – with CR and CS strategies and for the later final stages of recovery – with CS and S strategies.

The types of plant communities developing during succession in the different habitats of quarry were distinguished by floristic approach. The diversity of plant communities is maximum in the quarries after 10 years what is corresponding to the transition stage of the primary succession (Fig. 2).

At this time, herbaceous annual weeds, graminoids, willows and ericoid dwarf shrubs coexist in the vegetation. Later the species composition stabilizes and the number of plant community types decreases. This trend is observed in the quarries with different substrates. In the future, it is possible to forecast an increasing of species diversity thanks to increasing in number of cryptogamous plants and lichens but not vasculars.



**Figure 2.** Diversity of plant community types during primary succession in sandy/sandy loam quarries (North of the Western Siberia).

Speed and trends of succession processes in the different habitats of quarry vary significantly. This fact should be taken into consideration in the developing of all phytorestation projects. A polyvariant model of primary succession was developed [10]. According to this model plant community formation proceeds more intensively in trans-eluvial-accumulative sites (the foothills of the slopes) and accumulative sites (the bottom part of the quarry). As a result, the diversity of plant community types increases because the different internal elements of the quarry landform are occupied by various types of communities. The tops of dry eroded slopes exceeding 20 degrees require mandatory alignment. The spatial implementation of the polyvariant model is shown in the Figure 3.



**Figure 3.** Vegetation of the quarry after 40 years: a- communities with coniferous plants in eluvial and thans-eluvial sites (the background of the photo), and with willows and birch – in accumulative sites (the foreground of the photo); b - fens in accumulative sites at close groundwater level.

### 3.2. Land reclamation experience

The quarries developed more than 15 years ago were surveyed in 2014 in the North of the forest zone in the Nadym district. The vegetation cover of most of the investigated quarries have been restored by constructing the soil substrate using peat and planting of pine plantations (*Pinus sylvestris* L. subsp. *lapponica* (Fries ex Hartm.) Hartm. ex Holmb.). Vegetation is represented by dry lichen communities, slightly hydrated greenmosses-lichen communities and medium drained greenmosses communities.



The ground cover is fairly well developed (fig. 4a). In some areas of the quarries the vegetation has not recovered either independently or after recultivation (fig. 4b). Presumably in such areas the soil substrate was introduced in insufficient quantities or was not introduced at all. Nor were taken into account the features of the relief - a strong sensitivity to wind and water erosion.



**Figure. 4.** Reforestation with soil preparation (a) and without soil preparation (b), in quarries developed 15 years ago (Northern forest zone, Western Siberia). Photo 2014.

In forest lands restoration should be carried out with the planting of tree species. But recultivation of more northern territories usually perform with the herbal plants, sometimes with tree plantings in forest-tundra subzone.

Long-term observations of the biological recultivation results in the quarries in the forest-tundra subzone of Western Siberia showed that the vegetation recovering is carried out using imported herbs from the southern regions of Russia and is quite successful. In the first year after sowing grass mixture the vegetation cover forms with the dominance of annual-biennial rye *Secale cereale* L. (fig. 5a). Later large-grass meadow communities arise. *Bromopsis inermis* (Leyss.) Holub, *Elytrigia repens* (L.) Nevski, *Phleum pratense* L. and *Festuca rubra* L. are dominate or codominate in such communities (fig. 5b). The projective cover of herbaceous layer is up to 35%. After 3 years, local species begin to settle in such communities, but their projective coverage does not exceed 1%. Presumably, all this together determines the relatively low life expectancy of the described communities. However, this issue requires further research.



**Figure. 5.** Herbaceous plant communities formed in the first year after recultivation (a, *Secale cereale* dominate) and after 3 years (b, large-grasses meadow with *Bromopsis inermis*, *Elytrigia repens*, *Phleum pratense* and *Festuca rubra* codominating). Photo 2013 (a) and 2016 (b).

Interesting studies of the vegetation recovering in disturbed lands have been carried out for the Arctic tundra - this is probably the most northern experiment in Western Siberia. The trial was performed on the lawns in the Sabetta village and at sandy technological sites devoid of vegetation in Sabetta surroundings.

The sowing of grass mixes on the lawns of Sabetta village, made in 2015 and completed in 2016 by the gardening firm from the city of Tyumen, included in different proportions *Bromopsis inermis*, *Phleum pratense* and *Festuca rubra*. A special machine for sowing was used to seal the seeds in the soil to a depth of 2-3 cm. The standard of seeds per area unit was doubled, mineral fertilizers were used. The seeding sites were uneven and had height differences of 10 (20) cm on average. In the microrelief increases, communities of *Bromopsis inermis*, *Phleum pratense* and sometimes *Festuca rubra* formed. Projective cover of plants reaches up to 15% there. In the microrelief depressions water accumulates during the rainy period, so communities of these herbs are not evolved. In such depressions there is the development of single individuals of moisture-loving herbs from *Eriophorum* (*E. × medium* Andersson и *E. scheuchzeri* Hoppe) and *Deschampsia* (*D. borealis* (Trautv.) Roshev. и *D. glauca* C. Hartm.) genera and some others. Probably, without support and restoration, such lawns will eventually be replaced by communities that are formed in quarries with natural overgrowth.

We have accomplished experiments on the sowing of herbs in the vicinity of Sabetta village with seeding to a depth of 2-3 cm and various feeding options. They did not show significant results. Single surviving plants were observed in 2017 and 2018. The trials included single-species seeding and mixtures of herbs. The following species were used: *Bromopsis inermis*, *Phleum pratense*, *Festuca rubra*, *F. pratensis* Huds., *F. ovina* L., *Poa pratensis* L., *Lolium perenne* L., *L. multiflorum* Lam., *Trifolium repens* L., *T. pratense* L., *Lupinus albus* L., *Medicago sativa* L. In 2017, due to the short growing season, there were almost no sprouts. In 2018, only *Poa pratensis* was identified from rising plants.

The observed trends in the restoration of vegetation cover on sandy lands suggest that biological recultivation is a step that contributes to the natural processes of vegetation recovering.

### 3.3. The survival rate of *Salix gmelinii* cuttings while using different stimulants and the rooting systems

The examination results of experimental planting of *Salix gmelinii* cuttings in quarries in the vicinity of Gornoknyazevsk (West Siberian forest-tundra) are given in table 1. Measurements were done in 1 year and in 2 years after the experiment.

**Table 1.** The survival rate of *Salix gmelinii* cuttings planted in sandy quarry in 2014 using different stimulants and the rooting systems (the surroundings of Gornoknyazevsk, West Siberian forest-tundra). In each experiment 100 specimens are used.

Type of experiment	Proportion of survived shoots by years, %		Average height, cm	Parameters by 2016	
	2015	2016*		Average annual sprouts length, cm	Individuals with the dead annual shoots, pcs / %
The control planting	36	35	9.89 ± 0.74	4.10 ± 0.58	18 / 51.4
Growth-regulating powder E	41	42	15.91 ± 1.03	7.43 ± 0.86	22 / 52.4
Badivir	56	60	19.82 ± 0.95	7.38 ± 0.59	29 / 48.3
Laser irradiation	45	46	15.99 ± 0.96	5.76 ± 0.64	27 / 58.7
Laser irradiation + growth-regulating powder E	19	20	14.27 ± 1.70	6.57 ± 1.12	20 / 100.0
Laser irradiation + Badivir	32	30	12.60 ± 1.00	4.65 ± 0.71	30 / 100.0

\* increasing of survived shoots in 2016 compared to 2015 associated with the development of shoots from dormant buds

Based on the data presented in the table 1, the following conclusions can be done on the use of willows in the quarries recultivation in the forest-tundra subzone:

1. the cuttings of local willow species can be used for recultivation;
2. the use of stimulants (growth-regulating powder; Badivir; laser) allows to increase the survival rate of cuttings compared with the control, 1.2; 1.7 and 1.3 times, respectively;
3. combined application of laser with growth-regulating powder or Badivir showed a decrease in the survival of the cuttings of 0.6 and 0.9 times, respectively;
4. the use of different stimulators and rooting systems in one experiment leads to the suppression of cuttings, which is clearly seen from the comparison of number of specimens with dead annual shoots: their proportion amounts to 100% for trials with a combined impact and 48.3 to 58.7% for the other types of experiments.

#### 4. Conclusion

The results of the biomonitoring shown that some of community parameters, such as the species richness of vascular plants and the total vegetation cover can quickly grow in quarries and become comparable to those in some of the zonal tundra. However, these indicators cannot fully serve as criteria for the effectiveness of the restoration because there is a significant difference between anthropogenic quarry vegetation and natural plant communities in the composition of dominant species and spatial pattern.

The success of recultivation techniques depends on proper soil preparation and consideration of species environmental and geographical features.

The development and implementation of innovative methods of cuttings and rooting of the dominant shrub species of tundra communities by means of properly selected growth stimulants and rooting systems becomes promising. The using of different stimulators and rooting systems in one experiment leads to the suppression of cuttings. Such approach is irrational.

Generalization of our experience on long-term biomonitoring of vegetation regenerative changes on the quarries in tundra and forest-tundra zones of different sectors of the Russian Arctic allowed us to provide a basis for the development of science-based approaches to accelerated recovery.

As shown by our observations in the North regions, vegetation recovering of quarries and disturbed sandy sites involving methods of biological recultivation accelerates the process of natural revegetation through artificial coenoses.

It is necessary to continue observations and experiments on the dynamics and features of biological recultivation of quarries in the Northern territories of Russia.

#### References

- [1] Forbes B C 1993 Aspects of natural recovery of soils, hydrology and vegetation at an abandoned High Arctic settlement, Baffin Island, Canada *Proceedings of the Sixth International Conference on Permafrost* vol 1 pp 176-181
- [2] Haper K A, Kershaw G P 1996 Natural revegetation on borrow pits and vehicle tracks in shrub tundra, 48 years following construction of the CANOL No 1 Pipeline, N.W.T., Canada *Arctic and Alpine Research* vol 28 No2 pp 163-171
- [3] Jones G P Henry G H R 2003 Primary plant succession on recently deglaciated terrain in the Canadian High Arctic *Journal of Biogeography* vol 30 pp 277-296
- [4] Kershaw G P 2003 Long-term tundra disturbances: successful colonizers Social and environmental impacts in the North *Earth and Environmental Sciences* vol 31 Boston, London pp 159-171
- [5] Hagen D 2002 Propagation of native Arctic and alpine species with a restoration potential *Polar Researches* vol 21 No1 pp 37-47
- [6] Jorgenson M T, Kidd J G 2003 Long-term evaluation of methods for rehabilitation of lands disturbed by industrial development in the Arctic Social and environmental impacts in the North *Earth and Environmental Sciences* vol 31 (Boston, London) pp 173-190



- [7] Koptseva E, Egorov A 2017 The features of natural and artificial recovery in quarries of the forest-tundra zone of western Siberia *The Interconnected Arctic – UArctic Congress 2016*. Eds K Latola, H Savela (Springer Polar Sciences) pp 23-35
- [8] *Resolution of the Government of the Russian Federation* of July 10, 2018 N 800 “About carrying out recultivation and conservation of lands”
- [9] Patent N 2128911 1999 *The method of obtaining entomopathogenic drug Diprin* Date of publication 20.04.1999 (Russia)
- [10] Sumina O I 2013 *Formation of vegetation on technogenic habitats of the Far North of Russia* (St.-Petersburg, Russia)