Assessing Contributions of Aged Allochthonous Nutritional Subsidies to Macroinvertebrate Consumers in the Hudson and Susquehanna River Watersheds

Final Progress Report for

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Project Activities and Progress
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Field Activities. Fieldwork was completed for this project in June 2014. Sampling occurred in the Hudson-Mohawk watershed June 9-11, and sampling in the western Susquehanna River watershed occurred June 22-25. Data was collected from six sites in the Hudson-Mohawk watershed (**Figure 1**) and from seven sites in the Susquehanna River watershed (**Figure 2**). Sites in New York, which vary in the abundance of organic matter (OM)-rich sedimentary rocks that make up the lithology of the surrounding watershed, were selected based on a previous study by Longworth et al. (2007). Sites in the upper Susquehanna River watershed were those that had been sampled previously by myself in 2011, 2012, and 2013.

Sample collection and processing. Macroinvertebrates and potential food sources (including aquatic primary producers, terrestrial vegetation, terrestrial soils, sediments, biofilms, particulate OM, and shales) were collected from each site. Immediately upon return from the field in June 2014, samples were processed in the OSU Aquatic Biogeochemistry Laboratory. Throughout summer and fall 2014, all macroinvertebrates and potential food source samples were dried and homogenized in preparation for stable isotope analysis. In June 2015, selected macroinvertebrate and potential food source samples were sent to the National Ocean Sciences Accelerator Mass Spectrometry (NOSAMS) facility at Woods Hole Oceanographic Institution for natural abundance radiocarbon (^{14}C) analysis. In July 2015, selected macroinvertebrate and potential food source samples were prepared for stable isotope analysis and submitted to the University of California at Davis Stable Isotope Facility for $\delta^{13}C$ and $\delta^{15}N$ analyses and to the Colorado Plateau Stable Isotope Laboratory at Northern Arizona University for $\delta^{2}H$ analysis.

Data processing and analysis. MixSIAR was used to determine relative food source contributions to macroinvertebrate biomass. MixSIAR (Stock and Semmens 2013) is an isotopic mixing model that uses a Bayesian approach (Moore and Semmens 2008) via a graphical user interface (GUI) and R Statistical Software (R Core Team, 2014). Use of a Bayesian approach allows for the incorporation of uncertainty in potential food source contribution estimates, as there are a multiple sources of variation that could impact isotopic data. Some of those sources of variability include, but are not limited to, use of multiple potential food sources, isotopic fractionation, and spatial and temporal variability of isotopic signatures (Finlay et al. 2002, Moore and Semmens 2008). Comparisons of isotopic data and food source contributions were also made across sites and between the two study systems (upper Susquehanna vs. Hudson-Mohawk watershed streams).

Since biological processes such as OM respiration and excretion preferentially select lighter isotopes, this trophic fractionation must be accounted for when utilizing mixing models. For the purposes of our Bayesian modeling, trophic fractionations for $\delta^{13}C$, $\delta^{15}N$, $\delta^{2}H$, and $\Delta^{14}C$ were assumed to be 0.4 ± 1.3‰, 3.4 ± 1‰, 0‰, and 0‰, respectively (Post 2002, Doucett et al. 2007, Caraco et al. 2010). Organism isotope values were corrected to reflect these fractionations prior to being utilized in the mixing models. Additionally, dietary water can influence organism $\delta^{2}H$ values because a portion of ^{2}H (deuterium) in organism tissues is derived from environmental water. For the purposes of this report, the fraction of dietary water (ω) in all macroinvertebrate consumers was assumed to be 0.20 (Wilkinson et al. 2015).

Major Findings

Taxa of aquatic macroinvertebrates collected from each system were identified to genus and are listed in Tables 1 and 2. Chironomids were only identified to family and were treated as such in mixing models. Chironomids were not placed in functional feeding groups (FFGs) as chironomid FFG and trophic position can vary across subfamily and genus (Reuss et al. 2013).

Chironomids collected at each of our sites had $\delta^{15}N$ values similar to that of primary consumers. Not all FFGs were represented at all sites. In some cases, lack of adequate macroinvertebrate biomass prevented isotopic analyses from being completed on all samples. Organisms collected from the same site of the same genus were pooled when necessary to attain adequate biomass for isotopic analysis. Means and standard deviations of isotopic data for all organisms are listed in Tables 3 and 4. Differences in $\delta^{13}C$, $\delta^{15}N$, and $\delta^{2}H$ were found across functional feeding groups and sites. Most notable were differences in $\delta^{15}N$ values for the Schoharie Tributary compared to the other Mohawk-Hudson sites and for Little Muncy Creek and Lamb's Creek from the upper Susquehanna River sites (**Tables 3 and 4**).

Mixing models could not be run for all sites (including Couch Hollow Branch, Otsquago Creek, and Schoharie tributary, NY, and North Elk Run, Elk Run, Crooked Creek and Lamb's Creek, PA) due to the inability to isotopically constrain the macroinvertebrates by the isotopic signatures of the potential food sources collected. Additionally, only primary consumers (those organisms consuming only basal food resources and not other organisms) were considered in our initial model runs. The autochthonous (i.e., aquatic) potential OM food source end-member used for each mixing model was filamentous algae collected from each site (primarily *Cladophora* spp.). The allochthonous (i.e., terrestrial) potential OM food source end-member was riparian vegetation. One exception was Towanda Creek, where cyanobacteria appeared to be contributing to the food web, and was added as an end-member separate from filamentous algae. Proportional contributions to diet from algae and cyanobacteria were added to determine the total percentage of autochthonous OM contributing to consumer biomass at Towanda Creek. Organisms were primarily grouped by functional feeding group (FFG) to increase replication, but for those sites with enough individuals of the same genus (Wampecack Creek, NY), the proportion of diet was estimated for genus instead of FFG.

Mixing models were run for each site using a combination of $\delta^{13}C$ and $\delta^{15}N$ data, as well as for $\delta^{13}C$, $\delta^{15}N$, and $\delta^{2}H$ data (**Figures 5-10**). For those sites for which mixing models could be run, autochthonous OM was of primary importance. Mean proportional contributions ranged from 4 to 92% to macroinvertbrate diet in most of these systems, with the exception of Fly Branch, NY, where autochthonous OM contributed 4-10% to macroinvertebrate biomass. Additionally, a shredding macroinvertebrate and chironomids collected from Little Muncy Creek, PA were primarily reliant on allochthonous OM (mean proportional contributions of 56 and 70%, respectively). In most cases, different combinations of isotopes ($\delta^{13}C$ and $\delta^{15}N$ vs. $\delta^{13}C$, $\delta^{15}N$, and $\delta^{2}H$) used in the mixing models yielded similar results. The exception to this was again Fly Branch. Allochthonous OM was most important with both model runs, but the model which ran with $\delta^{13}C$, $\delta^{15}N$, and $\delta^{2}H$ significantly increased the percentage contribution of allochthonous OM. The mean range of allochthonous contributions for the model with only $\delta^{13}C$ $\delta^{15}N$ isotopes was 34-81% across FFGs, versus the model with $\delta^{13}C$, $\delta^{15}N$, and $\delta^{2}H$ isotopes with a mean range of allochthonous contributions from 90% to 96%. While autochthonous OM was of primary importance, with the exception of the two aforementioned sites, allochthonous OM still contributed significantly to macroinvertebrate nutrition. Mean proportional contributions of allochthonous OM to macroinvertebrate diet at sites other than Fly Branch and Little Muncy Creek ranged from 20% to 40%.

$\Delta^{14}C$ data also suggest that autochthonous OM was of primary nutritional importance in these systems. Macroinvertebrate $\Delta^{14}C$ values at Fly Branch, NY ranged from 23‰ to -59‰ (modern in age to 430 years BP; **Figure 11**), with the most ^{14}C-enriched macroinvertebrate being a shredder, which had a diet primarily composed of terrestrial vegetation (**Table 3 and Figure 11**). Macroinvertebrate $\Delta^{14}C$ values at Nowadega Creek, NY ranged from -1‰ to -114‰ (modern in age to 910 years BP; **Figure 11**). Similarly, organisms collected from the upper Susquehanna River sites had variable $\Delta^{14}C$ signatures, ranging from 6‰ to -58‰ (modern in age to 415 years BP, **Figure 12**). The Cowanesque River, PA site had the most $\Delta^{14}C$ depleted macroinvertebrates (**Figure 12**). The most likely cause of $\Delta^{14}C$ depletion observed in macroinvertebrates at these sites is $\Delta^{14}C$-DIC. The $\Delta^{14}C$ values of DIC at Fly Branch and Nowadega Creek, NY were -72.5‰ and -137.1‰ respectively. The $\Delta^{14}C$ values of DIC at Towanda Creek, Little Muncy Creek, Elk Run, Crooked Creek (2013 data in this case), Cowanesque River, and North Elk Run, PA were -28.7‰, -27.2‰, -56.7‰, -62.7‰, -65.7‰, and -15.1‰, respectively. Algal samples collected from these sites had similar $\Delta^{14}C$ values to the $\Delta^{14}C$-DIC. Soil CO_2, weathering carbonates, and DIC from groundwater are likely contributors to stream water DIC (Ishikawa et al. 2014, Keaveney et al. 2015a, 2015b), which is fixed by primary producers that are then consumed by macroinvertebrates, giving them an “old” apparent age. Algae that appears aged is most likely contributing to the majority of macroinvertebrate diet in these systems, rather than some form of aged allochthonous OM, such as shale or terrestrial soil OM, which is contrary to our original hypothesis. However, as mentioned earlier and was suggested by isotopic mixing models, allochthonous OM still contributed significantly to macroinvertebrate diet in these systems.

Other Accomplishments and Future Work

As part of my PhD dissertation, further analysis of the data from this study will include additional model runs in order to better understand some of the incongruences that resulted from initial model runs presented in this report (primarily at Fly Branch, NY). The additional model runs will also explicitly incorporate the $\Delta^{14}C$ values of both organisms and their potential dietary sources. Mixing models will also be run in order to determine basal food resources contributing to predator FFG diet. Additionally, a nonparametric multivariate statistical approach will be used to determine if relationships exist between site characteristics (stream size, land use, lithology, etc.), organism isotope values, and autochthonous vs. allochthonous dietary contributions. Manuscript preparation will occur concurrently with final data analysis. Findings from this study, along with my other dissertation findings, will be submitted for consideration for potential publication to the journals *Freshwater Biology*, *Limnology and Oceanography*, and *Biogeosciences*. In June of 2016, findings from this study, will be presented at a special session entitled “Use of Natural Abundance ^{14}C in Aquatic Food Web and Ecosystem Studies”, co-chaired by myself, at the Association for the Sciences of Limnology and Oceanography (ASLO) summer meeting in Santa Fe, NM.

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Tables and Figures

Figure 1. Sampling sites in the headwaters of the Hudson-Mohawk River Basin. Watersheds that contain varying amounts of organic matter (OM) in their lithologies appear in circles, and those that contain no OM in their lithologies appear in rectangles. NC-Nowadaga Cr., OC-Otsquago Cr., ST- Schoharie Trib., FB- Fly Br., WC-Wampecack Cr., CH- Couch Hollow Br. Figure modified from Longworth et al. 2007.

Figure 2. Upper Susquehanna River basin study stream sites. Blue area represents drainage basin, with grey lines representing sub-basin boundaries. Red lines represent large rivers in the drainage basin and blue lines represent study streams.

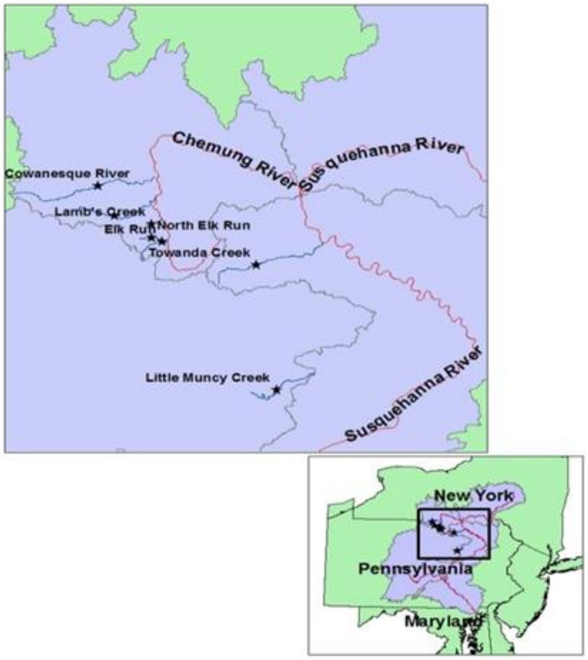


Table 1. Genera and functional feeding groups identified in Mohawk-Hudson watershed sites. Site abbreviations are as follows: Schoharie Tributary- ST, Otsquago Creek- OC, Wampecack Creek- WC, Fly Branch- FB, Nowadega Creek- NC, Couch Hollow Branch- CH.

Genera	**Functional feeding group**	**Sites collected from**
Ceratopsyche	Filtering collector	ST, OC, WC, FB, NC, CH
Ephemerella	Collector gatherer	ST, NC
Habrophebiodes	Scraper; collector gatherer	ST
Psephenus	Scraper	ST, WC, FB
Wormaldia	Filtering collector	ST, FB, CH
Amphinemura	Shredder	ST
Alloperla	Predator	ST
Procleon	Collector gatherer	ST, OC
Rhyacophila	Predator	ST, FB
Agnetina	Predator	ST, FB, CH
Epeorus	Scraper	ST, CH
Hexatoma	Predator	ST, FB
Pteronarcys	Shredder	ST
Boyeria	Predator	ST, NC
Nixe	Scraper	OC
Chironomidae (family)	Multiple	OC, WC, FB
Simuliidae (family)	Filtering collector	OC
Macrostemum	Filtering collector	OC
Lype	Scraper	OC
Muscidae (family)	Predator	OC
Anacroneuria	Predator	OC, WC
Ancyronyx	Collector gatherer	WC
Maccaffertium	Scraper	WC, FB
Isonychia	Filtering collector	WC, FB
Drunella	Scraper	FB
Pycnopsyche	Shredder	FB
Ephemera	Collector gatherer	FB, NC
Gammaridae (family)	Collector gatherer	FB, NC
Nigronia	Predator	FB
Hetaerina	Predator	FB, CH
Stylogomphus	Predator	FB
Caenis	Collector gatherer	NC
Laccophilus	Predator	NC
Hydrophilus	Predator	NC
Corixidae (family)	Piercer	NC
Argia	Predator	NC
Neoperla	Predator	CH
Acroneuria	Predator	CH
Beloneuria	Predator	CH
Cordulegaster	Predator	CH
Eccoptura	Predator	CH

Table 2. Genera and functional feeding groups identified in upper Susquehanna watershed sites. Site abbreviations are as follows: Towanda Creek- TC, Little Muncy Creek- LMC, Crooked Creek- CrCr, Cowanesque River- CR, North Elk Run- NER, Elk Run- ER, Lamb's Creek- LC.

Genera	**Functional feeding group**	**Sites collected from**
Glossosoma	Scraper	TC, LMC
Caenis	Collector gatherer	TC, CrCr, CR, NER
Ephemerella	Collector gatherer	TC, LC
Isonychia	Filtering collector	TC, LMC, CR
Gammaridae (family)	Collector gatherer	TC, LMC
Liodessus	Predator	TC, CrCr
Cheumatopsyche	Filtering collector	TC, ER, NER, LC
Stenacron	Scraper	TC, ER, CR
Maccaffetium	Scraper	TC
Stenonema femoratum	Scraper	TC
Leucrocuta	Scraper	TC, CR
Argia	Predator	TC, CrCr, NER
Chironomidae (family)	Multiple	TC, ER, LMC, CR
Ceratopsyche	Filtering collecter	TC, ER, CrCr, LMC, CR, NER, LC
Lestes	Predator	TC, NER
Hetaerina	Predator	TC, CrCr, LMC, NER, LC
Ranatra	Predator	TC
Boyeria	Predator	TC, CrCr, NER
Drunella	Scraper	ER, CrCr, LC
Neoperla	Predator	ER
Simuliidae (family)	Filtering collector	CrCr, CR, LC
Cernotina	Predator	CrCr, LC
Helicopsyche	Scraper	CrCr
Tipula	Scraper	CrCr, LMC, NER
Hexatoma	Predator	CrCr, CR, LC
Stenelmis	Omnivore	CrCr, LMC
Psephenus	Scraper	CrCr
Gyretes	Predator	CrCr
Agnetina	Predator	CrCr, CR
Ophiogomphus	Predator	CrCr
Heptagenia	Scraper	LMC, LC
Paraleptophlebia	Gathering collector	LMC, CR
Serratella	Gathering collector	LMC, CR
Hydropsyche	Filtering collector	LMC, CR, LC
Promoresia	Omnivore	CR
Agapetus	Scraper	LMC
Dolophilodes	Filtering collector	LMC, LC
Paragnetina	Predator	LMC
Helichus	Shredder	LMC
Culicidae (family)	Gathering collector	CR
Eccoptura	Predator	CR
Beloneuria	Predator	CR
Agabetes	Predator	NER

Trichocorixa	Predator	NER
Neoporus	Predator	NER
Pycnopsyche	Shredder	LC
Rhyacophila	Predator	LC
Chauliodes	Predator	LC
Acroneuria	Predator	LC
Leuctra	Shredder	LC
Stylogomphus	Predator	LC

Table 3. Mean and standard deviation of isotopic values for functional feeding groups (FFG) from the Mohawk-Hudson watershed. Isotopic values presented here are raw data uncorrected for trophic fractionation.

FFG (n)	**δ^{13}C (‰)**	**δ^{15}N (‰)**	**δ^{2}H (‰)**	**Δ^{14}C (‰)***
Nowadega Creek				
Filtering collector (3)	-28.5 ± 0.44	10.4 ± 0.29	-238 ± 4.22	-113.9 ± 0.2
Collector gatherer (4)	-27.1 ± 0.92	8.7 ± 0.26	-202.9 ± 30.07	-81.0 ± 7
Predator (6)	-28.9 ± 3.56	9.3 ± 1.73	-170.1 ± 16.49	-55.8 ± 48
Fly Branch				
Filtering collector (5)	-29.6 ± 0.86	7.4 ± 0.47	-197.6 ± 18.3	-44.2 ± 4
Collector gatherer (6)	-27.2 ± 0.28	6.9 ± 1	-160.2 ± 5.6	-28.2 ± 3
Shredder (1)	-27.1	4.8	-132.3	23.3
Scraper (3)	-28.8 ± 1.26	6.4 ± 0.69	-194.9 ± 30.20	-42.8 ± 17
Predator (10)	-29.5 ± 1.4	8.7 ± 0.60	-194.3 ± -21.96	-56.7 ± 4
Schoharie Trib.				
Filtering collector (2)	-28.3 ± 0.72	4.4 ± 0.74	-212.5 ± 12.17	ND
Collector gatherer (1)	-26.4	2.5	-222.6	ND
Scraper	-33.8 ± 0.33	2.9 ± 0.27	-242.8 ± 0.07	ND
Shredder (1)	-28.9	3.1	-183.3	ND
Predator (8)	-28.1 ± 1.12	5.9 ± 0.67	-191.4 ± 24.64	ND
Otsquago Creek				
Scraper (2)	-30.1 ± 0.33	6.9 ± 0.02	-234.2 ± 3.66	ND
Filtering Collector (2)	-30.8 ± 0.43	9.3 ± 0.39	-241.6 ± 1.29	ND
Chironomidae (2)	-27.5 ± 2.19	8.6 ± 0.76	-213.4 ± 26.34	ND
Wampecack Creek				
Scraper (1)	-32.6	8.5	-241.2	ND
Chironomidae (1)	-27.6	9.1	-166.7	ND
Filtering collector (4)	-30.4 ± 0.42	9.0 ± 0.28	-206.1 ± 6.49	ND
Predator (1)	-31.2	10.2	-215.3	ND
Couch Hollow Branch				
Scraper (2)	-32.6 ± 0.78	6.2 ± 0.56	-198.6 ± 6.48	ND
Filtering collector (2)	-30.0 ± 0.96	6.5 ± 0.61	-178.4 ± 34.14	ND
Predator (5)	-30.1 ± 0.92	7.8 ± 0.68	-169.3 ± 14.39	ND

* Sample replicate numbers for Δ^{14}C measurements do not match those for stable isotope measurements presented in FFG column and are as follows: Nowadega Creek FC- 3, CG- 3, P-2; Fly Branch FC- 2, CG- 4, Shr- 1, Scr- 2, P- 2.

Table 4. Mean and standard deviation of isotopic values for functional feeding groups (FFG) from the upper Susquehanna watershed. Isotopic values presented here are raw data and uncorrected for trophic fractionation. Sample replicate numbers for Δ^{14}C measurements do not match those for stable isotope measurements.

FFG (n)	**δ^{13}C (‰)**	**δ^{15}N (‰)**	**δ^{2}H (‰)**	**Δ^{14}C (‰)***
Little Muncy Creek				
Gathering collector (1)	-22.8	4.0	-180.6	ND
Filtering collector (4)	-22.4 ± 0.99	5.3 ± 0.32	-177.2 ± 17.89	-12.8 ± 9
Scraper (2)	-20.7 ± 2.51	4.9 ± 1.91	-207.7 ± 5.8	-32.2 ± 1
Shredder (2)	-25.3 ± 0.65	4.0 ± 0.60	-106.7 ± 1.40	ND
Predator (5)	-21.2 ± 0.64	6.4 ± 0.69	-173.4 ± 22.11	-12.0 ± 8
North Elk Run				
Gathering collector (1)	-27.2	9.4	-157.5	ND
Filtering collector (3)	-28.4 ± 0.31	11.4 ± 0.50	-160.1 ± 6.80	-9.6 ± 1
Shredder (1)	-27.3	7.2	-136.4	ND
Predator (5)	-26.5 ± 0.41	10.8 ± 0.51	-144.6 ± 19.97	0.5 ± 6
Cowanesque River				
Filtering collector (2)	-21.8 ± 0.07	11.0 ± 0.04	-225.8 ± 3.25	-52.9 ± 3
Gathering collector (2)	-20.9 ± 0.45	10.5 ± 0.87	-191.1 ± 3.77	ND
Scraper (1)	-20.6	10.4	-201.1	-39.3
Predator (2)	-21.4 ± 0.51	11.6 ± 0.04	-204.0 ± 12.74	-53.6
Crooked Creek				
Collector gatherer (1)	-26.1	7.4	-216.4	ND
Scraper (3)	-24.6 ± 2.47	8.7 ± 0.22	-248.8 ± 14.87	-57.0
Shredder (1)	-25.4	6.4	-165.7	-21.8
Predator (10)	-24.9 ± 0.66	9.6 ± 0.47	-187.6 ± 16.59	-45.5 ± 1
Towanda Creek				
Collector gatherer (1)	-26.2	10.2	-213.3	ND
Scraper (6)	-23.5 ± 1.57	10.5 ± 0.67	-208.4 ± 23.59	-27.9 ± 5
Filtering collector (6)	-22.7 ± 0.29	11.7 ± 0.09	-215.9 ± 9.95	-23.5 ± 3
Predator (7)	-23.2 ± 0.72	12.2 ± 0.33	-169.4 ± 16.50	-16.7 ± 1
Lamb's Creek				
Scraper (2)	-34.5 ± 4.29	4.2 ± 0.03	-208.73 ± 17.77	ND
Shredder (3)	-27.7 ± 0.53	2.8 ± 0.60	-117.1 ± 13.40	ND
Filtering collector (4)	-29.5 ± 0.52	5.3 ± 0.35	-181.6 ± 5.83	ND
Predator (5)	-30.6 ± 3.25	5.7 ± 0.60	-172.6 ± 26.21	ND
Elk Run				
Scraper (3)	-24.1 ± 0.18	9.9 ± 0.73	-224.9 ± 3.86	-41.9 ± 1
Filtering collector (5)	-23.8 ± 0.31	9.4 ± 0.24	-201.7 ± 12.68	-43.7 ± 2
Predator (2)	-22.2 ± 0.38	11.4 ± 0.12	-176.8 ± 3.98	-30.2

*Sample replicate numbers for Δ^{14}C measurements do not match those for stable isotope measurements presented in FFG column and are as follows: Little Muncy Creek FC- 3, Scr- 2, P-3; North Elk Run FC- 2, P- 3; Cowanesque River FC- 2, P-1; Crooked Creek Scr- 1, P- 4; Towanda Creek Scr- 3, FC- 3, P- 3; Elk Run Scr- 2, FC-2, P-1.

Figure 3. Mean δ^{13}C and δ^{15}N for all organisms at each site in the Hudson-Mohawk watershed.

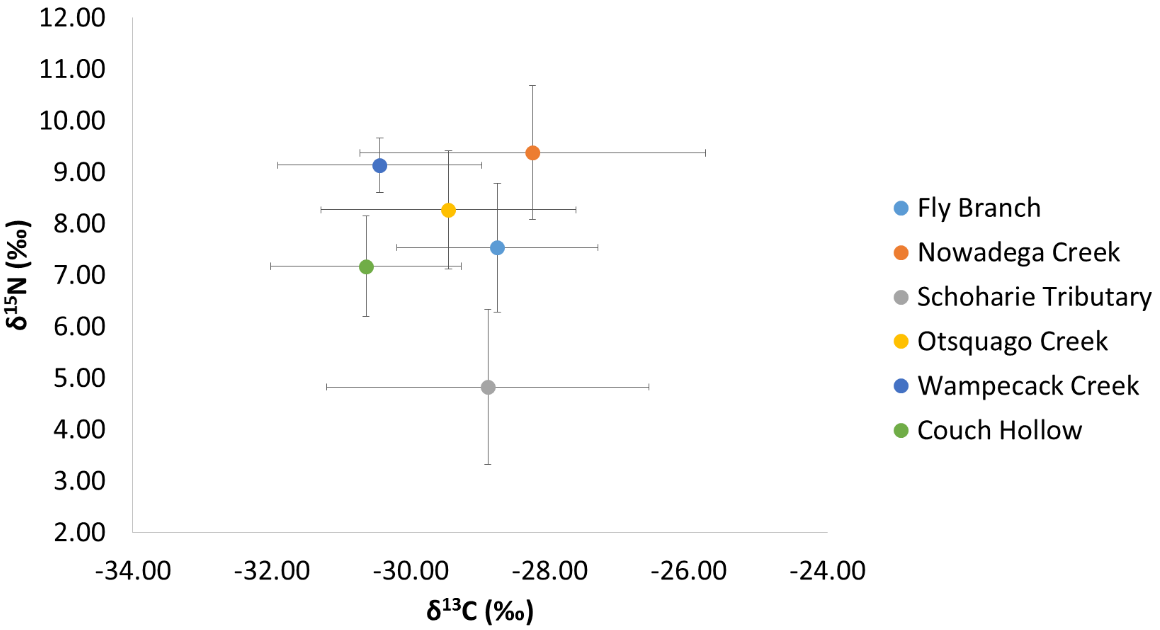


Figure 4. Mean δ^{13}C and δ^{15}N for all organisms at each site in the upper Susquehanna watershed.

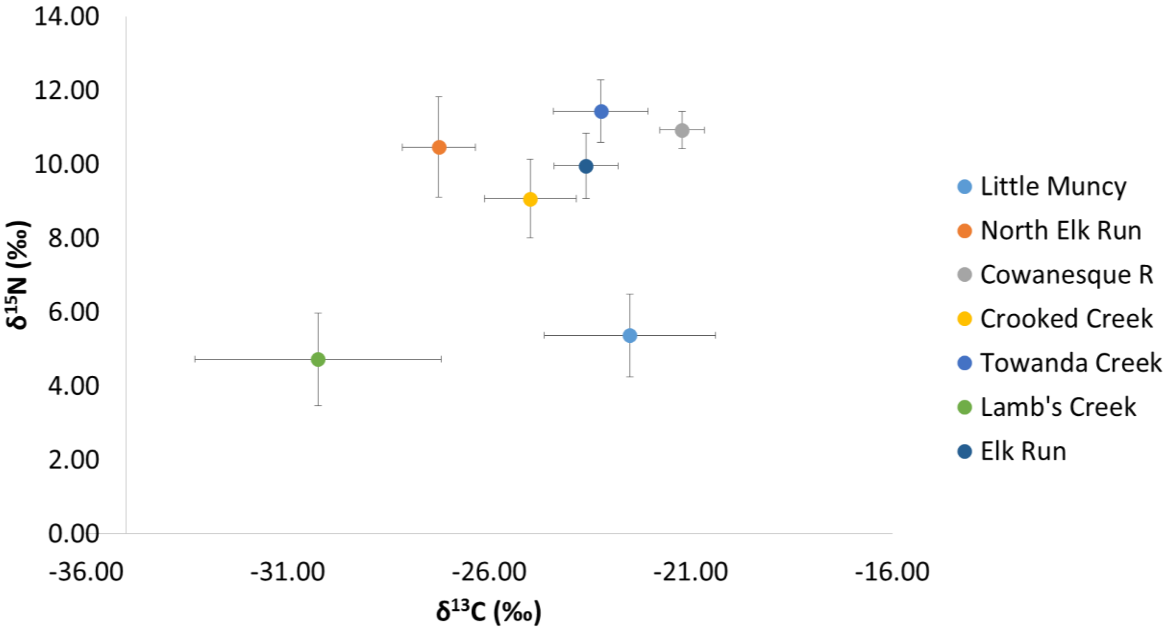


Figure 5. A) Mixing model findings for Fly Branch, NY using $\delta^{13}C$ and $\delta^{15}N$ isotopes. B) Mixing model findings for Fly Branch, NY using $\delta^{13}C$, $\delta^{15}N$, and $\delta^{2}H$ isotopes.

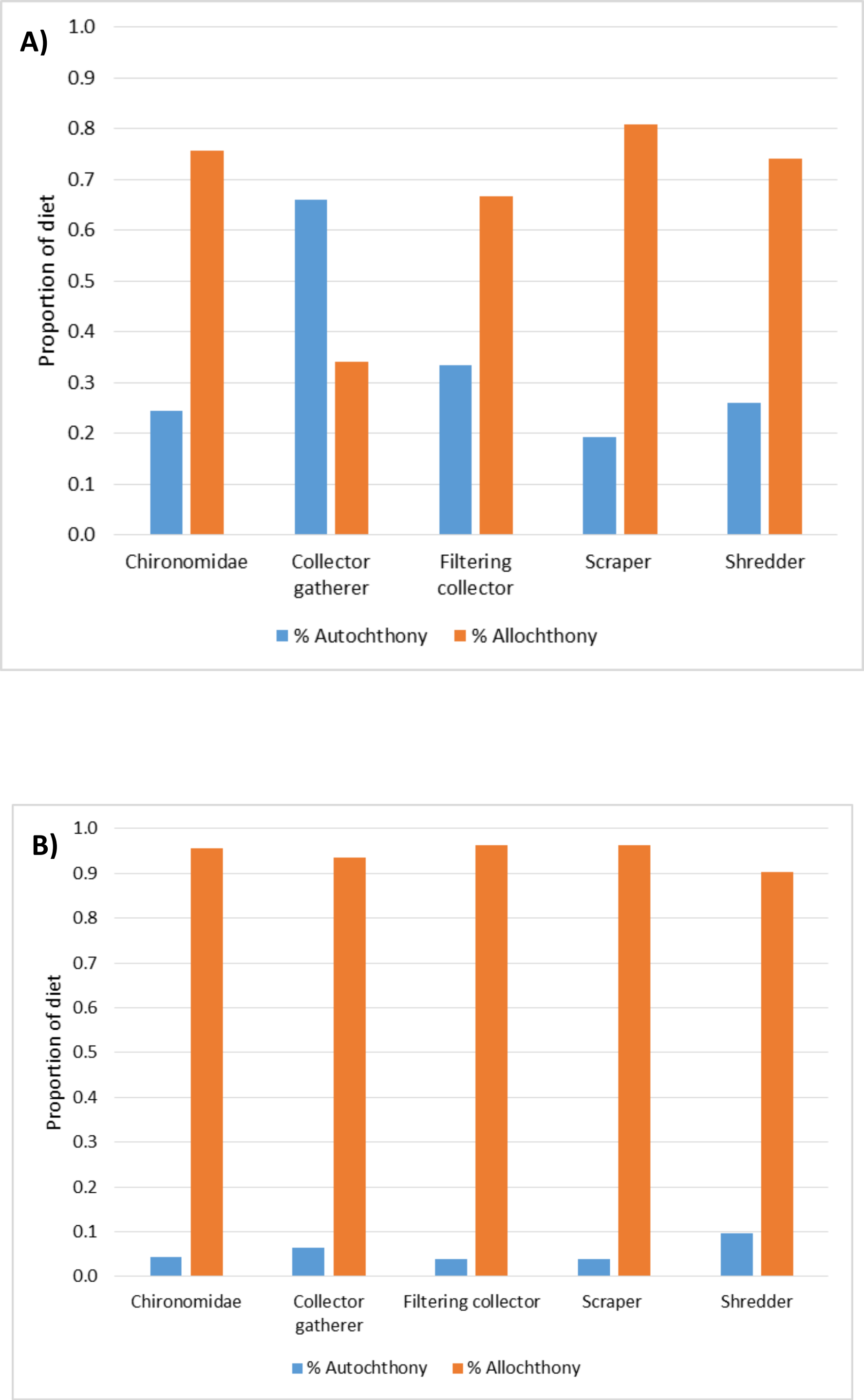


Figure 6. A) Mixing model findings for Nowadega Creek, NY using δ^{13}C and δ^{15}N isotopes. B) Mixing model findings for Nowadega Creek, NY using δ^{13}C, δ^{15}N, and δ^{2}H isotopes.

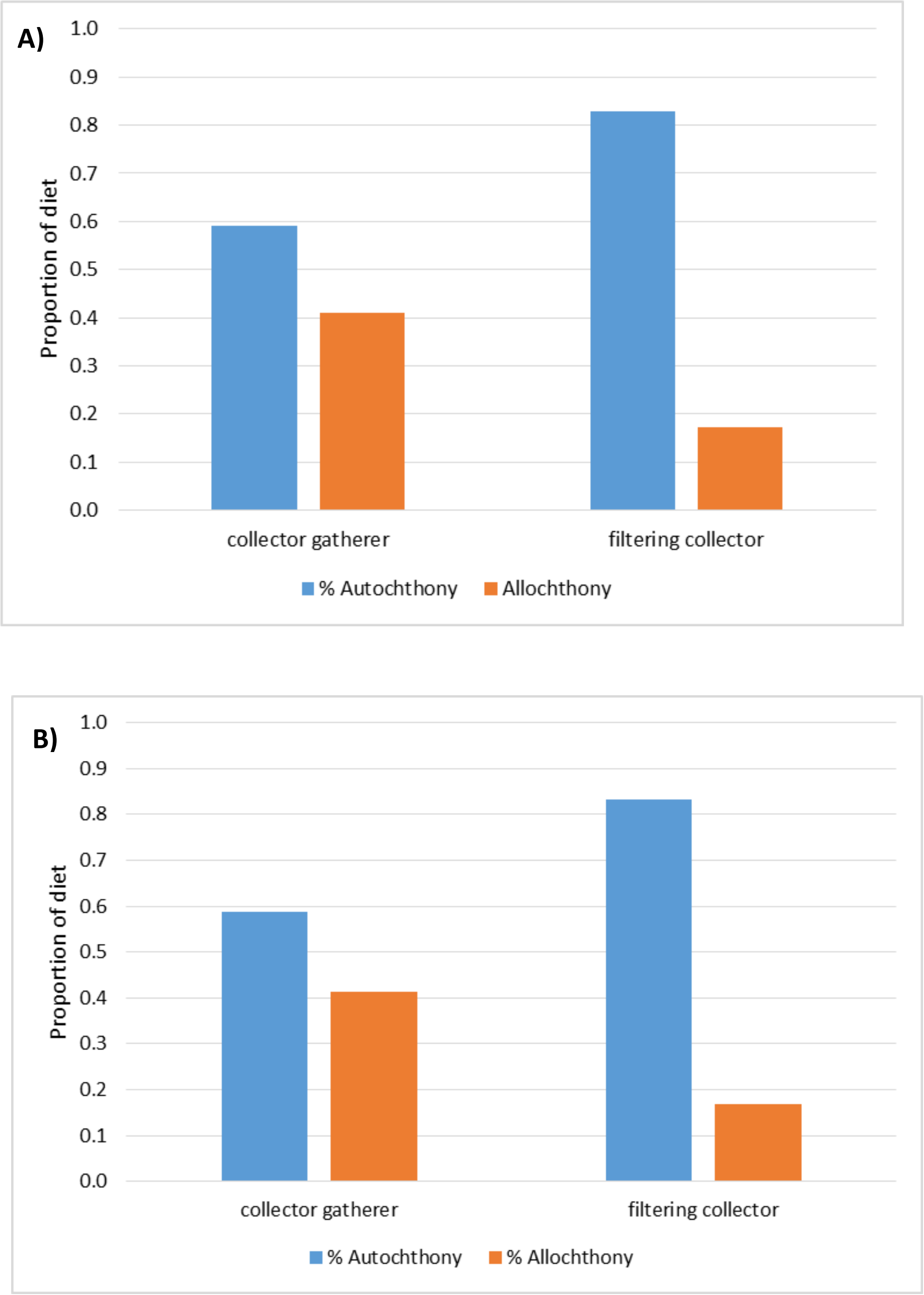


Figure 7. A) Mixing model findings for Wampecack Creek, NY using δ^{13}C and δ^{15}N isotopes. B) Mixing model findings for Wampecack Creek, NY using δ^{13}C, δ^{15}N, and δ^{2}H isotopes.

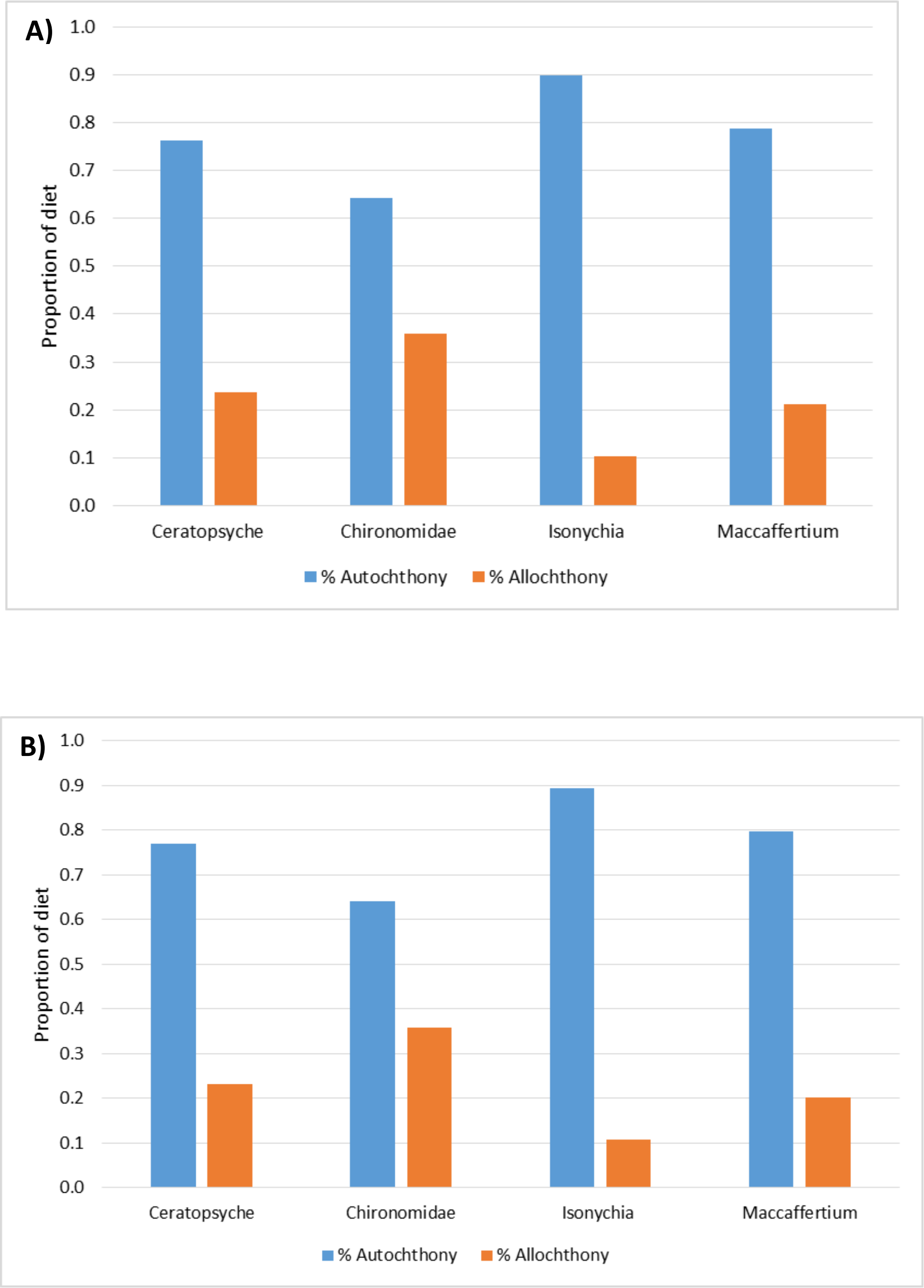


Figure 8. A) Mixing model findings for Little Muncy Creek, PA using $\delta^{13}C$ and $\delta^{15}N$ isotopes. B) Mixing model findings for Little Muncy Creek, PA using $\delta^{13}C$, $\delta^{15}N$, and $\delta^{2}H$ isotopes.

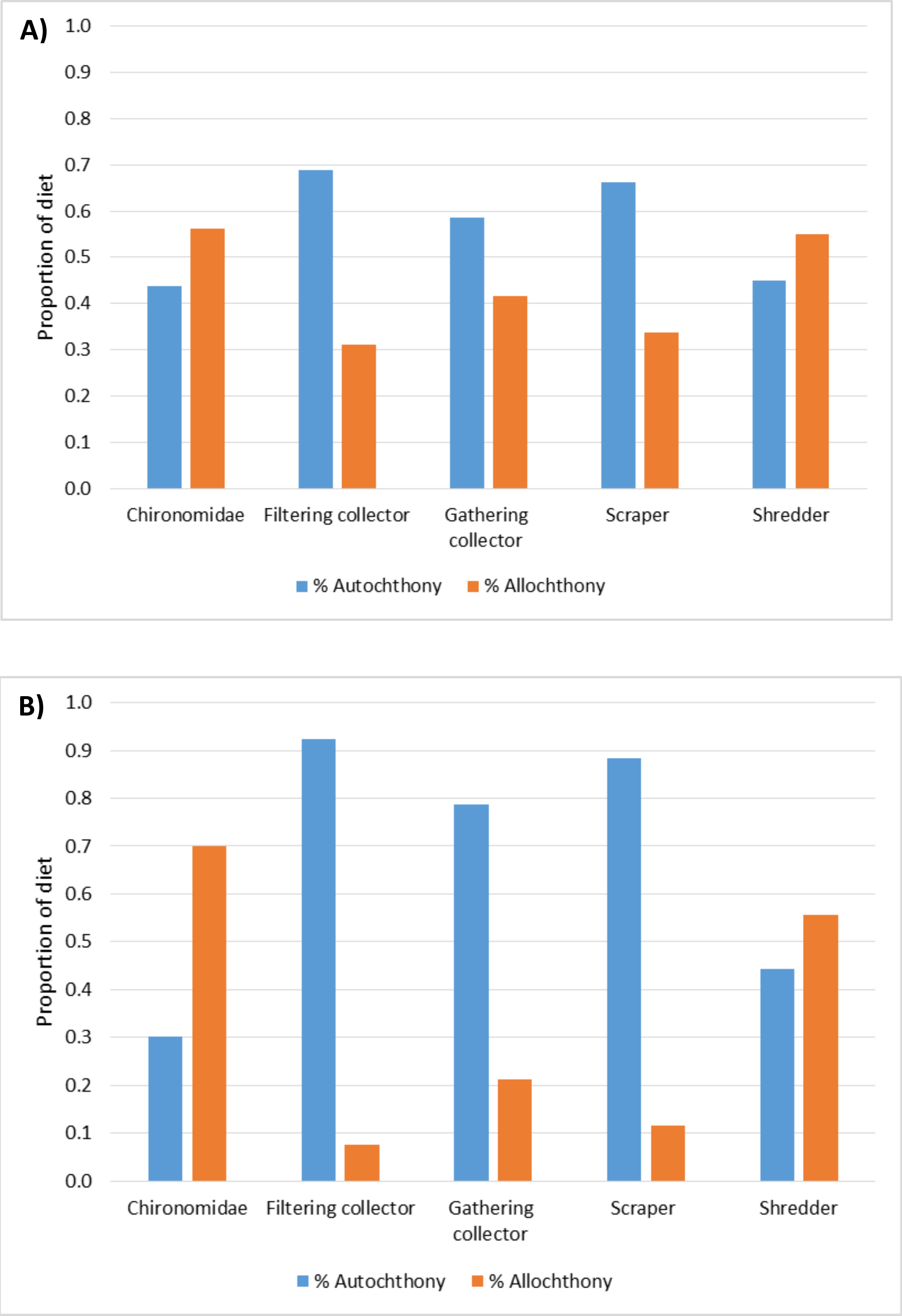


Figure 9. A) Mixing model results for Cowanesque River, PA using δ^{13}C and δ^{15}N isotopes. B) Mixing model results for Cowanesque River, PA using δ^{13}C, δ^{15}N, and δ^{2}H isotopes.

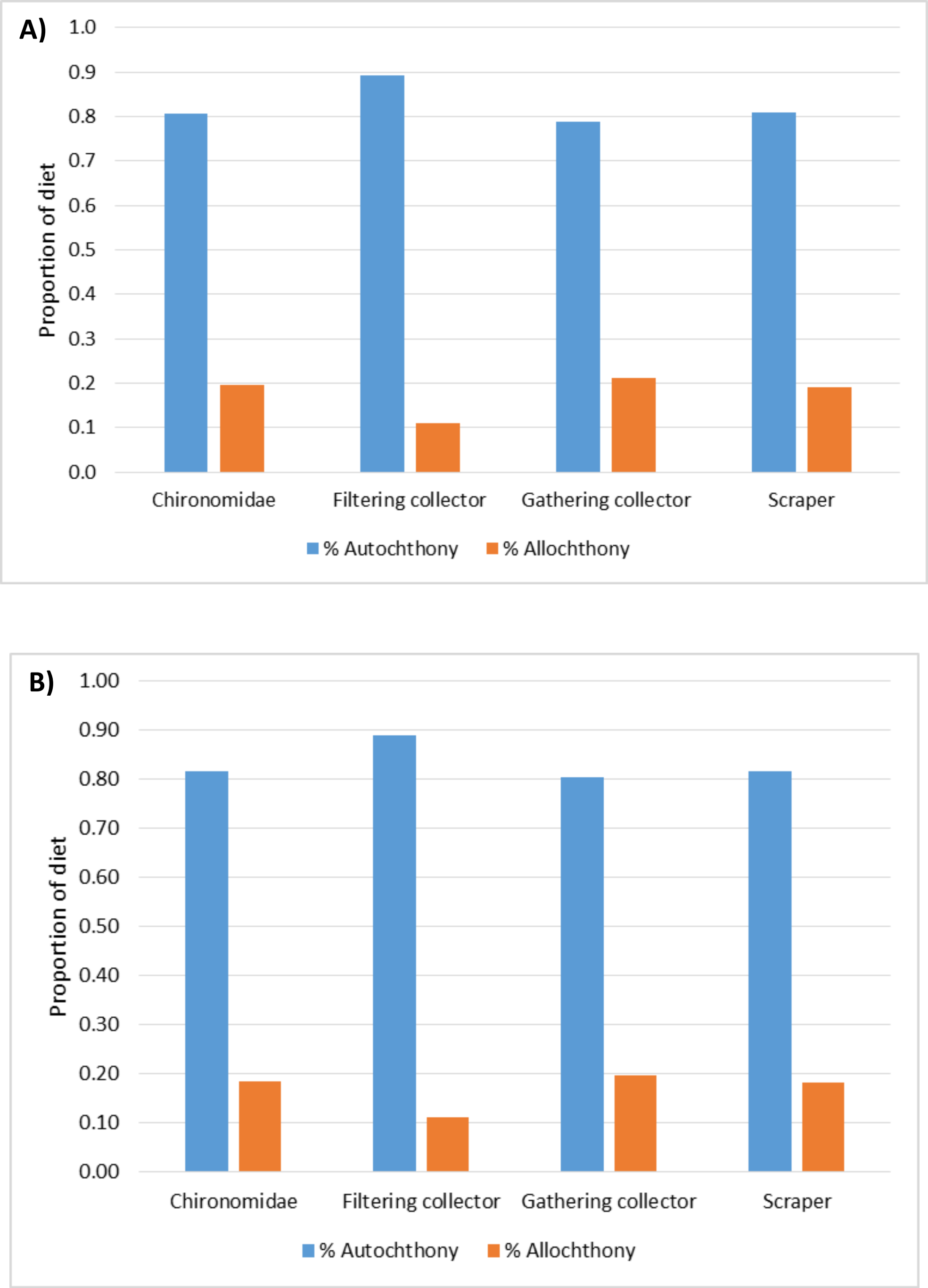
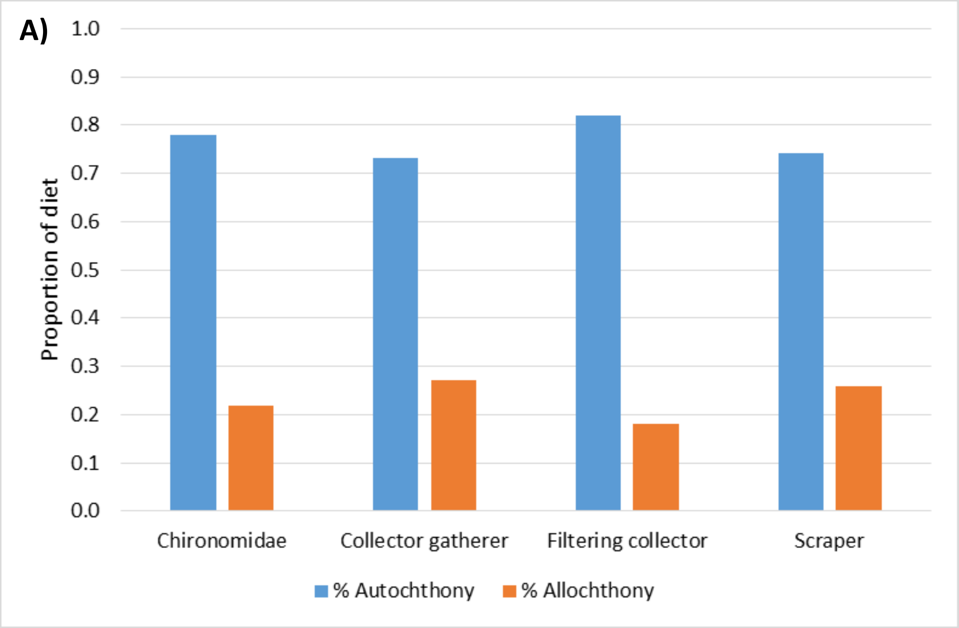


Figure 10. A) Mixing model results for Towanda Creek, PA using δ^{13}C and δ^{15}N isotopes. B) Mixing model results for Towanda Creek, PA using δ^{13}C, δ^{15}N, and δ^{2}H isotopes.



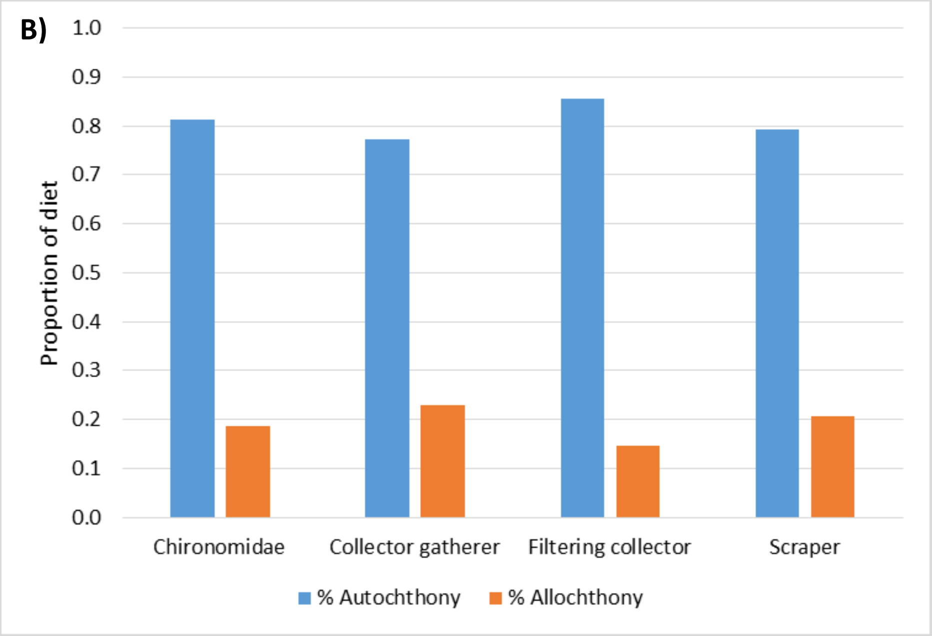


Figure 11. Hudson-Mohawk macroinvertebrate $\Delta^{14}C$ (‰) values.

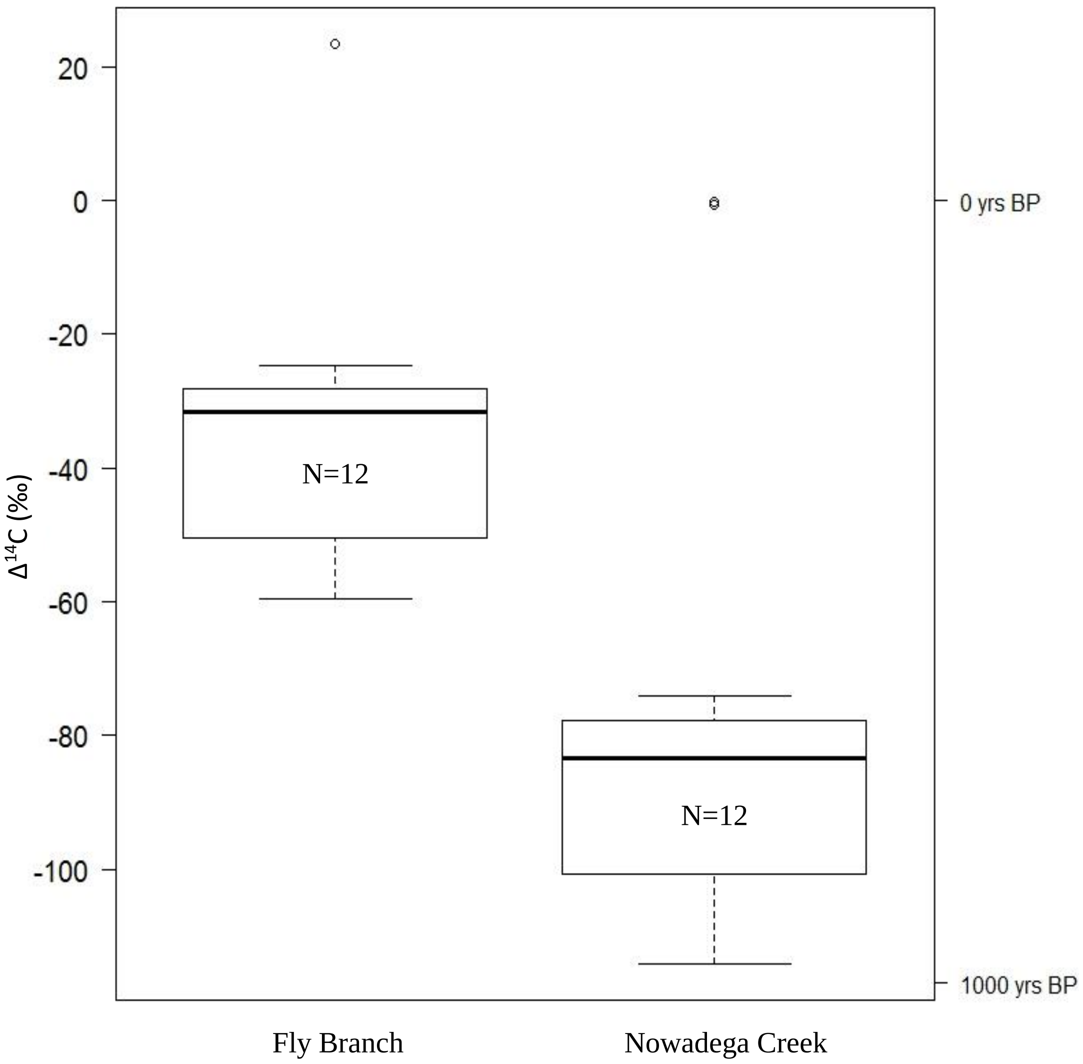


Figure 12. Upper Susquehanna macroinvertebrate $\Delta^{14}C$ (‰) values.