Annals of Agrarian Science

Journal homepage: http://journals.org.ge/index.php

Oribatid mite communities on former clay quarries under different reclamation strategy

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Received: 12 April 2019; accepted: 10 June 2019

A B S T R A C T

In order to establish or regenerate ecosystems in severely disturbed mining sites, reclamation activities are common practice. However, the effectiveness of reclamation strategy might be depended on the specific conditions of the area under question. To evaluate the effect of provided reclamation activities, we investigated structure and composition of oribatid mite communities at an early succession stage in the abandoned Kaspi clay pit. Effectiveness of natural succession and two alternative reclamation activities was evaluated: 1. M1 - do-nothing approach on land under natural secondary succession; 2. M2 - smoothed ground surface with sown seed mixture of herbs and pasture grasses; 3. M3 -three fenced plots with sown grasses and tree seedlings. Neighboring overgrazed natural meadow is chosen as control. Results show that the "do-nothing" approach with leaving post-mining sites without any reclamation is the worse strategy in development of soil oribatid community on lands without "source" area for vegetation (and consequently for soil humus layer) development. Reclaimed fenced areas were relatively poor by oribatid species richness compared to surrounding reclaimed (but not fenced) or natural areas. High abundance of stress tolerant species in fenced sites shows that the time interval between fencing (2012, 2013 and 2014) and sampling (2015-2016) was not enough for soil structure and faunal recovery and longer period is needed to establish sustainable oribatid communities.

Keywords: Oribatid mites, Colonization, Reclamation, Mining, Secondary succession, Overgrazing.

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1. Introduction

Natural regeneration of destroyed soil ecosystems (e.g. abandoned open mining areas) could take a long time [1-3]. Reclamation activities are frequently used to enhance ecosystem regeneration processes and help establishment of the biota in disturbed areas. However development of viable soil communities may still need several decades depending on the structure of reclaimed soil [4-6], distance from colonization sources [7-10], age of restored sites [11, 12] etc. Neighboring areas usually serve as a main source for colonization of soil arthropods , however the rate and mode of colonization is supposedly taxon specific. For instance, active dispersal ability of or batid mites (one of the most abundant and ecologically important groups) in the soil is limited to several centimeters [13] while ground beetles are fast, long distance runners . It has also been shown that the dispersal rate in slow-moving taxa (such as soil mites) can be assisted by passive pathways so that the species could frequently persist in remote non-viable habitat patches [14] and may play an important (if not concomitant) role in the structuring of mites communities at early stage of succession [13, 15-17]. Accordingly, deep knowledge of the processes that support the development of soil arthropod communities can help establishment in successful reclamation strategies.

Different activities can be employed during the reclamation process including but not limited to reshaping site surface, planting trees or sawing grasses, applying fertilizers and adding organic products and so on [18]. Depending on the target ecosystem component, different reclamation activities can be used. For instance, regeneration soil and its biota (as example in an open mining areas with heavily degraded soil surfaces) one has to provide soil substrate and allow recolonization of soil dwelling animals. In addition, other aids can also be applied to support soil process (e.g. sowing grasses). Accordingly, adopting particular reclamation strategy can have a significant role on regeneration efficiency.

Unfortunately there are still insufficient investigations studding soil recovery process in open mining sites and in particular recovery of arthropod communities [19] ensuring no effective reclamation management. Furthermore, any particular reclamation activities undertaken until now in Georgia are only based on expert opinions rather than scientifically informed [20] usually followed no post reclamation monitoring and evaluations.

In this work we investigated the effect of provided reclamation activities on the structure and composition of oribatid mite communities at an early succession stage in the abandoned Kaspi clay pit. Oribatid mites are one of the most diverse and abundant group in soil matrix [21] and play an essential role in soil food web [22]. In addition, diversity of oribatid mites are the most intensively studied in Georgia [23] making this group useful for ecosystem evaluation [24]. Thus, unraveling the effects of reclamation activities on the development of oribatid mite community can help to better understand the succession of soil process. In 2012 Heidelberg Cement Caucasus Company began reclamation of the former clay pitarea applying different management strategy including different combinations of surfaceres haping , herb sowing, providing organic source and fencing [20]. Our aim was to evaluate the response of oribatid communities towards provided reclamation activities and to identify the best management strategies. We hypothesized that the fenced and smoothened surface with sowed grass and added organic content supports fastest recolonization and highest diversity of oribatid mites due to higher food supply and less physical disturbance; Though natural succession can lead to formation of diverse oribatid community [10], we were keen to understand how much the community succession rate depends on regeneration time provided in absence of physical disturbance (such as trampling).

2. Material and Methods

2.1. Study area

Kaspi clay pit represents a south western suburb of the Kaspi city (Georgia) (41.93; 44.39). The climate of the area is sub-Mediterranean with average annual temperature 13°C and annual precipitation 490 mm. The area of the former pit represents a flat depression on the left bank of the river Kura (Fig. 1) with license area of approximately 100 ha and open Kaspi clay pit area - 28.32 ha [20]. After 50th of the last century irregular mining activities were initiated that continued until 2006, after that time Heidelberg Cement Caucasus Ltd resurrected active mining that lasted until 2010. The quarry is surrounded by farmland area,is covered by ruderal vegetation and is extensively used for livestock grazing. For reclamation purposes three type of management have been applied: approach 1. Do-nothing – about 10 ha of area was left untouched with natural secondary succession (M1 – first management category); approach 2 – reclamation activities included smoothened ground surface and sowing commercial seed mixture with herbs and pasture grasses (M2 – second management category); approach 3 – three plots in reclaimed area were fenced each in 2012, 2013 and 2014 to restrict cattle movement. In each plot hay was added immediately as a supply of organic source (M3 – third management category) and seedlings of different species (mostly *Elaeagnus angustifolia* (Russian olive) and *Celtis caucasica* (Caucasian hackberry)) were planted (Table 1; Fig. 1).

Unreclaimed area (M1) is represented with small irregular hills left after mechanical relocation of ground during the mining process (Fig. 1, Table 1). All the areas but M3 were subject of continuous overgrazing.

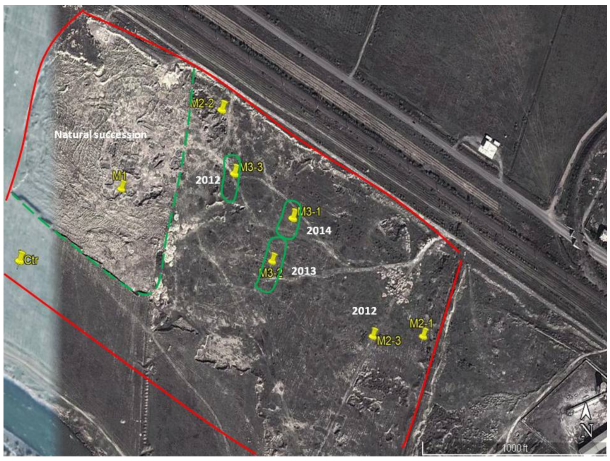


Fig. 1. *Kaspi clay pit with identification of sampling sites. Red solid line indicates area of reclaimed pit (M2), green solid lines show fenced plots (M3) and green dashed line shows area with natural succession (M1).*

Table 1. *Description of investigation sites with indication of observed and estimated (Chao) species richness. In the rightmost columns, site community data from the same management categories were pooled to evaluate overall management richness.*

Management Category	Sampling units	Site description	Coordinates	Site specific species richness		Management specific species richness	
				Species Richness	Estimated Richness	Species richness	Estimated richness
Ctr	Control	Natural overgrazed meadow. Plant coverage ~ 30%	N41°928 E44°391	23	30	23	29
M1	Not reclaimed	Natural succession on not reclaimed quarry. Overgrazed hills. Plant coverage < 20%	N41°929 E44°393	8	8	8	9
M2-1	Reclaimed	Natural seedlings of *Tamarix*	N41°927 E44°399	17	17	29	32
M2-2	Reclaimed	Grass sowed in 2012; Overgrazed; Plant coverage ~ 30%	N41°930 E44°527	23	24		
M2-3	Reclaimed	Grass sowed in 2012; Overgrazed; Plant coverage ~ 30%	N41°927 E44°398	17	19		
M3-1	Reclaimed fenced	Fenced in 2014; No grazing; Plant coverage ~ 50%	N41°929 E44°397	11	22	22	24
M3-2	Reclaimed fenced	Fenced in 2013; No grazing; Plant coverage ~ 80%	N41°928 E44°396	10	10		
M3-3	Reclaimed fenced	Fenced in 2012. No grazing; Plant coverage > 90%	N41°930 E44°340	15	15		

2.2. Sampling

In each management category (M1, M2, M3) and the surrounded control area (that was unaffected at least by mechanical disturbance), four 10 m^3 soil samples were taken randomly using soil corer in October 2015, February, May and July of 2016 (covering all four seasons). Soil samples were delivered in the laboratory and invertebrates were extracted using modified Berlese-Tullgren apparatus. Oribatid mites were collected in every 24 hours during one week. Extracted individuals were stored in 70% ethanol; temporary slides were made with lactic acid using hollow ground slides. Only adults were identified to species level using mainly keys of Weigmann [25] and Ghilarov and Krivolutsky [26]. Classification follows Schatz et al [27].

2.3. Data analysis

To compare species diversity and total abundance between different management units, we calculated total species richness for each management category as well as average species richness and individual density (per square meter) for each sampling unit. Later on, mean values were compared between management units using randomized block ANOVA where sampling period was used as a blocking factor and the management as a treatment. In addition to raw data, nonparametric estimators (Chao indices) and Simpson's diversity (1 - D) measures were used to consider sampling incompleteness in data analyses [28]. Cluster of faunal similarities we constructed using PAST software and based on Jaccard's similarity index.

3. Results

In total 3055 oribatid individuals belonging to 43 species from 25 families were identified (Table 2). Highest total number of species (29) was found in reclaimed overgrazed areas (M2-1 – M2-3) while lowest number (8 species) in not-reclaimed site (M1). Accordingly, this site showed lowest index of diversity (1-D = 0.15) (Table 1 and 3). Non-parametric estimators (Chao 1) showed the same trend and indicated a near complete inventory of species in almost all cases except Ctr where significantly more species are expected than sampled (Table 1). 82% of individuals were represented by 7 dominant species only (*Punctoribates punctum* (C.L. Koch, 1839)*, Oribatula (Z.) cognata* (Oudemans, 1902)*, Pilogalumna crassiclava* (Berlese, 1914)*, Tectocepheus velatus* (Michael, 1880)*, Epilohmannia cylindrica* (Berlese, 1904)*, Acrotritia ardua* (C.L. Koch, 1841)*, Ramusella clavipectinata* (Michael, 1885)) among which *P. punctum* composed 56% of total individuals and dominated in all samples. Rare species *Scutovertex armazi* Murvanidze & Weigmann, 2012*,* was found on natural meadow. Up to date this species was known from type locality only (Armazi Mountain) [29].

Table 2. *List of Oribatid mites found on Kaspi clay pit with number of individuals for each site*

Species	M1	M2-1	M2-2	M2-3	M3-1	M3-2	M3-3	CTR
Epilohmannia cylindrica (Berlese, 1904)	3	8	7	49	1	14	68	14
Acrotritia ardua (C.L. Koch, 1841)	13	7	18	16	0	9	24	12
Nothrus anauniensis (Canestrini & Fanzago 1876)	0	0	0	0	0	0	0	4
Trhypochthonius tectorum (Berlese, 1896)	0	2	0	0	0	0	4	0
Belba dubinini Bulanova (Zachvatkina, 1962)	0	1	17	6	0	7	3	1
Metabelba italica (Sellnick, 1931)	0	0	0	2	0	0	0	0
Berlesezetes cuspidatus (Mahunka, 1982)	0	0	0	0	2	0	0	0
Dorycranosus splendens (Coggi, 1898)	0	0	0	0	0	0	0	1
Liacarus brevilamellatus (Mihelcic, 1955)	0	0	0	0	0	0	8	0
Xenillus tegeocranus (Hermann, 1804)	0	0	0	0	1	0	0	2
Ceratoppia quadridentata (Haller, 1882)	0	0	0	1	0	0	0	0
Carabodes sp.	0	0	0	0	0	0	0	1
Epimerella smirnovi (Kulijev, 1962)	0	0	0	1	0	0	0	0
Oppiella nova (Oudemans, 1902)	0	0	0	0	0	0	0	2
O. fallax (Paoli, 1908)	0	0	0	3	0	0	0	0
O. subpectinata (Oudemans, 1900)	0	0	0	2	0	0	0	0
Ramusella clavipectinata (Michael 1885)	1	65	7	50	1	2	13	5
Quadroppia quadricarinata (Michael 1885)	0	0	0	1	0	0	0	0
Suctobelbella subtrigona (Oudemans, 1916)	0	0	1	0	0	0	0	0
Tectocepheus velatus velatus (Michael, 1880)	0	13	28	10	0	5	12	2
T. velatus sarekensis (Trägårdh, 1910)	6	13	0	12	1	0	9	0
Tectoribates ornatus (Schuster, 1958)	0	0	1	0	0	0	0	1
Camisia horrida (Hermann 1804)	1	0	0	0	0	0	0	0
Scutovertex armazi (Murvanidze &Weigmann, 2012)	0	0	0	0	0	0	0	1
S. minutes (Koch, 1836)	0	2	2	6	0	0	8	4
S. sculptus (Michael, 1879)	0	4	3	5	1	1	0	7
Peloptulus phaenotus (C.L. Koch, 1844)	0	0	0	0	0	0	3	0
Parachipteria fanzagoi (Jacot, 1929)	0	0	0	2	0	0	0	0
Oribatella colchica (Krivolutsky, 1974)	0	0	0	0	0	0	0	1
Oribatula tibialis (Nicolet, 1855)	0	0	0	0	3	0	0	0
O. (Z.) cognata (Oudemans 1902)	2	1	43	97	12	0	12	70
O. (Z.) exavata (Berlese, 1916)	0	3	6	0	0	0	0	0
O. (Z.) frisiae (Oudemans, 1900)	2	38	0	0	0	0	0	0
O. (Z.) terricola (V.D. Hammen, 1952)	0	8	13	0	0	0	0	0
Simkinia tianschanica (Krivolutsky 1967)	0	0	1	2	0	0	10	32
Scheloribates leavigatus (C.L. Koch 1836)	0	0	0	1	0	0	0	0
Ceratozetes minutissimus (Willmann, 1951)	0	0	0	0	1	0	0	1
Punctoribates punctum (Koch, 1839)	335	152	141	247	29	94	450	276
Galumna flagellate (Willmann, 1925)	0	0	0	0	0	7	0	107
Pergalumna nervosa (Berlese, 1914)	0	14	5	2	0	2	5	3
Pilogalumna crassiclava (Berlese, 1914)	0	20	32	34	0	6	6	24
P. tenuiclava (Berlese, 1908)	0	0	0	2	0	0	0	0
Protoribates capucinus (Berlese, 1908)	0	12	15	24	1	0	0	1

Table 3. *Diversity indexes of oribatid mites on former Kaspi clay pit*

	CTR	M1	M2-1	M2-2	M2-3	M3-1	M3-2	M3-3
Taxa_S	23	8	17	23	17	11	10	15
Individuals	572	363	363	575	340	53	147	635
Dominance_D	0.289	0.853	0.228	0.235	0.214	0.358	0.430	0.517
Simpson_1-D	0.711	0.147	0.772	0.765	0.786	0.642	0.571	0.483
Evenness_e^H/S	0.245	0.185	0.421	0.309	0.452	0.398	0.393	0.230

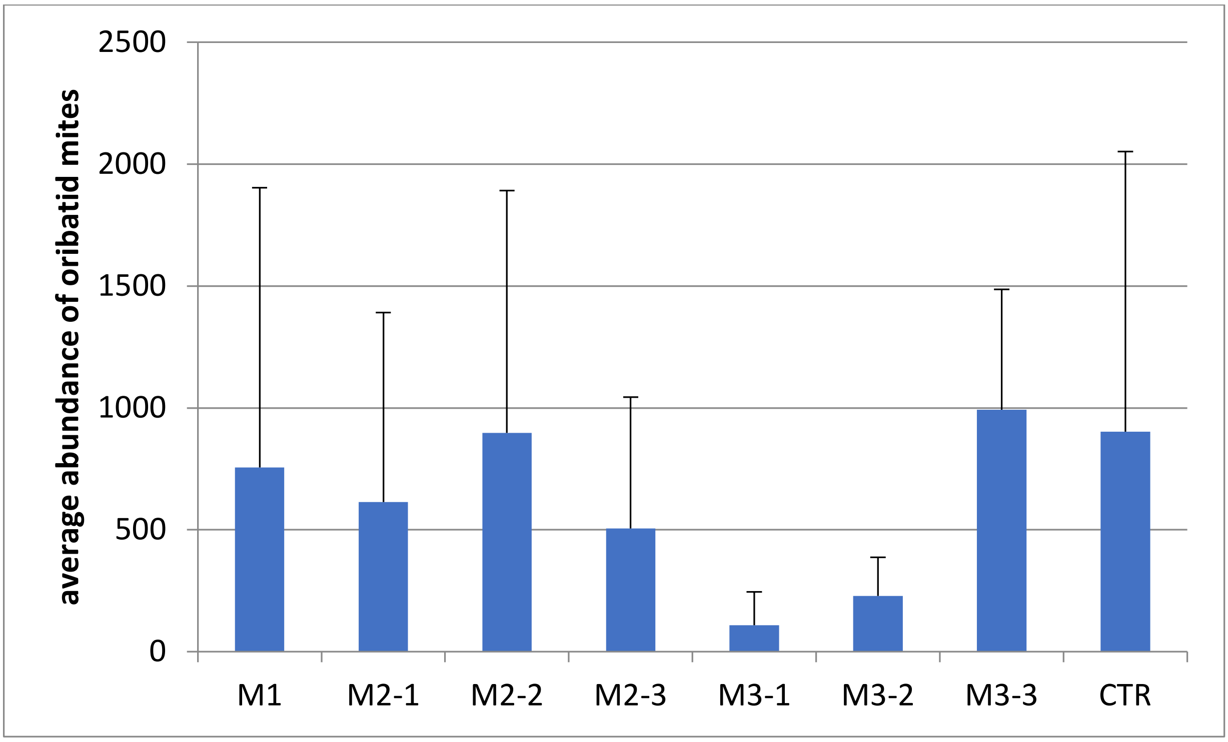
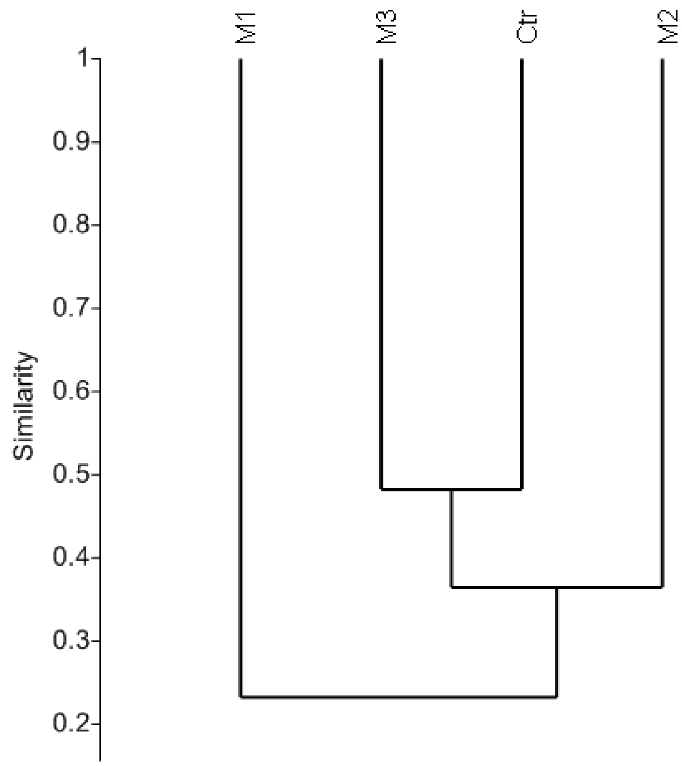


Fig. 2. *Average abundance of oribatid mites on investigated sites. Error bars indicates ±1 standard deviation.*

ANOVA model describing abundance and richness differences among management classes were significant (for main effects p ($F_{3,91}$) = 0.008 and p($F_{3,91}$) = 0.002 respectively). However, in case of abundance, only Ctr samples was significantly abundant (p = 0.027) compared to M3 samples, while there were no significant differences in other cases (Fig. 2). Similarly, sample species richness was significantly higher in Ctr cites compared to M3 (p = 0.006) and in M2 compared to M3 (p = 0.046).

Oribatid faunal composition showed higher similarity between Control and M3 sites while oribatids from unmanaged (M1) site were isolated from those with different management approaches (Fig. 3).

Fig. 3. *Cluster of faunal similarity between plots with different management activities (faunal similarity is based on Jaccard's coefficient).*



4. Discussion

Mining on Kaspi clay pit was stopped in 2009, while restoration activities were initiated in 2012 [20]. Our results show that the "do-nothing" approach with leaving post-mining sites without any reclamation is not effective strategy in development of soil oribatid community (and most probably whole soil ecosystem). This contradicts with our earlier finding which showed that natural succession can support even more diverse fauna than reclamation [10]. Effectiveness of natural succession is supported by other investigations as well [11, 25, 32]. Poor development of oribatid communities on M1 sites can be explained by two reasons: (1) time interval between stopping mining activities (2009) and sampling (2015) was not enough for development of oribatid fauna. More than 10 years are needed for faunal recovery [10, 19]; (2) there is no "source" area for vegetation (and consequently for soil humus layer) development around the whole area - M1 plots are surrounded by extensively overgrazed natural and reclaimed meadows without any forested territory. Intensive grazing leaves soil bare and exposed to wind erosion which makes it infertile and unsuitable for development of soil fauna. In our previous investigation neighboring forests served as a source for oribatid colonization on dump and abandoned quarry sites [10], hence we can conclude that presence of diverse habitat fragments speeds up secondary succession on former mining sites, while in their absence succession can be either very slow or impossible and active reclamation is strongly suggested.

In spite of high faunal similarity between control and fenced (M3) sites (Figure 2), opposite to our expectations, reclaimed fenced areas (that are protected from grazing) were relatively poor by oribatid species richness (plot species richness as well as total species diversity) compared to surrounding reclaimed (but not fenced) or natural areas. Fencing protects reclaimed sites from heavy overgrazing and leads to formation of dense vegetation cover with favorable conditions for soil fauna. However, as table 3 shows, evenness of species distribution in fenced sites tends to be lower compared to reclaimed unfenced areas and high abundance was provided by dominance of single species – *P. punctum.* This is true for M1 site as well, where high overall abundance is provided by *P. punctum*, when the rest seven species are presented by minor quantities (Table 2). This species (with another co-dominant species like*T. velatus*) is known as cosmopolite one and an effective colonizer of disturbed habitats in early stages of soil recovery [9, 10, 32]. High abundance of these stress tolerant species in protected sites shows that the time interval between fencing (2012, 2013 and 2014) and sampling (2015-2016) was not enough for soil structure and faunal recovery. Moreover, for sensitive species that are heavily dependent on habitat quality and passive dispersal opportunities, fencing may pose an additional barrier for animals (e.g. cattle) who could contribute to passive dispersal of oribatids. Indeed, occurrence of species such as *Ceratoppia quadridentata* (Haller, 1882), *Quadroppia quadricarinata* (Michael, 1885), *Epimerella smirnovi* (Kulijev, 1962), *S. armazi, Oribatella colchica* Krivolutsky, 1974, *Galumna flagellata* Willmann, 1925 in surrounding reclaimed areas which are not fenced, indicates that these species were not able to reach the fenced habitats. Previous investigations show that soil arthropods (and oribatid mites among them) can be passively dispersed by other vectors such as wind [13], birds [16], beetles [32, 34] and even frogs [35]. Nonetheless, it seems that none of above mentioned vector can be only responsible for mite colonization in Kaspi quarry areas. We suppose that the active livestock grazing in postmining sites while hindering effective development of vegetation cover and accumulation of organic material in soil [36], can support active translocation of soil arthropods from surrounding areas. Unfortunately, relatively little is known on the role of livestock in oribatid mite dispersal and our conclusions needs to be further corroborated.

Acknowledgement

This work was supported by Shota Rustaveli National Science Foundation (SRNSF) № PhDF17-124 “Oribatid mites – indicators of the disturbed ecosystems” and Heidelberg Cement company.

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