Distribution and Conservation Status of the Grandfather Mountain Crayfish

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Abstract: The Grandfather Mountain crayfish (*Cambarus eeseeohensis*) was described in 2005 from the Linville River in western North Carolina and considered to be endemic to the mainstem Linville River upstream of Linville Falls. Because of its limited distribution and the presence of non-native crayfish in the Linville River watershed, this species was considered imperiled. However, there has been limited survey effort for Grandfather Mountain crayfish and therefore the extent and nature of threats to persistence of the species were mostly unknown. We conducted surveys ($n = 41$) in 2011 throughout the Linville River watershed and surrounding watersheds to better determine the distribution of the Grandfather Mountain crayfish and assess impacts of exotic crayfishes on this species. We also conducted an evaluation of land ownership and water quality classifications to determine what protections were currently available for conservation of this crayfish. We found Grandfather Mountain crayfish to be widely distributed throughout the Linville River watershed in headwater streams, mid-order tributaries, and the mainstem Linville River. The species was also found in the adjacent Watauga River and Johns River watersheds. Populations of exotic crayfish within the known distribution of Grandfather Mountain crayfish were restricted to small areas and did not appear to be expanding, and Grandfather Mountain crayfish were still extant in areas with exotic crayfish. A large portion of the current range was in public ownership, and a high percentage of streams, had water quality classifications that provide protections. The Grandfather Mountain crayfish appeared to be at low risk of extinction but should remain a priority for monitoring.

Key words: *Cambarus eeseeohensis,* threat assessment, exotic species

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The Grandfather Mountain crayfish (*Cambarus eeseeohensis*) was described from the Linville River of North Carolina. (Thoma 2005). Evidence from geological data (Ross 1971, Hack 1982) and zoogeographical studies of stream fishes and salamanders (Hocutt et al. 1986, Starnes and Etnier 1986, Jones et al. 2006) strongly suggest that the upper Linville River was diverted from the upper Nolichucky River subbasin to the Santee River subbasin. Thus, Grandfather Mountain crayfish likely evolved in the Linville River from ancestral stock from the upper Tennessee River drainages following a stream capture event. At the time of the species description, Thoma (2005) considered Grandfather Mountain crayfish to be endemic to the mainstem of the Linville River above Linville Falls (Figure 1). However, subsequent examination of specimens vouchered at the North Carolina Museum of Natural Sciences showed that Grandfather Mountain crayfish had also been collected from headwaters of the adjacent Wilson Creek, Watauga River, and Johns River watersheds (Cooper and Russ 2013). Simmons and Fraley (2010) noted that Grandfather Mountain crayfish were considered conspecific with common crayfish (*Cambarus bartonii*) by biologists prior to being described. Thus, several specimens at the North Carolina Museum of Natural Science and unvouchered records from surveys conducted by Marsh (1998) from the upper Linville River identified as the common crayfish and an unknown but similar species were actually Grandfather Mountain crayfish (Simmons and Fraley 2010). There have been no targeted surveys for Grandfather Mountain crayfish since its description; therefore, the distribution of this species was largely unknown.

Taylor et al. (2007) noted five broad factors that can affect crayfish populations including habitat destruction, over-utilization, disease, introduction of exotic species, and restricted range. Three of these factors (habitat destruction, exotic species, and restricted range) are thought to be relevant for Grandfather Mountain crayfish. According to the North Carolina Department of Environment and Natural Resources (NCDENR 2010), the upper Linville River was being impacted by development pressures, agricultural runoff, and other land disturbing activities. Lodge et al. (2000) con-

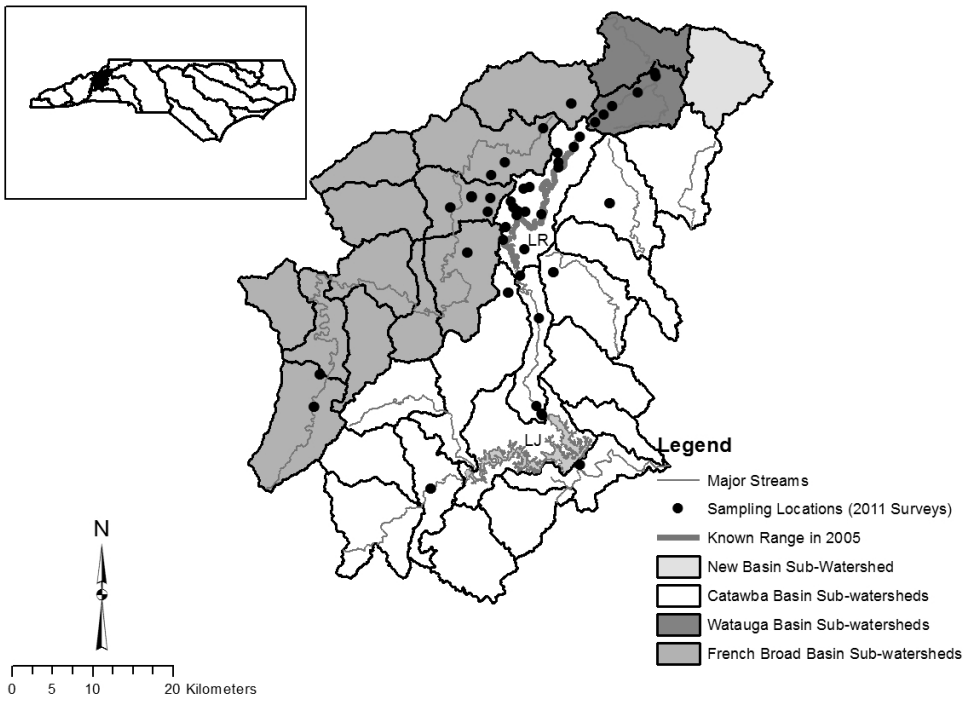

Figure 1. Historic known distribution and sampling locations for Grandfather Mountain crayfish. LJ = Lake James, LR = Linville River.

sidered invasive non-native crayfish as the primary threat facing crayfish populations. A population of virile crayfish (*Orconectes virilis*) has been established in the lower Linville River since at least 1993 (Cooper and Armstrong 2007) and the presence of this exotic crayfish was considered a potential threat to native crayfish populations by Thoma (2005). Finally, Thoma (2005) stated that the Grandfather Mountain crayfish was restricted to the main stem Linville River above Linville Falls, which constitutes less than 30 km of linear riverine habitat.

As of 2015 the Grandfather Mountain crayfish was being evaluated for listing as either threatened or endangered by the U.S. Fish and Wildlife Service under the Endangered Species Act. Presence of virile crayfish along with restricted range comprise the rationales for Thoma (2005) to categorize this species as threatened; however, Simon (2011) listed habitat destruction along with restricted range as factors for listing the species as endangered. Taylor et al. (2007) consider this species as threatened due to restricted range. However, as noted above, a comprehensive survey of Grandfather Mountain crayfish has not been accomplished. Therefore, the objectives of this study were to obtain updated distribution information for Grandfather Mountain crayfish and determine species conservation status by evaluating potential threats to the species.

Methods

Distribution

Surveys for Grandfather Mountain crayfish were conducted June through October 2011 throughout the Linville River watershed and adjacent watersheds to more fully assess the distribution basin-wide distribution and identify extra-basin populations of Grandfather Mountain crayfish as well as to document the presence or absence of non-native species. Forty-one sites (Figure 1) were visited during this study to assess the distribution and population health of Grandfather Mountain crayfish. Sites were selected for ease of access and variability of stream sizes. Twenty-one sampling locations were in the Linville River watershed, five were in the Watauga River watershed, ten in the Toe River watershed, and one each in the Elk River, Johns River, North Fork Catawba River, Warrior Fork-Catawba River, and the Silver Creek-Catawaba River watersheds. At each sampling site, crayfish were collected from a specified length of stream within an entire wetted perimeter using a combination of seine hauls and hand collecting. The total area sampled at each location was determined by multiplying the length of the reach by average stream width. The total number of crayfish collected was divided by the total area sampled to determine density. At each site, all crayfish collected were identified, enumerated, measured (carapace length), and gender and reproductive condi-

tion were determined. Habitat parameters were estimated at each site using the Ohio Qualitative Habitat Evaluation Index methodology (OEPA 2006). They included substrate composition, bank vegetation, stream gradient, and floodplain condition. Streams were classified using Strahler stream order (Strahler 1957). Mean densities of Grandfather Mountain crayfish among stream orders were compared using a one-way ANOVA test using the statistical software package Statistix version 10. A $P < 0.05$ was used to determine statistical significance. All sites sampled in this survey were in second- to fifth-order streams, but since only two sampling sites were in fourth-order streams, they were combined with fifth-order streams for this comparison. Occupancy was determined by the ratio of the sites where Grandfather Mountain crayfish were collected to the total number of sites surveyed (i.e., naïve occupancy). Confidence intervals for naïve occupancy were calculated using methods described by Ewing and Gangloff (2016). The total amount of occupied stream length was estimated by multiplying the total stream length by naïve occupancy rate (IUCN 2013). Additional location data, which were not used in the occupancy calculations, were also taken from collections in the North Carolina Museum of Natural Sciences (Cooper and Russ 2013).

Threats

During sampling, particular attention was paid to areas where exotic species were known to occur or where they had the potential to overlap with Grandfather Mountain crayfish. In order to determine how vulnerable Grandfather Mountain crayfish is to potential habitat degradation, we evaluated existing habitat conservation measures within the species' known range. We calculated the percentage of stream length within the range of Grandfather Mountain crayfish that were designated by the North Carolina Department of Environment and Natural Resources (NCDENR) as Trout Waters (TR), High Quality Waters (HQW), or Outstanding Resource Waters (ORW). These designations confer stringent erosion, sediment controls, and buffer widths, require the use of best management practices, and limit or restrict new waste water discharges (NCDENR 2011). Lengths of streams designated as TR, HQW, and ORW were calculated from a GIS layer available from the North Carolina Center for Geographic Analysis (NC CGIA; http://data.nconemap.gov/ accessed May 2015). The total length of streams for the range of Grandfather Mountain crayfish was calculated using GIS from data available from the North Carolina Stream Mapping Program (http://www.ncstreams.org/; accessed June 2015). Similarly, the proportion of land in conservation ownership within the range of Grandfather Mountain crayfish was determined by dividing the area of the subwatersheds (HUC 12) where Grandfather Mountain crayfish were found by the area of land owned by the US Forest Service, National Park Service, North Carolina Department of Parks and Recreation, and the North Carolina Forest Service. Areal extent of conservation lands and occupied subwatersheds were calculated using GIS from data available from the NC CGIA (http://data.nconemap.gov/; accessed May 2015).

Table 1. Crayfish species collected during this study from four river basins in North Carolina (C = Catawba River basin, L = Linville River basin, T = Nolichucky River basin, and W = Watauga River basin), including number of sites collected from and individuals collected in each basin.

Species	River basins	Sites	Number
Grandfather Mountain crayfish (*Cambarus eeseeohensis*)	L, W	24	230
Acuminate crayfish (*Cambarus acuminatus*)	C, L, T	9	44
Mitten crayfish (*Cambarus asperimanus*)	C, L, T, W	10	31
Common crayfish (*Cambarus bartonii*)	C, T, W	12	400
Upland burrowing crayfish (*Cambarus dubius*)	L, W	7	24
Chattahoochee crayfish (*Cambarus howardi*)	C, L	2	37
Longnose crayfish (*Cambarus longirostris*)	T	3	34
Big river crayfish (*Cambarus robustus*)	T, W	10	72
Rusty crayfish (*Orconectes rusticus*)	C	1	3
Virile crayfish (*Orconectes virilis*)	L	2	47
White River crayfish (*Procambarus acutus*)	C	1	1

Results

Distribution

Eleven species of crayfish represented by 923 individuals (Table 1) were collected during this study. Grandfather Mountain crayfish was the most common crayfish found in the Linville River watershed as well as in the head waters of the Watauga River. Grandfather Mountain crayfish were found in 19 of 21 sites for a naïve occupancy rate of 90% (95% CI = 70%–99%) in the Linville River watershed (Figure 2), including sites downstream of Linville Falls. The species was collected at 5 of 6 sampling locations in the Watauga River sub-watershed (Figure 2) for a naïve occupancy rate of 83% (95% CI = 36%–99%). No Grandfather Mountain crayfish were found outside the Linville River or upper Watauga River watersheds during these surveys (Figure 2). In the Linville River watershed, Grandfather Mountain crayfish were collected in all stream sizes surveyed ranging from second- to fifth-order streams. Where the species was found, numbers of Grandfather Mountain crayfish collected ranged from 1 to 96 individuals per site, conferring densities ranging from 0.01 to 4.4 crayfish m^{-2} with a mean of 0.6 crayfish m^{-2} (95% CI = 0.3 – 0.99 crayfish m^{-2}). The density of Grandfather Mountain crayfish was not significantly different among stream orders ($F = 0.53$, df = 2. 8, $P = 0.61$). The estimate of total occupied stream length was 446 km (95% CI = 319 – 498 km) of stream out of a total possible 503 km of stream in the survey area.

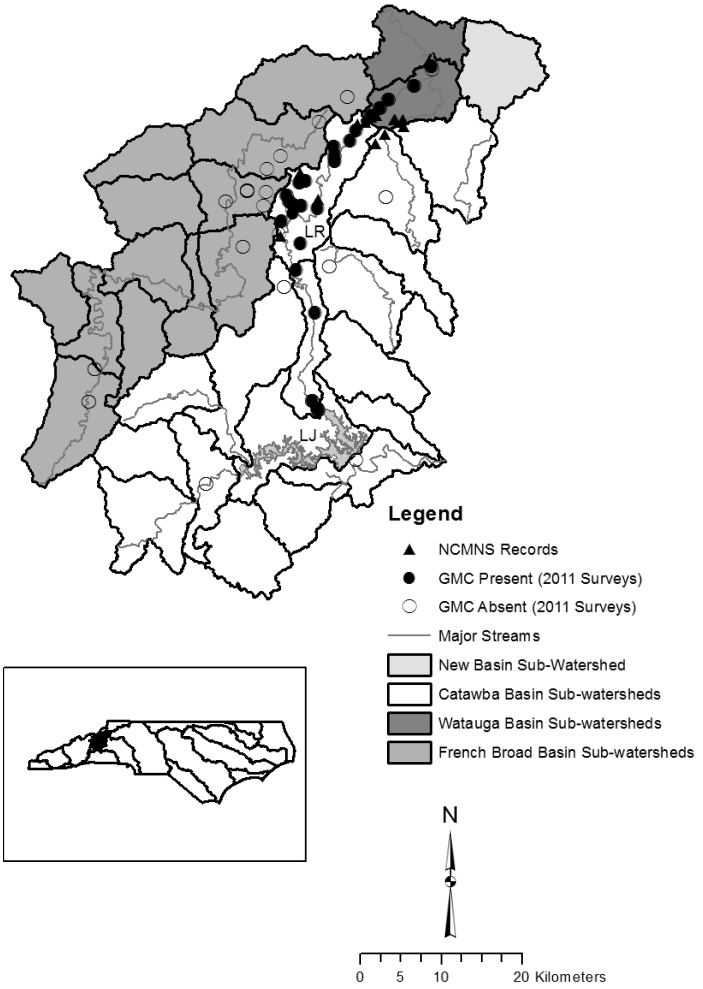

Figure 2. Known distribution of Grandfather Mountain crayfish (GMC). NCMNS = records from the North Carolina Museum of Natural Sciences (Cooper and Russ 2013). GMC present = sites where the Grandfather Mountain crayfish was collected during this study. GMC absent = sites where Grandfather Mountain crayfish were not found during this study.

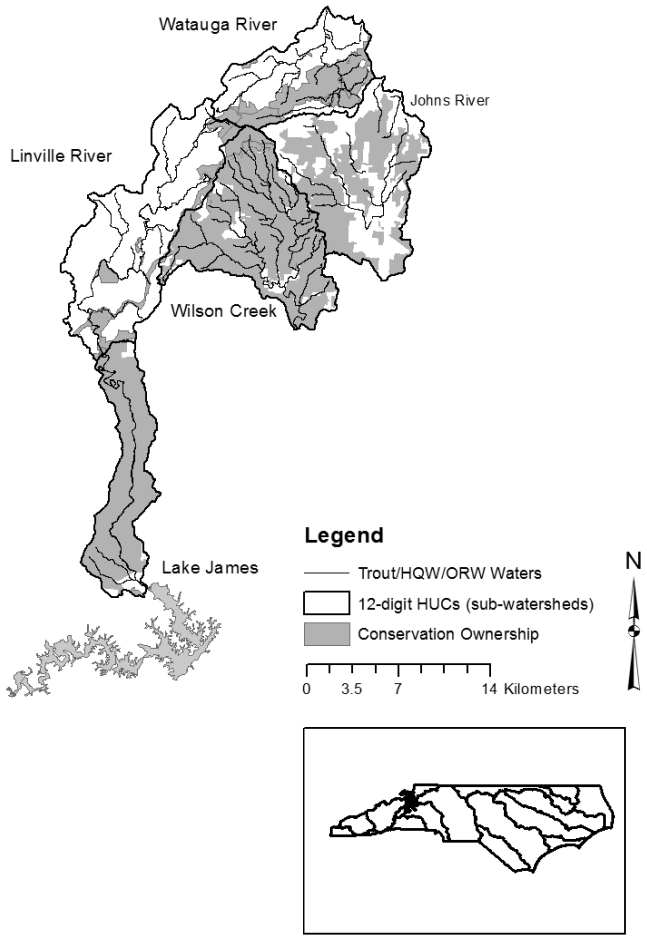

Figure 3. Locations of conservation lands (lands managed by state and federal governmental agencies and NGOs primarily for conservation) and streams with supplemental water quality designations. Only sub-watersheds where the Grandfather Mountain crayfish has been collected are shown.

Threats

Exotic Species.—The exotic virile crayfish was found at the two downstream-most sites in the Linville River near the confluence with Lake James: 47 virile crayfish were collected at these sites, but only one was an adult. No virile crayfish were found upstream of these two sites. Densities of Grandfather Mountain crayfish at these same two sites were 0.13 and 0.2 crayfish m^{-2}. The introduced acuminate crayfish (*Cambarus acuminatus*) was collected at two sites in the upper Linville River subbasin above Linville Falls: one adult male in the West Fork of the Linville River and five juveniles accuminate crayfish were collected from Crossnore Creek. The densities of Grandfather Mountain crayfish at these latter two sites were 0.26 and 0.29 crayfish m^{-2}, respectively.

Habitat Protection.—There are approximately 503 stream km in the Linville River watershed and the headwaters of the Watauga River subwatershed where Grandfather Mountain crayfish is known or is likely to occur. Approximately 232 km (46%) of stream in these areas are designated as HQW or ORW waters and 129 km (26%) are designated as TR waters (Figure 3). Approximately 210 km^2 of the land is in federal ownership, mostly by the U.S. Forest Service, but also a lesser amount owned is by the National Park Service. The North Carolina Division of Parks and Recreation manages most of the 15 km^2 of state-owned lands in these watersheds. The Nature Conservancy and the Grandfather Mountain Stewardship Foundation are nongovernmental organizations, (NGOs) that also protect land in the headwaters of the Grandfather Mountain crayfish range. In total, roughly 64% of the land area of Grandfather Mountain crayfish's range is in public or NGO ownership with resource conservation as a primary management objective (Figure 3).

Discussion

Based on our results, Grandfather Mountain crayfish are primarily found in the Linville River and upper Watauga River watersheds and are more widespread than originally reported by Thoma (2005). Originally, the species was considered extant only in the Linville River above Linville Falls (Thoma 2005), but our surveys found populations of the species throughout the entire Linville River watershed downstream to the confluence with Lake James. In addition, while Thoma (2005) stated that Grandfather Mountain crayfish only inhabited the mainstem of the Linville River, we collected them from all stream sizes surveyed (second-to-fifth-order). Additionally, Cooper and Russ (2013) reported collections from first-order streams in the Linville River, upper Watauga River, upper Johns River, and Wilson Creek sub-watersheds. Thus, the species is likely found in most streams in the Linville River watershed as well as in many tributary streams in the upper Watauga River sub-watershed. However, distribution of Grandfather Mountain crayfish in the upper Johns River and Wilson Creek sub-watersheds remains relatively unknown. Several collections from the headwaters of the Johns River system, with vouchers in the North Carolina Museum of Natural Sciences, claim to include this species. However, we sampled one location in the Johns River watershed and found no Grandfather Mountain crayfish. Other survey work lower in the Johns River system also failed to detect the species (North Carolina Wildlife Resources Commission unpublished data). Future efforts should focus on further assessing distribution in the Johns River watershed.

Grandfather Mountain crayfish were the most common crayfish collected in the Linville River watershed and upper Watauga River subwatershed. Although this study found that mean density of Grandfather Mountain crayfish was approximately 0.6 m^{-2} across all surveyed sites, we have no estimate of the areal extent of stream habitat within its occupied range and thus there is no way to estimate a reliable population size for the species with the current data. However, the crayfish occupies an estimated 446 km on linear stream habitat in the Linville and Watauga River subwatersheds. Populations are likely large enough to ensure that the species is at low risk of extinction.

We have no information on population trends for this species. This study can be useful as a baseline to assess future population trends; however, we can reasonably deduce from these results that there has likely been no appreciable decline in occupancy for this species since the initial assessment by Thoma (2005). If Grandfather Mountain crayfish did evolve in the Linville River basin following a stream capture event (Thoma 2005), then the Linville River watershed likely represents the majority of the historically occupied range. The species collected at approximately 90% of the sites surveyed in the Linville River watershed, indicating it is still extant throughout most of its assumed historical range. How the species arrived in the headwaters of the Johns River and the Watauga River watersheds is unknown. A possible mechanism is overland migration of this species which can happen with some crayfish species (Fetzner and Crandall 2003), but we cannot rule out smaller scale stream captures as well as possible introductions via bait buckets or other human-driven mechanisms.

Introduction of non-native crayfish species is a primary conservation concern for the Grandfather Mountain crayfish (Thoma 2005). The nearby existence of virile crayfish in Lake James is reason for elevated concern for Grandfather Mountain crayfish. However, it appears that virile crayfish population in the lower Linville River is not a major threat to the Grandfather Mountain crayfish. Though virile crayfish have been present in the system at least since 1993, the species has not established a significant presence in the Linville River nor advanced its distribution significantly upstream of Lake James. In a portion of its native range in Missouri, the virile crayfish is most commonly found in deeper areas of warm, fertile, moderate pH, moderately turbid, low gradient streams and lakes (Pflieger 1996), and the species may have difficulty establishing itself in the cool to cold, infertile, acidic, and high gradient Linville River system.

Acuminate crayfish were collected in our study for the first time from two locations above Linville Falls. This species is considered native to the Catawba River basin including the lower Linville River below Linville Falls. However, these two pockets above Linville Falls likely are the result of introductions. Acuminate crayfish were found in very low numbers with only one adult and five juveniles collected from two locations. It may be that the introductions are very recent and the populations will increase over time, but this cannot be discerned from our study. Because Grandfather Mountain crayfish currently coexist with acuminate crayfish below Linville Falls, it is unlikely Grandfather Mountain crayfish will be driven to extinction by this introduction; however, the populations of these two species will need to be monitored closely in these two streams.

Grandfather Mountain crayfish appear to be reasonably well protected. A high percentage of the streams within its range (≈72%) have supplemental water quality designations by the North Carolina Department of Natural Resources. Large portions of the surrounding land are protected as well. As noted, more than 60% of the land in occupied sub-watersheds is in some form of public or NGO ownership with resource conservation as a primary management objective. While this does not guarantee protection, it likely offers a significant amount of protection for Grandfather Mountain crayfish. These organizations usually follow best management practices or have internal constraints which require them

to seek technical guidance from the North Carolina Wildlife Resources Commission or other resource management agencies in order to avoid or mitigate impacts to sensitive resources prior to any major disturbance activity.

Anecdotal observations indicate that Grandfather Mountain crayfish are at least somewhat tolerant of minor water and habitat quality perturbations. For instance, one collection location was adjacent to a golf course which had no riparian zone on one bank, was paved all the way to edge of the stream, and experienced moderate siltation. This site had a density of 0.6 crayfish m^{-2} which is similar to many sites that are more pristine.

Another factor offering some protection from the threat of extinction is the distribution of Grandfather Mountain crayfish. The species is now known to inhabit at least five subwatersheds on both sides of the Eastern Continental Divide: two in the Linville River watershed, two in the Johns River watershed (Catawba-Santee Basin) and one in the Watauga River watershed (Tennessee River Basin). Any single threatening event that would simultaneously affect all four of these populations is unlikely. This reduced threat to localized perturbations affords a reduced extinction risk for a species than if it were more locally restricted (Menhinick 1987, Mace et al. 2008).

The Grandfather Mountain crayfish might be considered rare in the sense that it is not widely distributed though our results show it is more widely distributed than once believed. Taylor et al. (2007) considered restricted geographic range as a factor to designate as species imperiled even when the species is not experiencing a decline. However, this concept is not universally accepted. Flather and Sieg (2007) and Mace et al. (2008) stated that rare species should also be experiencing population declines or be projected to undergo a population decline in the foreseeable future in order to be considered imperiled. The preference of using one approach over another may depend on how a particular agency or biologist chooses to characterize extinction risk (Ewing 2012). The latter approach has been adopted by the U.S. Fish and Wildlife Service (USFWS) when determining species status under the Endangered Species Act. According to USFWS (2010), a species does not necessarily warrant listing because of stochastic or anthropogenic events such as natural catastrophes, invasive species, etc., even when the species is rare. There must also be some likely or realized stressor acting on the species or its habitat that may affect a species' status now or within the foreseeable future. The Grandfather Mountain crayfish does not appear to be facing any imminent threats and there is no evidence to support a current or predicted population decline. Therefore, we do not bleieve this species should be considered as threatened or endangered under the Endangered Species Act but should remain a priority for monitoring. Future monitoring and status assessment should consider potential impacts from emerging broad scale threats such as changes in temperature, precipitation patterns, and frequency and magnitude of large storms.

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