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Primary Research Paper

Effects of pulsed and pressed disturbances on the benthic invertebrate community following a coal spill in a small stream in northeastern USA

Matthew P. Harper[1] & Barbara L. Peckarsky[1, 2]
[1]*Departments of Entomology, Ecology and Evolutionary Biology, Cornell University, Ithaca, NY USA 14853*
[2]*Rocky Mountain Biological Laboratory, Crested Butte, CO USA 81224*
*(*Author for correspondence: E-mail: mph26@cornell.edu)*

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Abstract

In September 1999, a coal-carrying train derailed and spilled 180,000–270,000 kg of coal into the Cayuga Inlet near Ithaca, New York. This study determined the immediate effects of the coal spill and the clean up procedures on the aquatic invertebrate community, and whether the stream recovered from this event after 2 years. Benthic invertebrate samples were taken both upstream and downstream of the coal spill immediately following clean-up efforts and two years later. Just after the coal spill, the total abundance and species richness of aquatic invertebrates were significantly lower downstream of the spill, suggesting that the disturbance caused increased mortality and/or emigration compared to a reference site upstream. Taxa affected most were grazers and turbidity-susceptible invertebrates. Two years later the invertebrate communities were similar upstream and downstream of the spill, except for an increase in the percent of the dominant genus, *Hydropsyche* (Trichoptera: Hydropsychidae). We speculate that long-term effects of channelization of the stream that occurred during the clean-up prevented the invertebrate assemblage from returning to the conditions observed in a reference site upstream of the coal spill. We propose that large scale environmental clean-ups should be designed to avoid altering ecosystems permanently, and that streams should be allowed to recover naturally without destructive human intervention.

Introduction

Pulsed disturbances from catastrophic spills of hazardous materials can result in short-term effects on aquatic environments. For example, coal spills in streams have been shown to cause simplification of food chains (Cherry & Guthrie, 1977), reduction in fish populations (Cherry et al., 1976), and reduction in both aquatic invertebrate densities and species richness (Guthrie et al., 1978; Cherry et al., 1979a, b; Scullion & Edwards, 1980; Forbes & Magnuson, 1981; Larrick et al., 1981; Duchrow, 1982; VanHassel & Wood, 1984). These effects have been attributed to two different mechanisms. First, physical disturbance, such as increased turbidity and smothering of substrates caused by the coal can have detrimental effects on invertebrates with higher oxygen requirements, exposed gills, or preferences for low-sediment environments (Duchrow, 1982; Cherry et al., 1979a). Second, the chemical effects of the coal indirectly lower invertebrate abundance, because reduced water quality kills bacteria and fungi negatively affecting the decomposing detritus or biofilm on which the invertebrates graze (Guthrie, et al., 1978, Cherry et al., 1979b, Forbes & Magnuson, 1981, Larrick et al., 1981, VanHassel et al., 1984).

The objectives of this study were to quantify the short-term effects of a coal spill and its subsequent clean-up on the aquatic invertebrate community, and to determine the extent to which it had recovered two years later. Previous research indicated that short-term negative effects would occur on abundance and species richness of invertebrates, especially grazers and taxa sensitive to increases in turbidity. We hypothesized that the invertebrate community would recover completely two years following the coal spill (Duchrow, 1982, Specht et al., 1984). However, we suspected that recovery might be incomplete if channelization permanently altered the channel (Yount & Niemi, 1990).

Materials and methods

At 16:48 on 1 September 1999 five coal-carrying cars of a Norfolk-Southern railroad train derailed, three of which spilled their contents into the Cayuga Inlet, a third order stream running parallel to the tracks in Tompkins County, NY. Clean-up crews estimated between 180,000 and 270,000 kg of coal entered the stream. Norfolk-Southern and New York State Department of Environmental Conservation officials began an extensive clean-up effort the same day that the spill occurred, which included constructing an impoundment of boulders and cobble across the stream to provide a road for large vehicles to access the railroad tracks. They also stabilized the bank adjacent to the tracks with rip rap, attempted to contain the coal by placing large plastic curtains along the river bank, and mechanically removed large amounts of coal from the stream and its banks.

Whereby the coal spill was a "pulsed" disturbance, the clean-up activities could be considered a "pressed" disturbance, because they more permanently altered the channel downstream of the spill (Yount & Niemi, 1990). After the 2–3 week clean-up was completed, the dam was removed, and a large flood occurred on the 16–17 September that raised the water level and removed the majority of the residual coal out of the river or downstream of the area of immediate impact.

To measure the effect of the coal spill and subsequent clean up activities on the stream communities, invertebrate samples were taken from the Cayuga Inlet in Tompkins County, NY near Blacksler Hill Road on 21 September 1999 at one site upstream (reference) and one site downstream (impact) of the coal spill and the temporary impoundment. On 15 October 2001, ~ two years later, invertebrate samples were taken at the same locations to quantify the extent of recovery of the invertebrates from the effects of the coal spill and clean-up activities.

Six traveling kick samples were taken from riffles immediately upstream (reference site) and downstream (impact site) of the coal spill and the temporary impoundment and consisted of a sampler moving across a transect of the stream collecting invertebrates in a D-frame net (mesh size 0.8 mm) for a period of one minute. All invertebrates were preserved in 70% ethanol and identified in the laboratory to the lowest taxonomic level possible, which was genus in most cases. Chironomidae (Diptera) and Tubificidae (Oligochaeta) were identified to family.

Total invertebrate abundance was measured by counting all individuals obtained during the 1-min traveling kick samples. Taxonomic richness was also measured from all invertebrates collected in each sample. Two other metrics were obtained using random subsamples of 100 invertebrates from each sample: proportion of EPT, and percent of the dominant taxon. Proportion of EPT was calculated as the fraction of individuals in the sample that belonged to Ephemeroptera, Plecoptera, and Trichoptera, which are three orders that are generally most sensitive to reduced water quality (Eaton & Lenat, 1981). The percentage of the dominant taxon provides a measure of evenness of distribution of individuals among taxa. Abundance and richness of grazers were also compared between upstream and downstream sites (Ephemeroptera: *Baetis, Caenis, Eurylophella, Stenonema*, Trichoptera: *Helicopsyche*, Coleoptera: *Psephenus*, and Gastropoda: *Physella*), which we suspected would be selectively affected by the coal spill. Finally, abundance and richness of invertebrates belonging to orders that Duchrow (1982) found to be highly sensitive to increases in turbidity (Trichoptera, Megaloptera, Ephemeroptera, and Isopoda) were compared.

Non-parametric (distribution free) Wilcoxon Rank Sum tests were used to compare the upstream and downstream sites in both 1999 and 2001 with respect to total invertebrate abundance, taxon richness, proportion EPT, and percent dominant taxon. Wilcoxon Rank Sum tests were also used to compare the effects of the coal spill on grazers and invertebrates susceptible to turbidity during these two different collection periods (SAS Institute, 2001).

Results

Immediately following the coal spill (1999) there were significantly lower total invertebrate abundance and taxon richness at the site downstream than upstream of the impoundment and the coal spill (Fig. 1a and b). Abundance of total invertebrate grazers was also significantly reduced at the site downstream of the coal spill in 1999 (Fig. 2a), while the taxon richness of grazers did not differ between upstream and downstream sites ($Z_1 = 1.77$, df = 1, $p = 0.077$; Table 1). Abundance of invertebrates in the orders especially vulnerable to turbidity (Trichoptera, Megaloptera, Ephemeroptera, and Isopoda) was also significantly reduced at the site downstream of the coal spill 1999 (Fig. 3a), while the taxon richness of those orders did not differ between sites upstream and downstream of the coal spill ($Z_1 = 1.44$, df = 1, $p = 0.150$; Table 1). Finally, the proportion of EPT ($Z_1 = 1.73$, df = 1, $p = 0.084$; Table 1) and percent dominant taxon (Fig. 4a) did not differ between the upstream and downstream sites indicating that these aspects of the invertebrate community were not affected by the coal spill in the short term.

Results of samples taken two years later (2001) suggested that the invertebrate community had completely recovered from the coal spill and clean-up, because total invertebrate abundance, taxon richness (Fig. 1c and d), and grazer abundance (Fig. 2b) no longer differed between the upstream and downstream sites. Furthermore, taxon richness ($Z_1 = 0.00$, df = 1, $p = 1.000$) and proportion EPT ($Z_1 = 0.16$, df = 1, $p = 0.871$) remained similar between upstream and downstream sites as in 1999 (Table 1). Abundance of turbidity-susceptible invertebrates had also recovered two years after the coal spill (Fig. 3b), and taxon richness of turbidity-susceptible invertebrates no longer differed between upstream and downstream sites ($Z_1 = 0.08$, df = 1, $p = 0.932$; Table 1).

Hydropsyche spp. (Trichoptera, Hydropsychidae) was the dominant taxon in the benthic community at all sites in both 1999 and 2001 (Fig. 4a). However, the only difference between the upstream and downstream invertebrate communities two years after the coal spill was that the percent of this dominant taxon was significantly higher at the site downstream of the coal spill in 2001 (Fig. 4b).

Discussion

Previous research conducted on streams directly affected by coal particles has shown that the benthic invertebrate communities initially suffer an impact characterized by a decline in total abundance and species richness.(Guthrie et al., 1978; Cherry et al., 1979a, b; Scullion & Edwards, 1980; Forbes & Magnuson, 1981; Larrick et al., 1981; Duchrow, 1982; VanHassel & Wood, 1984). These same trends were observed in the benthic communities of the Cayuga Inlet following a coal spill in September 1999. However, two years following the stress, the aquatic invertebrate communities had not completely recovered with respect to evenness of distribution of individuals among taxa. These findings suggest that the pressed disturbance of channel modification during the clean-up may have had long-term effects on the stream invertebrate communities.

The significant decline in total invertebrates and taxa richness following the coal spill with no significant effects on EPT demonstrated that the negative effects of the coal spill were not limited to the most sensitive invertebrates of the community. These effects could be attributed to two different mechanisms. First, a change in water chemistry could have caused invertebrate mortality, due to increased levels of $Fe(OH)_x$ and a decline in pH that occur when coal is added to water (Vinikour, 1979; Cherry et al., 1979b; Scullion & Edwards, 1980). Second, Cherry et al. (1979a) reported that in some cases the physical effects of increased turbidity and smothering by the coal particles are more deleterious than the toxicity created by the coal/water mixture. Turbidity may have played an extremely important role in the Cayuga Inlet since a temporary impoundment was constructed, then removed, and coal was then removed from the stream bank by bulldozers before the first samples were collected. This suggests that the turbidity caused by coal particles and sediment stirred up during the clean-up phase contributed in part to the generalized taxonomic effects that were observed. The same patterns that Cherry

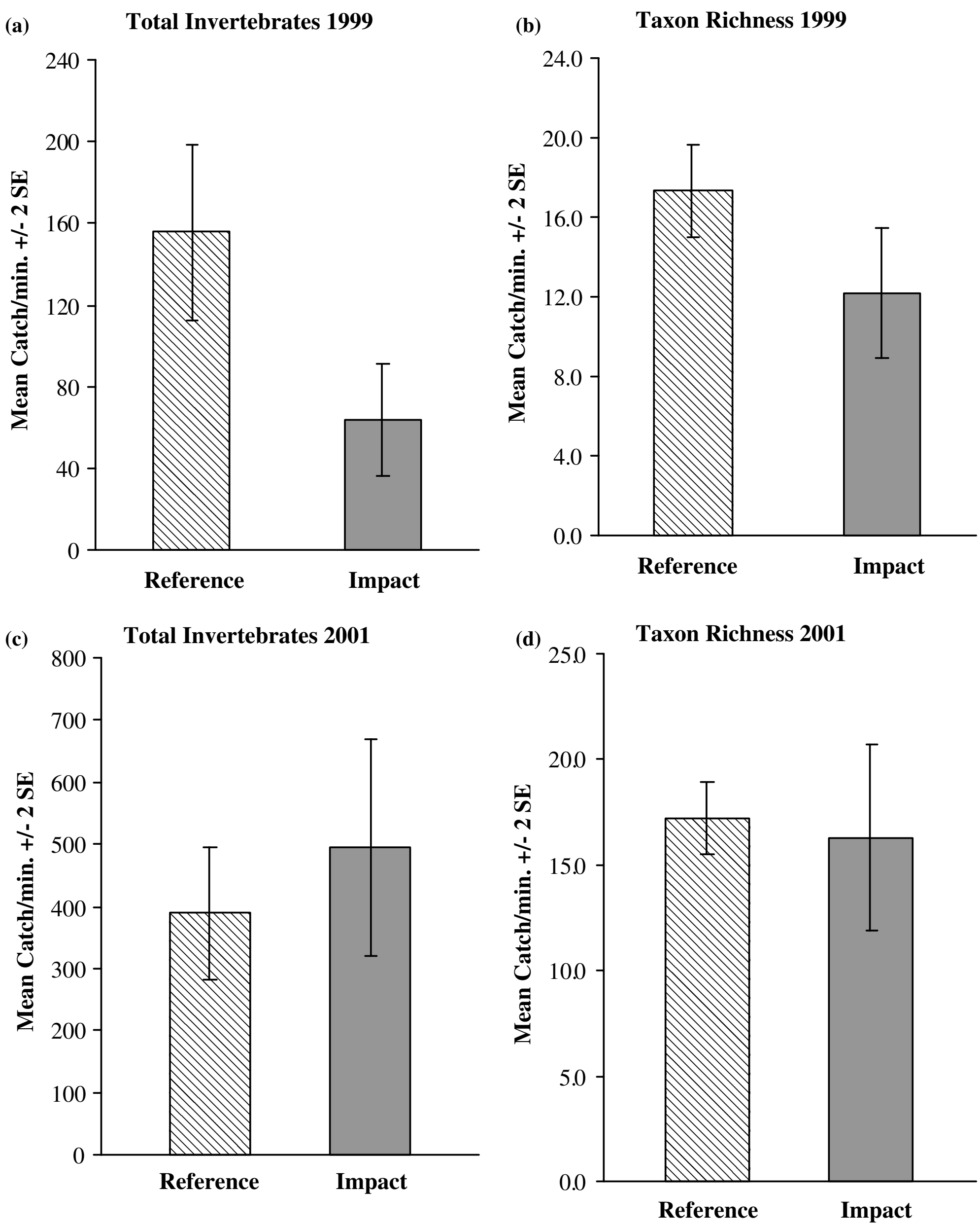

Figure 1. Mean abundance of total invertebrates and taxon richness (±2SE) at reference site (upstream) and impact site (downstream) of the coal spill in 1999 and 2001. (a) Total abundance ($Z_1 = 2.32$, df = 1, $p = 0.020$) and (b) taxon richness ($Z_1 = 2.49$, df = 1, $p = 0.013$) were significantly reduced at the impact site of the coal spill in 1999. (c) In 2001, total invertebrate abundance ($Z_1 = -0.72$, df = 1, $p = 0.471$) and (d) taxon richness ($Z_1 = 0.72$, df = 1, $p = 0.466$) did not differ between reference and impact sites.

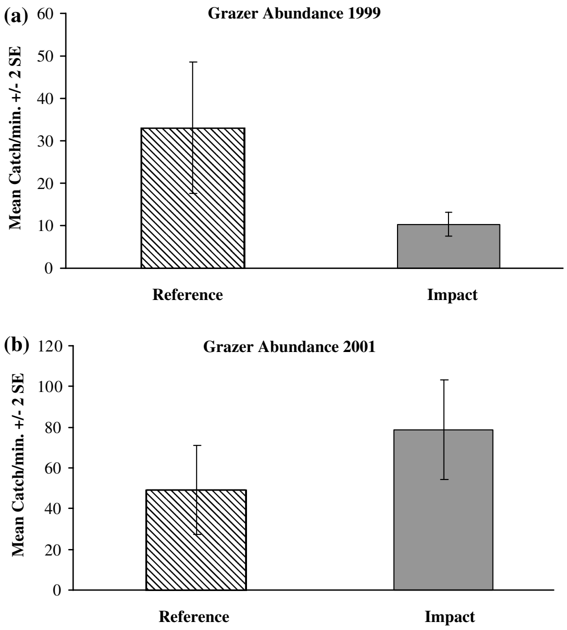

Figure 2. (a) In 1999, mean (±2SE) abundance of invertebrate grazers was significantly reduced at the impact site ($Z_1 = 2.81$, df = 1, $p = 0.005$); (b) In 2001, grazer abundance did not differ between impact and reference sites ($Z_1 = -1.68$, df = 1, $p = 0.092$).

et al. reported in 1979 are supported by the observation that insect orders more susceptible to turbidity suffered disproportionately greater declines than those with low tolerance to reduced oxygen (e.g., mayflies and stoneflies, Duchrow, 1982).

The EPT index did not vary between reference and impact sites on either sampling date, suggesting that the coal disturbance did not target Ephemeroptera, Plecoptera, and Trichoptera, which are insect orders that are generally less tolerant to disturbance (Eaton & Lenat, 1991). However, the immediate impact of the coal spill was most pronounced in grazer species, which may have been due to an indirect effect of chemical inhibition of their algal or bacterial food sources (VanHassel et al., 1984). Therefore, both smothering effects and the change in water chemistry caused by the addition of coal to the channel may have contributed to the immediate invertebrate kill or emigration observed in the stream following the coal spill.

Two years later we expected the effects of the coal spill to have dissipated, but the stream remained channelized as a result of the clean-up. At that time all of the invertebrate bioassessment indices measured indicated that the stream had fully recovered, except for the significantly higher percent dominance of the Trichoptera, *Hydropsyche*. This observation suggests that a factor other than the coal spill had a long-term impact on the distribution of individuals within taxa, which is one of the components of the diversity of the invertebrate assemblage of this stream (Yount & Niemi, 1990). During the clean-up of the coal spill, the stream channel of the Cayuga Inlet was modified and rip-rap was added to stabilize the banks. The resultant substrate in the

Table 1. Mean values (and 2 SE) of the invertebrate metrics that showed no significant differences between reference and impact sites in 1999 or 2001

Invertebrate metrics	Location	Mean	2 SE
Grazer taxon richness 1999	Reference	4.7	0.8
	Impact	3.7	1.0
Turbidity susceptible invertebrate taxon richness 1999	Reference	7.3	1.1
	Impact	6.2	1.7
EPT 1999	Reference	8.3	0.8
	Impact	6.7	1.8
EPT 2001	Reference	9.0	1.5
	Impact	9.0	2.5
Grazer taxon richness 2001	Reference	5.7	0.7
	Impact	5.8	1.6
Turbidity susceptible invertebrate taxon richness 2001	Reference	10.7	0.8
	Impact	10.8	2.9

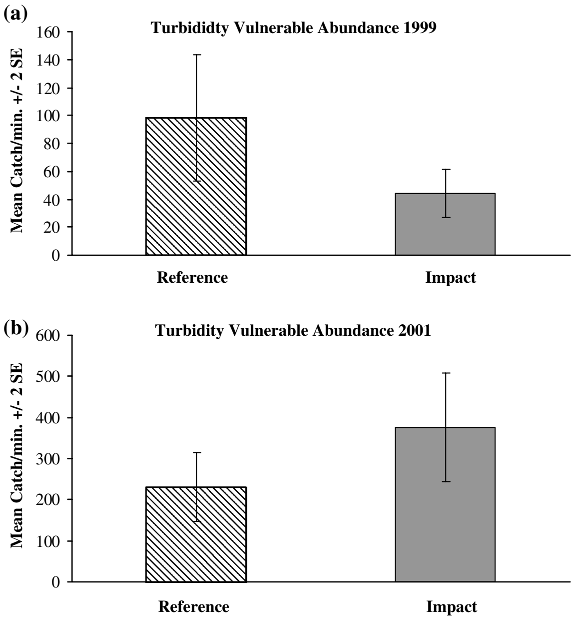

Figure 3. (a) In 1999, the abundance of invertebrates belonging to orders vulnerable to turbidity (Trichoptera, Megaloptera, Ephemeroptera, and Isopoda) was significantly reduced at the impact site ($Z_1 = 2.00$, df = 1, $p = 0.045$); (b) In 2001, abundance of turbidity-sensitive invertebrates did not differ between impact and reference sites ($Z_1 =$ -1.52, df = 1, $p = 0.128$).

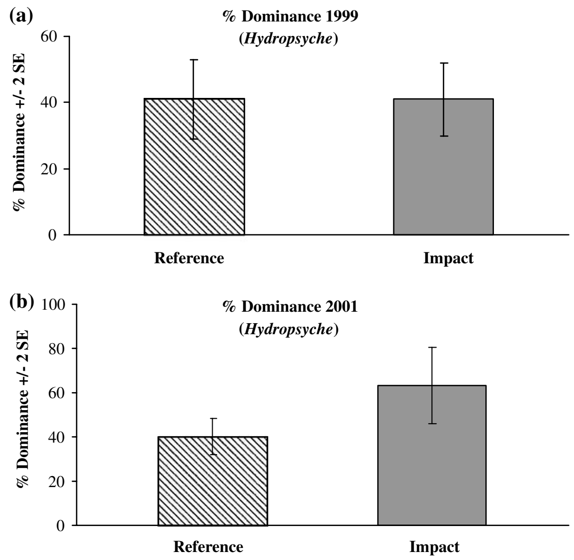

Figure 4. (a) In 1999, mean (± 2SE) percent dominant taxon did not differ between the reference and impact sites ($Z_1 = -0.08$, df = 1, $p = 0.936$); (b) In 2001, mean percent dominance was significantly higher in the impact than in the reference site ($Z_1 = -2.82$, df = 1, $p = 0.005$).

modified stream channel was highly uniform and comprised predominantly of medium-sized cobbles, which could have provided optimal suspension-feeding habitat for *Hydropsyche* to attach their retreats and silken catch nets (Georgian & Thorp, 1992).

The recovery process after any disturbance involves an adjustment of the community to a new steady state determined by a change in carrying capacity. Longest recovery times are generally associated with stressors leading to long-term alterations in physical stream habitat. If a river channel never returns to its pre-disturbance state, then the macroinvertebrate composition may be changed forever (Yount & Niemi, 1990). Although Whitaker et al. (1979) found that macroinvertebrate communities quickly stabilized after channel modification, returning to their steady state one year after the initial disturbance, most studies have shown that channelization is one of the most detrimental long-term stressors to stream communities (Zimmer & Bachman, 1978, Haynes & Makarewicz, 1982, Yount & Niemi, 1990). Further sampling of these sites on the Cayuga Inlet will determine whether *Hydropsyche* will eventually return to the reference condition.

Overall, grazers and turbidity-susceptible invertebrates were more negatively affected by the disturbance. Although the stream had generally recovered from the effects of the coal spill two years later, the proportion of the dominant taxon, the net-spinning caddisfly, *Hydropsyche*, increased in the area of the stream receiving the initial impact. Because coal has not been reported to alter stream invertebrate community structure beyond one year, we suspect that some other factor, such as the channelization of the stream during clean up, has altered the stream community structure over the long term (pressed disturbance). Thus, while negative effects of coal were short-term, environmental managers should place more emphasis on minimizing potential long-term consequences of invasive clean up measures. With less human intervention after such disturbances, streams may have a better chance of eventually returning to their natural condition (Poff et al., 1997), rather than changing the stream and its inhabitants indefinitely.

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