ASSESSMENT OF VEGETATION CHANGE AFTER BIOSOLIDS TREATMENT: USE OF REMOTELY SENSED VEGETATION TIME SERIES

Leslie N. Brown[1]
José B. Lim[1]
Kaan Ersahin[1]
Gary A. Borstad[1]
Eduardo Loos[1*]
Jaimie Dickson[2]
Peter Martell[2]

[1]ASL Environmental Sciences Inc.[*], #1-6703 Rajpur Place, Victoria, BC V8M 1Z5
[2] Teck Highland Valley Copper Partnership, P.O. Box 1500, Logan Lake, B.C. V0K 1W0
* Presenter

ABSTRACT

Highland Valley Copper has run an experimental treatment program for many years, to use treated, de-watered sewage sludge (biosolids) as a supplement to the capping of waste rock and tailings materials before revegetation. This is an attempt to improve water retention on coarse-grained materials, as well as provide a source of nutrients. In 2012, we used the 12-year remotely sensed vegetation time series compiled by Teck and ASL to evaluate the effects of biosolids applications at selected tailings and waste rock sites. The vegetation maps allowed us to compare rates of vegetation change at a number of these treated areas with nearby untreated sites. Though our findings were based on a rather small number of sites, we concluded that while the short-term effects of biosolids on vegetation growth were site dependent, over the longer term (~10 years or more) there was a small, positive effect at all sites, in the form of increased growth rates at biosolids treated sites relative to nearby untreated sites.

Qualitative assessment of community composition showed that, like the short-term effects on growth rate, the effects of biosolids varied by site. In some areas, the application of biosolids appeared to have little influence on community composition. In these locations, capping with overburden had a greater effect. In other areas, treatment with biosolids appeared to promote communities dominated by grasses. This is in agreement with an earlier study that also showed a response to biosolids treatment by grasses.

Keywords: Highland Valley Copper, reclamation, vegetation, remote sensing, waste rock, tailings.

INTRODUCTION

Highland Valley Copper (HVC) near Kamloops, British Columbia has had a major mine reclamation program underway since 1983, in which the establishment and development of self-sustaining

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[*] Borstad Associates Ltd. merged with ASL Environmental Sciences Inc. in 2009, and has since operated as the remote sensing division (ASL Borstad Remote Sensing). ASL is a corporate member of the Canadian Land Reclamation Association (CLRA).

vegetative cover are important elements. The success of the program has been monitored since its inception using standard biological sampling techniques. Aerial multispectral surveys were initiated in 2001 to monitor the success of the vegetation establishment over the entire mine, and have been acquired annually since then. In addition, high resolution satellite imagery has been acquired since 2011. Previous reports on this work (Borstad Associates, 2006; ASL Borstad Remote Sensing, 2009-2013) have demonstrated the ability of the remote sensing surveys to provide synoptic, quantitative and thematic maps of the vegetation cover on the mine site. The continuous, 2-dimensional coverage they provide can be used to extrapolate from and between the more detailed observations at ground sampling sites, with the additional value of information on temporal changes over large areas, some of which are inaccessible from the ground.

As part of their reclamation program, HVC began in 1996 an experimental treatment program using treated, de-watered sewage sludge (biosolids) to supplement the capping of waste rock and tailings materials before revegetation (Bloodgood *et al*., 1998). It was hoped that biosolids could improve water retention on coarse-grained materials, as well as provide a source of nutrients. The program became operational in 1998. A 2003 study examined the effects of the biosolids on soil and foliar chemistry, soil water retention, and the biomass and composition of subsequent vegetation development (Straker *et al.*, 2003). This document reports the results of a 2012 study of the effects of biosolids applications on subsequent vegetation growth at experimental sites, using the 2001-2012 remote sensing time series.

METHODS

Remote sensing data

Aerial multispectral surveys over revegetated areas have been performed every year between 2001 and 2012 (except for 2004) using a Compact Airborne Spectrographic Imager (CASI) (Richards *et al.*, 2003; Borstad *et al.*, 2009; Martínez *et al.*, 2013). In an endeavour to move from airborne to satellite technology, in 2011 and 2012 we also acquired a multispectral image data from the Worldview-2 (WV2) and Quickbird-2 (QB2) satellites, respectively. The satellite and the airborne data were acquired within one day of each other. . The acquisition of both airborne and satellite data allowed us to cross-calibrate the two datasets before integrating the satellite data into the existing time series.

Vegetation indices and remote sensing biomass

Two vegetation indices were calculated from the satellite and airborne reflectance data. The ‘Greenness Index’, also called the Normalized Difference Vegetation Index (NDVI), is a well-known index commonly used in remote sensing to serve as a proxy for green vegetative cover or biomass (Lyon *et al*., 1998; Peñuelas and Filella, 1998; Rouse *et al*., 1974). Our ‘Normalized Yellow Index’ provides an index of desiccation and/or senescence to assist with interpretation of low NDVI values (Borstad Associates, 2006). As the CASI, WV2, and QB2 spectral configurations are different, the vegetation indices were calculated using slightly different wavelengths. Before including the WV2 and QB2 NDVI in the time series, cross-calibration was performed by pairwise comparison of NDVI calculated from both WV2 – CASI and QB2 - CASI sensors. For application to Highland Valley, we calibrated NDVI to ‘remote sensing biomass’ (RSB) based on a comparison of CASI and *in situ* biomass measurements made over a wide range of conditions between 2001 and 2005 (Borstad Associates, 2006).

Study sites

Study sites included tailings impoundments (Trojan and Highmont) and waste rock dumps (Bethlehem, Table 1). Among the tailings sites, some had been capped with overburden and others had not. All waste rock sites were capped. In general, capping is applied at HVC where deposits are unsuitable to permit direct revegetation (Straker *et al*., 2003). For each class of site (tailings or waste rock, capped or not), untreated sites located close to biosolids treated sites and similar in age were studied as controls. A total of 16 biosolids treated sites and 14 untreated controls were used.

Table 1. Summary of sites selected for biosolids analysis, showing dates of seeding, capping and biosolids application. Blue shading indicates biosolids treated sites.

Area and Material		Site ID	Capped	Biosolids	Seeded/Planted
Trojan Tailings (not capped)		2	no	1996	1996
		3	no	2000	2000
		4	no	2001	2001
		9, 10	no	2001	2001, 2004 (partial)
		11	no	2001	2001
		5, 8	no	no	1991, 1998
		6	no	no	1993, 1998
		7	no	no	1998
Trojan Tailings (capped)		16	2003	2005	2005
		1, 12	2003	no	2004, 2005
		15	2003	no	2004
Highmont Tailings (not capped)		13	no	2008	2008
		14	no	2000	2000
		12	no	no	1996
Bethlehem Waste Rock Dumps (capped)	North	D, E	pre-2002	1999	1999
		F, G	pre-2002	no	1994, 1997
		H	pre-2002	no	1992, 1994 (partial)
	West	M	pre-2002	1997	1998
		N	pre-2002	1997	1984, 1987, 1998
		O	pre-2002	no	1987
		P	pre-2002	no	1984
	South	J	pre-2002	1997	1997
		K, L	2007	1997, 2007	1983, 1997
		I	pre-2002	no	1984

The dates given in Table 1 show that the sites ranged in age from 30 years since their first seeding or planting to 5 years for the most recent site at Highmont. Waste rock sites tended to be older than tailings sites, all (with the exception of sites K and L) having been seeded and (where applicable) treated with biosolids at least 3 years before the beginning of the remote sensing time series. Many of the tailings sites were seeded and/or treated during the course of the remote sensing time series (since 2001), which was useful for the assessment of shorter-term effects of biosolids. Treatments applied prior to the most recent disturbance at each site are not listed.

A variable that was not taken into account during this study was the *application rate* of the biosolids, and whether they were top-dressed or incorporated. Any effect was expected to be minor, since, according to the Straker *et al*. (2003), biosolids applications of 50-200 dry tonnes per hectare yielded similar vegetation biomass after 2-3 years; as well, top-dressing has not been used since the initial trials in 1996 and 1997. We note that HVC sites that do not receive biosolids are typically treated annually with chemical fertilizers for the first 3 (for waste rock) to 4 (for tailings) years after seeding.

Field observations

Vegetation community composition was qualitatively estimated from site photographs acquired in August 2012.

RESULTS

Figures 1 and 2 show mean NDVI time series for all sites included in the biosolids study. In general, the NDVI trajectories for sites with similar histories were similar, with the possible exception of site 15, which had greener vegetation than other similar sites in 2005 (Figure 1D).

Short-term effects

Of the 16 biosolids treated sites, eight (tailings sites Trojan 4, 9-11, 16, Highmont 13 and waste rock sites Bethlehem K and L) received biosolids during the years for which NDVI data are available. The timing of biosolids additions is indicated by the coloured arrows in Figure 1A, C, E and Figure 2E. In each case, NDVI dropped to zero (or less) in the year in which biosolids were applied, indicating coverage of the existing vegetation by the biosolids.

At Highmont Tailings (Figure 1E) and Bethlehem (Figure 2E), biosolids treated sites demonstrated clear increases in growth in the years following their 2007-08 treatment, relative to untreated sites or sites that had been treated before 2001 (Figures 1F and 2F). However, at Trojan the trends were different: Trojan sites displayed little or no change in growth rates in the years following the 2001 biosolids application (Figure 1A) – in fact their early growth patterns were similar to untreated sites (Figure 1B). On the other hand, capped sites displayed rapid growth in the years following the 2003 capping, whether they were treated with biosolids or not (Figure 1C and D).

It appears that at Trojan, capping with overburden provided growth-promoting conditions in a way that biosolids did not. Although we do not know the physical properties of the two types of materials, it may be that overburden is better at retaining moisture, for example, than biosolids. In a previous study, we showed that vegetation at Trojan Dam was highly responsive to precipitation, whereas at Highmont Tailings it was not (Borstad Associates, 2009; Martínez *et al*., 2011). There are, of course, other differences between these sites that make it hard to be sure of the underlying mechanisms. The uncapped Trojan sites, for example, were treated earlier than the other sites; perhaps there were differences in biosolids composition, application rates or application methods that changed over time.

To summarize, our analysis suggests that short-term biosolids effects vary by site. At Highmont, biosolids treatment resulted in increased growth, whereas at Trojan, capping with overburden appeared to be more important for growth promotion. Since Bethlehem sites received both biosolids and capping in the same year, we cannot resolve the separate effects of these treatments at this site. This interpretation is made on the basis of only a handful of sites; an examination of more sites is warranted to draw more definite conclusions.

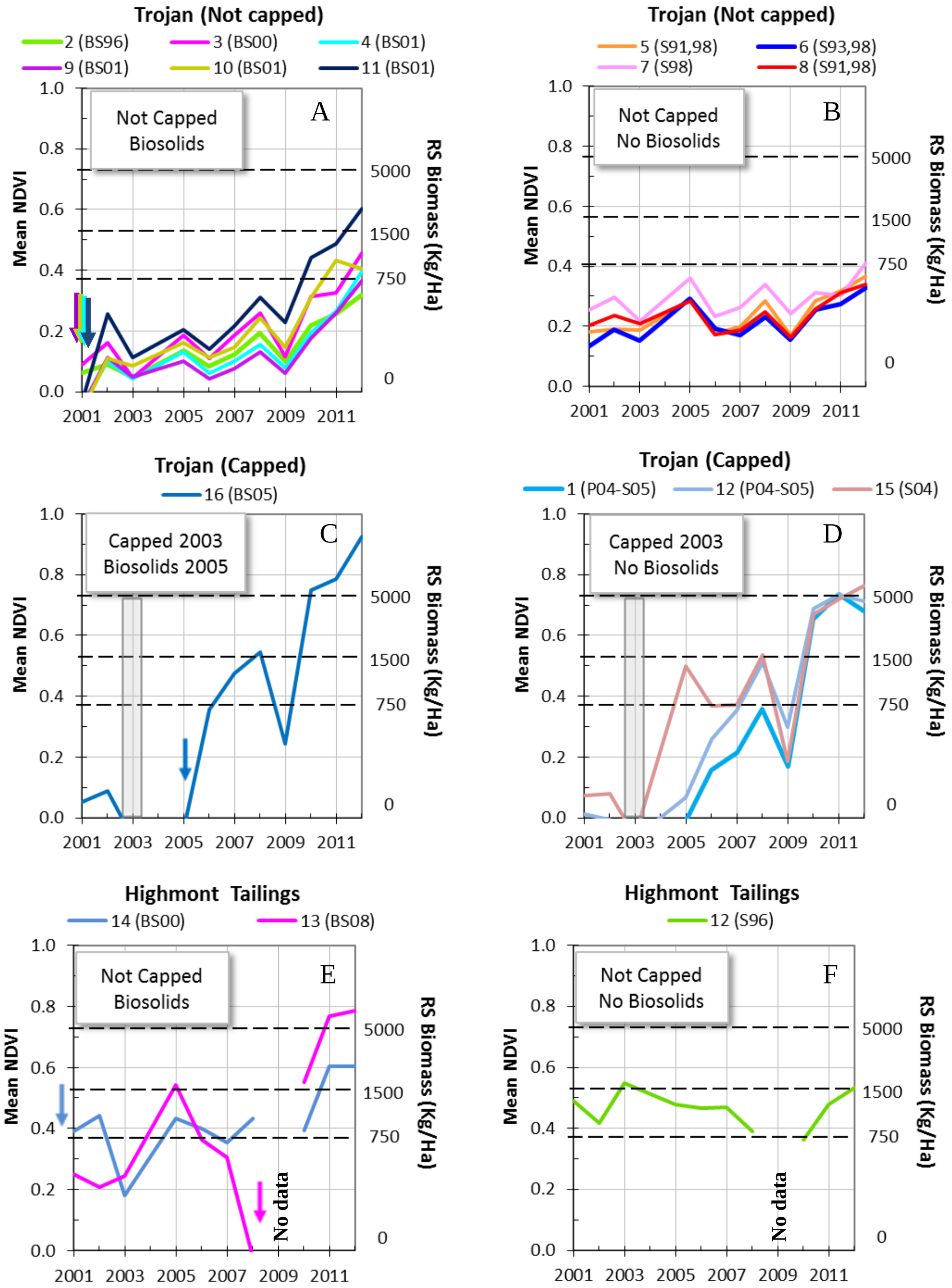

Figure 1. Summary of NDVI time series at tailings sites.

The horizontal dashed lines represent NDVI corresponding to reclamation thresholds[†] at 750, 1,500 and 5,000 kg/ ha. Coloured arrows indicate the timing of biosolids treatments. Grey bar indicate years when sites were capped with overburden. (BSyy) = year of biosolids application, (Syy) = year of seeding, (Pyy) = year of planting.

[†] When this work was undertaken in 2012, biomass thresholds were used to determine reclamation success. However, Teck is currently in the process of developing new performance indicators that will include biodiversity.

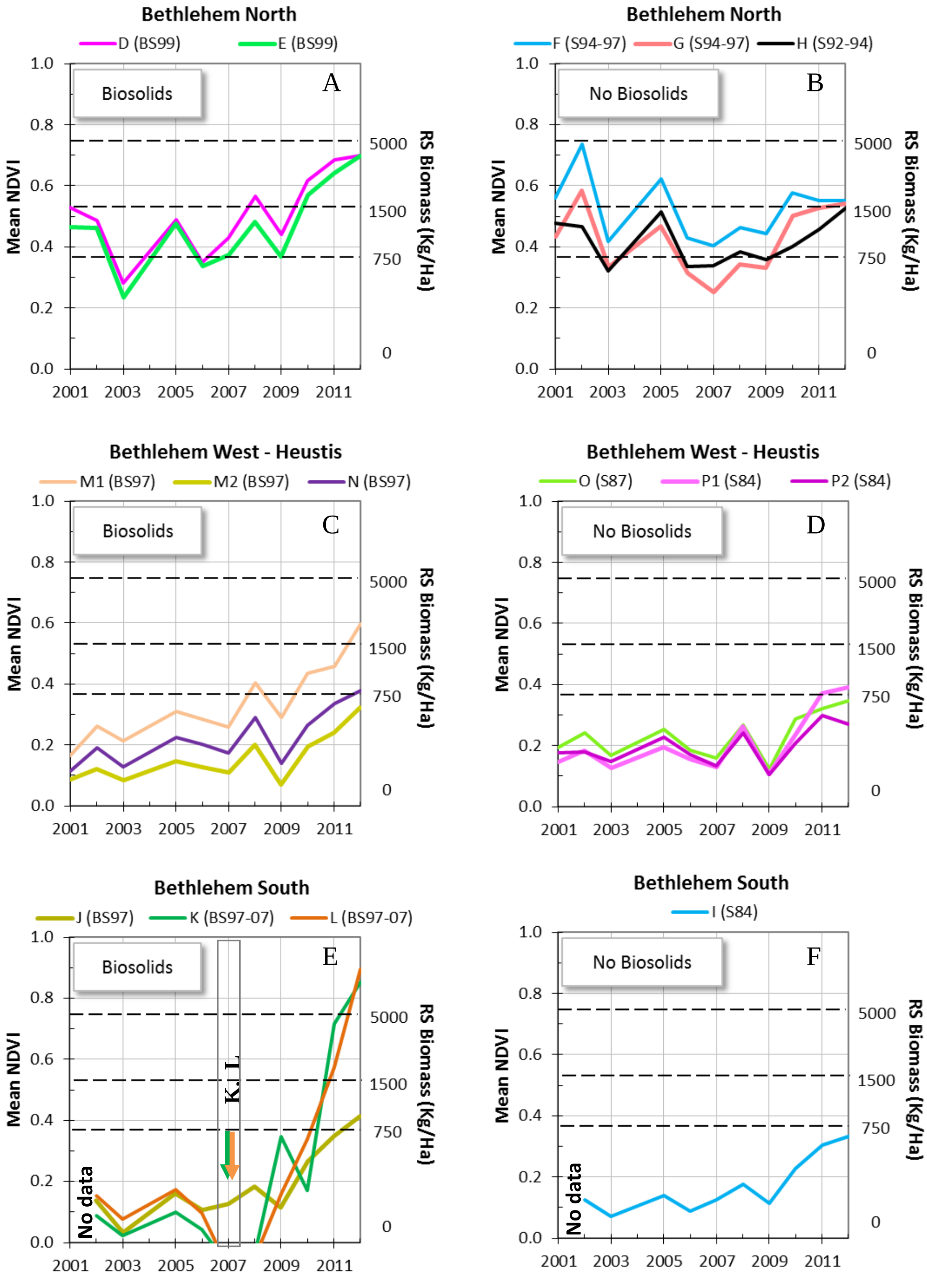

Figure 2. Summary of NDVI time series at waste rock sites. For an explanation of annotations see Figure 1. With the exception of sites K and L, biosolids treatments were applied prior to the beginning of the remote sensing time series.

Longer term effects

An interesting facet of the time series at all sites is a rise in NDVI in the last 3 years of the record following a low year in 2009 for the majority of sites. The reason for the drop in 2009, which at some sites was quite strong, is unclear – 2009 was not unusually hot or dry in the weeks preceding the remote sensing survey – however, the effect was apparently transitory, as sites that experienced a decrease in 2009 all appeared to have fully recovered in 2010.

In general, biosolids sites displayed steeper post-2009 increases than non-biosolids sites at the same location even when biosolids treatment occurred before 2002. This phenomenon, summarized in Figure 3 for all sites treated prior to 2002, was statistically significant for the 2010-12 rates of change ($p=0.0027$ for a 1-tailed t-test), and also for the 2001-09 rates of change (p (1-tailed) = 0.0005). These findings suggest that the addition of biosolids benefits vegetation growth in the medium and long term.

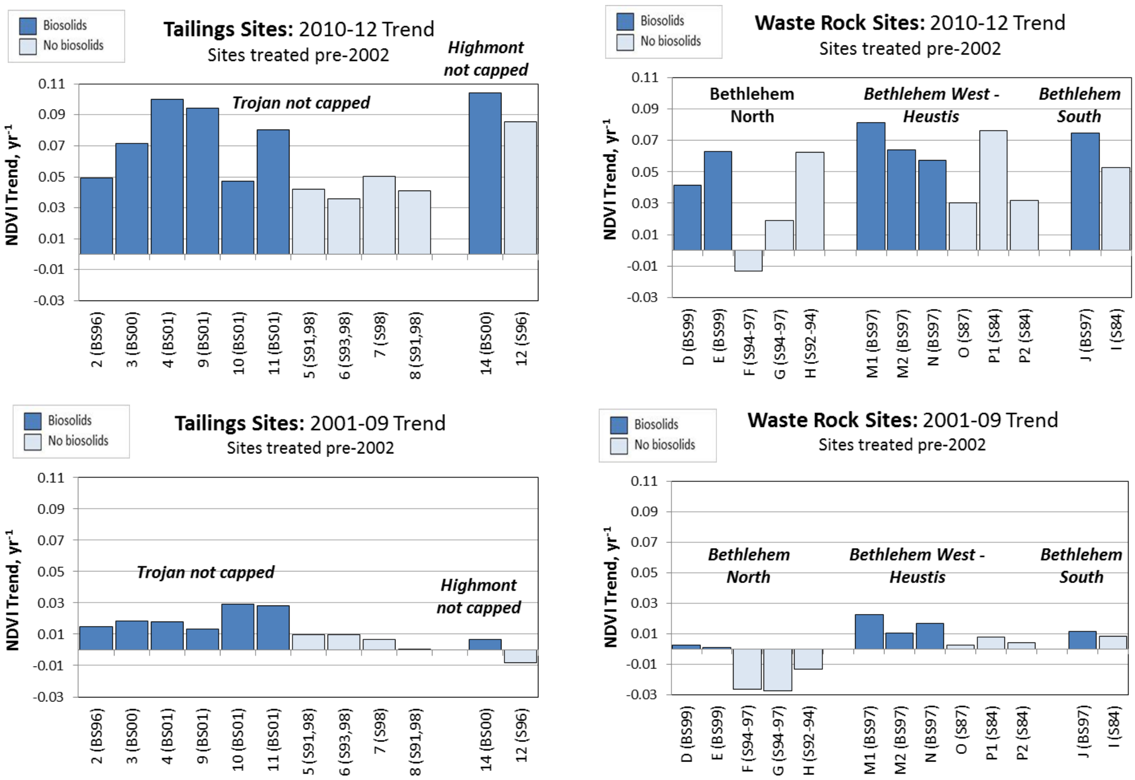

Figure 3. NDVI rates of change between 2010 and 2012 (left) and 2001-2009 (right), for sites treated with biosolids and/or capped with overburden before 2002, and corresponding untreated sites. Dark blue bars indicate biosolids treated sites; light blue bars untreated sites.

As observed for the shorter term, there also appear to be effects of capping in the medium and long term. However, the effects were reversed, such that capped sites grew more slowly than non-capped (Figure 4, $p=0.02$ for 2010-12 and 0.09 for 2001-09 growth rates). On the other hand, of the sites that were treated before 2002, all capped sites were waste rock and all non-capped sites were tailings, so we cannot be certain that these differences were due to capping and not differences in substrates.

Our conclusion is that in the long term there are beneficial effects that can be attributed to biosolids. The long-term effects of capping are less clear in that they cannot be separated from differences due to substrate material.

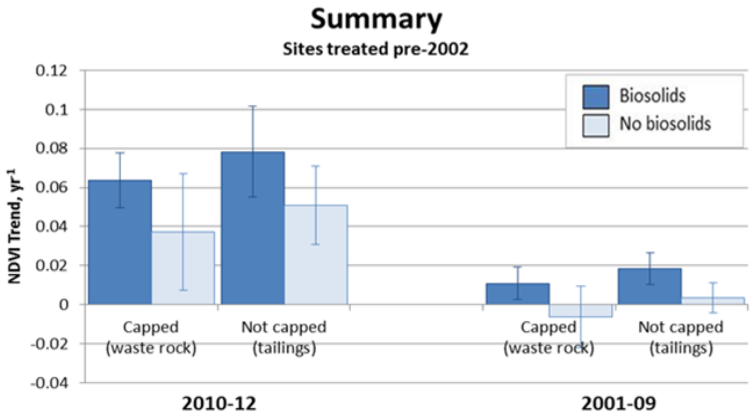

Figure 4. Summary of the effects of biosolids treatment and capping on NDVI rates of change between 2010-12 and 2001-09. Plot shows the means and standard deviations for sites shown in previous figures.

Qualitative effects

Photos in Table 2 illustrate the nature of the plant communities at biosolids and non-biosolids test sites. For non-capped sites at Trojan Tailings, we observed little difference between sites with and without biosolids treatment: all were relatively sparsely vegetated with heterogeneous plant communities. An exception was site 11 (treated with biosolids in 2001) which was more densely vegetated. This site is in area affected by floods in early spring, so the denser vegetation may reflect greater water availability there. Trojan capped sites were also characterized by similar vegetation at biosolids and non-biosolids sites, but in this case it was dense grasses. We concluded that at Trojan the strongest influences on vegetation density and composition appear to be capping and possibly water availability, not biosolids treatment. This is consistent with the findings from the NDVI time series which indicated an effect of capping.

At Highmont Tailings (not capped), the non-biosolids site 12 was highly diverse, with heterogeneous plant communities varying from very sparse to dense. Biosolids sites (13 and 14) were more densely vegetated with a higher percentage of grasses, except for the north end of site 13 which was sparsely vegetated, chiefly with non-grass species. However, in this area exposed tailings were visible suggesting it may have received only limited quantities of biosolids. It should also be kept in mind that at Highmont the non-biosolids site was more mature (seeded 1996) than the two biosolids sites (seeded 2000, 2008).

Waste rock sites were less well documented than the tailings sites, but for most of Bethlehem, biosolids appeared to be promoting strong growth of grasses, for both recently planted (K) and more mature sites (D). We only have one photo of a non-biosolids site (I) in these areas, but there the vegetation was heterogeneous and sparse. This is consistent with the findings at Highmont Tailings.

Table 2. August 2012 field photographs from tailings and waste rock sites.

Area and Material	Biosolids	No Biosolids
Trojan Tailings Not Capped	 *Site 3*: very sparse vegetation, native species, subject to desiccation  ***Site 11***: heterogeneous dense cover of grasses, mustard, natives, some alfalfa	 *Site 7*: heterogeneous, moderately sparse cover  ***Site 8:*** heterogeneous, sparser cover
Capped	 ***Site 16***: homogeneous dense grasses	 *Site15:* homogeneous, dense grasses
Highmont Tailings Not Capped	 *Site 13 north*: sparse cover of yarrow, alfalfa & grasses. Exposed tailings.  *Site 13 south*: dense grasses with some alfalfa, yarrow	 *Site 12 east:* dense cover of grasses, legumes, and some mustard  *Site 12 central*: heterogeneous, very sparse cover of grasses, yarrow, and cryptogamic crust
Bethlehem Waste rock Capped	 *Site E*: Homogenous dense grasses  *Site K*: Homogenous dense grasses	 *Site I*: heterogeneous sparse cover, grasses, natives, some trees and shrubs

The western portion of Bethlehem differed from the other areas at Bethlehem, in that the vegetation consisted of homogeneous, sparse grasses subject to desiccation at both biosolids and non-biosolids sites, probably due to limited water availability.

In summary, growth at Trojan appears to be limited by a factor that is not ameliorated by the addition of biosolids, but is improved by capping: from the discussion of short-term effects on growth rates, that factor may be related to water retention. In other areas (both Highmont Tailings and waste rock sites) biosolids appear to be promoting vigorous growth of grasses. This is consistent with the report by Straker *et al*. (2003) that “grass species account for almost all of the measured response to [biosolids] treatment on the trial sites.” However, Straker’s group reported declines in grasses following an initial (3-4 years) increase, which was not evident from our study. An exception to this trend is the western portion of Bethlehem (a waste rock area), where vegetation was limited at all sites, again perhaps by water.

CONCLUSIONS

We hope that the biosolids study will provide valuable information regarding the effects of biosolids applications, and particularly, *where* they have been useful and *where* other factors could be limiting reclamation success. We caution that our findings are based on a rather small number of sites, especially given the variety of site types. To increase the confidence in the findings, a follow-up study would be advisable. Other variables, such as biosolids application rate, source and class of biosolids, could be examined. Also, maps of NDVI change rates could be used for higher resolution analysis of variability in vegetation growth rates at biosolids-treated sites and surrounding areas, examining the patterns of growth rates corresponding to other factors such as slope or substrate. Spatial analysis of this type can provide additional levels of information beyond that achieved from examinations of specific sites.

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