Effects of substrate composition, stream-bed stability, and sediment supply on survival and trophic role of a dominant stream grazer

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Introduction

Understanding the effects of disturbance on river environments and their biotic communities has long been a goal of stream ecologists and resource managers (e.g. Ress et al. 1988). Food web structure and energy flow patterns through river communities can be highly altered by changes in geomorphic processes such as the frequency and intensity of scouring floods (Power 1992), sediment composition and supply, and channel shape and stability (Ligon et al. 1995). Such changes often result from dams and diversions built to store and redistribute water within and between watersheds (Dynesius & Nilsson 1994). Sediment movement during high flows is an important mechanism regulating benthic invertebrate populations (Holomuzki & Biggs 2000). Large, univoltine taxa with relatively blunt body forms are more susceptible to being dislodged or crushed by moving sediment particles, and their populations are slower to recover from scouring floods than small, multivoltine taxa with higher immigration rates (e.g. Townsend & Hildrew 1994). In northern California rivers with regulated flows, bed-scouring winter floods are often reduced or eliminated. As a consequence, functionally important food chains become shorter as large predator-resistant grazers, such as the stone-cased caddisfly Dicosmoecus gigipes, come to dominate the primary consumer trophic level and reduce energy flow to higher trophic levels (Power et al. 1996, Wootton et al. 1996).

Bed scour can also be reduced or eliminated, even at high flows, in incised channels with reduced sediment supplies. Under such conditions, large-bodied, predator-resistant invertebrates could become the dominant primary consumers, even at flows that would normally scour the stream bed and drastically reduce their populations. This study (1) explored the effects of sediment composition on larval Dicosmoecus survival during simulated bed scour, (2) compared responses to scouring flows by Dicosmoecus populations in bedrock-dominated stream reaches with low sediment supply and reaches with abundant sediment, and (3) compared the effects of Dicosmoecus on algal and primary consumer abundances in stable, sediment-starved and scoured stream reaches.

Study sites

Bear Creek is a fourth-order tributary of the middle Rogue River (T37-38S; R1W-1E) and Jenny Creek is a fifth-order tributary of the middle Klamath River (T39-40S; R3E), SW Oregon. This region is characterized by mild, wet winters and hot, dry summers. Discharge peaks occur most commonly between late November and early April. During the wet seasons of 1996 and 1997, both streams experienced scouring floods (one bankful event in 1996, two or more in 1997), but in 1998-2000 neither stream experienced flows sufficient to cause extensive bed scour. Both streams have storage reservoirs within their upper reaches, and numerous small diversion dams and reservoirs along their main channels and major tributaries, which trap large volumes of sediment during high flows. As a result, both streams have extensive sediment-starved, bedrock-dominated reaches that do not scour even at bankful flows. Stable, sediment-starved reaches alternate with sediment-rich reaches downstream of tributaries that experience considerable bed scour during high flows. Bear Creek is shaded by a dense canopy of cottonwood and alder for much of its length, while the main stem of Jenny Creek has an open canopy, resulting in much higher primary production.

Methods

Scouring flows were simulated, and the effect of sediment grain size tested on Dicosmoecus mortality in a narrow wooden chamber (1.25 m long × 0.25 m wide × 0.95 m deep) mounted on a central beam which allowed it to be tipped back and forth. A layer of sediment 15 cm deep was added to the chamber and it was filled with stream water to a depth of 50 cm. Up and down 'teeter-totter' motion of the
chamber produced sediment movement similar to
that observed in natural channels during high flows,
in which surface particles saltate and slide over sta-
tionary deeper layers. When tipping is reversed, sur-
faced particles stop briefly, then slide in the reverse
direction, similar to changes in direction of particles
in natural channels exposed to complex, turbulent
flows. Sediment sizes used in the trials were coarse
sand (2 mm particle diameter), gravel (24 mm; range
14–32 mm), and a gravel layer with five cobbles
placed on the surface (64 mm; range 57–72 mm). In
addition, trials were run with no sediments, to simu-
late turbulent flows in channels lacking mobile sedi-
ments. Trials were run during April 1997 and 1998
using third instar Dicosmoecus larvae collected from
Bear Creek and other local streams, and during June
and July 1998 using fifth instar larvae collected from
Jenny Creek. Four trials, of 15-min duration, were
run for each sediment–instar combination. At the
end of a trial, water was removed from the trough
using a hand-operated diaphragm pump, sediment
was spread evenly on a tarp, and living and dead lar-
vae were removed and counted. Surviving larvae
were held in plastic tubs of aerated stream water, and
those found dead after 8 h were combined with
counts of larvae killed during the trial, to estimate
percent mortality. Two-way ANOVA (arc sine trans-
formed data) was used to assess the effects of sedi-
ment size and larval instar on percent mortality.

Dicosmoecus populations were censused in late
May to mid June, 1996–1999 in Bear Creek and
within a 0.0875-m² quadrat were conducted at 0.5-
to 1.0-m intervals along cross-stream transects in
sediment-starved reaches experiencing little or no
bed scour, and in reaches with abundant sediment
and bed scour.

In 1997 (flood year), food web structures were
compared in sediment-starved and sediment-rich
reaches of Jenny Creek, approximately 2 weeks prior
to and 2 weeks after Dicosmoecus larvae entered pre-
paration diapause. Relative changes in abundances of
common organisms within primary producer and
consumer trophic levels would reveal potential
impact of Dicosmoecus on energy flow to higher
trophic levels (e.g., WOOTON et al. 1996). On 21 July,
fifth instar Dicosmoecus densities remained high in
sediment-starved reaches (144–190/m²) and were
much lower in sediment-rich reaches (10–28/m²). By
8 August, densities were reduced by 80–90%, and by
21 August no active larvae were present.

On 21 July and 22 August, six algae and six
benthic invertebrate samples were collected from
reaches with low and high Dicosmoecus densities.
Algae were scraped from cobble surfaces (n = 6 cob-
bles from each site; 9.8 cm² area scraped per cobble)
and collected on glass-fiber filters (Whatman A/E).
In the lab, filters were dried and weighed, then ashed
(480 °C, 2 h) and re-weighed. Individual cobbles
(mean diameter, 69.4 mm; range, 61–79 mm) also
served as sampling units for benthic invertebrates.
Samples were collected by placing a D-frame dip net
(0.33-mm mesh) downstream of a cobble and rolling
it into the net. Macroinvertebrates were washed from
the cobble surface, retained in the net, and net con-
tents were preserved (80% ethanol). In the labora-
tory, macroinvertebrates were sorted from sediments
debris under 10× magnification, identified to family
or genus, and enumerated. Differences in densities
of major groups, before and after Dicosmo-
ecus went into diapause, were compared using t-tests.

Results and discussion

Sediment size and instar had significant effects
on Dicosmoecus survival in simulated bed-scour
trials (Fig. 1) (two-way ANOVA, P = 0.0001
substrate; P = 0.044 instar; P = 0.56 substrate ×
instar interaction). Mortality was highest in tri-
als with cobble-size particles but was very low
in no sediment and sand trials. Third instar lar-
vae suffered higher mortality in all sediments.
These data show that stream-bed composition
probably plays an important role in determin-
ing population responses to scouring flows,
with the mortality of large-bodied, univoltine
taxa, like Dicosmoecus, being reduced down-
stream of dams and diversions that trap
gravel-cobble-size sediments.

Fig. 1. Effects of sediment composition on percent
mortality of third (open bars) and fifth (dark bars)
instar Dicosmoecus gilvipes larvae during simulated
bed scouring flows (values are means ± 1 S.E.;
n = 4).
Population censuses revealed that *Dicosmoeucus* densities were consistently higher in sediment-starved reaches (Fig. 2). Although densities fluctuated among years, they were similar between years with and without scouring flows (e.g., 1996 and 1997 versus 1998–2000), suggesting that populations were not significantly reduced during floods. *Dicosmoeucus* densities in reaches with mobile sediments, in contrast, were lowest in flood years, and increased 2- to 3-fold in years without significant bed scour.

Enhanced survival, resulting in higher *Dicosmoeucus* densities in sediment-starved reaches clearly had strong effects on algal standing crops (Fig. 3) and densities of other primary consumers (Fig. 4). Algal abundance increased 8-fold after *Dicosmoeucus* went into diapause in high density, sediment-starved reaches (P < 0.0001; t-test), but increased by only 20% in scoured reaches with low *Dicosmoeucus* densities (P > 0.05). Small, mobile primary consumers (mayflies and midges) responded with large density increases (P < 0.001 for both), whereas densities of the pleurocerid snail, *Juga silicula* increased by a smaller, but significant (P < 0.02) amount. Changes in densities of these groups in low *Dicosmoeucus* reaches were not significant (P > 0.05 for all comparisons).

Taken together, these results show that differences in sediment composition and supply strongly influence population densities of *Dicosmoeucus*, with strong indirect effects on lower trophic levels. The large difference in *Dicosmoeucus* densities between the two streams was likely due to differences in productivity, suggesting that the effects of artificial channel stabilization on food web structure and energy flow may be magnified in more productive, sunlit streams. Few studies have examined the effects on stream communities of small dams that do not regulate winter flows. The present results suggest that small dams, by altering sediment supply, may affect food webs in ways qualitatively similar to larger dams that eliminate scouring flows (see Power 1992, Power et al. 1996). Since small diversion dams can be much more numerous within a watershed than large irrigation storage or flood control dams, their ecological effects at the watershed scale

Fig. 2. Spring (late May–mid June) population densities of *D. gibwipes* in sediment-starved stream reaches that did not experience bed scour during high winter flows (circles) and reaches, downstream from tributary junctions, with abundant sediment that experienced extensive bed scour during high flows (squares) (values are means ± 1 S.E.).

Fig. 3. Algal biomass before and after *Dicosmoeucus* larvae went into prepupation diapause, illustrating relative grazing pressures in unscoured stream reaches with high *Dicosmoeucus* densities (dark bars) and scoured reaches with low *Dicosmoeucus* densities (open bars) (values are means ± 1 S.E.; n = 6).
Fig. 4. Densities of common primary consumers and total macroinvertebrates before and after *Dicosmoecus* went into prepupation diapause in unscored stream reaches with high *Dicosmoecus* densities (dark bars) and scored reaches with low *Dicosmoecus* densities (open bars) (values are means ± 1 S.E.).

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References


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