Evaluating a Rapid Assessment Method Using Salamander Community Metrics

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Headwater ecosystems in Appalachia have been subjected to human alterations including mountain-top mining activities, road construction, forest harvesting, conversion to pastureland, and housing development (Hagen et al. 2006; Palmer et al. 2010). These activities degrade or eliminate habitat for stream and riparian dwelling organisms including amphibians, which have exhibited widespread declines due to habitat degradation (Stuart et al. 2004).

Salamander communities are an important component of headwater ecosystems and represent a useful indicator of headwater ecological function due to their susceptibility to environmental stressors (Welsh and Ollivier 1998). Salamanders are major contributors to energy flow and nutrient cycling in eastern forests, often acting as the dominant predators in headwater ecosystems (Spight 1967; Burton and Likens 1975; Ohio EPA 2001). Headwater systems provide critical habitat for salamanders due to the absence of predation by fish (Barr and Babbit 2002; Schneider 2010). Population studies demonstrate significantly lower salamander abundances in watersheds affected by alterations such as clearcutting and residential developments (Pough et al. 1987; Petranka et al. 1993; Hyde and Simons 2001; Knapp et al. 2003; Willson and Dorcas 2003; Maigret et al. 2014). Many salamander species have highly permeable skin, unshelled eggs, limited dispersal capability, and biphasic life histories that require both aquatic and terrestrial habitats, resulting in sensitivity to habitat degradation (EPA 2002). Salamander communities recover slowly from above-ground disturbance, with recolonization after clearcutting requiring as much as 50 years (Petranka et al. 1993, Ford et al. 2002).

Habitat rapid assessment methods have been developed to estimate ecosystem characteristics at site-specific scales as an alternative to direct measurements of biotic communities, including salamander population studies (Brinson 1993; Whigham 1999; Kentula 2007; Wardrop et al. 2007). Recently, rapid assessment techniques have been developed for headwater ecosystems because most traditional evaluation methods (i.e. benthic macroinvertebrate and water chemistry studies) are constrained to the narrow windows of time when water is present in the channel, making them impractical for year-round application in areas with ephemeral hydrology (Mack et al. 2000; Berkowitz et al. 2011). Habitat rapid assessment approaches employ easily attainable measurements, which are combined using simple multimetric equations to produce a single habitat assessment score ranging from zero to 1.0 (Brinson 1993, 1995; Rowe et al. 2009; Noble et al. 2010) with a score of zero indicates the absence of habitat function, and a score of 1.0 indicates that ecosystem characteristics are comparable to highly functional habitats within the region (Smith et al. 1995). Available literature sources often form the basis for selecting the features and characteristics incorporated into a rapid assessment approach. The current study 1) evaluates the ability of a habitat rapid assessment approach to differentiate between catchment alteration categories impacting salamander habitat, 2) measures salamander communities exposed to a range of catchment alterations, and 3) identifies ecosystem characteristics related to salamander community metrics.

SEAL SALAMANDER
(*Desmognathus monticola*)

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MATERIAL AND METHODS

Ten high-gradient headwater systems in western West Virginia were selected for this study. Study sites included both the stream channel and a 7.62 m (50 ft) wide riparian buffer zone. Study sites exhibited the range of conditions commonly observed within the region (Berkowitz et al. 2011; 2013) (Table 1).

Riparian salamander community sampling utilized eight plywood cover boards placed at each site as described in Willson and Gibbons (2009). Cover boards were overturned once per month from August – November 2011 and March – June 2012, and the species and abundance of all salamanders detected were recorded. Identification of any ambiguous or larval specimens was verified by Dr. Thomas Pauley, Marshall University. Salamander sampling within the stream channel utilized basket samplers (Talley and Crisman 2007). Each basket sampler was filled with 4.5 kg of purchased cobble (average diameter 2.8-cm, average mass 38.5 g) and leaves collected on-site. Basket samplers remained in place for approximately one month allowing colonization by salamanders and sampled April 2011, October 2011, January 2012 and April 2012 for both adult salamanders and larval species. Salamander species richness, defined as the total number of species detected among all sampling dates, and salamander abundance, defined as the total number of individuals detected on each sampling date and summed across all sampling dates, were determined (Heyer et al. 1994). Salamander richness and abundance measurements combined both cover board and basket sampler data.

The rapid assessment utilized applies the hydrogeomorphic approach developed for wetlands (Brinson 1993; Smith et al. 1995) and streams (Noble et al. 2010; Rowe et al. 2009; others). The method combines nine variables using a simple multimetric equation (Figure 2, Table 2). Complete variable definitions and sampling methods are described in Noble et al. (2010). In addition to the nine rapid assessment variables collected, forest stand age was also examined using tree cores collected within the dominant riparian canopy layer.

Rapid assessment scores for each catchment alteration category (e.g., forested, forest harvesting, pasture, mining) were compared using ANOVA following testing for normality using the Shapiro-Wilk test (α=0.05). Post Hoc multiple comparisons applied Tukey and LSD tests. Salamander abundance was compared with all 9 rapid assessment variables (Table 2), as well as stand age, using simple linear regression and Pearson

FIGURE 1.
Configuration of the habitat rapid assessment equation.

$$\text{Habitat Assessment Score} = \left\{ \left[\frac{CCANOPY + \min(EMBED, SUBSTRATE)}{2} \right] \times \left[\frac{\left(\frac{LWD + DETRITUS}{2}\right) + \left(\frac{\left(\frac{SNAG + TDBH + SRICH}{3}\right) + WLUSE}{2}\right)}{2} \right] \right\}^{1/2}$$

TABLE 1.
Headwater catchment condition, characteristics, and habitat rapid assessment score.

Catchment condition	Catchment area (ha)	Elevation (m)	Time since last alteration (yr)	Habitat rapid assessment score
Forested	6.53	239	82	0.95
Forested	4.13	248	94	0.94
Forested	12.90	228	109	0.95
Forested	1.28	726	103	0.87
Forest harvesting	8.90	780	95	0.72
Forest harvesting	1.03	265	77	0.71
Pasture	4.37	251	67	0.50
Mining	9.13	247	13	0.46
Mining	1.39	372	17	0.25
Mining	3.12	274	12	0.21

SLIMY SALAMANDER
(*Plethodon glutinonsus*)

Product Moment Correlation analysis (JMP, SAS Institute 2012). For each regression analysis, the distribution of residuals was tested for normality with the Shapiro-Wilk test. Salamander abundance data was square-root transformed to satisfy normality assumptions, a common procedure for estimates of animal abundance (Sokal and Rohlf 1995). Due to the likelihood of overlap in the variance explained by assessment variables, habitat variables most strongly affecting salamander abundance were determined using forward stepwise regression with tail probability values between 5% and 10% (F to enter = 3.84, F to remove = 2.71, Tolerance = 0.001) (Kutner et al. 2004).

RESULTS AND DISCUSSION

Results demonstrate that the rapid assessment method was capable of differentiating between sites exhibiting different catchment alterations (Figure 2a). Watersheds composed of mature forest exhibited habitat rapid assessment scores >0.87, while areas subject to alteration displayed decreased scores with average habitat assessment scores of 0.72, 0.50, and 0.31 in forest harvesting, conversion to pasture, and mining impacted locations respectively. Results show statistically significant differences in rapid assessment scores between catchment alteration categories ($F(3,9)=34.1$; $P \leq 0.001$). Additionally, post hoc multiple comparisons further indicate differences between catchment alteration categories. Due to the small number of sites in this study, we sought to place the 10 sites examined in the current study into a larger regional context by examining rapid assessment results from 84 additional headwater systems across the study area (Figure 2b). Significant differences in habitat rapid assessment scores were also detected between catchment alteration categories ($F(3,84)=107.1$; $P \leq 0.001$) in the larger dataset with post hoc comparisons indicating similarity between forest harvesting and agriculture impacted sites, and differences between all other alteration categories. The findings of the current study correspond well with the results from the larger dataset. The fact that both the current dataset and a more statistically robust set of rapid assessment scores responded to a variety of catchment alterations promotes confidence in the current study results.

Results also indicate that the rapid assessment method responds as expected when examining a habitat recovery chronosequence, with recently altered areas exhibiting low rapid assessment scores and older, later seral stage areas displaying higher rapid assessment scores (Figure 2c). Berkowitz et al. (2013) reported similar results for a rapid assessment method evaluating biogeochemical functions in Appalachian headwater ecosystems.

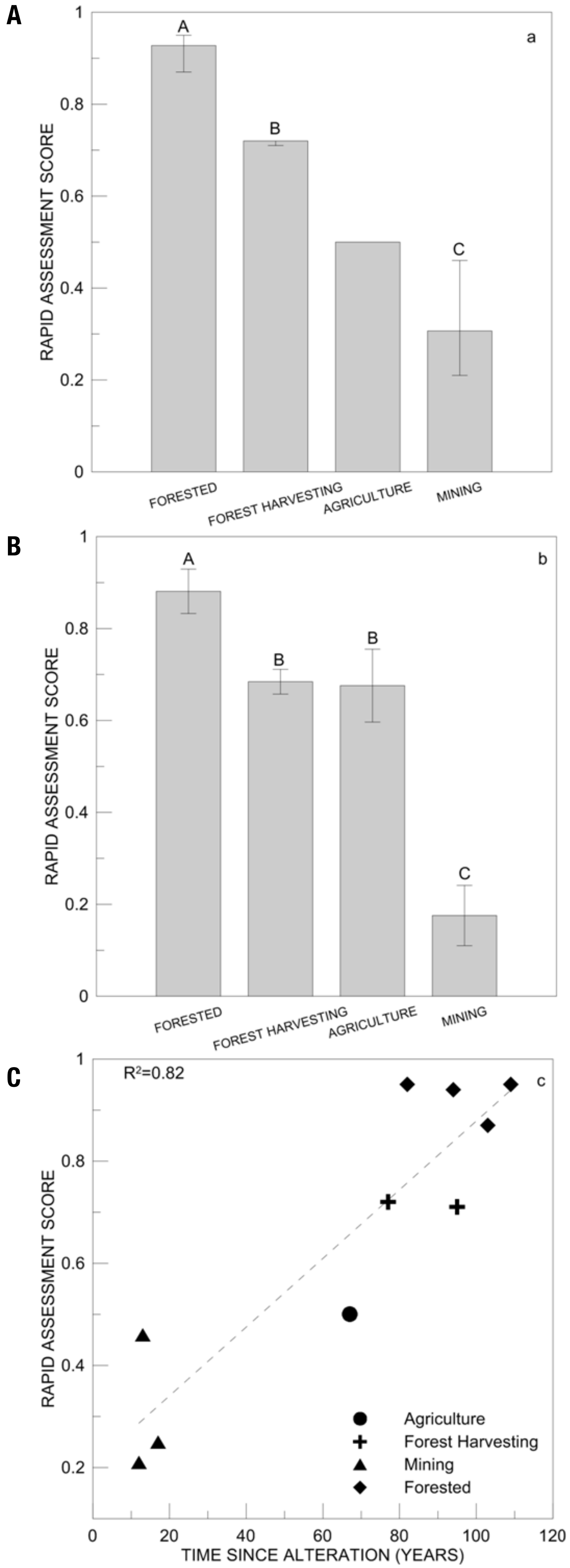
Total salamander abundance ranged from 0 – 36 individuals per site. Salamander abundance was significantly related with six of the nine rapid assessment variables tested as well as stand age (Tables 3 and 4). The high number of rapid assessment variables significantly related to sala-

TABLE 2.
Summary of rapid assessment variables, description and rationale for selection. (Modified from Noble et al. 2010.)

Assessment variable	Description and rationale for selection
1. Percent canopy cover (CCANOPY)	Percent canopy cover over the stream channel affects habitat by altering temperature and nutrient cycling (Todd and Rothermel 2006).
2. Channel substrate embeddedness (EMBED)	Embeddedness estimates the degree to which coarse substrates are covered, surrounded, or buried by fine sediments, which influences available cover for macroinvertebrates and amphibians (Wiederholm 1984).
3. Channel substrate size (SUBSTRATE)	Median size of bed material within the stream channel. Substrate provides cover and habitat for macroinvertebrates and salamanders (Gordon et al. 2006).
4. Large wood (LWD)	Abundance of large wood within stream and riparian area. Large wood provides refuge and cover for a variety of species (Fischenich and Morrow 2000).
5. Riparian area detritus cover (DETRITUS)	Abundance of detrital material covering the riparian surface. Detritus is a source of food and cover for macroinvertebrates and salamanders.
6. Riparian snag density (SNAG)	Number of snags per 30 m of stream reach. Snags provide habitat for many wildlife species (McComb and Muller 1983).
7. Riparian tree diameter at breast height (TDBH)	Average riparian tree diameter at breast height. Tree diameter is used as a surrogate for successional status, which is related with habitat structure (Rheinhardt et al. 2009).
8. Riparian tree species richness (SRICH)	Native tree species diversity per 30 m of stream reach. Diversity of the tallest vegetation layer is an indicator of overall community composition and successional patterns (Rheinhardt et al. 2009).
9. Watershed land use (WLUSE)	Percent forest cover occurring within the headwater catchment. Land use conditions determine the structure and function of downstream environments (Bolstad et al. 2003).

SLIMY SALAMANDER
(*Plethodon glutinonsus***)**

FIGURE 2.



mander abundance suggests that the components included in the rapid assessment were selected appropriately.

Tree diameter accounted for the most variation in both salamander abundance and species richness. These results are consistent with Ford et al. (2002), who demonstrated a positive correlation between basal area and species richness, diversity and relative abundance of Desmognathus aeneus and D. quadramaculatus. The significance of tree diameter as a predictor for salamander community metrics points to the importance of mature forest structure, a characteristic which takes decades to develop following disturbance (Petranka et al. 1993). This conclusion is reinforced by the results of the simple linear regression showing a significant relationship between stand age and the salamander community metrics measured. In comparison to tree diameter, the other habitat characteristics measured were less reliable predictors of salamander community metrics, possibly because tree diameter is a better indicator of overall forest stand maturity than characteristics such as canopy cover or detritus which can develop rapidly during stand regeneration (Summers 2010).

Based on stepwise model selection results, percent forested area also provided a significant predictor of salamander abundance. Within the study areas, non-forested land use types consisted of anthropogenic alterations (e.g., mining, roads, and urban development). Welsh and Ollivier (1998) documented a strong negative relationship between watershed disturbance and the number of stream salamanders captured. Maigret et al. (2014) also observed significantly lower abundances of stream (Desmognathus spp.) and riparian (Plethodon glutinosus) salamanders within 5 years of tree harvesting. Mechanisms involved in salamander community changes as a result of watershed alterations include impacts to stream and riparian habitats (Welsh and Ollivier 1998) as well as metapopulation changes caused by reduced habitat continuity (Lowe and Bolger 2002).

TABLE 3.
Results of simple linear regressions[a] relating habitat variables to salamander abundance[b].

Predictor	P	Pearson Correlation
DBH	<0.001	0.91
DETRITUS	0.005	0.81
CANOPY	0.013	0.75
SRICH	0.025	0.70
LWD	0.026	0.70
SNAG	0.065	0.60
SUBSTRATE	0.67	0.15
EMBED	0.46	0.26
WLUSE	0.048	0.64
Stand Age	0.011	0.76

[a]Significance was determined at $\alpha = 0.05$.
[b]Square root transformed. Sample size = 10.

Results suggest that human alterations including surface mining and conversion to pasture negatively impact habitat suitability for salamanders as reported by Riedel et al. (2008), Muncy (2014), and others. Notably, forest harvesting in the stream riparian areas examined in this dataset occurred >77 years ago. These areas exhibited forested watersheds (88-100% forest cover) and high tree diameter values (average diameter = 29.2-33.0 cm). As a result, salamander abundances are within the range observed within unaltered stream catchments. These data agree with the findings of Petranka et al. (1993) and Ford et al. (2002), who indicate that recolonization of deforested sites by salamanders takes at least 50 years, and support the recovery trajectory predicted by the habitat rapid assessment method (Figure 2c).

SUMMARY

Landscape and vegetation alterations such as forest harvesting, mining and conversion to pasture in Appalachian headwater streams negatively affect salamander communities by reducing or eliminating suitable habitat. This study illustrates that the rapid assessment method tested was capable of differentiating between stream catchment alteration categories impacting salamander habitat in both the small dataset examined and in a large 84-site regional dataset. The rapid assessment also provided a useful tool for evaluating habitat recovery and supports the development of restoration trajectory curves. Based on study results, salamander conservation in Appalachian headwater stream and adjacent riparian areas should focus on establishing and maintaining mature forested habitats characterized by large trees. Results showed a significant correlation between rapid assessment outputs and salamander community metrics, reinforcing the utility of rapid assessment methodologies for providing useful measurements of salamander habitat function when time constraints or other factors prohibit salamander surveys. ■

TABLE 4.
Amphibian species observed and total abundance at 10 headwater study locations including Forested (F), Forest Harvesting (FH), Pasture (P), and Mining (M).

	Headwater catchment condition									
Species Observed	**F**	**F**	**F**	**F**	**FH**	**FH**	**P**	**M**	**M**	**M**
Desmognathus fuscus	X			X		X				
D. monticola	X		X	X						
D. ochrophaeus				X		X				
Eurycea bislineata				X	X		X	X		
Gyrinophilus porphyriticus		X		X						
Plethodon cinereus						X				
P. glutinosus	X	X	X	X	X	X	X			
P. richmondi		X			X			X		
Pseudotriton ruber				X		X				
Salamander abundance	5	10	13	34	19	36	2	3	0	0

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