COARSE ORGANIC MATTER DYNAMICS IN URBANISED TRIBUTARIES OF THE ST. JOHNS RIVER, FLORIDA

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Abstract
Urbanisation can impact stream ecosystems by altering hydrology, channel geomorphology and riparian conditions. In this case study of four streams in the vicinity of Jacksonville, Florida, USA, we investigated how inputs, exports and within-channel storage of organic matter vary with differing urban–rural land use. Inputs ranged from 600 to 1000 g ash free dry mass (AFDM) m\(^{-2}\) y\(^{-1}\). Decreased riparian cover did result in significantly lower coarse particulate organic matter (CPOM) input. Export, estimated using leaf analogues, increased with urban land use. It appeared that estimated export was mostly influenced by stream hydrology and the extent of retentive structures. Monthly CPOM biomass ranged from 50 to 2000 g AFDM m\(^{-2}\). Streams shaded by riparian cover showed little seasonal pattern in CPOM biomass. However, the stream that lacked riparian shading had peak CPOM biomass in summer due to macrophyte production. This case study demonstrates how urbanisation can affect stream ecosystems at multiple spatial scales and highlights the importance of riparian vegetation management in urban settings.

Keywords: coarse particulate matter, urban streams, litter decomposition, detritus movement, riparian vegetation.

Introduction
In forested streams the dominant food resource for resident consumers is coarse particulate organic matter (CPOM) supplied via terrestrial inputs. Many studies of CPOM dynamics have outlined the biological, chemical

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and physical processes that regulate input, storage and transport within stream ecosystems (Fisher & Likens, 1973; Hynes, 1975; Fisher, 1977; Vannote et al., 1980; Cummins et al., 1983; Wallace et al., 1995; Webster & Meyer, 1997; Webster et al., 1999; Chadwick & Huryn, 2005). These processes include movement of materials to stream channels, consumption, storage and downstream transport. Quantifying the dynamics of coarse detritus therefore provides insight into both ecosystem structure and function (Webster & Meyer, 1997; Chadwick & Huryn, 2005; Lepori et al., 2005) and, as such, may be a useful indicator of stream degradation caused by urbanisation (Miller & Boulton, 2005; Walsh et al., 2005).

Land use change, particularly urbanisation, is potentially the greatest threat to forested, headwater catchments (Meyer & Wallace, 2001). Urbanisation has been shown to affect streams by altering hydrology, channel geomorphology and riparian conditions (Booth, 1990; Davenport et al., 2001; Paul & Meyer, 2001; Hatt et al., 2004; Naiman et al., 2005; Walsh et al., 2005) and these changes can directly affect both inputs and storage of CPOM (Meyer et al., 2005). For example, higher peak flows associated with urbanisation can result in scouring of stream banks and increased CPOM inputs from riparian stores. However, increased CPOM export also occurs with elevated discharge. Higher peak flow associated with urbanised catchments can lead to increased tractive forces that can compromise protective structures like submerged sticks, branches and debris dams (e.g. Bilby, 1981; Boulton & Lake, 1992). Furthermore, development along riparian areas can result in changes to riparian vegetation which can dramatically alter both the types and quantities of CPOM inputs (Miller & Boulton, 2005; Roy et al., 2005).

It is well known that riparian areas influence stream ecosystems (Gregory et al., 1991; Naiman & Décamps, 1997). Only a few studies have examined the importance of riparian zones for streams in urbanised environments (e.g. Sweeney et al., 2004; Roy et al., 2005; Walsh et al., 2007) and some of these studies have found that intact riparian zones minimise urbanisation impacts to stream ecosystems. In urban settings, intact riparian zones buffer non-point source pollution (Osborne & Kovacic, 1993; Carpenter et al., 1998), stabilise and reduce stream bank erosion (Sudduth & Meyer, 2006), and provide organic matter for detritivores (Miller & Boulton, 2005). However, the ability of riparian zones to maintain stream ecosystems decreases with increased urban development. In fact, Roy et al. (2005) suggest that management practices that utilise only riparian restoration are likely to be insufficient for the maintenance of ecosystem health. Furthermore, Walsh et al. (2007) suggest that catchment urbanisation and the resulting changes in hydrology degrade streams more than removal of riparian vegetation.

Prior to widespread urban development in the Lower St. Johns River Basin, the northeast Florida landscape was dominated by hardwood swamps, pine scrub and upland forests. Development has resulted in a loss of forested areas and increases in land cover (including roads, parking lots and rooftops) that prevents rainwater infiltration (sensu Schueler, 1994; Arnold & Gibbons, 1996). The goals of this case study were threefold. First, we examined how differing levels of urbanisation affect CPOM dynamics, including input, storage and retention. Second, we demonstrate how loss of riparian cover, as a result of urban development, alters CPOM dynamics. Finally, we evaluate the potential for measures of CPOM dynamics to be used as indicators of degradation due to urbanisation.

**Study streams**

Four streams in the Lower St. Johns River Basin, Florida with differing urban–rural land use were the focus of this study (Fig. 1, Table 1). Streams are identified by number following Chadwick et al. (2006). The streams drained relatively small catchments ranging from 91 hectares to 262 hectares. All streams had sandy substrata, low channel gradients and habitats composed of runs with occasional woody snags. Red maple (Acer rubrum L.), sweetgum (Liquidambar styraciflua L.) and water oak (Quercus nigra L.) were the most common riparian trees. One stream lacked canopy cover due to urban development that resulted in the removal of riparian trees. In this stream (11), aquatic macrophytes (mostly invasive Hydrilla verticillata [L.f.] Royle with some Myriophyllum sp. and Alternanthera philoxeroides [Mart.]) were abundant. Urbanisation in each catchment was quantified as the per cent total impervious areas (TIA) and ranged from 0 % to 46 % (see Chadwick et al., 2006 for a complete description of this methodology; Table 1). As well as differing levels of impervious surface coverage, two streams were modified for flood control which included retention ponds and removal of riparian trees (see above).

**Inputs of CPOM**

Ten vertical traps (0.25 m²) and ten lateral traps (0.5 m long × 0.2 m high × 0.3 m deep) located adjacent to the streambed were placed randomly along both sides of a 100 m reach in each stream and were used to quantify CPOM inputs. Traps were set in October 2003 and emptied monthly until October 2004. For each of the 20 traps, the collected material was returned to the laboratory and sorted into dominant organic matter types (pine needles, maple leaves, sweetgum leaves, oak leaves, other leaves, seeds/cones, woody debris, and other material), dried to constant mass (60 °C) and then weighed. A portion from each sample was ashed (550 °C) and weighed to calculate ash free dry mass (AFDM). Because
Table 1. Selected physical and chemical conditions in the study streams. TIA = percent total impervious area, Area = catchment area (Ha), Con = conductivity (µS cm\(^{-1}\)), DOC = dissolved organic carbon (mg L\(^{-1}\)), nutrients are in mg L\(^{-1}\), Q = discharge (L s\(^{-1}\)).

<table>
<thead>
<tr>
<th>Site</th>
<th>TIA</th>
<th>Area</th>
<th>Con</th>
<th>DOC</th>
<th>pH</th>
<th>NH(_4)</th>
<th>NO(_3)</th>
<th>PO(_4)</th>
<th>NH(_3)</th>
<th>TIA</th>
<th>Area</th>
<th>Con</th>
<th>DOC</th>
<th>pH</th>
<th>NH(_4)</th>
<th>NO(_3)</th>
<th>PO(_4)</th>
<th>NH(_3)</th>
<th>TIA</th>
<th>Area</th>
<th>Con</th>
<th>DOC</th>
<th>pH</th>
<th>NH(_4)</th>
<th>NO(_3)</th>
<th>PO(_4)</th>
<th>NH(_3)</th>
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</thead>
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<tr>
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<td>262</td>
<td>383</td>
<td>7.4</td>
<td>0.07</td>
<td>0.06</td>
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<td>29</td>
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<td>26</td>
<td>91</td>
<td>373</td>
<td>9</td>
<td>7.6</td>
<td>0.08</td>
<td>0.14</td>
<td>0.11</td>
<td>14</td>
<td>urban commercial</td>
<td>8</td>
<td>46</td>
<td>231</td>
<td>403</td>
<td>9</td>
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FIG. 1. Location of the study catchments in the Lower St. Johns River Basin. Shaded areas denote the catchment extent upstream of the sample points.
lateral traps only sampled input from one side of a stream bank, values were doubled to estimate total lateral inputs.

Average monthly input of organic matter per stream was calculated using bootstrapping techniques (i.e. the average of 1000 estimates generated by resampling with replacement; Manly, 1997). Total annual input was then calculated by summing across monthly estimates to create 1000 estimates for each stream. Statistical comparisons between streams for vertical and lateral inputs were made by comparing 95% confidence intervals. Non-overlapping confidence intervals indicated a significant difference. We used this simple bootstrapping procedure, rather than more typical parametric statistical methods, to deal with uneven sample sizes caused by trap vandalism. Differences in the proportion of average annual input for each CPOM type were assessed using $\chi^2$ tests. Comparisons were made both among streams and between vertical and lateral input in each stream.

Total CPOM inputs (i.e. vertical and lateral inputs summed) ranged from ~600 to ~1000 g AFDM m$^{-2}$ (Fig. 2). At all streams, most CPOM entering the channel was via vertical inputs. Accordingly, lateral inputs comprised <10% of total input. Monthly vertical inputs ranged from ~10 to ~150 g AFDM m$^{-2}$ and were highly variable (Fig. 3). Monthly lateral inputs ranged from <1 to ~20 g AFDM m$^{-2}$ (Fig. 3). Unlike vertical inputs, lateral inputs tended to follow seasonal patterns with the lowest levels of input occurring in summer. The urban stream with riparian clearing (11) had the lowest rates of inputs, due to the lack of a developed riparian canopy. This pattern appeared particularly pronounced in autumn during leaf abscission. Based on non-overlapping confidence intervals, the urban stream with riparian clearing (11) had significantly lower input than the other three streams. There was no overall relationship, however, between TIA and CPOM input.

The average contribution of CPOM types (e.g. wood, leaves, needles etc) varied significantly among streams for vertical ($\chi^2_{21} = 197$; p < 0.001) and lateral input ($\chi^2_{21} = 177$; p < 0.001; Fig. 4). Differences between the distribution of inputs by CPOM type within each stream did not vary between lateral or vertical input, except for stream 11 ($\chi^2_{7} = 17.0$; p = 0.03; p < 0.001) where there was proportionally more lateral than vertical input of wood.

Overall, organic matter inputs lacked association with increased urbanisation among the four streams. However, at the reach scale, riparian clearing resulted in decreased inputs. These results are not particularly surprising given that most inputs were from vertical sources that would be constrained by the characteristics of reach-scale riparian vegetation rather than any catchment-scale factors. We did find indications that urbanisation alters the types of input to these streams. The clearest example of this is the increasing proportion of red maple litter found with increasing catchment urbanisation. This shift is likely to be related to ornamental planting of this tree during urban development. However, with only four streams, this pattern is tenuous. Based on these results, it does not appear that organic matter inputs provide enough resolution to be used as an indicator of the impacts of urbanisation unless riparian vegetation removals are directly associated with urban development.

**Export of CPOM**

Export of CPOM was measured using leaf analogues (8 cm edged, equilateral triangles cut from blue, polyethylene tarpaulin; Chadwick & Huryn, 2005). Five hundred individually labelled leaf analogues were released into each stream reach in September 2003. After one month, we surveyed each 100 m reach and recorded the distance moved from the release point. Percent recovery and median distance travelled were calculated for each stream. The relationship of both % recovery and...
FIG. 3. Mean monthly inputs of coarse particulate organic matter collected from lateral and vertical traps in the four study streams. Error bars are 1 SE.

FIG. 4. Proportion of mean annual contribution of coarse particulate organic matter types collected from lateral (lat) and vertical (vert) traps in the four study streams.
Table 2. Coarse particulate organic matter (CPOM) retention measured with leaf analogues.

<table>
<thead>
<tr>
<th>Site</th>
<th>% analogue recovery</th>
<th>Median distance travelled (m)</th>
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<tbody>
<tr>
<td>11</td>
<td>44</td>
<td>88</td>
</tr>
<tr>
<td>26</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>17</td>
<td>1</td>
<td>30</td>
</tr>
<tr>
<td>8</td>
<td>13</td>
<td>35</td>
</tr>
</tbody>
</table>

urbanised catchments is mainly due to changes in overland flow paths (i.e. increased impervious surfaces), but could also be associated with decreases in evapotranspiration and additions from watering of lawns and leaking water pipes (D. Dobberfuhl, unpublished data). At the reach scale, retentive structures, in this case macrophytes, are clearly regulated by riparian conditions (i.e. incident light). Similar to measures of organic matter inputs, exports are regulated by multiple factors and are likely to be too variable to make reliable indicators of urbanisation impacts.

**Storage of CPOM**

Benthic samples were collected approximately monthly in each stream from five randomly selected locations using a petite ponar grab (0.023 m²). Samples, comprising three grabs taken across the channel (right lateral, middle, and left lateral), were combined for each location. Samples were emptied into a 20-litre bucket and all coarse material was removed by hand to a polyethylene bag. The remaining material was sieved through a 250 µm sieve and then washed into the polyethylene bag. All samples were preserved in the field with ~5 % formaldehyde. In the laboratory, collected material was sieved into five fractions (2 cm, 2 mm, 1 mm, 500 µm and 250 µm). The coarsest fraction (> 2 cm) was split into major litter types (see above). The remaining fractions were sorted under magnification and all invertebrates were removed. Coarse benthic organic matter (CBOM) was processed and analysed in the same manner as CPOM inputs (see above). Samples were not taken unless there was surface water present (hence no samples taken from stream 26 in spring, as it lacked water).

Mean annual CBOM ranged from ~400 to ~2500 g AFDM m⁻² (Fig. 5). Based on non-overlapping confidence intervals, streams could be classified into three groups; however, groupings were not related to urbanisation. The streams with the highest CBOM had intact riparian canopies and lacked major flood control structures (i.e. 26 and 8).

Monthly CBOM standing stocks ranged from ~50 to ~3000 g AFDM m⁻², with only minor seasonal patterns (Fig. 6). The stream (11) that lacked riparian canopy cover had peak CBOM standing stocks in summer and this was due to macrophyte (*Hydrilla verticillata*) production.

The average contribution of types of CBOM (e.g. wood, leaves, needles, macrophytes etc) varied between streams (Fig. 7). Miscellaneous organic matter (i.e. material that passed through the 2 mm sieve) was the dominant type found in each stream and comprised between ~40 % and 80 % of all material collected. Wood was the second most common and comprised ~10 % to 40 % of all CBOM. In the stream without riparian cover, *H. verticillata* contributed ~20 % to the total CBOM.

The streams with both the most and least amounts of CBOM are subject to flood control management (riparian clearing and retention ponds). Riparian clearing resulted in the highest CBOM, but this was attributable to macrophyte production. The stream with the lowest CBOM has a retention pond that regulates storm flows via a stand pipe (Table 1). The other two streams had similar CBOM levels indicating that catchment-scale urbanisation has minimal effects on CBOM storage for streams in northern Florida.
The variation in CBOM storage suggests that differences in these streams, rather than being related to urbanisation (i.e. ‘urban stream syndrome’ – Walsh et al., 2005), reflect urban development activities that occur at reach scales. We have observed that many streams in the Jacksonville area have \textit{H. verticillata}, but the presence of macrophytes is related to available light rather than other urbanisation factors. We have also observed many different sizes and types of retention pond. The influences of these structures on CBOM storage are unknown. For stream 17 it is likely that flow regulation is responsible for CBOM levels. Upstream of this study reach a large retention pond is managed for storage of large rainfall events (e.g. hurricanes) and is periodically drained to the stream channel to maintain levels. This periodic flushing can result in scouring of the study reach. We never observed these flows, but this is the likely reason for the low levels of CBOM found in this stream.

In this case study, riparian condition (e.g. removal of vegetation vs. intact vegetation) influenced organic matter dynamics to a greater degree than catchment-scale urbanisation. Interestingly, CPOM dynamics in these streams showed a major shift from \textit{allochthonous} to \textit{autochthonous} sources and this was driven by invasive macrophytes. This shift has potentially large effects on the habitat structure and ecosystem processes of these streams. Primary concerns about the effects of \textit{H. verticillata} on these streams include early morning hypoxia due to plant respiration and effects on food webs due to the change in carbon sources.

As with the other measures of organic matter dynamics, CBOM storage is not a robust measure for impacts of urbanisation. This again is due to the fact that urban development is varied and can result in a wide range of conditions that may affect stream reaches. In this case study the potential for invasive macrophytes to colonise and the varied approaches used for flood control result in the different amounts of CBOM storage.

**Conclusions**

Understanding the complex interactions responsible for regulating the amounts and types of organic matter in stream ecosystems could provide baseline knowledge needed for the management and conservation of aquatic resources in urbanised catchments. However, stream organic matter dynamics are known to be both spatially and temporally variable.


Waringer, J.E. (1994). Urbanisation has been suggested as potentially affecting stream CPOM dynamics by altering hydrology, channel geomorphology and riparian conditions, however inconsistent responses (i.e. increases or decreases in CPOM input, export and storage relative to non-urbanised conditions) have been measured (Walsh et al., 2005).

This case study demonstrates inconsistent responses of coarse organic matter input, export and storage to catchment-scale urbanisation. It does support the notion that reach-scale conditions, which can vary widely due to urban development, can be the primary influence on organic matter dynamics. Based on this, the utility of using measures of organic matter dynamics as indicators of impacts driven by urbanisation appear to be limited. However, it is clear that measures of organic matter can provide an insight into how urban development affects stream reaches. Specifically for this case study, flood control management strategies, such as riparian clearing and retention ponds, influence amounts and types of organic matter found in these streams.

References


