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## Effects of stocked trout on stream invertebrate communities

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### ABSTRACT

Brown trout (*Salmo trutta*) are commonly stocked in streams and rivers worldwide to enhance recreational fisheries, but this practice can adversely impact other organisms in these ecosystems. We used nonmetric multi-dimensional scaling ordinations to evaluate the response of the invertebrate community to trout stocking in two streams in New York State. Most importantly, we used estimates of trout population mortality (natural and harvest mortality rates) to inform the timeframe within which the invertebrate response was evaluated because the potential impact of trout stocking is highly dependent on the abundance of stocked trout. We found that although brown trout are stocked at greater densities than native brook trout (*Salvelinus fontinalis*) the mortality rate of stocked trout was high (0.15 daily mortality rate which corresponds to 99.9% annual mortality), thus predatory impacts of fish upon invertebrates were likely to be pulsed and could only occur within a short temporal period. Despite the high mortality rate of stocked brown trout, we found a significant multivariate divergence of invertebrate community structure within two months of trout stocking in both streams.

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non-metric multi-  
dimensional scaling

## Introduction

For more than a century, the introduction of hatchery-reared salmonid fishes into streams and lakes has been used to enhance angling opportunities where natural trout populations were reduced, extirpated due to anthropogenic impacts, or naturally absent (Schramm & Mudrak 1994; Hanisch et al. 2012). Nevertheless, stocked trout can impact native organisms through several mechanisms – including competition, predation, and displacement of wild fish (Kerr & Grant 2000; Zimmerman & Vondracek 2007) – and disruption of aquatic-terrestrial linkages (Epanchin et al. 2010). Trout stocking can also reduce the abundance and diversity of aquatic invertebrate species, alter trophic foodwebs (Flecker and Townsend 1994; Kerr & Grant 2000), and disrupt nutrient cycles (Schindler & Parker 2002; Eby et al. 2006). Stocking streams with trout has introduced non-native predators into a wide variety of ecosystems throughout the world, yet evidence of ecological impacts from this practice is highly variable and continues to merit careful examination (Nasmith et al. 2012).

Results from studies examining the ecological impacts of stocked or introduced trout in streams and lakes at varying spatial scales have ranged from finding little or no effect (Allan 1982; Zimmerman & Vondracek 2007; Hanisch et al. 2012; Meyer et al. 2012) to observing large impacts on invertebrate abundances, biomass, or density (Flecker and Townsend 1994; Huryn 1998; Nakano 1999; Baxter et al. 2004). For example, Baxter et al. (2004) showed that stocked rainbow trout

monopolized terrestrial invertebrates and caused native fish to shift their diet to insect grazers, thereby increasing algal biomass. Conversely, Vondracek and Zimmerman (2006) found that the presence of stocked brown trout was not associated with decreased invertebrate biomass or density in stream enclosures. These and other contrasting results illustrate the difficulty in evaluating impacts of non-native fish introductions on aquatic ecosystems.

One of the major challenges to detecting natural and anthropogenic environmental impacts is the high level of temporal and spatial variability inherent in natural populations and communities (Martin et al. 2012). Many studies examining effects of hatchery trout introductions take place at the microhabitat scale, in artificial stream settings, or in forced sympatry and therefore may not accurately reflect responses in a natural setting (Fausch 1998). The extent to which conclusions from small-scale experiments with trophically simple food webs can be extrapolated to whole ecosystems is widely debated (Carpenter et al. 1985; Benton et al. 2007). Thus, in order to assess whether the limits of natural variation have changed in response to an anthropogenic impact, it is important to evaluate the natural variation inherent in an ecosystem both before and after the impact. We also consider it important to evaluate the response at an appropriate spatial scale and in a natural setting.

The New York State Department of Environmental Conservation (NYSDEC) typically stocks approximately 3.6 million one to two-year-old trout each year into more than 10,000 km of streams in New York State to provide a harvest fishery for recreational angling. Based on previous mortality estimates from trout population surveys conducted by the NYSDEC (unpublished data), we expected that stocked trout populations would experience high natural mortality (i.e. predation, starvation) and angler harvest rates in our study systems; therefore, potential impacts upon stream invertebrate communities would be restricted to monthly rather than annual timescales. We therefore expected to find significant reductions in stream invertebrate abundance and community structure immediately after stocking, followed by diminishing effects as the trout population declined due to natural and fishing mortality. To assess this, we first estimated angler harvest mortality using creel surveys (i.e. sampling survey targeting recreational anglers) and apparent natural mortality using stream surveys. We then tested for statistical interactions between time periods (before and after stocking) and treatment reaches (stocked versus unstocked) on the structure of the stream invertebrate community.

## Materials and methods

### Study streams

Kayaderosseras and Big creeks are fourth order streams in the northeastern U.S. that receive stocked trout subsidies from the NYSDEC in order to improve recreational angling opportunities. The salmonid populations in these streams are composed of native brook trout and stocked and naturalized non-native brown trout. The stocked sections of each stream evaluated in this study receive approximately 3000–4000 brown trout in spring and early summer each year. Additional stream characteristics are provided in Table 1.

**Table 1.** Study stream characteristics during the study period. Fish densities and physical characteristics were obtained within two weeks of stocking. Stream width, depth, and temperature are mean values of 10 transect samples with 10 points each within the stream reach.

Characteristic	Big	Kayaderosseras
Stocked trout density (fish m <sup>-2</sup> )	0.23	0.11
Native trout density (fish m <sup>-2</sup> )	0.04	0.01
Mean width	6.8	12.7
Mean depth (m)	0.19	0.27
Conductivity (μS)	635	224
NH <sub>4</sub> <sup>+</sup> (μg/L)	32	8.8
% Overhead cover	49	51
% Instream cover	29	13
Mean temperature (°C)	18	16

## Sampling design

To detect and quantify potential impacts of trout stocking on stream invertebrate communities, we sampled invertebrates within one control reach paired with three impacted reaches on the two streams (Kayaderosseras and Big). Kayaderosseras Creek is stocked with brown trout twice per fishing season, therefore we sampled before and after stocking two times in that stream. Big Creek is only stocked once annually, so we only sampled before and after stocking once on that stream. Preliminary habitat surveys indicated that the habitat and character of our study streams changed longitudinally upstream from the stocked reaches. To avoid confounding the invertebrate community response to trout stocking with changes in habitat, we selected control reaches located directly (i.e. within 500 m) upstream from the uppermost impact reach that were also upstream from barriers to fish movement. This ensured that these control reaches were representative of similar habitat as impact reaches and that invertebrate taxa did not differ longitudinally prior to treatment.

## Invertebrate sampling

To sample invertebrate assemblages, five points at each site were selected randomly and stratified by habitat type (i.e. pool vs. riffle) in each stream reach. These sites were sampled using Hess stream bottom samplers (WILDSCO, Yulee, FL, USA) with 500  $\mu\text{m}$  mesh. To collect the samples, the Hess frame was securely placed on the stream bottom and the substrate was scrubbed to dislodge organisms clinging to stones, which were then swept into the cod-end of the sampler by the stream current. In order to maintain consistency between samples, a five-minute standard sampling time was used. Macroinvertebrates were identified to taxonomic family and counted. Population density for each invertebrate family was expressed as number per  $\text{m}^2$ .

## Fish sampling and mortality estimation

Subsequent to stocking (within two weeks), two electrofishing three-pass depletion population estimates were conducted from 2011 to 2013. On each stream we selected three study reaches. Sites selected for electrofishing were proximal to stocking locations and representative of the habitat within the study stream. In all surveys, electrofishing effort consisted of three sequential surveys of a stream section isolated by using blocking seines or natural features (shallow riffles) to approximate a closed population compatible with a depletion estimation approach. A Leslie–Delury binomial model was used to estimate fish abundance from three pass depletions, and fish population density was expressed as fish  $\text{m}^{-2}$ . A number of steps were taken to ensure that our sampling methods did not violate the assumptions of the Leslie–Delury model. The closure assumption was met by block-netting at the upper and lower end of the reach. If the number of fish was not strongly depleted within the first three passes, a fourth pass was conducted. Finally, time between passes was kept to a minimum (i.e. less than one hour) to ensure consistent catchability. Apparent mortality was estimated using a maximum likelihood estimation approach (negative log likelihood; Fournier et al. 2012).

A subset of 37 captured stocked ( $n = 37$ ) and wild ( $n = 37$ ) (i.e. resident, naturally reproducing brown (*Salmo trutta*) and brook (*Salvelinus fontinalis*) trout were kept to compare feeding habits of stocked trout relative to wild trout. Stomach contents were dried and weighed, then dry weight was divided by fish weight (g) to calculate a relative dry weight.

## Creel surveys and harvest rate estimation

Beginning in April 2011, stocked trout were fin clipped prior to release in the study streams to allow for later identification of hatchery trout. Fin clips varied by year to allow for cohort identification. Roving creel surveys based on instantaneous angler counts and on-stream angler interviews were

conducted by trained NYSDEC creel agents on impact study reaches to estimate the harvest rate of stocked trout. Surveys spanned the full fishing season (1 April–15 October) and were stratified by weekend days and weekdays for three years. Using data collected from the creel surveys, angler effort (hours/acre), harvest rates, and catch per unit of effort were estimated using methods outlined in Pollock et al. (1994) to estimate harvest mortality in order to better understand stocked trout population dynamics and establish the final sampling date to test for stocking impacts.

### Statistical analysis

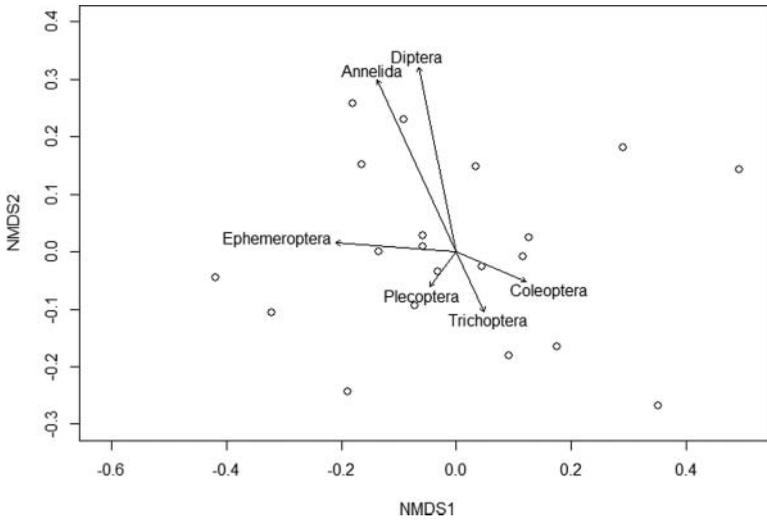
To detect changes in invertebrate community composition resulting from trout stocking, we used nonmetric multi-dimensional scaling (NMDS) ordinations on density data for the 63 invertebrate families captured in the two study streams. Nonmetric multi-dimensional scaling, commonly regarded as one of the most robust ordination methods available to ecologists (Minchin 1987; Legendre & Legendre 2012), maps observed community dissimilarities nonlinearly onto ordination space and can handle nonlinear species responses of any shape. To fit NMDS models, we used the function ‘metaMDS’ in package ‘vegan’ (Oksanen et al. 2013) in Program R Version 2.15.2 (R Foundation for Statistical Computing, Vienna, Austria) which uses a dissimilarity matrix based on the ‘Bray–Curtis’ dissimilarity calculation:  $BC_{ij} = \frac{2C_{ij}}{S_i + S_j}$ , where  $C_{ij}$  is the sum of the lesser value for only those species in common between both sites, and  $S_i$  and  $S_j$  are the total number of specimens counted at both sites (P. Legendre & L. Legendre 2012). P. Legendre and L. Legendre (2012) recommend assessing stress (i.e. goodness of fit) as: 0.05–0.10 provides an excellent representation in reduced dimensions, 0.1–0.2 is great, 0.2–0.3 is marginal, and stress greater than 0.3 provides a poor representation.

Using the NMDS ordinations scores, we generated community dissimilarity convex polygons and class centroids to determine whether invertebrate community densities changed as a function of treatments. We then plotted the convex polygons that enclose the invertebrate assemblage within the ordination space of a given factor (e.g. before vs. after stocking). Significance was assessed based on permutations ( $n = 999$ ) using the squared correlation coefficient as a goodness of fit statistic. For example, if the invertebrate community within a stream changed after stocking, the polygons should diverge in ordination space, resulting in two separate polygons. All univariate statistical analyses were conducted in Program R version 2.15.2.

### Results

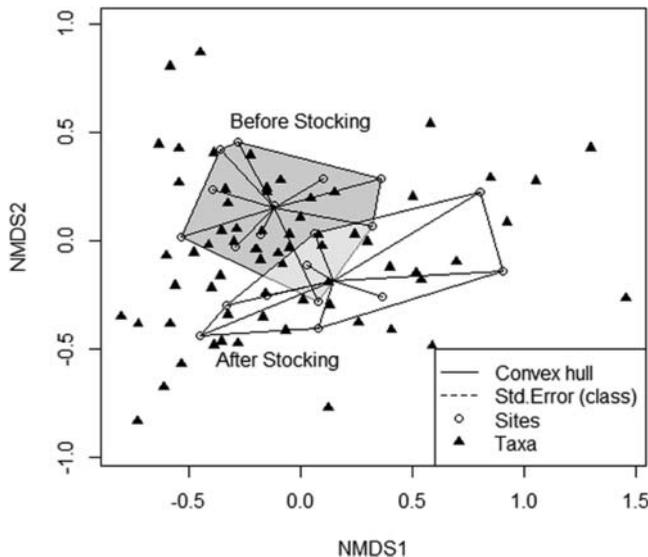
Apparent mortality estimates conducted on the two study streams from 2011 to 2013 indicated that stocked trout had a mean daily mortality rate of approximately 0.15, which translates to approximately 99.9% annual mortality. Harvest rates were low, averaging approximately 0.04 over the course of the fishing season. When the two sources of mortality are combined, it is evident that few fish survived beyond the fishing season. These estimates were confirmed empirically as only one stocked trout, out of approximately 10,530 released into these streams over the three-year period, survived an entire year. Based on these findings, any major impacts to the invertebrate community would likely take place on a relatively short timescale (i.e. pulsed impact). Therefore, our after-impact sampling was conducted within two months of trout stocking.

The NMDS ordination for invertebrate density converged at a ‘two axes’ solution with a final stress level of 0.16, indicating strong representation in ordination space. This can be interpreted as the two axes explaining approximately 84% of data variance. To further investigate this result, we summarized invertebrate taxa by order and conducted a *post hoc* permutation goodness of fit test to determine which taxa significantly increased or decreased in density as a function of trout stocking (Figure 1). Of the taxonomic orders tested, only Diptera ( $r^2 = 0.32$ ,  $P = 0.023$ ) and Annelida ( $r^2 = 0.33$ ,  $P = 0.042$ ) diverged significantly. Surprisingly, the abundance of both taxa increased after trout



**Figure 1.** Nonmetric multi-dimensional scaling plot of invertebrate community densities post-stocking summarized by taxonomic order in study streams. Vectors point in the direction of increasing density of taxa and the length of a vector indicates the strength of the relationship. Only Diptera and Annelida showed significant divergence.

stocking, rather than decreased as predicted. Using NMDS ordinations fit to all treatment levels and interactions, we found that communities diverged before and after stocking ( $P = 0.02$ ). This finding was also supported visually when we plotted class centroids and convex polygons for significant factors, as evidenced by separated polygons (Figure 2). Note that due to extremely high flows, we were unable to sample one of the intended treatment sites for Big Creek before or after stocking. We were also unable to sample one of the Kayaderosseras sites after stocking on either of the two occasions, resulting in 11 pre-stocking samples and 9 post-stocking samples.



**Figure 2.** Two-dimensional NMDS ordination plots comparing invertebrate community assemblage densities in Kayaderosseras and Big creeks before and after stocking. Convex hull polygons illustrate divergence between groups that are significantly different based on goodness of fit permutations.

Finally, the relative dry weight of stomach contents was lower for trout of hatchery origin than wild trout, though the difference was not significant ( $p = 0.20$ ;  $T$ -test).

## Discussion

Although many studies have evaluated the effects of trout stocking on native salmonid populations, the direct and indirect effects on the food web and community structure have not been as thoroughly examined. We addressed this using a multivariate approach (i.e. NMDS and non-parametric analysis of variance of dissimilarities) and found significant divergence of community structure before and after stocking. This type of response indicates a lack of functional complementarity in these systems (Frost et al. 1995), as the density of only a few taxa within the invertebrate community shifted in response to trout stocking. The fact that we observed different responses when comparing population and community metrics is not without precedent, as there are numerous instances in the literature in which substantial shifts in community or ecosystem level processes have been linked to changes in the populations of a single species (Vitousek 1986; Carpenter & Kitchell 1996; McIntosh & Townsend 1996). For instance, Schindler et al. (1985) found that although zooplankton biomass did not change with acidification, community composition shifted. These results highlight the need to assess potential impacts at multiple scales, ranging from individuals to whole ecosystems, as the response of individuals or populations does not always reflect community or ecosystem responses.

Trout provide one of the most widespread examples of intentional introductions of non-native fishes into freshwater streams worldwide (Flecker & Townsend 1994). The centuries-long practice of stocking non-native trout in streams and rivers throughout much of North America has been among the primary causes of decline for many native salmonid species (Krueger & May 1991; Dunham et al. 2004); however, the magnitude and severity of impacts to other native fish and invertebrate populations varies considerably from system to system (Allan 1982; Rahel 2002; Baxter et al. 2004). These equivocal results could stem from detection problems resulting from spatial and temporal heterogeneity (Downes 2002), confounded effects with land use changes (Flecker & Townsend 1994), or from the capacity of diverse systems that evolved in the presence a native salmonid species to be resilient to the impacts of invaders (Hanisch et al. 2012; Lepori et al. 2012; Benjamin et al. 2013). While the immediate effects of trout stocking were variable in our study streams, the high propagule pressure of repeated stocking over time has established non-native trout populations, which was evidenced by the presence of wild non-native brown trout at all stocking sites in our study.

A unique feature of the approach we used in this study was to quantify the duration of stocked trout impacts by estimating natural mortality and angler harvest mortality rates in recipient streams to guide our invertebrate sampling design. Although conducting multiple pass depletions to estimate mortality of stocked trout requires extensive effort, many agencies routinely conduct these types of stream fish surveys for a variety of purposes. This provides an opportunity to use existing data to estimate fish mortality with little additional field effort, which can reduce the duration of an impact monitoring program. For example, we determined that the majority (>99.99%) of stocked trout did not survive an entire year, thus entire-year sampling would be inappropriate for our study systems and unlikely to detect stocking effects. Our results confirmed that pulsed, rather than long term impacts, upon invertebrate densities were more pronounced immediately after stocking (i.e. within two weeks) by comparison with samples taken more than a month after stocking. This approach also minimizes the potential confounding effects of temporal heterogeneity that can often mask invertebrate community response to impacts (Flecker & Townsend 1994).

Most fishery resource managers are charged with the dual, often conflicting responsibility of providing and enhancing angling opportunities for the public while simultaneously protecting native organisms (Meyer et al. 2012). This dual mandate suggests that stocking of non-native trout is likely to continue in the foreseeable future. As a result, efforts to evaluate and monitor the potential impacts of trout stocking in recipient ecosystems should incorporate the simple approaches utilized

in this study to provide a rapid, quantitative assessment of potential impacts of trout stocking upon invertebrate communities.

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## Disclosure statement

No potential conflict of interest was reported by the authors.

## Notes on contributors

*Dr. Alexander Alexiades* is a community and spatial ecologist interested in the effects of disturbance on aquatic species communities and ecosystem function. His research focuses on population and community level ecosystem dynamics in freshwater systems in tropical and temperate regions.

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