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## Appendix 1

Voucher specimens are housed in the herpetological collections of the following institutions: Adolpho Lutz collection (AL), now in MNRJ; Eugenio Izecksohn collection (IE), Universidade Federal Rural do Rio de Janeiro, Itaguai, Brazil; Museu de Biologia Prof. Mello-Leitão (MBML), Santa Teresa, Brazil; Museu Nacional do Rio de Janeiro (MNRJ), Rio de Janeiro, Brazil; Universidade de São Paulo, Museu de Zoologia (MZUSP), São Paulo, Brazil; Forschungsinstitut und Natur-Museum Senckenberg (SMF), Frankfurt a. M., Germany; Staatliches Museum für Naturkunde Stuttgart (SMNS), Stuttgart, Germany; National Museum of Natural History, Division of Amphibians and Reptiles (USNM), Washington, D.C., USA; Werner C. A. Bokermann collection (WCAB), now transferred to MZUSP; Zoologisches Forschungsmuseum Alexander Koenig (ZFMK), Bonn.

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# The effects of flooding on Hellbender salamander, *Cryptobranchus alleganiensis* DAUDIN, 1803, populations

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**Abstract.** Knowledge of the effects of floods on salamanders is understudied and, as one might expect, anecdotal. This study focuses on the flooding of two different rivers and populations of the large aquatic Hellbender Salamander, *Cryptobranchus alleganiensis*, and their habitats. The effects of flooding on *C. alleganiensis* populations in the North Fork of White River (NFWR), Ozark County, Missouri, USA were examined using location of tagged individuals, population estimates, stream survey observations, and stream flow data. Differences observed between 1969 and 1980 in a 4.6 km section of NFWR's benthic structure, relief, volume of water, and visible changes in riverine habitat are discussed and compared. There was no evidence that a massive flood in winter 1969 effected NFWR *C. alleganiensis* populations. Evidence supports the stability of hellbender populations in a large riffle between 1970 and 1980 despite four major flooding events during this time period. Our surveys and riverine observations support the hypothesis that a 2003 flood of the Middle Prong of Little River (MPLR), Blount County, Tennessee, USA could have eliminated most of the *C. alleganiensis* population. The effects of floods on streambeds may provide the best evidence of the floods' effects on hellbender populations and perhaps other aquatic salamanders.

Key words. Cryptobranchidae, *Cryptobranchus alleganiensis*, flooding, Great Smoky Mountains National Park International Biosphere.

## Introduction

Factors suspected in causing amphibian declines have been surveyed, analyzed, and discussed, but the effects arising from natural flooding appear to be understudied and were not cited in the substantial review by BRADFORD (2005). There are few published studies supporting flooding as a factor for salamander population declines. GROBMAN (1944) considered frequent flooding the reason for the absence of *Plethodon glutinosus* populations from the Mississippi River alluvial plain. Comparative surveys in a Southern Illinois forested nature preserve in 1989 counted approximately 92 % more ambystomatid individuals and one more species than after extensive Mississippi River flooding in 1993 and 1995 (BRUNKOW et al. 2000a, b). Floods have been suspected of causing declines in aquatic salamanders, including Hellbender, *Cryptobranchus alleganiensis*, populations (DODD 1997). Evidence of flooding's impacts on *C. alleganiensis* populations is limited to anecdotal accounts of the effects of damming on *C. alleganiensis* populations (NICKERSON & MAYS 1973a) and two instances of a dead individual found following floods (HUMPHRIES 2005, MILLER & MILLER 2005).

We have observed major flooding and the effects of flooding on streams during our studies of *C. alleganiensis*. Planning a research project to evaluate the effects of such an event within a natural river, not micro-managed by human controls, was futile due to the unpredictable nature of floods. However, we have accumulated substantial amounts of information on hellbenders and their habitats over the course of several decades. This paper is a synthesis of our data coupled with other insights from the current literature.

Herein we use accumulated data to examine the effects of flooding on hellbender populations and habitats in a 4.6 km section of the North Fork of White River (NFWR), Ozark County, Missouri, USA, a third order river of the White River system, between 1969 and 1980. Data from hellbender populations and habitat from Middle Prong of Little River (MPLR), Blount County, Tennessee, USA, a small first order stream within the Great Smoky Mountains National Park International Biosphere (GSMNP-IB), was collected during 2000-2003. Stream characteristic data for NFWR and MPLR are presented in Table 1.

## Materials and methods

Mark and recapture studies of *C. alleganiensis* were conducted via skin diving in NFWR during the late spring and summers of 1969-1971, followed by annual surveys through 1980 (Nickerson & Mays 1973a,b; Nickerson et al. 2002). One hundred and sixty nine survey days were spent on the 4.6 km NFWR research section. Survey days per year were: 1968 = 2, 1969 = 41, 1970 =54, 1971 = 15, 1972 = 15, 1973 = 7, 1974 = 3, 1975 = 3, 1976 = 2, 1977 = 5, 1978 = 2, 1979 = 3, 1980 = 17; and by month were: Jan = 1, Feb = 2, March = 6, April =10, May = 6, June = 44, July = 41, Aug = 12, Sept = 18, Oct = 21, Nov = 5, and Dec = 3. During the months of December, January and February, daily surveys were abbreviated and only two hours were spent in the water during the January survey. The water flow data (1944-2007) for NFWR were collected by the United States Geological Survey (USGS) stream flow gauging station downstream from the 4.6 km research section (USGS 2007a as listed in the Appendix). The NFWR drains 1453 square kilometers of watershed and the research section's streambed ranges from 198-202 m in elevation.

Skin-diving gear was also worn to survey MPLR, a small first order stream of the third order Little River (LR) system within the Tennessee River drainage, during the summers of 2002 and 2003. Because the stream was so small and shallow, it was stream-crawled. We followed the USGS/ United States Department of the Interior Amphibian Monitoring Protocol developed for monitoring amphibian populations within the GSMNP-IB, i.e., recording the number of survey person hours/amphibian (hellbender) found. The MPLR survey sites were all located downstream from the entrance to the Great Smoky Mountains Institute - Tremont (GSMI-T). The entire LR drainage, including MPLR, above Townsend, Tennessee is only 275 square kilometers. The LR-USGS stream flow gauging station is ca. 400 m downstream from the junction of the West Prong of Little River (WPLR) (USGS 2005 as listed in the Appendix). Rock-lifting, without turning, was the standard methodology used for hellbender discovery for both surveys.

## Results and discussion

### North Fork of White River

The 4.6 km NFWR riverine and riparian habitats remained relatively stable between 1969 and 1980. The river followed the same streambed. The location of riffles with gravel, cobble, scattered rocks and embedded boulders remained in similar locations. Three exceptions to riverine and riparian habitat stability included a riparian clearing near a riffle located approximately 1.5 km downstream from the start of the 4.6 km research section for a new canoe ranch, the construction of a boat ramp and toilet facility by the Missouri Department Conservation (MDC) near a large riffle located approximately 0.2 km downstream from the start of the 4.6 km research section, and the loss of an alcove formed by a downed sycamore tree. Siltation from the canoe ranch development filled the interstitial gravel spaces within the adjacent riffle, as was evidenced by the location and sequential timing of the development and siltation events (Nickerson & Mays 1973 b). Interstitial space is essential in maintaining invertebrate populations which serve as food sources for many vertebrate species, including larval and adult *C. alleganiensis* (Cooper 1975, Nickerson et al. 2003, Pitt & Nickerson 2006). The MDC construction created a silted eddy below the boat ramp on the east bank, but siltation did not initially appear to fill the interstices of gravel within the huge riffle downstream.

One of the larger floods that occurred between 1944 and 1969 of the NFWR peaked at a mean daily flow of 18,500 cubic feet/second (cfs) five months before our mark-recapture study began in the spring of 1969 (Fig. 1) (USGS 2007a, b as listed in the Appendix). During late spring and summer 1969 and 1970 NFWR mark-recapture studies, rain was scarce, so the mean daily stream flow





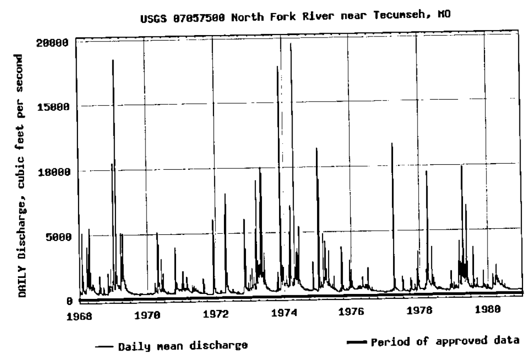


Fig. 1. Daily streamflow data from North Fork of White River near Tecumseh, MO, USA from 1 January 1968 to 31 December 1980 (source: USGS 2007b, see Appendix for web link).

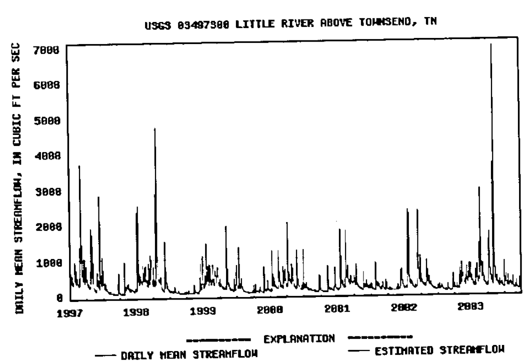


Fig. 2. Daily streamflow data from Little River above Townsend, TN, USA from 1 January 1997 to 1 October 2003 (source: USGS 2005, see Appendix for web link).

was low; 320 to 1,220 cfs in 1969 and 350 to 1,300 cfs in 1970 (USGS 2007a, b as listed in the Appendix). Sometime during the spring of 1970, a huge sycamore tree, *Planatus occidentalis*, located at the beginning of the 4.6 km research section, was swept outside of the section by a flood or floods. There were three flood peaks of mean daily stream flow (5100, 3700, 4200 cfs) before our late spring-summer studies began in 1970 (Fig. 1).

The possibility of substantial portions of the hellbender population being displaced, killed, or seriously injured by flooding seems logical. However, the 1969 NFWR mark-recapture studies produced estimates of a very large, dense, and healthy population of *C. alleganiensis* (428 individuals/km) just five months after the massive winter flood of 1969 (Nickerson & Mays 1973a,b). If any of the three minor, typical floods or the massive, atypical flood that all occurred shortly before our sampling caused substantial damage to individuals within this population, these injuries should be reflected in more physical abnormalities. However, only 14 of 479 individuals (2.9 %) examined during initial capture had any visible evidence of injury and all injuries were minor except for one individual missing a limb. Injury rates of 8 % (Wheeler et al. 2003), 12.5 % (Hiller et al. 2005), 25 % (n = 121) (Pfingsten 1990), and 25 - 43 % (Miller & Miller 2005) for hellbender populations in other rivers have been reported, suggesting that an injury occurrence value of 2.9 % is low. If large numbers of hellbenders were directly exposed to the turmoil of these floods, i. e., swept out from under tumbling rocks, a far higher number of major injuries would be expected. This hypothesis is further supported by the consistent hourly hellbender capture rate of eight to 12 *C. alleganiensis*/survey hour throughout the sampling period of 1969-1980 despite four subsequent massive floods that occurred during this time period (USGS 2007b as listed in the Appendix). Furthermore, population estimates of hellbenders occupying the same riffle in NFWR remained statistically similar in 1970 and 1978, using the Peterson-Lincoln method and pooled Jolly method analyses (Nickerson & Mays 1973a, Peterson 1979).

## Middle Prong of Little River

Adult hellbenders are usually observed in late summer during the annual draining of the GSMI-T seasonally dammed pool in MPLR, located upstream of our 2002 and 2003 survey sites. In 2002, eight survey person hours (PH) produced four gilled *C. alleganiensis* larvae (one each 2.00 PH) in MPLR. Despite the small sample size, our experience shows that eight hours of sampling on a stream with the dimensions of MPLR is sufficient to determine a reasonable index of population level. Additionally, this is a discovery rate better than that from Little River in 2000 (one *C. alleganiensis*/2.54 PH) with a more experienced survey group (Nickerson et al. 2002).

On 26 May 2003, a "storm of the century" reached the MPLR watershed. The Tennessee Valley Authority rain gauge at GSMI-T overflowed its 23.4 cm capacity. The resulting flood for the LR registered a record peak of almost 7,000 cfs mean daily stream flow at the nearby USGS stream recorder near Townsend, Tennessee (Fig. 2, USGS 2005). Residents near MPLR stated that the clashing of tumbling boulders created sounds like thunder.

After the 26 May flood, MPLR followed the same channel as before the flood, but sections were considerably modified by the removal or repositioning of large rocks and boulders, exposed bed-rock with recently gouged surfaces, damage to streamside vegetation and banks, and the scattered accumulation of gravel and sediment from a washed out road. The streambed appeared as if it had been scoured. It is difficult to believe that in such a torrent a hellbender could have escaped severe injury, death or being swept into the nearby WPLR and perhaps farther into LR. Even with marked individuals and population estimates one can never be certain that individuals in populations will be in the same area or even present during next year's field season. However, field studies have shown that hellbenders exhibit remarkable site fidelity with little individual movement and small home ranges (Ball 2001, Coatney 1982, Hillis & Bellis 1971 Humphries 1999, 2005, Nickerson & Mays 1973a,b, Peterson & Wilkinson 1996). Our NFWR survey data show that all recaptured individuals after the 1969-1970 summer tagging season were found in the same areas where they were originally tagged, and the last tagged recapture was on 15 October 1975. Additionally, when groups of hellbenders were found in an area, groups were located in those areas every year between 1969 and 1980. Further, the limited data on gilled and recently transformed larvae show only two gilled larvae (13.3%) found outside of a 92 m section of NFWR during the initial eight years of surveying and support restricted movement for larvae (Nickerson et al. 2003). Hellbenders can even be removed from a riffle for four months, exposed to stressful conditions, and successfully reestablish in the same riffle when returned (Nickerson 1980).

Following the 2003 May flood, 44.6 PH of surveying failed to produce any *C. alleganiensis* within MPLR. However, an adult hellbender within the 2003 survey section was observed out of the water on a rock at about 15:00 h on 24 August 2003 (K. Farmer pers. comm.). This hellbender had either survived the flood in MPLR, perhaps in the refuge of the dammed pool upstream, or had moved back into MPLR within the three months following the massive 26 May flood. Hellbenders have been known to move 990 m upstream within 11 days in NFWR, which has relief of less than a one m/km (Nickerson & Mays 1973a). The relief in MPLR is as much as 40 m/km; however, the confluence of MPLR with WPLR is less than 990 m from the confluence of WPLR with LR. Both confluences end at right angles with large deep pools nearby. These pools could serve as refuges for hellbenders after the onset of counter-currents reducing the speed and direction of stream flow (see Fig 1 in Nickerson et al. 2002). This hypothesis is supported by the discovery of three hellbenders within the pool created by the confluence of WPLR with LR during the 2003 (post-flooding) sampling season. Additionally, based on previous sampling, the section of LR immediately downstream from the WPLR/LR junction is an area of known *C. alleganiensis* concentration (Nickerson et al. 2002). The histogram of the LR population sample in Nickerson et al. (2002, Fig. 2A) has several missing or reduced age classes, as compared to that of the NFWR (Nickerson & Mays 1973a), which may indicate low or lack of recruitment during some years. Perhaps a more lengthy survey period could determine if these missing classes are absent. Recruitment from first and second order streams may be quite important in maintaining populations within some major river systems. The benthic structure of small, shallow first order streams such as MPLR may be quite susceptible to flood damage. We believe these data support the hypothesis that flooding modified by increased turbulence from substantial relief (<



Tab. 1. Table of stream characteristics of the North Fork of White River, Ozark County, MO, and Little River, Townsend, TN.

| | NFWR | MPLR |
|---|---|---|
| Non-flood discharge (cfs) | <2500 | <1500 |
| Minor or typical flood discharge (cfs) | 2500-10000 | 1500-4000 |
| Major flood discharge (cfs) | >10000 | >4000 |
| Relief (m/km) | 1 | 40 |
| Geology | Karst | Metamorphic |

40 m/km) of MPLR, which affected the benthic structure of the stream, is a potential factor in reducing recruitment of *C. alleganiensis* in this river system.

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**Appendix**

USGS web links referred to in text:

USGS 2005 (accessed 17 November 2005): http://waterdata.usgs.gov/tn/nwis/discharge?site_no=03497300&agency_cd=USGS&begin_date=1997-01-01&end_date=2003-10-01&format=gif&set_logscale_y=0&date_format=YYY-MM-DD&rdb_compression=file&submitted_form=brief_list

USGS 2007a (accessed 20 January 2007): http://waterdata.usgs.gov/nwis/dv?referred_module=sw&search_site_no=07057500&search_site_no_match_type=exact&state_cd=29&station_type_cd=Y______&index_pmcode_00060=1&sort_key=site_no&group_key=NONE&sitefile_output_format=html_table&column_name=agency_cd&column_name=site_no&column_name=station_nm&period=&range_selection=date_range&begin_date=1943-01-01&end_date=2007-01-20&format=gif&set_arithscale_y=on&date_format=YYYY-MMDD&rdb_compression=file&list_of_search_criteria=state_cd%2Csearch_site_no%2Cstation_type_cd%2Crealtime_parameter_selection

USGS 2007b (accessed 20 January 2007): http://waterdata.usgs.gov/nwis/dv?referred_module=sw&search_site_no=07057500&search_site_no_match_type=exact&state_cd=29&station_type_cd=Y______&index_pmcode_00060=1&sort_key=site_no&group_key=NONE&sitefile_output_format=html_table&column_name=agency_cd&column_name=site_no&column_name=station_nm&period=&range_selection=date_range&begin_date=1968-01-01&end_date=1980-12-31&format=gif&set_arithscale_y=on&date_format=YYYY-MM-DD&rdb_compression=file&list_of_search_criteria=state_cd%2Csearch_site_no%2Cstation_type_cd%2Crealtime_parameter_selection

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