

**THE DISTRIBUTION AND FEEDING ECOLOGY OF LARVAL SEA
LAMPREYS IN THE HUDSON RIVER BASIN**

A Final Report of the Tibor T. Polgar Fellowship Program

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ABSTRACT

Anadromous fishes are important members of the Hudson River fish community, but not all members have been well studied. Sea lampreys (*Petromyzon marinus*) have largely been ignored, and as a result even their distribution within the Hudson River is poorly understood. Sea lampreys are currently present in four tributaries of the Hudson River: 1) Cedar Pond Brook, 2) Catskill Creek, 3) Roeliff Jansen Kill, and 4) Rondout Creek. Catskill Creek and its tributary, Kaaterskill Creek, produce the majority of sea lamprey in the Hudson River. The Roeliff Jansen Kill is also important for sea lampreys in the Hudson River, as sea lampreys appear to grow faster here than at other tributaries. Sea lampreys are likely to increase their range in the Hudson River in the near future as the removal of barriers to migration continues, but global climate change poses a serious long term threat to lamprey populations in the Hudson River.

Isotopic analysis demonstrated that site influenced the importance of terrestrially derived plant material (allochthonous) and aquatic plant sources (autochthonous) to sea lamprey larvae. For instance, larval lamprey from the Kaaterskill Creek depended on up to 60% on allochthonous sources, while those at Cedar Pond Brook only obtained ~1% of their nutrition from the same source. Changes in watershed land use were not associated with nutritional source dependence, and local sources may be more important than watershed level effects. Larval lamprey were isotopically distinct from all macroinvertebrates measured, suggesting that they exploit resources in different proportions from measured invertebrates and help more fully utilize organic material in streams. This study provides important data about the current distribution of sea lampreys in the Hudson River, and is the first to examine sea lampreys and the invertebrate community simultaneously with stable isotopes.

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INTRODUCTION

Sea Lamprey in the Hudson River

Anadromous fishes, or those species that spawn in freshwater but migrate to marine ecosystems for the majority of their growth, are important members of many coastal ecosystems. The historic abundance of anadromous fishes, combined with their ease of capture during spawning migrations, has provided economic and social opportunities for numerous societies (Hardy 1999; Bolster 2006; Bottom et al. 2009). Early European settlers, familiar with migratory fishes, were still impressed by the abundance and diversity of species that greeted them upon their arrival to North America (Collette and Klein-Macphee 2002). However, after initially utilizing these vast resources, Europeans rapidly overexploited the fisheries, while simultaneously limiting access to and destroying the freshwater habitats upon which anadromous fishes depended (Hardy 1999; Lichter et al. 2006; Limburg and Waldman 2009). Current estimates suggest that >90% of the historic biomass of these migratory fishes has already been lost (Limburg and Waldman 2009).

The Hudson River is a biologically diverse ecosystem which currently contains ten anadromous fish species (Levinton and Waldman 2006) and has been the focus of extensive research (Jackson et al. 2005). The anadromous fish community in the Hudson River has been, in general, well studied. However, research efforts have not been evenly divided between all species, and gaps in the current understanding of this important group remain (Waldman 2006). Sea lampreys (*Petromyzon marinus*) are the most poorly studied member of the Hudson River anadromous fish community. Sea lampreys were neglected because they were not considered economically or socially important in North America,

are often difficult to sample effectively, and perceptions about this species have been dominated by research efforts on invasive populations in the upper Great Lakes.

Sea lampreys belong to the most primitive group of vertebrate lineages (Order: Cyclostomata), and exhibit an anadromous, semelparous (i.e., a species that spawns only once) life history. Unlike most other anadromous fishes, which spend a shorter time in fresh than in the marine waters, sea lampreys spend protracted periods in freshwater (up to 17 years) before a relatively brief time at sea (1-3 years; Beamish 1980). In addition, unlike many other anadromous fishes in the Northeast where at least some adults are iteroparous (i.e., they spawn more than once), sea lampreys are an obligatory semelparous species (Saunders et al. 2006). Because of the limited information available, there is no way to know historical abundance, or which streams were utilized by sea lampreys prior to large scale habitat alteration by European settlers. Even recent records of sea lampreys (i.e., those within the last 100 years) are difficult to find, and are often anecdotal.

Although sea lampreys have not often been considered an important member of the anadromous fish community, they may provide or have provided many of the same ecosystem services as other anadromous species (Holmlund and Hammer 1999). Sea lamprey larvae and carcasses of spent adults may have provided important food subsidies to freshwater aquatic and terrestrial systems (Nislow and Kynard 2009). In Maine, sea lamprey spawning coincides with first feeding of salmonid parr (juveniles), and spent adults, eggs, and embryos of sea lampreys may all provide important food sources to these young salmonids (Saunders et al. 2006). In addition, sea lampreys continue to spawn after other anadromous species during the spawning run (Saunders et al. 2006). A

sea lamprey adult was observed at a spawning site as late as June 26th during the course of this study. Also, sea lamprey body shape and swimming style are unlike any other anadromous species, and they may prefer habitats not utilized by other anadromous species. In the Great Lakes (where sea lampreys are invasive) barriers are designed that specifically exploit their climbing style and exclude them from upstream reaches (McLaughlin et al. 2006).

Stable Isotope Analysis of Lower Trophic Levels in Stream Food Webs

To better understand what role sea lampreys may play in freshwater food webs stable isotope ratio analysis was used to examine young-of-year (YOY) larval lamprey, different functional feeding groups of aquatic insects, and primary producers. Briefly, many elements consist of two or more stable isotopes that differ slightly in mass due to different numbers of neutrons in the nucleus. These small differences can be quantified with mass spectrometers, and the ratios can provide important insights into biophysical processes. All living organisms develop isotopic signatures based upon the source materials they utilize for growth and development (Michener and Lajtha 2007). The lighter isotope is preferentially incorporated into biological materials because it is energetically less expensive to fix (i.e., fractionation), but, when the organism produces waste, it favors compounds with the lighter isotope for expulsion. Ultimately, the organism becomes more enriched in the heavier isotope than the food source. These differences in fractionation develop natural tracers in food webs, which can be used to follow the flow of nutrients as they move through the ecosystem. The predictable

fractionation of isotopes as they move through food webs also allows for the estimation of the trophic level at which an organism is feeding (Peterson and Fry 1987).

Although extensive visual examination of larval lamprey gut content has documented materials they consume (primarily detritus), the source(s) of the detrital material is still largely unknown (Moore and Mallatt 1980, Sutton and Bowen 1994, Mundahl et al. 2005). In contrast to visual identification methods, natural abundance isotopic analysis represents potentially a more robust and quantitative approach for assessing the sources of organic matter (OM) supporting the somatic growth and energetic maintenance of an organism or population (Cole and Solomon 2012; Roach et al. 2011). Naturally occurring isotopes of C, N, H, O and S in OM may be used to assess, both qualitatively and quantitatively, different OM sources supporting organism nutrition and through food webs and even ecosystems, provided the isotopes of these elements can be measured in both the potential food sources and the target organisms (Peterson and Fry 1987; Michener and Lajtha 2007). Simultaneous use of multiple natural isotopes can help resolve with greater accuracy the dietary and nutritional sources of a given species than with a single isotope (Peterson and Fry 1987; Caraco et al. 2010). Natural abundance stable isotopes can also be used to help establish at which trophic level organisms are feeding using predictable fractionation values (Post 2002).

Understanding the nutritional sources supporting larval lamprey is important for their conservation and to understand better how they interact with the larger stream community. In addition, although stable isotopes have only been applied in a limited number of studies of larval lampreys (Hollett 1995; Shirakawa et al. 2009; Limm and Power 2011), isotopes have been widely used to examine macroinvertebrates (Vander

Zanden and Rasmussen 1999; Finlay 2001). Many macroinvertebrates have a similar feeding ecology to larval lamprey, but to date only a single study has simultaneously examined larval lampreys and stream macroinvertebrates with stable isotopes together (Bilby et al. 1996). All species of larval lampreys are filter feeders (Mallatt 1982), as are many aquatic invertebrates (Voshell 2002), but it is unclear if they utilize food sources in the same proportions. This study attempts to develop a more complete picture of the stream community by concurrently examining stable isotopes of both invertebrates and lamprey.

Therefore, the purpose of this study was twofold: 1) to identify the current distribution of sea lampreys in the Hudson River estuary below the Troy Dam, and 2) to determine the likely OM supporting YOY larval lampreys and selected macroinvertebrates utilizing stable isotope analysis. It was hypothesized that YOY sea lamprey nutrition will be predominantly composed of allochthonous materials, and that larval lamprey will be isotopically similar to macroinvertebrate filterers. It was also hypothesized that the increased urbanization and agricultural land uses within the watershed will increase the reliance on autochthonous sources, because more nutrients and light will enter the stream. This will be reflected by more positive isotopic values in the consumers (including sea lamprey larvae).

METHODS

Surveys for Sea Lamprey

In the present study, 23 tributaries of the Hudson River below the Troy Dam were surveyed for sea lampreys in the summer of 2013 (Figure 1). At 19 of these sites a full

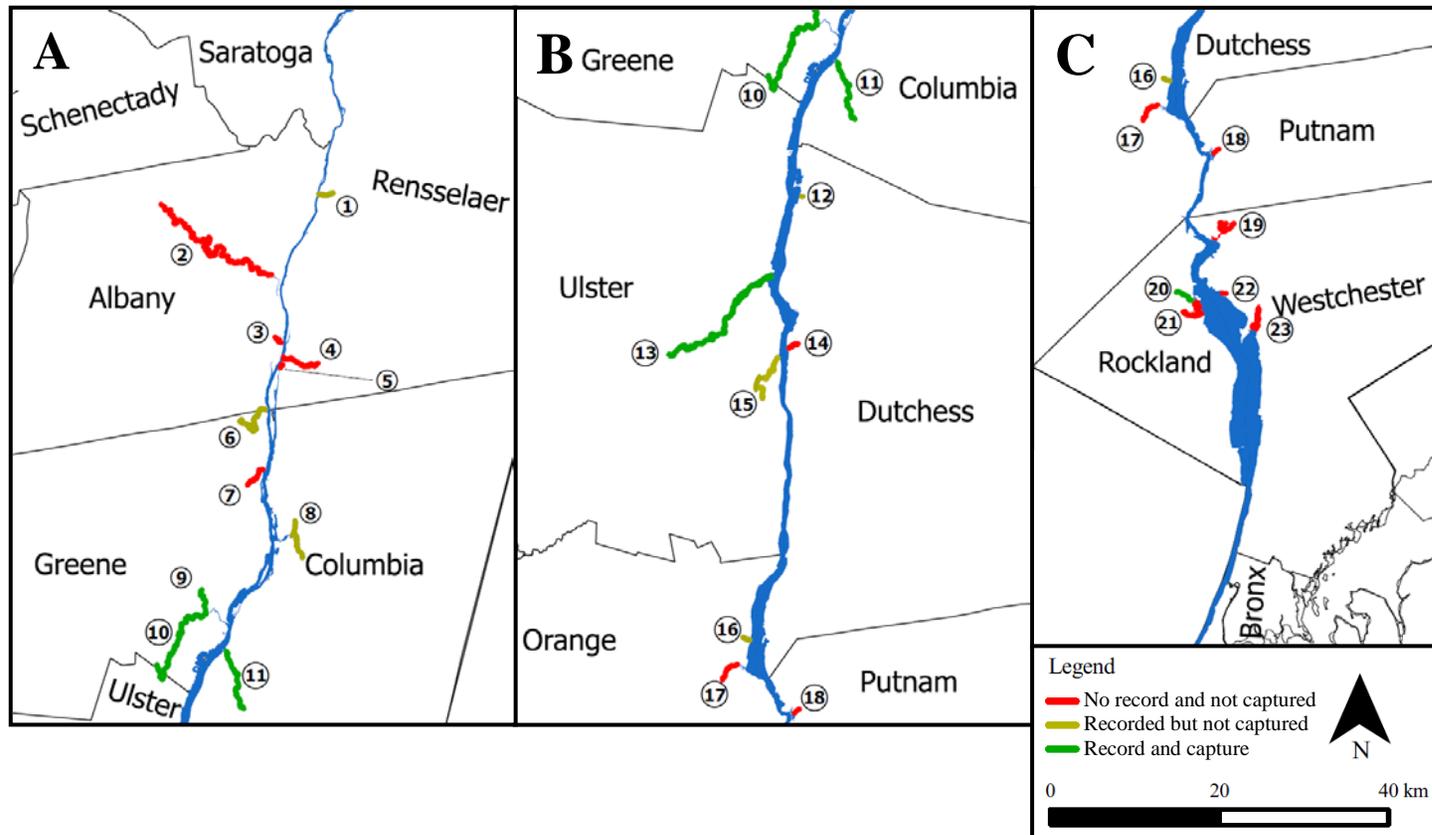


Figure 1: Tributaries to the Hudson River below the Troy dam (A), in the mid-Hudson River (B), and in the lower Hudson (C) sampled. The length of each stream is the area below the first impassable barrier for sea lamprey (*Petromyzon marinus*). Numbers are tributaries and are as follows: 1-Poesten Kill, 2-Normans Kill, 3-Vloman Kill, 4-Vlockie Kill, 5-Muitzes Kill, 6-Hannacroix Creek, 7-Coxsackie Creek, 8-Stockport Creek (including Claverack and Kinderhook Creek), 9-Catskill Creek, 10-Kaaterskill Creek, 11-Roeliff Jansen Kill, 12-Saw Kill, 13-Rondout Creek, 14-Indian Kill, 15-Black Creek, 16-Quassaick Creek, 17-Moodna Creek, 18-Indian Brook, 19-Annsville Creek, 20-Cedar Pond Brook, 21-Minisceongo Creek, 22-Furnace Brook, 23-Croton River.

workup was performed, while at the remaining four only sampling for sea lampreys was performed. A full workup included measuring local habitat characteristics, physical and chemical sampling of the stream, a macroinvertebrate sample, and a survey for sea lampreys at the site. In those sites where a full workup was not conducted, conditions were determined to be extremely unlikely to support lampreys, usually because of siltation or high water temperatures. However, to validate the expectation, sampling for lamprey was conducted in the same manner as at all other sites. Individuals who visited the site during sampling were also interviewed. Any pertinent information they provided to the study was noted and is reported.

To determine the composition of the surface area of the sampled stream reach, a diagonal transect across the stream from bankfull to bankfull was walked. Bankfull was defined as the point at which water would exit the river and enter the flood plain. At every step along the transect two points were randomly selected and the bottom composition was determined following the New York State Department of Environmental Conservation (NYSDEC) bottom composition scale for at least 100 points (NYSDEC 2009). If a transect was too short to sample 100 points, a second transect was set and the process repeated.

Aquatic macroinvertebrate samples were collected by sampling the nearest riffle to the sample site, walking along a 5 m diagonal transect, and kicking into a D-frame net (mesh size 500 μm) for five minutes. During two sampling events the 500 μm net was lost and a 600 μm sampler was used instead (at the Black Creek and Moodna Creek). The entire sample was immediately placed in 70% ethanol and stored at ambient temperature. Upon return from the field invertebrates were picked from detrital material and classified

to order. Cleaned invertebrate samples were then subsampled in a tray divided into 25 blocks (1.7 cm² per block). Blocks were randomly selected and all macroinvertebrates with heads present in the block were identified to genus. Macroinvertebrates which could not be identified to genus were identified to the next lowest level and then assigned to a genus, based upon the assignment of other positively identified members of the same group. Blocks were selected until at least 100 individuals had been identified. Individuals belonging to Chironomidae and Simuliidae were never classified below the family level, and did not count towards the 100 classified macroinvertebrate individuals. The number of individuals belonging to each group in the overall sample was calculated by multiplying the measured proportions in the subsample by the number of individuals in the overall sample. The estimated sample was then used to calculate the Shannon diversity index (SDI) and Hilsenhoff's Biological Index (HBI). The SDI was calculated as follows:

$$[1] \quad S' = - \sum_{i=1}^R p_i \ln p_i$$

Where p_i is the proportion of individuals in the overall sample (excluding Chironomids) belonging to the lowest taxonomic group identified. The HBI was calculated as follows:

$$[2] \quad H' = \sum_{i=1}^R \frac{n_i a_i}{N}$$

Where n_i is the number of animals in the taxonomic grouping, a_i is the biological tolerance value, and N is the total number of animals in the sample (excluding Chironomids; Bode et al. 1996).

To determine if sea lamprey were present at a site, a backpack electrofisher (Haltech, HT-2000) was used to electrofish for larval lampreys. A low shock (5 Hz, 150

V, 2:2 pulse pattern) was used to cause larval lampreys to emerge from the substrate. Animals that emerged from the substrate were captured before they could burrow. It was observed that the weak pulsed electrical output encouraged larval lampreys to emerge and attempt to burrow rapidly, in contrast to a continuous pattern which generally caused them to forego burrowing and attempt to escape the electric field or remain burrowed. Electrofishing occurred for 15 minutes at each site, which allowed the sampling of all habitats that appeared likely to support sea lamprey larvae (a mixture of loosely packed sand and fine organic matter; Slade et al. 2003).

Collections for Stable Isotopes Analysis

For stable isotope analysis, YOY larval lampreys were collected following the procedure described above. The smallest size class at a site was assumed to be YOY (Hardisty 1961). Larval lamprey were then stored at $\sim 0^{\circ}\text{C}$ in sand and stream water from where they were collected, until they could be returned to laboratory to be frozen at -20°C . Animals were never held alive for more than 24 hrs. Sand was added to allow larval lamprey to rest; otherwise, it was observed that they would continue to attempt to burrow until they were too exhausted to move. Common aquatic invertebrates of the local macroinvertebrate community were collected by kick netting in nearby riffles and then hand-picking individuals. Predatory animals were separated from other groups and all were stored in stream water at $0-4^{\circ}\text{C}$ for 36-48 hours to allow them to void their guts. Potential primary food sources were also collected simultaneously by hand picking terrestrial leaves, soil, aquatic plants and algae, and undisturbed sediment from the areas in which ammocoetes were collected.

Samples for stable isotope analysis were dried to constant mass at ~60°C and then homogenized by grinding in a clean porcelain mortar. Samples were then stored in desiccation chambers. Stable isotope values were calculated as follows:

$$[3] \quad \delta X = 1000 \left[\frac{R_{sample}}{R_{standard}} - 1 \right]$$

where R_{sample} is the ratio of the heavy to light isotope in the sample and $R_{standard}$ is the ratio in an agreed upon standard. To eliminate leading zeroes and ease readability the sample was then multiplied by 1000. Values were reported as “per mil” (‰) and designated by the notation δ with a superscript designating which heavy isotope has been measured. Subsamples of every sample type were packed in clean tin capsules and analyzed for $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ at the University of California, Davis (PDZ Europa ANCA-GSL (EA) attached to a PDZ Europa 20-20 isotope ratio mass spectrometer (IRMS)). Standard deviations for replicate analyses of standards for the instrument were $\leq 0.2\text{‰}$ for $\delta^{13}\text{C}$ and $\leq 0.3\text{‰}$ for $\delta^{15}\text{N}$.

Analysis of Distribution, Abundance, and Isotope Data

A logistic regression model was used to quantify the probability of encountering sea lampreys at a site (i.e., presence or absence). Logistic regression calculates the probability of an event occurring based upon categorical or quantitative variables. If sea lamprey presence could be linked to macroinvertebrate data, extensive archived data on the latter could be used to predict potential sea lamprey distribution. The final model included only the percent Ephemeropteran (mayfly) abundance, as no other measured values were important for the model.

To determine if sea lamprey isotopic values were driven by land use changes, the percent land use in each watershed was calculated from the 2006 National Land Cover Database (Fry et al. 2011) and the National Hydrography Dataset (USGS 2013). Land use was divided into four groups: 1) urban/developed, 2) agriculture/pasture, 3) forested/natural, and 4) open water. The percent land use of the watershed was correlated with the average isotopic values of YOY larval lampreys from that site.

Stable Isotope Mixing Modeling

The Bayesian stable isotope mixing model MixSIR (Moore and Semmens 2008) was used to estimate the contributions of potential food sources to YOY larval lamprey nutrition. Bayesian statistics allow for backward reasoning (after observation of an event) to predict the likely occurrences that led to that observation. MixSIR applies this statistical analysis to stable isotope mixing models, allowing for the incorporation of the uncertainties around source isotopic values and fractionation estimates to better predict food source dependence and confidence of the importance of a given dietary item to the organism (Moore and Semmens 2008).

Each site was modeled separately because of apparent differences in isotopic values of primary producers and consumers. Potential food sources for lampreys and invertebrates at each site were divided into two groups (i.e., autochthonous and allochthonous). Autochthonous sources were considered to be all types of aquatic plants collected at a site, including algae and macrophytes (e.g., *Elodea* sp., *Potamogeton* sp., and *Myriophyllum* sp.). Allochthonous sources were the terrestrial plants collected at a site and included *Acer* spp., *Vitis riparia*, *Quercus* sp. and *Rosa multiflora*. Terrestrial

surface soils and aquatic surface sediments were also considered for inclusion within allochthonous and autochthonous sources in the model respectively, but they were intermediate between these terrestrial and aquatic plants. Therefore, because these sources were likely amalgamations of terrestrial and aquatic plants, which were already accounted for in the model, they were not included explicitly in the final model. The final models included all the measured terrestrial plants at a site as the allochthonous source, and all of the measured aquatic plants, including algae, as the autochthonous source.

Isotopic values of larval lampreys, invertebrates, and potential nutritional sources were determined from measurements of samples collected in the present study. On the basis of prior work (Sutton and Bowen 1994), larval lampreys were assumed to be one trophic level above primary producers and follow published fractionation values of $0.4 \pm 1.3\text{‰}$ for $\delta^{13}\text{C}$ and $3.4 \pm 1.0\text{‰}$ for $\delta^{15}\text{N}$ (Post 2002). Invertebrates were also considered to be one trophic level above primary producers and the same fractionation values as for larval lampreys were utilized. All models were run with 1,000,000 iterations (i.e., MixSIR attempted to find a solution to the model for each iteration). Results conformed to the recommended guidelines for determining if the model output had estimated true posterior distributions (Moore and Semmens 2008).

RESULTS

Sea lampreys were found in four tributaries to the Hudson River: the 1) Roeliff Jansen Kill (Columbia County, confluence at river km 178), 2) Catskill Creek (Greene County, river km 182), 3) Rondout Creek (Ulster County, river km 146), and 4) Cedar Pond Brook (Rockland County, river km 63; Figure 1). Sea lampreys were not found in

all Hudson River tributaries for which prior records of these animals existed (Table 1; Figure 1).

Table 1: Sites assessed for sea lamprey (*Petromyzon marinus*) in the Hudson River.

Stream Name	County	River km	Lamprey Reported	Prior Source	Lamprey observed in this study
Annsville Creek	Westchester	71	N	NA	N
Black Creek	Ulster	135	Y	Schmidt and Limburg 1989	N
Catskill Creek	Greene	182	Y	Numerous	Y
Cedar Pond Brook	Rockland	63	Y	www.piplon.org (2002)	Y
Coxsackie Creek	Greene	204	N	NA	N
Croton River	Westchester	55	N	NA	N
Furnace Brook	Westchester	63	N	NA	N
Hannacroix Creek	Albany	212	Y	Greeley and Bishop 1933	N
Indian Brook	Putnam	85	N	NA	N
Indian Kill	Dutchess	137	N	NA	N
Kaaterskill Creek	Greene	182	Y	Schmidt and Cooper 1996 Bryan et al. 2005	Y
Moodna Creek	Orange	92	N	NA	N
Minisceongo Creek	Rockland	64	N	NA	N
Muitzes Kill	Rensselaer	217	N	NA	N
Normans Kill	Albany	225	N	NA	N
Poesten Kill	Rensselaer	241	Y	New York State Museum specimen (2007)	N
Quassaick Creek	Orange	100	Y	NYSDEC specimen (2005)	N
Roeliff Jansen Kill	Columbia	178	Y	Brussard et al. 1981 Waldman 2006	Y
Rondout Creek	Ulster	146	Y	Greeley and Greene 1937 Hudson River Almanac 2007b	Y
Saw Kill	Dutchess	158	Y	Smith 1985	N
Stockport Creek	Columbia	195	Y	Hudson River Almanac 2005 Anonymous 2013	N
Vlockie Kill	Rensselaer	219	N	NA	N
Vloman Kill	Albany	220	N	NA	N

Sea lamprey presence was not correlated with percent bottom cover (i.e., percent cover of rock, rubble, gravel, sand, or silt; Table 2), percentage of Trichopterans, Plecopterans, Dipterans, or Chironomids in the invertebrate sample, species richness, the SDI, or the HBI (Table 3). Although it was not significant (Chi-square, $df = 1$, $X^2 = 2.20$, p -value = 0.14), sea lampreys were never found at sites that did not also have Plecopterans. A logistic regression found that sea lamprey presence was likely (> 50%) when the percent of Ephemeroptera exceeded 44% (coefficient estimate = 0.10, standard error = 0.05, z -value = 2.05, p -value = 0.041; Figure 2).

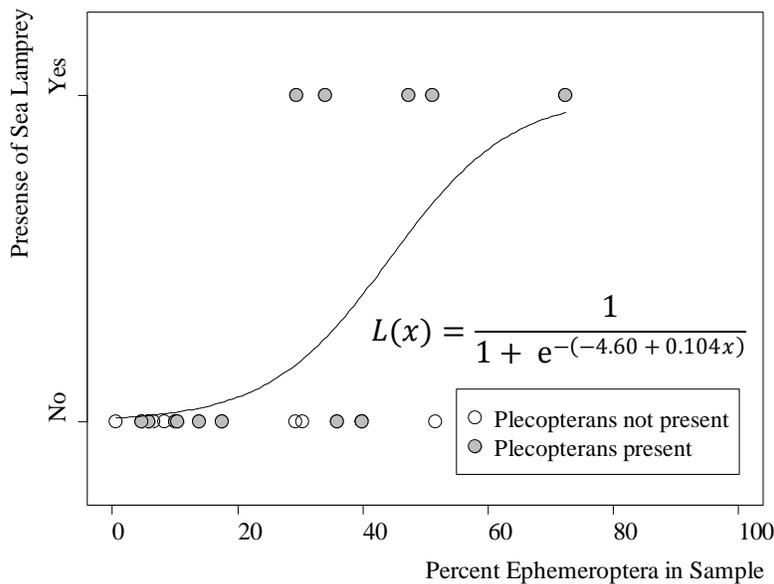


Figure 2: Logistic regression model predicting the presence or absence of sea lamprey (*Petromyzon marinus*) in Hudson River tributaries as a function of percent Ephemeroptera in the macroinvertebrate sample. Plecoptera presence was not included in the model, but sea lamprey were always found at sites which also had Plecopterans.

Table 2: Physical properties and pH measured at the sample sites in the Hudson River.

Stream Name	County	Width (m)	Bottom type (%)					Embeddedness	pH
			Rock	Rubble	Gravel	Sand	Silt		
Annsville Creek	Westchester	15.7	4	7	65	16	8	100	7.4
Black Creek	Ulster	77.0	0	5	75	9	12	<20	8.0
Catskill Creek	Greene	59.0	0	36	63	0	0	0	8.1
Cedar Pond Brook	Rockland	17.5	4	37	46	12	2	<5	8.7
Claverack Creek	Columbia	51.0	2	15	56	11	17	ND	8.5
Coxsackie Creek	Greene	24.0	3	40	32	10	14	50	8.4
Croton River	Westchester	140.0	ND	ND	ND	ND	ND	10	ND
Furnace Brook	Westchester	10.2	2	9	83	6	0	10	7.9
Hannacroix Creek	Albany	16.5	22	36	33	5	4	ND	8.8
Indian Brook	Putnam	6.0	6	22	68	2	2	<5	7.9
Indian Kill	Dutchess	7.0	ND	ND	ND	ND	ND	ND	ND
Kaaterskill Creek	Greene	62.0	21	17	48	8	5	80	7.7
Kinderhook Creek	Columbia	44.0	67	5	25	4	0	ND	8.2
Moodna Creek	Orange	19.0	11	16	42	4	28	20	7.8
Minisceongo Creek	Rockland	15.5	5	29	42	16	8	10	8.4
Muitzes Kill	Rensselaer	19.0	7	35	36	10	12	60	8.5
Normans Kill	Albany	45.0	83	5	1	5	6	0	8.0
Poesten Kill	Rensselaer	14.5	35	23	14	24	4	10	8.0
Quassaick Creek	Orange	24.4	ND	ND	ND	ND	ND	ND	ND
Roeliff Jansen Kill	Columbia	30.0	17	32	44	6	1	0	8.1
Rondout Creek	Ulster	49.0	ND	ND	ND	ND	ND	ND	7.8
Saw Kill	Dutchess	18.0	35	19	40	0	5	80	8.0
Stockport Creek	Columbia	335.0	0	10	67	12	11	66	8.3
Vlockie Kill	Rensselaer	1.1	32	0	44	17	7	50	8.1
Vloman Kill	Albany	125.0	ND	ND	ND	ND	ND	100	ND

Table 3: Macroinvertebrate data collected in the present study listed by site.

Stream Name	County	Number of Species	SDI	HBI	Percent Composition						
					Ephemeroptera	Plecoptera	Trichoptera	Coleoptera	Diptera	Chironomidae	Non-insects
Annsville Creek	Westchester	16	1.68	4.75	10	1	9	51	14	13	14
Black Creek	Ulster	18	2.27	3.70	10	3	38	7	39	38	0
Catskill Creek	Greene	16	2.04	4.50	72	1	21	2	4	3	0
Cedar Pond Brook	Rockland	8	1.57	5.37	52	<1	31	0	17	15	0
Claverack Creek	Columbia	10	1.83	5.01	29	0	41	2	25	14	2
Coxsackie Creek	Greene	3	0.13	5.98	1	0	0	1	31	31	67
Furnace Brook	Westchester	8	2.61	4.51	6	0	53	30	10	6	1
Hannacroix Creek	Albany	13	1.09	6.88	6	1	2	6	5	5	80
Indian Brook	Putnam	15	2.16	3.07	18	22	48	1	10	9	1
Kaaterskill Creek	Greene	13	1.90	4.65	51	<1	34	1	14	11	0
Kinderhook Creek	Columbia	19	2.42	4.99	36	<1	27	24	12	4	0
Moodna Creek	Orange	16	2.05	4.24	5	1	60	13	13	9	0
Minisceongo Creek	Rockland	12	1.46	4.93	34	0	34	4	27	25	0
Muitzes Kill	Rensselaer	14	1.36	4.60	7	0	16	15	60	52	2
Normans Kill	Albany	19	2.48	5.73	40	1	2	4	48	46	4
Poesten Kill	Rensselaer	21	2.33	4.72	40	2	15	3	40	36	0
Roeliff Jansen Kill	Columbia	22	2.53	4.35	29	3	35	12	14	13	6
Rondout Creek	Ulster	18	2.27	4.55	47	0	19	20	13	3	0
Saw Kill	Dutchess	18	1.77	4.17	14	0	77	2	4	2	1
Stockport Creek	Columbia	9	1.49	5.45	30	0	2	1	34	34	30
Vlockie Kill	Rensselaer	14	1.99	4.35	8	0	30	53	9	6	0

The average length of YOY larval lamprey was different between sites (ANOVA, $df = 4$, F -test = 11.53, $p < 0.001$). The Roeliff Jansen Kill YOY larval lamprey were larger (28.8 ± 3.5 mm, SD) than larvae from all other sites (18.8 ± 2.6 mm, SD; Figure 3).

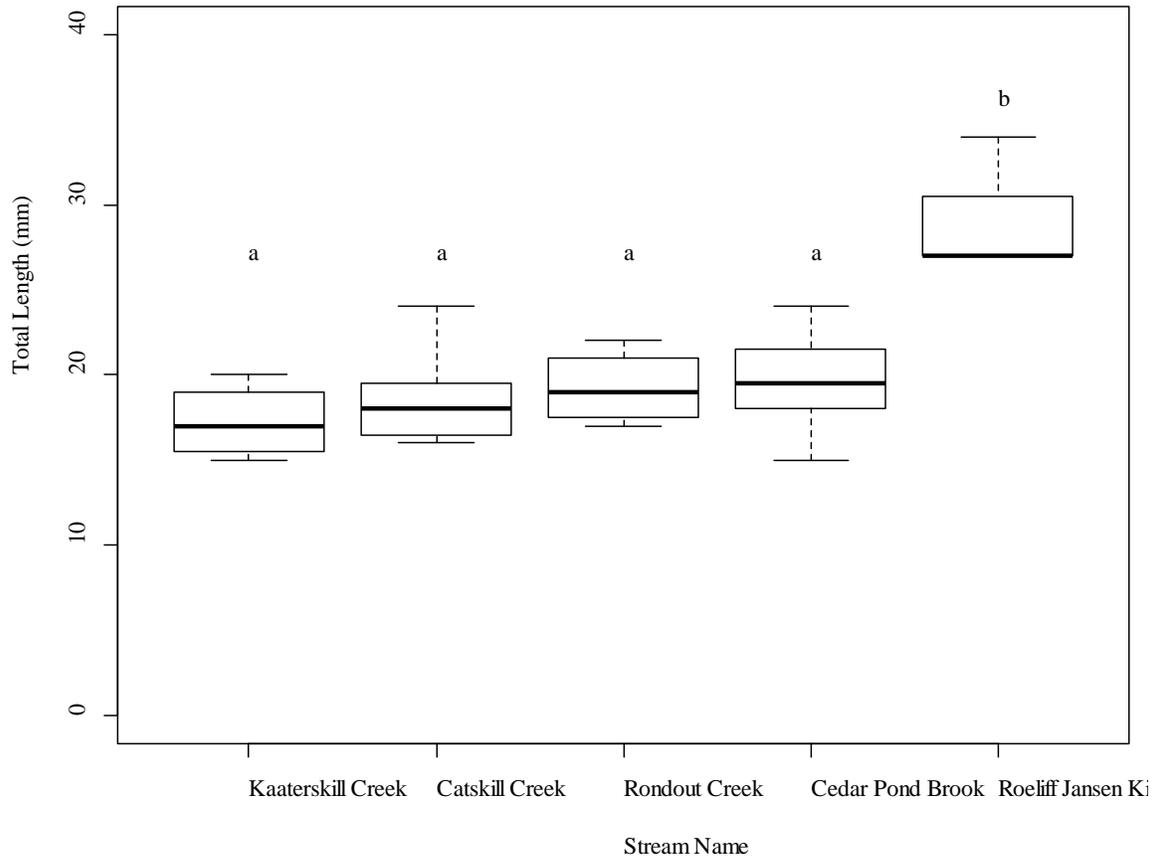


Figure 3: Average size of young of year lamprey from all streams at which lamprey were captured. The black line is the median and boxes are the second and third quartiles. Sites that are different are marked by different letters.

Isotope Modeling Results

YOY larval lamprey isotopic values were different from measured macroinvertebrates at every site, even though many of the macroinvertebrate groups measured are also filterers (i.e., Hydropsychidae, and Isonychiidae; Figure 4).

Contributions of autochthonous and allochthonous sources to YOY larval lamprey varied

by site from almost complete dependence on autochthonous sources (median contribution 98.7% at Cedar Pond Brook), to less than half of their nutritional needs (40.3% at Kaaterskill Creek; Figure 5). Larval lamprey dependence on autochthonous or allochthonous sources was not associated with urban land ($df = 2$, t -value = 1.6, p -value = 0.25), agricultural lands ($df = 2$, t -value = -1.17, p -value = 0.36), or forested lands ($df = 2$, t -value = 0.34, p -value = 0.77).

DISCUSSION

Sea lamprey presence/absence was associated with only a few of the metrics collected. These results are consistent with prior work that has found that sea lamprey distribution at the level of the stream difficult to predict from habitat data (Neeson et al. 2007). Sea lamprey larvae utilize marginal habitat in the hyporheic zone (i.e., area along the edge of the stream in which ground and surface waters mix), potentially limiting the feasibility of utilizing high level generalizations about streams to predict their presence. Subsurface flows, ground water temperature, and oxygen content may all play important roles at the local level and are difficult to scale up. In addition, larvae may be experiencing conditions different from the surface waters and the macroinvertebrate communities that were examined during the course of this work.

Macroinvertebrate assemblages provide a tool to help other researchers in the Hudson River select sites where they might expect to find sea lampreys. Plecopterans are associated with cool, unpolluted, highly oxygenated waters (Stewart and Stark, 2008), conditions which are highly favorable to sea lamprey growth and development (Morman

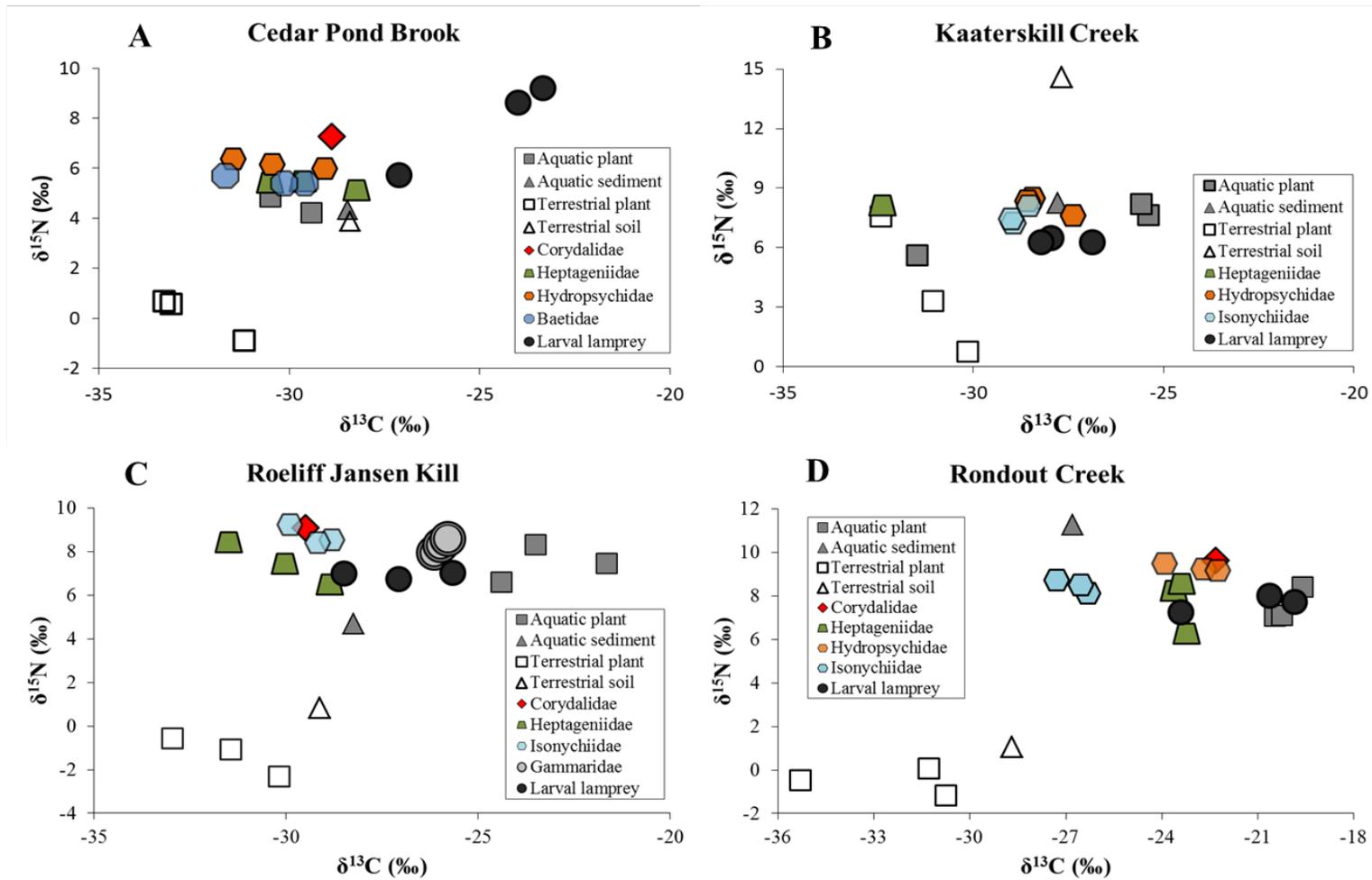


Figure 4: Stable isotope ratios of macroinvertebrates, young of year sea lamprey larvae, and potential food sources. $\delta^{13}\text{C}$ vs. $\delta^{15}\text{N}$ for (a) Cedar Pond Brook, (b) Kaaterskill Creek, (c) Roeliff Jansen Kill, and (d) Rondout Creek

Table 4: Sites for which sea lamprey (*Petromyzon marinus*) have been reported in the Hudson River and the capture confirmation or explanation of discordance.

Stream Name	Lamprey Reported	Lamprey Observed	Reason for Disagreement With Historic Data
Black Creek	Y	N	Single larvae captured during large sampling effort, animals may be extremely rare
Catskill Creek	Y	Y	
Cedar Pond Brook	Y	Y	
Hannacroix Creek	Y	N	Historic record (1934), possible lampreys currently spawn higher than sampling site
Kaaterskill Creek	Y	Y	
Poesten Kill	Y	N	Single record of an adult, possible migrant looking for spawning site
Quassaick Creek	Y	N	Single record of a dead adult, possible migrant looking for spawning site
Rondout Creek	Y	Y	
Roeliff Jansen Kill	Y	Y	
Stockport Creek	Y	N	Maybe currently extirpated, interview with an anonymous resident suggest this to be the case; no current observations
Saw Kill	Y	N	American Brook Lamprey record, sea lampreys may occasionally attempt to spawn here

et al. 1980; Jobling 1981). The association of sea lamprey with Ephemeropterans may also be because Ephemeropterans can be abundant and most diverse in rocky-bottomed, 2nd and 3rd order streams (Waltz and Burian 2008), often where adult sea lampreys spawn. In areas in which sea lampreys are no longer able to access historic grounds, the percentage of mayflies may provide a way to help establish where sea lamprey occurred historically and inform potential restoration efforts.

Assessed Tributary Narratives

A narrative of each sampled stream listed alphabetically by stream name, is reported below. Sites for which a record of sea lampreys existed are summarized in Table 4. This survey was conducted in the summer following Hurricane Sandy, and within two years of Hurricane Irene and Tropical Storm Lee, all of which caused serious flooding in the Hudson River.

Flooding events can wash larval lampreys out of streams (Potter 1980), and these events likely

depressed lamprey populations in the Hudson Valley. As a result, 2013 may have been an atypical year for sea lampreys in the Hudson River.

Annsville Creek (Westchester County, river km 71)

Annsville Creek enters the Hudson River in Peekskill, NY, but is surrounded by large stretches of forest. Residential communities are adjacent to much of the river and many small historic dams remain limiting habitat availability for sea lampreys. Sampling access below barriers to migration is also limited. Sea lampreys were not found at this site although the appropriate habitat for adult spawning and larval rearing appeared to exist. Plecopterans were present, but Ephemeropteran diversity (three genera) and percent composition (10%) was low. If efforts with local land owners were made to remove many of the small historical dams (which likely also present a public safety risk) sea lampreys and other migratory species might begin to exploit this stream.

Black Creek (Ulster County, river km 135)

Black Creek is a small, high quality stream south of Kingston, NY whose watershed is primarily forested. Black Creek still supports a large alewife run (Schmidt and Limburg 1989), and these workers also reported capturing a single sea lamprey larva. However, there are no reports of adults from this stream. There is abundant and extensive sandy habitat for larvae, and a series of riffles throughout the stream which would provide spawning habitat. In addition, the invertebrate community was very diverse, and included Plecopterans. However, it was composed primarily of Chironomids (38%), with Ephemeropterans making up only 10% of the invertebrate community (Table 3). Neither sea lamprey adults nor larvae were observed at this site, though

the site was visited during the spawning period in June and then again in July. It is unclear why they are not common within this stream, but it may be related to temperature. Upper reaches of the Black Creek are dammed by many small (< 2 m) barriers, which potentially allow heating to occur, even though large stretches are forested. Temperatures at or above 31°C are lethal to larval lampreys in the laboratory (Jobling 1981). In natural systems even approaching thermal tolerance values likely acts synergistically with other stressors to limit lamprey populations.

Catskill Creek (Greene County, river km 182)

Catskill Creek is known to support sea lampreys, and numerous authors have collected sea lampreys or reported their spawning here (Greeley and Greene 1937, Smith 1985, Waldman 2006, NYSDEC 2012a). During interviews, multiple individuals reported seeing sea lampreys spawning there (Anonymous, *personal communication*). Catskill Creek splits into two tributaries outside of the city of Catskill, NY, the southerly branch is the Kaaterskill Creek (discussed separately) and the northerly branch is Catskill Creek. Catskill Creek has a relatively short stretch of unobstructed stream that sea lampreys can access (~3 km) before they reach the first impassable barrier (a dam in Leeds, NY). Larval lampreys were easy to find (catch per unit effort 1.2 animals per minute) and a spawning adult was observed on June 26th. Catskill Creek appears to be sediment starved (potentially as a result of dams further up river), and it may have supported higher numbers of sea lampreys in the past. The total number of lampreys utilizing this stream was hard to estimate because many areas of the stream were too deep (> 2 m) to sample with a backpack electrofisher. Human activities upstream should take into account that sea lampreys downstream may be vulnerable to degradation of the aquatic habitat, especially during the May-June spawning period.

Cedar Pond Brook (Rockland County, river km 63)

Cedar Pond Brook flows into the Hudson River at Stony Point, NY. The lowest portions of this stream are heavily urbanized, but the headwaters are located in extensive state park lands. Sea lampreys have been documented from Cedar Pond Brook recently (2002, www.piplon.org/fishes.htm), but their distribution and abundance within the river is unknown. An impassable dam for sea lamprey is located ~ 4 km upstream of the mouth of this stream. Sea lampreys utilized all portions of the stream that were above the tidally influenced areas (first two km). The majority of larvae observed were YOY, and they were locally abundant (two individuals/m²) but patchy. Sea lamprey larvae did not appear to utilize all appropriate habitats, and the majority of animals observed were from a single sand bar. In addition, animals older than YOY were rare, constituting < 5% of the observed population. The apparent lack of age classes suggests that sea lampreys are not surviving well in this stream. However, sea lampreys may still be recovering from hurricanes that likely washed large numbers larvae out of the stream, and age class structure may reappear with enough time.

To conserve sea lampreys in this stream, excessive salting of nearby areas during the winter should be discouraged (salt is lethal to larval lamprey at low concentrations; Reis-Santos et al. 2008). In addition, bank erosion, which is occurring at a number of locations within the stream, should be addressed wherever feasible. Finally, removal or passage of dams may allow sea lampreys to better exploit more upstream habitat.

Coxsackie Creek (Greene County, river km 204)

Coxsackie Creek, near Coxsackie, NY, is surrounded by agricultural lands, and is highly influenced by their contribution. The invertebrate diversity was poor (three genera were present,

besides Chironomids) and composed primarily of the crustacean *Gammarus* sp., which are omnivorous and tolerant (Table 3). Siltation was also clearly occurring, with 62% of bottom samples having 0.5 – 5 mm of deposition. Eutrophication is also likely occurring, as large mats of filamentous algae were present. No sea lampreys were observed while surveying, and in its current state this stream would not support them.

Croton River (Westchester County, river km 55)

The Croton River, near Croton-on-Hudson, NY, is fed by the New Croton Reservoir, the final receiving reservoir in the East-of-Hudson component of New York City's water supply system. Eutrophication appeared to be an issue as water was turbid and visibility was limited to < 50 cm. Sea lampreys were not observed at this site, although abundant larval lamprey habitat appeared to be available. Only a short stretch would be available to sea lampreys and may preclude successful spawning.

Furnace Brook (Westchester County, river km 63)

Furnace Brook near Cortlandt, NY, is extensively dammed although there is a short stretch below the first complete dam and the head of tide sea lampreys could access. The invertebrate community was only moderately diverse (six genera, not including Dipterans), and included no Plecopterans and few Ephemeropterans (Table 3). Sea lampreys were not observed at this site, although it may have historically supported them. The extensive damming along this stream may be preventing natural processes and is likely degrading the quality of the limited habitat available. It is hard to recommend large scale efforts to remove or mitigate dams here,

because of how numerous they are in the stream. Many of these dams are not functional, and deserve to be inspected, as they may begin to pose a public safety hazard as they continue to age.

Hannacroix Creek (Albany County, river km 212)

Hannacroix Creek was historically a tributary utilized by sea lampreys (Greeley and Bishop 1933) and is currently surrounded by forest and agricultural lands. Reaches lightly influenced by tidal inputs were sampled, although these areas are not ideal for sea lampreys, because access to higher reaches was difficult. Invertebrates were generally dominated by non-insect groups (~80%, i.e., Crustacea, primarily *Gammarus* sp.), but Plecopterans (*Agnatina* sp.) were present, suggestive of high quality habitat potentially upstream (Table 3). No larval lampreys were observed though American eel (*Anguilla rostrata*) were found occasionally. Sea lampreys may be able to exploit upper reaches, and further efforts should be made to determine if they still utilize Hannacroix Creek.

Indian Brook (Putnam County, river km 85)

Indian Brook enters the Hudson River by flowing through Constitution Marsh, a large wetland. The stream has a short stretch (~100 m) beyond head of tide of moderate gradient with potential lamprey habitat, before a series of falls that would prevent migration further upstream. The water quality at this site is likely extremely high as evidenced by the macroinvertebrate community, which included three Plecopteran genera (*Pteronarcys* sp., *Acroncuria* sp., *Leuctra* sp.) and seven genera which are listed as sensitive to very sensitive (e.g., *Dolophilodes* sp., *Lepidostoma* sp.; Table 3). During the spring a fyke net, operated by the Audubon Society, is deployed across the mouth of the stream to capture in-migrating American eels (glass eels).

Audubon staff reported that they have not seen or captured any lampreys. Water quality does not prevent lampreys from utilizing this stream, but the limited habitat available may prevent successful exploitation. Other tributaries to Constitution Marsh provide similar habitat, and lampreys may intermittently spawn in them, but they are unlikely to succeed to any serious degree.

Indian Kill (Dutchess County, river km 137)

The Indian Kill is a small stream that passes through Margaret Lewis Norrie State Park before meeting the Hudson River. No lampreys were seen during the survey at this stream although American eels were common. Schmidt and Cooper (1996) said that this stream had high water quality, but reported that DO was < 100% saturation. The stretch has excellent potential larval lamprey habitat as extensive loosely packed sand is present. However, the stream is very shallow and the survey did not observe any riffles that would support spawning adult lampreys.

Kaaterskill Creek (Greene County, river km 182)

Kaaterskill Creek is a tributary of Catskill Creek, but is more turbid and much sandier than the Catskill Creek. The additional sand provides excellent and extensive larval lamprey habitat. Interestingly, a private land owner reported, during an interview, that he had observed "...thousands of eels below the falls [at the junction of Cauterskill Rd and Cauterskill Ave] when kayaking on the river" (Anonymous, *personal communication*). He had not determined if they were sea lampreys (which are often called lamprey eels) or American eel, but it appears likely they were sea lampreys. Sea lampreys can be visible in the day during the spawning run, and would congregate below a natural barrier if it slowed their migration upstream. In contrast,

American eel generally are nocturnal and congregate in sanctuaries together but not in the open during daylight. Above the falls, larvae of multiple sizes were easily collected, suggesting multiple successful spawning events over the course of numerous years. The New York State Museum also reported in their collection a lamprey more than 9 km from the falls. Therefore, Kaaterskill Creek is likely the most important stream for sea lamprey in the Hudson River. Based on the unobstructed length of the Kaaterskill (~17 km) and the observation that habitat quality generally appeared to be high along its entire length, the majority of sea lampreys in the Hudson River may originate in this river. Efforts should be made to continue “business as usual” in this stream as it appears critical for sea lamprey success in the Hudson River.

Minisceongo Creek (Rockland County, river km 64)

Minisceongo Creek, in West Haverstraw, NY, is a heavily urbanized stream that has extensive heavy industrial activity near its mouth. However, the water was cool and clear when sampling occurred. In addition, numerous trout (likely Brown, *Salmo trutta* or Brook trout, *Salvelinus fontinalis*) were observed at the sample site. Sea lampreys were not captured at this site, although there appeared to be appropriate habitat for adults and larval lamprey. Large amounts of trash and some signs of sedimentation and pollution were also observed at the site. In addition, this stream is immediately adjacent to a river which does contain sea lamprey. Local conditions may be limiting sea lamprey usage of this stream, and cleanup efforts may be able to establish a sea lamprey run here.

Moodna Creek (Orange County, river km 92)

It was not possible to sample the main body of Moodna Creek and the first tributary on the southern side was sampled instead. Moodna Creek was highly modified by hurricane Irene and large portions of both banks were eroded. Construction activities occurred throughout the summer to stabilize the banks and rebuild washed out bridges/roads which precluded access to the river. Sea lampreys were not captured in the tributary, but American eels were not observed either, suggesting a barrier further downstream. It is possible that the tributary has a blockage not visible from aerial photographs or roads that is precluding migratory fish access. Plecopterans were present at the sampled site, although mayflies were extremely rare (<5% of invertebrate community). Without being able to sample the main stem, the presence of sea lampreys in this tributary cannot be conclusively ruled out.

Normans Kill (Albany County, river km 225)

The Normans Kill is south of Albany, NY, and urban sprawl is encroaching on a number of banks, likely increasing erosion and sedimentation. The water of the main body was always turbid near Albany and further upstream, though it was visited during both low and high flow events. Upstream habitat is protected by forested areas in some regions, and some tributaries appear to be transporting large amounts of loosely packed sand, which would provide excellent habitat for sea lamprey larvae. There are natural rapids near the mouth of the river, but these likely do not prevent sea lamprey access to the river. The Normans Kill is noted as a high quality warm water stream (NYSDEC 2007), and as a result likely does not support lamprey. There are no reports of sea lampreys in the Normans Kill though the NYSDEC has surveyed the stream

multiple times (NYSDEC 2007). If sea lampreys utilize the Normans Kill they may use small tributaries that are cool enough to support larvae year round.

Poesten Kill (Rensselaer County, river km 241)

The Poesten Kill is a highly urbanized stream that passes through Troy, NY, and the stream was filled with trash and refuse when sampled. However, the macroinvertebrate community was rich, and two species found at this site (i.e., *Siphonurus* sp., *Haploperla* sp.) were found nowhere else in the Hudson River during the course of this study (Table 3). American eels were extremely abundant, and both large and small eels were encountered frequently. The site appeared to offer excellent conditions for sea lampreys from a community perspective. However, no sea lampreys were found although a sea lamprey adult has been collected in recent years within the creek (Hudson River Almanac 2007a). The adult may have been brought in attached to another fish or may have been searching for spawning sites. It is also possible that adults do spawn in this stream but that conditions are inappropriate for larval development. American eel are known to feed on larval lamprey (Perlmutter 1951; Denoncourt and Stauffer 1993), and the proximity to the urban environment may result in high levels of salt runoff during winter.

Quassaick Creek (Orange County, river km 100)

Quassaick Creek is a small, highly urbanized stream, in Newburgh, NY with barriers to sea lamprey migration ~1 km from its mouth. Trash and filamentous algae were present throughout the stream when sampled. However, water clarity was high, and the bottom was visible at all depths (~1 m). No lamprey larvae were found, but American eels were common. A

recent report (June 27 2005) of a deceased sea lamprey adult in this stream (Hudson River Almanac 2005) suggest that adults do occasionally enter the creek. Currently, however conditions appear wholly unsuitable for larval growth and development. Besides a variety of pollutants, salting of the local roads may also pose a threat to sea lamprey larvae here.

Roeliff Jansen Kill (Columbia County, river km 178)

The Roeliff Jansen Kill (locally known as the “Roe-Jan”) is a high quality, cool water stream that has a long stretch (> 6 km) before the first barrier (NYSDEC 2012b). Land use in downstream reaches is primarily forest with small amounts of residential, while the upstream is primarily agricultural. Sea lampreys have been captured here before (Brussard et al. 1981; Waldman 2006), and numerous individuals who were interviewed along the Roe-Jan had seen sea lampreys in the stream. One individual reported observing them spawning yearly at the Mill dam immediately below the Mill Road bridge (Anonymous, *personal communication*). At this location there is an old dam on top of a natural rapids which likely limits further upstream movement. High rains and the closure of the Mill Road precluded visual confirmation of adult migrations within the stream during the spawning run. Prior to construction of the dam, this may still have been the upper limit of sea lamprey migration. To confirm if the barrier was completely impassable, the survey sampled above the barrier where habitat conditions also appeared suitable for lampreys, but did not find any individuals. Likely lamprey redds were observed further downstream in June.

Larvae were abundant at the local level, but their distribution was patchy and often areas that appeared appropriate by visual inspection did not contain any larvae. YOY larvae captured here were larger (29 ± 4 mm, SD) than at all other sites (19 ± 3 mm, SD; Figure 3), suggesting

growing conditions for lamprey in the Roe-Jan are the most favorable in the Hudson River. Farmers in this watershed should be encouraged to maintain buffer strips and local residents should be educated not to develop highly mowed and treated lawns (wherever possible) to maintain this habitat. Any work that is conducted within the stream or immediately adjacent should take into account that the habitat is highly unique and important for sea lampreys.

Rondout Creek (Ulster County, river km 146)

Rondout Creek is a large tributary of the Hudson that passes through Kingston, NY before emptying into the Hudson River. The stream is highly urbanized around the Kingston metropolitan area, but generally forested further upstream. Agriculture is also an important land use in the watershed, but is primarily concentrated around the main body of the stream. A historic record (Greeley and Greene 1937) and recent reports (Hudson River Almanac 2007b), have documented sea lamprey utilization of this river. Larval lampreys were found immediately downstream from High Falls, NY, and this is likely the upper limit for sea lampreys. Appropriate habitat is available upstream but the steep waterfalls and high flows likely preclude adults reaching these areas. Larvae were common in sandbars along the shoreline at High Falls. However, the depth of the stream (>2 m) made it difficult to estimate how many larvae might be present. There may be numerous larval lampreys utilizing this river in deeper areas. There appear to be no immediate threats to sea lamprey usage of this habitat, unless access is limited by the currently passable Eddyville Dam further downstream.

Saw Kill (Dutchess County, river km 158)

The Saw Kill has a short stretch of stream (~100m) before the first large natural falls and above the head of tide. Invertebrate diversity was high (17 families were collected not including Chironomids), and there were numerous groups (five genera) that are listed as sensitive (Table 3). The Saw Kill is unusual in that it is the only stream in the Hudson River, north of New York City, for which a record of American brook lamprey (*Lethenteron appendix*) has been reported (Smith 1985). When surveyed no lampreys of any kind were found, although adult sea lampreys have been observed at the falls (E. Kiviat, *personal communication*). The habitat available for larval lampreys below the falls is extremely limited and likely not a successful rearing area for sea lampreys. American brook lampreys are small (usually < 200 mm) non-parasitic lampreys that likely migrate only short distances to spawn. This animal probably did not migrate from more southerly populations near New York City to the Saw Kill, but was possibly washed downstream from the headwaters of the Saw Kill. There may be, or was, a population of American brook lampreys further upstream that attracts sea lampreys occasionally to the stream (Fine et al. 2004). In the present survey, sampling for American brook lamprey was attempted at upstream locations, but suitable access points were unavailable. Researchers working with permission from land owners should examine the headwaters of the Saw Kill to determine if an undocumented population of American brook lampreys is present.

Stockport Creek (Columbia County, river km 195)

Stockport Creek, located north of Hudson, NY, has a long, tidally influenced delta region that is surrounded by private residences and forest. There is a small waterfall (approximately three m in height) under the Route 9 bridge that separates the upper river from the tidal portion,

but likely does not limit sea lamprey migration. Upstream of the falls Stockport Creek eventually splits into Claverack Creek and Kinderhook Creek. The Claverack Creek has a dam within 500 m of its mouth, but the dam has been severely damaged and would not prevent migration. However, only eight insect genera were present (excluding Dipterans; Table 3) and water temperatures approached sea lamprey lethal limits (30°C in stream, lethal limit is 31°C). Although extensive appropriate habitat appeared to be present no lampreys were found.

Kinderhook Creek appeared to have high water quality and provide potential habitat. The invertebrate community was very diverse (18 genera excluding Dipterans; Table 3) and abundant. Upstream of the mouth are multiple dams currently used for hydropower that are built on top of a series of natural falls. Water temperatures in the stream were also close to the lethal limit for sea lamprey (30°C in stream, the lethal limit is 31°C). Therefore, lower reaches are unlikely to support larval lampreys, and adults likely need to penetrate further upstream to successfully reproduce.

An interviewed individual currently working at one of the hydropower facilities reported regularly seeing small sea lampreys damaged or killed in the turbines when removing dead, impinged, American eels (Anonymous, *personal communication*). Their size and direction of capture (i.e., as they moved downstream) suggest these animals were migratory transformers heading out to sea to feed. He also reported not having seen any for "...a couple of years..." Surveys for lampreys above the dams in Valatie, NY were conducted, but no lampreys or eels were found. Habitat upstream looked to be of high quality and it is likely if sea lampreys could access the habitat, they would utilize it. The long, protracted larval period may allow rare adult penetrations into upper reaches to produce successful migrants for long periods. This may result

in a net sink for the lamprey population as migrating adults are attracted to the scent of larval lamprey and congregate below successful spawning areas, wasting their reproductive output.

Vlockie Kill (Rensselaer County, river km 219)

The Vlockie Kill, near Castleton-on-Hudson, is a small stream that has short stretch (~0.5-1 km) available to migratory sea lamprey. Although this site was surrounded by forest there was a large amount of siltation present (possibly from tidal influence), human refuse, and few fish were observed. The Vlockie Kill may be suffering from modifications upstream that have allowed the mobilization of silt/fines. No sea lampreys were found and they will not exploit this habitat unless siltation is significantly reduced.

Vloman Kill (Albany County, river km 220)

The Vloman Kill is south of Albany, NY and has a very limited stretch available for migratory fishes (<1 km) below the first barrier. The delta floodplain was surveyed for sea lampreys during low tide but none were found. The water was very turbid and the bottom was primarily fine clay particles which were anoxic at a few mm in depth. It was therefore not suitable for sea lamprey larvae. Two barriers to upstream movement are present, and these are likely able to restrict all anadromous fish movement into higher reaches. Individuals nearby reported that they had never seen sea lampreys at the Vloman Kill, but had observed them frequently and in large numbers in the Catskill Creek.

Stable Isotope Analysis

At Cedar Pond Brook, lampreys were primarily supported by autochthonous sources (Figure 5), because aquatic plants had isotopic values high enough to explain the high isotopic values of lampreys (both in respect to $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$). Although the model explained larval lamprey isotopic values with autochthonous sources, lampreys at this site may actually be receiving N and C contributions from anthropogenic waste sources, such as sewage or leaky septic systems, however, these sources was not sampled. Anthropogenic waste is more positive with respect to both $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ than natural sources (McClelland et al. 1997; Cravotta 2002),

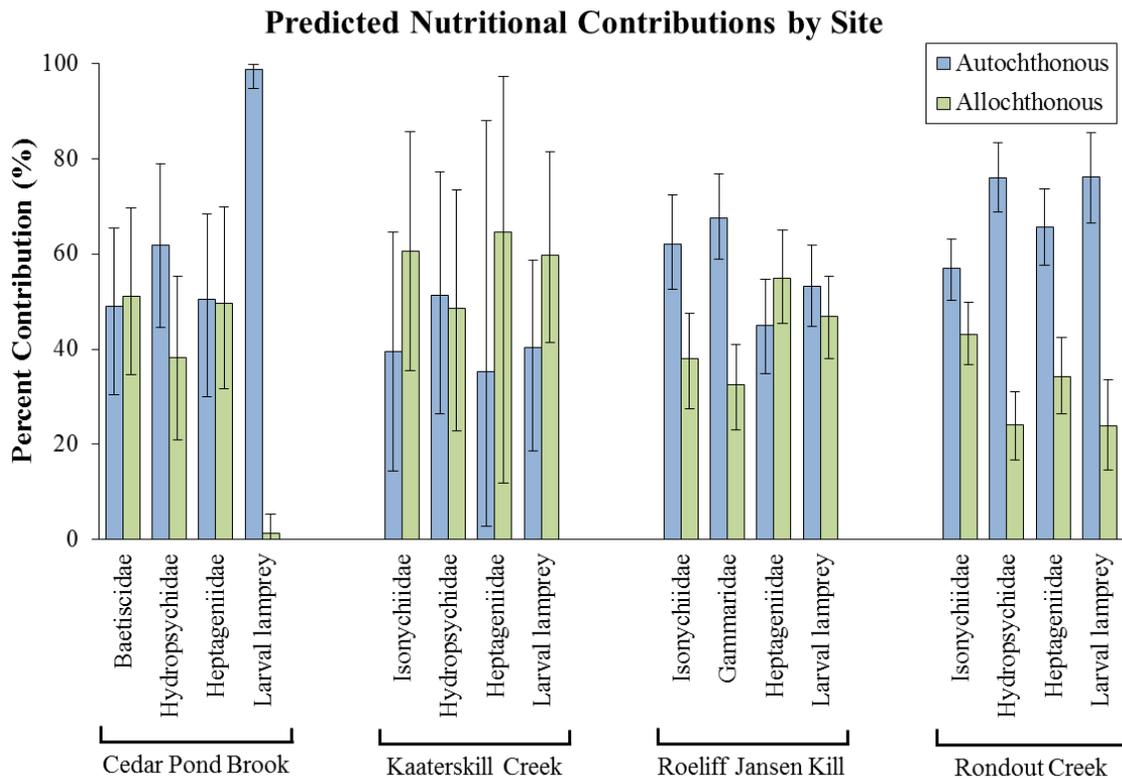


Figure 5: Median percent contributions of different nutritional resources (i.e., autochthonous and allochthonous) to macroinvertebrates and sea lamprey larvae from different streams calculated by the Bayesian model MixSIR. Lower and upper error bars correspond to the 5% and 95% posterior proportional contributions respectively.

and larval values (range of $\delta^{13}\text{C} = -27$ to -23 , and of $\delta^{15}\text{N} = 6$ to 9) would be easily explained by this source ($\delta^{13}\text{C} = -25$ to -20 , and of $\delta^{15}\text{N} = -2$ to 13 ; Cravotta 2002). The stream was filled with large amounts of trash, and is immediately downstream of a county park. Larval lampreys may also have access to liquefied wastes traveling in subsurface waters, and may utilize this source if it exists.

The macroinvertebrates measured at the site did not appear to be relying on the same materials and were well explained by sources. Therefore, larval lamprey (which spend time burrowed in sediments and rarely emerge) may be relying on sources not often consumed by the invertebrates measured. Interestingly, one larval lamprey had lower isotopic values ($\delta^{13}\text{C} = -27.1$, $\delta^{15}\text{N} = 5.7$) than the other two lampreys at the site ($\delta^{13}\text{C} = -23.3$ and -24.0 , $\delta^{15}\text{N} = 9.2$ and 8.6 ; Figure 4). The first lamprey was larger (24 mm) than the other two lampreys (18 and 19 mm), suggesting it may have been spawned earlier in the year. If it was spawned earlier it was likely further upstream and was washed downstream to the site where it was collected later. It may still have been coming to isotopic equilibrium with its sources at the collection site (Tieszen et al. 1983), and its isotopic signature may have reflected sources further upstream. Larval lampreys may be very sensitive to differences in local site conditions, and may offer a way to detect anthropogenic waste in streams.

Predicted contributions of sources from modeling to different groups at Kaaterskill Creek were similar, and uncertainty was large for all estimates (Figure 5). A single aquatic algae sample had a $\delta^{13}\text{C}$ signature similar to terrestrial plants, which resulted in a large standard deviation for autochthonous sources in the model. Kaaterskill Creek appears to be more dependent on allochthonous sources as all groups had more elevated values than at any other site. The water at the site was moderately turbid, and the bottom of the stream was not readily visible at all depths.

The turbidity appeared to be the result of suspended particulate matter, which may have been the result of runoff from local fields transporting soil material. If this is the case the system may be more dependent on allochthonous carbon, because particulates shade algal growth but also provide a source of nutrition (Rounick et al. 1982; Bartels et al. 2012).

At the Roeliff Jansen Kill (where growth of lampreys was fastest; Figure 3), larval lampreys were dependent approximately equally on autochthonous and allochthonous sources (Figure 5). Larval lamprey growth may be dependent on the quality of food available, but is also known to depend on the density of animals (Morman 1987). Further work could be done to determine if lamprey in the Roeliff Jansen Kill are growing faster because of better nutrition or for another reason. Source contributions to larval lamprey at this site were more similar to those of Heptageniid mayflies, which are scrapers, than the collecting-filtering Isonychiids mayflies. Larval lamprey filtering/collecting is *assumed* to be similar to other invertebrates, but may not be similar to other groups. Lampreys are unlike all other filter feeders, and have no good proxy among any extant group (Mallatt 1982). Part of the success of lamprey as a group maybe their ability to exploit a habitat and feeding style that no other group has adapted to fill.

At Rondout Creek, autochthonous sources were more important than allochthonous sources for all groups. Again lampreys were more similar to Heptageniid mayflies (scrapers) and Hydropsychiid caddisflies (sedentary collector-filterers), than the more mobile collector-filtering Isonychiids. The Rondout is wide (> 10 m) and slow moving above the barrier to sea lamprey migration, and likely produces high amounts of algal growth. Large black fly (Simuliidae) larvae, which are also filter feeders, were also very common at the site, often completely covering rocks in areas of high current. It seems likely that algal sources upstream provide large

amounts of productivity to communities immediately downstream where these animals were captured. Lamprey throughout the Rondout may not be as dependent on autochthonous sources.

Larval lampreys appear capable of exploiting a variety of sources to meet nutritional requirements. In addition, larval lampreys may be sensitive to some types of human pollution, which could be detected with isotopic analysis. Further work is needed to determine if they could be useful as bio-monitoring tools. Their limited distribution and the difficulty of sampling for larval lamprey may prevent wide scale use, but at sites in which they do occur, they could offer unique information about their environment. Larval lampreys were also isotopically unique from the macroinvertebrate community in which they occur, and appeared to rely on a different proportion of autochthonous and allochthonous sources.

CONCLUSIONS

The current distribution of larval lampreys in the Hudson River is restricted to only a few tributaries (i.e., Cedar Pond Brook, Catskill Creek, Roeliff Jansen Kill, Rondout Creek). However, densities of larval lampreys at the local scale can be high (~ 2 individual/ m^2). Sea lampreys were found in fewer locations than previously reported in the Hudson River. However, many of the reports are for adult animals, which were likely seeking suitable spawning habitat and are not as sensitive as larvae. In at least one case (i.e., Stockport Creek), there appears to be a true reduction in their range in recent years. Sea lampreys may be able to make rare, successful spawning events that produce larvae for extended periods, but attract easily visible adults for long periods by means of odor trails (Fine et al. 2004). The barriers to migration at Stockport Creek would be difficult for sea lamprey to pass except during exceptionally high flow years. Animals unable to penetrate above the falls and dams likely do not produce larvae, but any adult

that made it upstream would have excellent habitat available for spawning and the subsequent larvae. In at least one location (i.e., Saw Kill), undocumented populations of American brook lampreys may be present based on a prior capture report (Smith 1985) as well as reports of sea lampreys entering the stream. Sea lampreys are attracted to the larvae of any lamprey species (Fine et al. 2004), but adult sea lampreys would not be able to successfully reproduce in the mouth of the Saw Kill.

Currently, Catskill Creek is the most important producer of sea lampreys, and the Kaaterskill Creek (which is a tributary to the Catskill Creek) is its most important tributary. The Kaaterskill Creek has a long stretch (> 10 km) of unobstructed habitat appropriate for both sea lamprey larvae and adults, making this unique to the Hudson River. The Roeliff Jansen Kill is also an important tributary for sea lamprey in the Hudson River. Sea lampreys in the Roe-Jan appear to grow more quickly than at any of the other tributaries where they were captured. More work is needed to determine if growth rates are actually higher throughout the Roe-Jan, or if larval growth is more dependent on local conditions.

Sea lampreys prefer cool water, and as a result climate change is likely to restrict and reduce sea lamprey numbers in the Hudson River. Although climate change is a threat to the future of sea lamprey in the Hudson River, past and present anthropogenic activities have also likely limited populations through the construction of dams and pollution of stream waters. However, sea lampreys in the Hudson River were likely never as abundant as other members of the diadromous fish community. The erosion of decaying dams and the removal of barriers to migration may allow sea lampreys to exploit more habitats, potentially providing a buffer against climate change impacts. Sea lampreys are an unusual member of the Hudson River that have been little studied, but their uniqueness and importance as members of the anadromous fish

community make them deserving of more directed research efforts. Additionally, their presence indicates high stream quality and thus restoration efforts might be able to use their presence as a criterion for achievement of some restoration goals.

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