Waste Management xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Waste Management

journal homepage: www.elsevier.com/locate/wasman

Comparison of plant and bacterial communities between a subtropical landfill topsoil 15 years after restoration and a natural area

Xun-Wen Chen [a], James Tsz-Fung Wong [a], Anna Oi-Wah Leung [b], Charles Wang-Wai Ng [a,*], Ming-Hung Wong [a,c,d,*]

[a] Department of Civil and Environmental Engineering, The Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong Special Administrative Region, China
[b] Croucher Institute for Environmental Sciences, and Department of Biology, Hong Kong Baptist University, Kowloon Tong, Hong Kong Special Administrative Region, China
[c] Consortium on Health, Environment, Education and Research (CHEER), and Department of Science and Environmental Studies, The Education University of Hong Kong, Tai Po, Hong Kong Special Administrative Region, China
[d] School of Environment, Jinan University, Guangzhou, China

ARTICLE INFO

Article history:
Received 2 June 2016
Revised 14 August 2016
Accepted 17 August 2016
Available online xxxx

Keywords:
Man-made ecosystem
Plant
Soil bacterial community
Sanitary landfill
Restoration
Nutrients cycling

ABSTRACT

Engineered sanitary landfills are becoming more and more common worldwide. Ecosystem restoration of capped sanitary landfills is essential to restore the disturbed environment. Comparing plant communities, as well as bacterial communities, in landfills and natural areas, offers an efficient way to assess the restoration status. However, such studies on the restored engineered landfills are limited. Here we present an ecological restoration case in an engineered landfill in a subtropical region. Part of the South East New Territories (SENT) landfill in Hong Kong was capped and restored, by using 16 plant species growing on top of the final cover soil, during 1997–1999. In 2014, plant survey and soil properties analyses were conducted in a restored site (AT) and a natural site (CT, an undisturbed area, serving as a control). The similarity between the biota communities (i.e., plant and soil bacteria) of the two sites was assessed. Plant and soil bacterial communities at AT were significantly different ($R = 1$, $P < 0.01$, ANOSIM) from those at CT. A lower plant diversity but a higher soil bacterial diversity were observed at AT. The soil bacterial community structure was potentially driven by soil pH, moisture content, cation exchange capacity (CEC), N, and P. The engineered landfill had not been restored to an ecosystem similar to the natural environment 15 years after restoration. Establishing similar soil properties in the landfill topsoil would be important to achieve a bacterial community similar to the natural area. This study can also offer a quick and inexpensive method for landfill engineers to assess the bacterial restoration of man-made ecosystems using plant and soil properties rather than DNA analyzing techniques.

1. Introduction

Landfilling is one of the major measures adopted for managing solid waste worldwide. Non-sanitary landfills, common in the past, were constructed using several soil layers beneath and on top of the waste to prevent contamination of the environment (USEPA, 1993; Qian et al., 2002). However, leachate and landfill gas can migrate and discharge to the environment, leading to groundwater contamination and greenhouse gas emission. On the contrary, the sanitary landfill, can minimize leachate and gas emission by applying a liner system (USEPA, 1993).

Restoration of closed landfills is essential to compensate for ecosystem disturbances, minimize adverse effects on the environment and render it safe for further use. In order to assess the status of a landfill restoration, a control area (undisturbed natural area) could be used for comparison with the restored area, in terms of plant and bacterial diversity, communities structure, abundance and similarity (SER, 2004; Perillo et al., 2009; Orsi et al., 2011). Developing countries, following economic developments worldwide, begin to seek for advanced and budgeted measures for waste management. More sanitary landfills can be expected (Hoornweg and Bhada-Tata, 2012) with the aim of successful restoration. Since

* Corresponding authors at: Room 3556, Department of Civil and Environmental Engineering, The Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong Special Administrative Region, China (C.W.-W. Ng). Office B3-2/F-33, Department of Science and Environmental Studies, The Education University of Hong Kong, Tai Po, Hong Kong Special Administrative Region, China (M.-H. Wong).

E-mail addresses: xchenat@ust.hk (X.-W. Chen), tfwongah@connect.ust.hk (J.T.-F. Wong), aleung@hkbu.edu.hk (A.O.-W. Leung), cecwwng@ust.hk (C.W.-W. Ng), minghwong@eduhk.hk (M.-H. Wong).

http://dx.doi.org/10.1016/j.wasman.2016.08.015
0956-053X/

specific limits for rainfall infiltration, landfill gas emission and slope angle are available (USEPA, 1993), evaluating the performance in preventing rainfall infiltration, landfill gas emission and slope stability are relatively manageable. However, evaluating the ecological success and ecosystem function are difficult and critical.

Previous studies focused more on the restoration process in non-sanitary landfills which were subjected to the influence of landfill gas and therefore searching for plants with methane tolerance seemed to be important (Chan et al., 1997, 1998; Marchiol et al., 2000). The ecological performance of a non-sanitary landfills was investigated (Chan et al., 1997), and the results showed that higher plant coverage, plant diversity, and microbial activities were observed at landfill sites, compared with those at reference sites. It was also pointed out that non-sanitary landfills could support ecological succession to typical and natural forests (Kim et al., 2004). Other studies on landfill restoration were also conducted at non-sanitary landfills (Biederman and Whisenant, 2009; Carrington and Diaz, 2011; Kim and Lee, 2005a, 2005b; Rawlinson et al., 2004), however, with more focus on the effects of soil manipulation, by adding wood chips (Biederman and Whisenant, 2009) and compost (Carrington and Diaz, 2011) as amendments, in affecting plant growth and development.

However, studies on the ecological performance of engineered sanitary landfills are scarce. In arid or semi-arid regions, a capillary barrier is applied as a landfill capping system (Barnswell and Dwyer, 2012). On the contrary, in humid regions (e.g., Hong Kong) sanitary landfills incorporate a geomembrane (HDPE) to prevent water percolation and landfill gas emission (Chan and Wong, 1998; Wong et al., 2015). A high degree of soil compaction (90–95%) has also been applied for slope stability (Fredlund and Rahardjo, 1993; Ng and Menzies, 2007). Therefore, sanitary landfills can ensure safety and minimum environmental impacts, but they change the soil water storage status and soil structure, compared with non-sanitary landfills and natural areas. In natural or man-made terrestrial ecosystems, the nutrient cycle (e.g., carbon, nitrogen and sulfur etc.) is mainly regulated by plants and associated microorganisms (e.g., bacteria for nitrogen fixation, nitrification and denitrification) (Bormann and Likens, 1967; Kertesz and Frossard, 2015; Parton et al., 2015; Schmidt et al., 2011). Briefly, plants capture carbon and nutrients from the atmosphere and soil respectively. These would then be transferred to the rhizosphere (via root exudates or litter) and utilized by bacteria (e.g., decomposition and mineralization). The nutrients are released back to the soil and hence available for the plants (Schulze and Mooney, 1994). Plants and bacteria are crucial components that related to the ecological performance of restored landfills.

Soil microbial communities in the topsoil layer serve as essential bio-indicators to assess the ecological performance of the soil environment (Morris and Blackwood, 2015). Most studies focused on bacteria in the refuse itself or the topsoil in non-sanitary landfills (Semrau, 2011). However, with promising performance, sanitary landfills are widely used nowadays. In this case, the ecological performance of sanitary landfills is the interest of both ecologists and environmental engineers. In addition to the safety and pollution control aspects, it is necessary to investigate how this emerging man-made ecosystem will behave, in terms of the plant and bacterial communities structures. Studies comparing the similarity of bacterial communities between a sanitary landfill and a natural area, as a measure to assess the ecological performance, are scarce.

Here, we present a restoration case of a sanitary landfill in a subtropical region. The South East New Territories (SENT) landfill in Hong Kong covers a total area of over 100 ha. It began accepting waste in 1994 and was designed to handle municipal solid waste for two decades (HKEPD, 2014). In 1997, phase I of the landfill was saturated with municipal solid waste and capped with a cover system. Sixteen plant species, including seven exotic species (as pioneer species) and nine native species, were used for the restoration (Chen et al., 2015). Plants were allowed to grow for two years (1998–1999) prior to the continuing monitoring (2000–2012). It was found that the plant communities between the restored landfill and natural area were significantly different. This leads to the current study which focuses on the soil bacterial community in the restored sanitary landfill (containing geomembrane in the final cover system). It was hypothesized that the soil bacterial community in the restored landfill would be similar to the nearby natural area. The objectives of the present study were to (1) investigate the similarity of soil bacterial communities between the restored sanitary landfill and the natural area and (2) explore the feasibility of applying soil properties and plant growth parameters to assess the ecological performance of the soil bacterial community and offer a quick and inexpensive method for landfill restoraion management.

2. Materials and methods

2.1. Study sites

One site (AT, 22°16′35.4″N 114°16′40.2″*E*) within the SENT landfill, capped and restored in 1997 (the earliest-restored area), was selected for study of the soil bacterial community. The landfill final capping system included the final intermediate cover, cushion geotextile, geomembrane, geonet, filtration geotextile and general cover layer (HKEPD, 2014). In detail, leachate migration to the bottom soil and rainfall infiltration into the waste are minimized by implementing the liner system (hydraulic barrier layers). Landfill gas emission is controlled using the gas extraction system with perforated pipes/wells placed within the refuse. For the final cover, there are three layers of soil (total depth: 1.5 m) above the high-density polyethylene (HDPE) membrane and the geocomposite draining layer: (a) 300 mm of screened compacted construction and demolition (C&D) fines, incorporated with different soils and/or organic matter, (b) 900 mm of lightly compacted C&D waste, and (c) 300 mm of final topsoil (completely decomposed granite and volcanic soil), incorporated with horticultural soil in planting pits with a hydro-seeding cover (Urbis Ltd, 1996; Chan and Wong, 1998) (Fig. A1). The other site (CT, 22°16′48.6″N 114°17′07.8″*E*), located approximately 150 m away from the east boundary of the landfill, served as a control (Fig. 1).

2.2. Soil sampling

According to our previous study on more other sites (four sites in total, area of each site: 100 m^2) within the landfill (Wong et al., 2016), similar to site AT, the most abundant plant species were *Acacia* and *Leucaena* at other sites. Site AT was the earliest site restored (in 1997), and has been subjected to the longest succession period among all sites. Essential soil properties (i.e., moisture content, cation exchange capacity, nitrogen and phosphorus) that might affect the bacterial community were similar among all sites (including AT, represented as site C in Wong et al. (2016)). Therefore, AT could serve as a representative site for studying the landfill restoration, in order to obtain the initial data to investigate the similarity between AT and CT.

Soil sampling was undertaken in July 2014, representing the summer season in the region. A line transect (25 m) was randomly placed at each site (AT and CT, approximately with area of 45×23 m^2 and 50×20 m^2, respectively). After removing litter from the soil surface, soil samples at depths between 5 and 10 cm were collected, with three replicates at each 5 m interval along the transect. Five individual soil samples were collected,