**Supplementary Information**

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Code for Monte Carlo simulations in R

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**Table S4.** Tracing the origin of carbon. Proportion of autochthonous and allochthonous sources in macroinvertebrates in the reference and treatment streams following sucrose addition.

**Method S1**

**Derivation of macroinvertebrate tissue isotopic ratio turnover rate** *λ* (day-1) from the isotopic half-life (*t*1/2, days) relationship with invertebrate biomass *M* (g).

We have (Vander Zanden and others, 2015):

equivalent to,

Assuming an exponential decrease of tissue isotopic ratio over time, we have (Hobson and Clark, 1992; Vander Zanden and others, 2015):

with *δt* isotopic value (‰) of the organism at time *t*, *δ0* initial isotopic value (‰) at equilibrium with the old diet, *δn* isotopic value (‰) after equilibration with the new diet, λ tissue isotopic turnover rate (day-1), and *t* time since the diet switch (days).

With, the equation simplifies to:

At isotopic ratio half-life we have:

And so we have:

**Method S2**

**Code for Monte Carlo simulations in RStudio using R version 3.5.0**

Relative changes (effect size) of autotrophs and natural terrestrial organic matter in the diet of macroinvertebrates with data from the BACI (before and after control impact) design; example with proportion of terrestrial organic matter in Leuctra (results in Fig. 5). Raw data displayed in Table S2 and S3. The same simulations were also run for changes in macroinvertebrate densities (data in Table 1 and results in Fig. S2)

# averages

B=0.89

A=0.40

C=0.79

I=0.15

# standard deviations

sigmaB=0.12

sigmaA=0.19

sigmaC=0.14

sigmaI=0.12

# effect size equation

f=((B-A)-(C-I))/C

f

# Monte Carlo simulations

runs = 10000

simB <- rnorm(runs,mean=B,sd=sigmaB)

simA <- rnorm(runs,mean=A,sd=sigmaA)

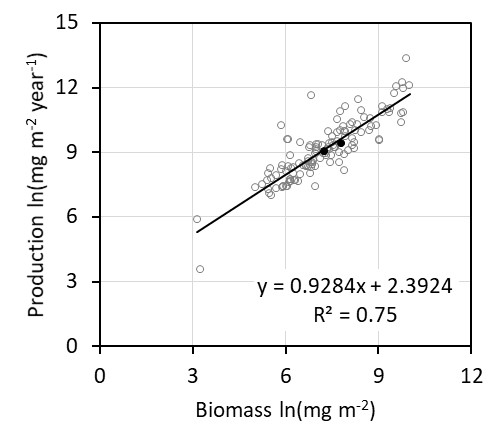
simC <- rnorm(runs,mean=C,sd=sigmaC)

simI <- rnorm(runs,mean=I,sd=sigmaI)

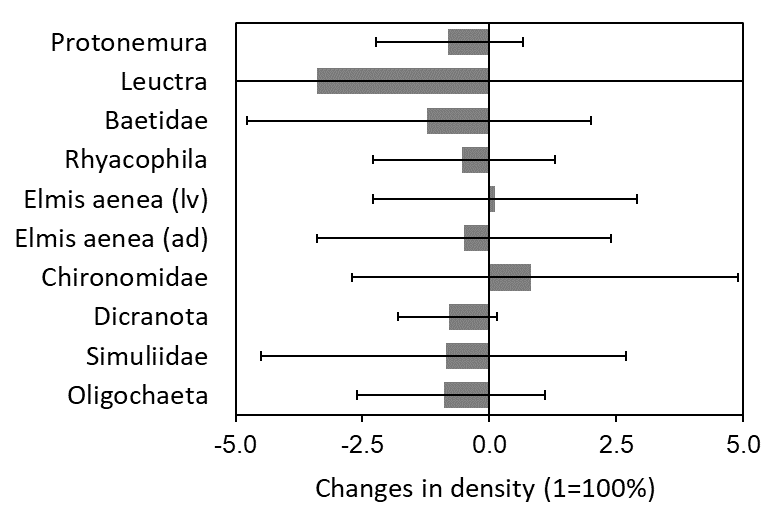
simf=((simB-simA)-(simC-simI))/simC

quantile(simf, probs=c(0.25,0.5,0.75))

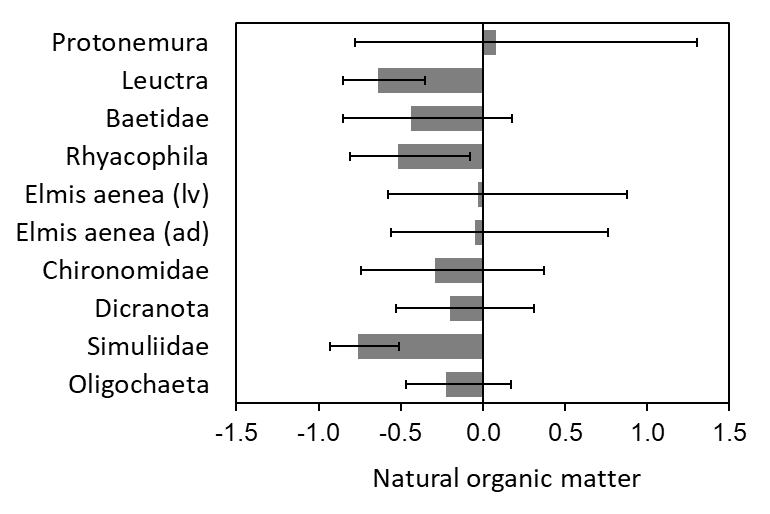
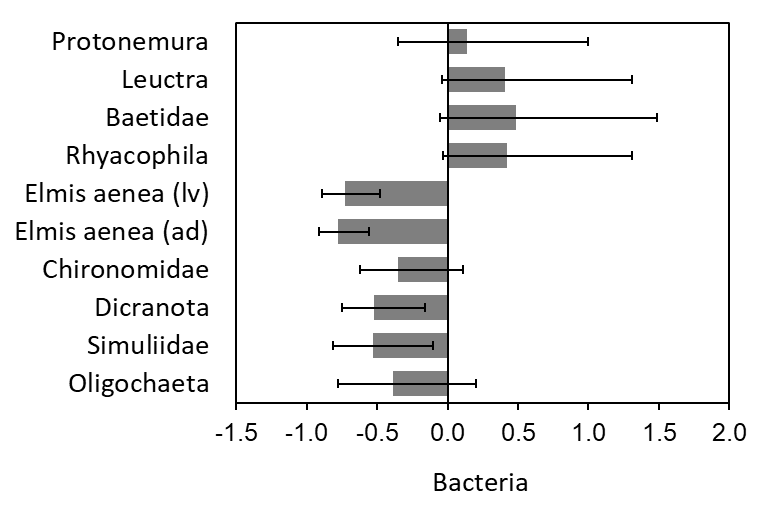
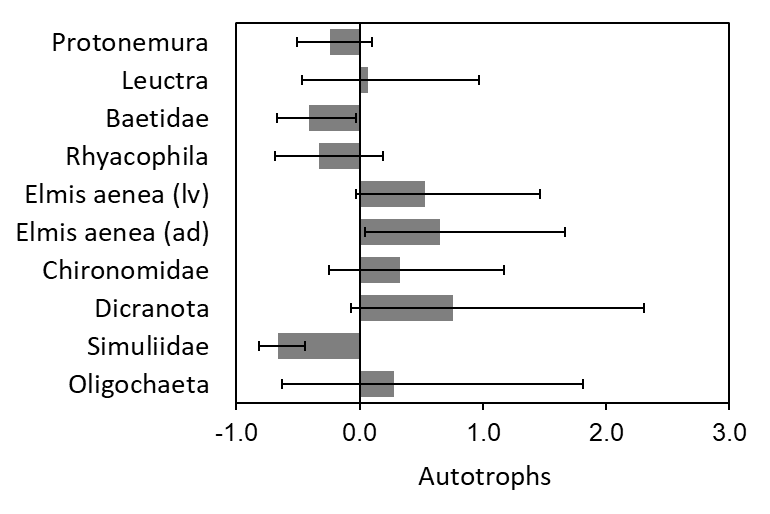
**Tables and Figures**



**Figure S1.** Biomass and annual secondary production of stream macroinvertebrate communities (ash free dry mass, AFDM) from the global synthesis of Patrick and others, 2019 (open grey circles). Glensaugh biomass and daily production estimates (black filled circles) were scaled to annual production (×365 days) and converted to AFDM for comparison, with AFDM=0.9\*DM (Eklöf and others, 2017).



**Figure S2.** Relative changes inmacroinvertebrate densities (individuals m-2) due to sucrose addition calculated as the median from 10000 Monte Carlo simulations using the BACI experimental design. Error bars represent the interquartile range. lv=larvae, ad=adult



**Figure S3.** Relative changes (size effects) in primary carbon sources (1=100%): fractions of autotrophs, bacteria and natural terrestrial organic matter carbon sources in macroinvertebrates due to sucrose addition. Size effects were calculated as the median from 10000 Monte Carlo simulations using the reference stream (Birnie *after*) and treatment stream (Cairn *impact*). Error bars represent the interquartile range. lv=larvae, ad=adult

**Table S1.** Carbon isotopic ratio (δ13C ±1SD, ‰), fraction of carbon derived from added sucrose FS (±1sd) in macroinvertebrates at equilibrium with the new diet (see method), tissue isotopic turnover rate (λ, day-1), carbon isotopic turnover (*τ*) 21 days after diet shift, and growth rate (*G*, day-1) at average stream water temperature of 10.5°C.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Order** | **Species or taxa** | **Before**  **δ13C** | **After**  **δ13C** | **Control**  **δ13C** | **Impact**  **δ13C(eq)** | **Impact**  **FS(eq)** | **λ** | **τ** | ***G*** |
| Plecoptera | *Protonemura meyeri* | ND | -37.29 ±0.73 | ND | -27.31 ±0.70 | 0.39 ±0.04 | 0.15 | 0.98 | 0.022 |
|  | 1*Leuctra* | -28.07 ±0.62 | -31.24 ±0.93 | -28.66 ±1.06 | -22.66 ±1.64 | 0.46 ±0.12 | 0.12 | 0.98 | 0.022 |
|  | 2Perlodidae | ND | -30.11 ±0.73 | ND | -24.56 ±0.70 | 0.31 ±0.06 | 0.18 | 0.99 | 0.022 |
| Ephemeroptera | Baetidae (*Baetis rhodani*) | -31.13 ±1.47 | -37.03 ±0.05 | -29.24 ±0.40 | -23.66 ±0.66 | 0.50 ±0.07 | 0.10 | 0.97 | 0.037 |
| Trichoptera | 3Limnephilidae | -31.46 ±1.23 | -34.71 ±0.69 | -29.57 ±0.15 | -34.54 ±0.69 | -0.08 ±0.08 | 0.11 | 1.01 | 0.023 |
|  | *Beraea maurus* | ND | -28.99 ±0.73 | ND | -27.14 ±0.70 | 0.11 ±0.06 | 0.13 | 1.00 | 0.023 |
|  | *Odontocerum albicorne* | -29.91 ±1.58 | -30.42 ±0.90 | -28.32 ±0.38 | -28.46 ±0.95 | 0.02 ±0.12 | 0.13 | 1.00 | 0.023 |
|  | *Plectrocnemia conspersa* | ND | -30.67 ±0.73 | ND | -25.95 ±0.32 | 0.25 ±0.04 | 0.08 | 0.97 | 0.023 |
|  | 4*Rhyacophila* | -32.93 ±1.26 | -33.42 ±1.01 | -28.56 ±0.53 | -21.49 ±0.93 | 0.44 ±0.12 | 0.07 | 0.93 | 0.023 |
| Coleoptera | *Oreodytes sanmarkii* (ad) | -31.61 ±0.46 | -32.91 ±0.77 | -29.04 ±0.94 | -29.31 ±0.04 | 0.06 ±0.07 | 0.09 | 1.00 | 0.013 |
|  | *Elmis aenea* (lv) | -30.83 ±0.28 | -33.98 ±0.33 | -29.25 ±0.23 | -30.88 ±0.28 | 0.07 ±0.03 | 0.12 | 1.00 | 0.013 |
|  | *Elmis aenea* (ad) | -34.12 ±0.92 | -33.52 ±1.04 | -30.93 ±0.32 | -31.37 ±0.21 | -0.06 ±0.08 | 0.11 | 1.00 | 0.013 |
|  | *Elodes sp.* (lv) | -29.66 ±0.97 | -30.11 ±0.71 | -28.07 ±0.03 | -22.78 ±0.81 | 0.35 ±0.09 | 0.09 | 0.97 | 0.013 |
| Diptera | 5Chironomidae | -28.35 ±1.41 | -34.00 ±2.53 | -29.30 ±0.23 | -27.92 ±1.47 | 0.31 ±0.15 | 0.11 | 1.00 | 0.039 |
|  | *Dicranota* sp. | -29.32 ±2.17 | -30.88 ±0.13 | -28.81 ±0.46 | -28.03 ±0.31 | 0.13 ±0.12 | 0.08 | 0.99 | 0.034 |
|  | Simuliidae | -28.27 ±0.23 | -34.16 ±0.01 | -28.50 ±0.18 | -16.85 ±0.59 | 0.78 ±0.04 | 0.11 | 0.94 | 0.034 |
| Oligochaeta | Oligochaeta | -28.02 ±0.40 | -27.83 ±0.74 | -26.81 ±0.90 | -26.24 ±0.74 | 0.03 ±0.10 | 0.06 | 0.99 | 0.016 |
| Hydracarina | Hydracarina | ND | -34.07 ±0.73 | ND | -25.76 ±0.70 | 0.38 ±0.05 | 0.14 | 0.98 | 0.021 |

1 *L. hippopus*, *L. moselyi*, *L.* *fusca*, *L. inermis*, *L. nigra*

2 *Isoperla* sp., *Diura bicaudata*

3 *Allogamus auricolis*, *Potamophylax* sp.

4 *R. munda*, *R. oblitera*, *R. dorsalis*

5 mostly Orthocladinae

lv=larvae, ad=adult

**Table S2.** Partitioning the green web (autotrophs) and brown web (bacteria and soil OM). Proportion (%) of C sources (mean ±SD) in macroinvertebrates in the reference stream (Birnie Burn) *before* and *after* sucrose addition. OM=organic matter

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Order** | **Species or taxa** | **Before**  **autotrophs** | **Before**  **soil OM** | **After**  **autotrophs** | **After**  **bacteria** | **After**  **soil OM** |
| Plecoptera | *Protonemura meyeri* | ND | ND | 62 ±19 | 25 ±19 | 13 ±11 |
|  | 1*Leuctra* | 11 ±12 | 89 ±12 | 22 ±15 | 38 ±23 | 40 ±19 |
|  | 2Perlodidae | ND | ND | 22 ±17 | 33 ±22 | 45 ±20 |
| Ephemeroptera | Baetidae (*Baetis rhodani*) | 45 ±14 | 56 ±14 | 47 ±23 | 34 ±24 | 20 ±15 |
| Trichoptera | 3Limnephilidae | 46 ±12 | 54 ±12 | 48 ±21 | 34 ±23 | 18 ±13 |
|  | *Beraea maurus* | ND | ND | 17 ±16 | 27 ±20 | 56 ±22 |
|  | *Odontocerum albicorne* | 35 ±18 | 65 ±18 | 21 ±16 | 34 ±22 | 46 ±21 |
|  | *Plectrocnemia conspersa* | ND | ND | 25 ±18 | 36 ±23 | 39 ±19 |
|  | 4*Rhyacophila* | 63 ±15 | 37 ±15 | 34 ±20 | 39 ±24 | 27 ±18 |
| Coleoptera | *Oreodytes sanmarkii* (ad) | 48 ±11 | 53 ±11 | 31 ±19 | 40 ±24 | 29 ±19 |
|  | *Elmis aenea* (lv) | 44 ±13 | 57 ±13 | 37 ±20 | 39 ±24 | 24 ±17 |
|  | *Elmis aenea* (ad) | 74 ±13 | 26 ±13 | 34 ±20 | 40 ±24 | 27 ±18 |
|  | *Elodes sp.* (lv) | 26 ±11 | 74 ±11 | 19 ±15 | 32 ±22 | 49 ±21 |
| Diptera | 5Chironomidae | 10 ±7 | 91 ±7 | 36 ±21 | 39 ±24 | 26 ±18 |
|  | *Dicranota* sp. | 35 ±20 | 65 ±20 | 21 ±16 | 36 ±22 | 42 ±20 |
|  | Simuliidae | 7 ±5 | 93 ±5 | 39 ±21 | 38 ±23 | 24 ±17 |
| Oligochaeta | Oligochaeta | 6 ±5 | 94 ±5 | 15 ±16 | 23 ±20 | 62 ±26 |
| Hydracarina | Hydracarina | ND | ND | 44 ±21 | 37 ±24 | 19 ±14 |

1 *L. hippopus*, *L. moselyi*, *L.* *fusca*, *L. inermis*, *L. nigra*

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3 *Allogamus auricolis*, *Potamophylax* sp.

4 *R. munda*, *R. oblitera*, *R. dorsalis*

5 mostly Orthocladinae

lv=larvae, ad=adult

**Table S3.** Partitioning the green web (autotrophs) and brown web (bacteria and soil OM). Proportion (%) of C sources (mean ±SD) in macroinvertebrates in the treatment stream (Cairn burn) for the *control* and *impact* periods of sucrose addition. Note: sucrose was also added as a source for Simuliidae and represented 59 ±14%. OM=organic matter

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Order** | **Species or taxa** | **Control**  **autotrophs** | **Control**  **soil OM** | **Impact**  **bryophytes** | **Impact**  **algae** | **Impact**  **bacteria** | **Impact**  **soil OM** |
| Plecoptera | *Protonemura meyeri* | ND | ND | 18 ±12 | 29 ±19 | 34 ±13 | 19 ±16 |
|  | 1*Leuctra* | 21 ±14 | 79 ±14 | 10 ±8 | 17 ±13 | 58 ±12 | 15 ±12 |
|  | 2Perlodidae | ND | ND | 13 ±9 | 23 ±18 | 39 ±14 | 25 ±17 |
| Ephemeroptera | Baetidae (*Baetis rhodani*) | 30 ±20 | 70 ±20 | 11 ±8 | 18 ±13 | 57 ±12 | 14 ±12 |
| Trichoptera | 3Limnephilidae | 33 ±20 | 67 ±20 | 62 ±17 | 18 ±15 | 6 ±5 | 15 ±13 |
|  | *Beraea maurus* | ND | ND | 17 ±12 | 23 ±18 | 19 ±12 | 41 ±21 |
|  | *Odontocerum albicorne* | 26 ±20 | 74 ±20 | 23 ±14 | 20 ±16 | 14 ±10 | 43 ±21 |
|  | *Plectrocnemia conspersa* | ND | ND | 15 ±11 | 26 ±19 | 31 ±13 | 29 ±18 |
|  | 4*Rhyacophila* | 28 ±20 | 72 ±20 | 9 ±7 | 16 ±14 | 60 ±13 | 15 ±11 |
| Coleoptera | *Oreodytes sanmarkii* (ad) | 31 ±21 | 69 ±21 | 26 ±14 | 24 ±17 | 14 ±10 | 36 ±20 |
|  | *Elmis aenea* (lv) | 30 ±20 | 70 ±20 | 34 ±16 | 26 ±18 | 12 ±9 | 28 ±18 |
|  | *Elmis aenea* (ad) | 44 ±20 | 56 ±20 | 42 ±16 | 19 ±14 | 10 ±8 | 30 ±19 |
|  | *Elodes sp.* (lv) | 24 ±19 | 76 ±19 | 10 ±8 | 20 ±17 | 48 ±14 | 21 ±14 |
| Diptera | 5Chironomidae | 31 ±20 | 69 ±20 | 20 ±13 | 31 ±20 | 28 ±13 | 22 ±16 |
|  | *Dicranota* sp. | 22 ±15 | 78 ±15 | 21 ±13 | 25 ±19 | 19 ±11 | 35 ±19 |
|  | Simuliidae | 27 ±20 | 74 ±20 | 6 ±4 | 8 ±6 | 20 ±16 | 7 ±6 |
| Oligochaeta | Oligochaeta | 24 ±21 | 76 ±21 | 15 ±11 | 18 ±15 | 19 ±12 | 49 ±21 |
| Hydracarina | Hydracarina | ND | ND | 15 ±11 | 25 ±18 | 39 ±13 | 21 ±16 |

1 *L. hippopus*, *L. moselyi*, *L.* *fusca*, *L. inermis*, *L. nigra*

2 *Isoperla* sp., *Diura bicaudata*

3 *Allogamus auricolis*, *Potamophylax* sp.

4 *R. munda*, *R. oblitera*, *R. dorsalis*

5 mostly Orthocladinae

lv=larvae, ad=adult

**Table S4.** Tracing the origin of carbon. Proportion (%) of autochthonous and allochthonous sources (mean ±SD) in macroinvertebrates in the reference and treatment streams following sucrose addition. Note the fraction of sucrose was more accurate when determined directly (see Fs in Table S1). OM=organic matter

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  |  | **Reference stream (after)** | | **Treatment stream (impact)** | | |
| **Order** | **Species or taxa** | **Autoch-thonous** | **Alloch-thonous** | **Autoch-thonous** | **Alloch-thonous** | **Sucrose** |
| Plecoptera | *Protonemura meyeri* | 62 ±22 | 38 ±16 | 48 ±23 | 27 ±17 | 25 ±17 |
|  | 1*Leuctra* | 36 ±19 | 64 ±23 | 35 ±17 | 26 ±13 | 38 ±16 |
|  | 2Perlodidae | 34 ±21 | 66 ±24 | 39 ±21 | 34 ±17 | 27 ±17 |
| Ephemeroptera | Baetidae (*Baetis rhodani*) | 54 ±27 | 46 ±21 | 37 ±17 | 25 ±13 | 37 ±17 |
| Trichoptera | 3Limnephilidae | 56 ±25 | 44 ±19 | 77 ±23 | 17 ±13 | 6 ±15 |
|  | *Beraea maurus* | 27 ±19 | 73 ±25 | 40 ±22 | 45 ±21 | 15 ±16 |
|  | *Odontocerum albicorne* | 33 ±20 | 67 ±25 | 42 ±21 | 46 ±21 | 11 ±16 |
|  | *Plectrocnemia conspersa* | 38 ±22 | 62 ±24 | 42 ±23 | 35 ±19 | 22 ±17 |
|  | 4*Rhyacophila* | 47 ±24 | 53 ±23 | 33 ±17 | 27 ±13 | 39 ±17 |
| Coleoptera | *Oreodytes sanmarkii* (ad) | 45 ±24 | 55 ±24 | 49 ±23 | 40 ±20 | 11 ±16 |
|  | *Elmis aenea* (lv) | 49 ±24 | 51 ±22 | 58 ±25 | 32 ±18 | 11 ±15 |
|  | *Elmis aenea* (ad) | 47 ±24 | 53 ±23 | 59 ±22 | 33 ±19 | 9 ±15 |
|  | *Elodes sp.* (lv) | 31 ±20 | 69 ±25 | 36 ±20 | 31 ±15 | 33 ±17 |
| Diptera | 5Chironomidae | 48 ±25 | 52 ±23 | 50 ±24 | 28 ±17 | 21 ±17 |
|  | *Dicranota* sp. | 35 ±20 | 65 ±23 | 45 ±23 | 40 ±20 | 15 ±16 |
|  | Simuliidae | 50 ±25 | 50 ±22 | 16 ±9 | 11 ±7 | 73 ±17 |
| Oligochaeta | Oligochaeta | 24 ±20 | 76 ±28 | 33 ±19 | 53 ±21 | 14 ±16 |
| Hydracarina | Hydracarina | 54 ±25 | 46 ±20 | 43 ±22 | 29 ±16 | 28 ±17 |