Swimming against the tide: resilience of a riverine turtle to recurrent extreme environmental events

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Swimming against the tide: resilience of a riverine turtle to recurrent extreme environmental events

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Extreme environmental events (EEE) are likely to exert deleterious effects on populations. From 1996-2012 we studied the nesting dynamics of a riverine population of painted turtles (*Chrysemys picta*) that experienced seven years with significantly definable spring floods. We used capture-mark-recapture methods to estimate the relationships between >5-m and >6-m flood events and population parameters. Contrary to expectations, flooding was not associated with annual differences in survival, recruitment, or annual population growth rates of the adult female segment of the population. These findings suggest that female *C. picta* exhibit resiliency to key EEE, which are expected to increase in frequency under climate change.

**Keywords:** turtles; population alteration; climate change; floods; *Chrysemys picta*
1. INTRODUCTION

Extreme environmental events (EEE), including major floods, droughts, fires, and hurricanes, are expected to increase in frequency with climate change [1]. Such EEE can unpredictably impact populations of many organisms [2]. Biological responses to past EEE range from transient (e.g. loss of three-quarters of the bird population during a ten-week period of severe cold and persistent snow cover in England during 1962-1963; [3]) to persistent (e.g. extirpation of some desert plant populations in response to a severe, four-year drought; [4]). Recent studies notably have indicated persistent alterations in amphibian and reptile populations---many already imperiled by anthropogenic activities---purportedly due to climate change [5,6].

Although EEE are predicted to increase in frequency with climate change [1], in most scenarios they cannot be anticipated. Thus assessing the biological impacts of EEE typically requires fortuitous information collected on populations during or after such events [2]. Moreover, although most studies that assess the effects of single EEE provide insightful information, repeated events should provide the most robust assessment of the impacts of EEE on population biology. Long-term field studies during which multiple EEE have occurred are one source that can provide this critical information.

We have marked painted turtles (Chrysemys picta) at a study site along the Mississippi River beginning in 1995. Since then, seven EEE (i.e. major floods) have been documented, and increased frequency of substantial flooding in this region is expected under climate change [7]. Painted turtles typically inhabit still wetlands and thus would rarely experience the dramatic flow rates of floods (figure 1), which can damage biota and habitat considerably [8]. Although adult females are generally philopatric [9], we hypothesized that EEE would alter the population of C. picta. Specifically, we predicted that a flood occurring just before the crucial nesting season would yield fewer marked turtles returning to nest at this site because many would be swept
downstream. We also predicted an increase of “new” or unmarked (non-primiparous) turtles at the site because many non-resident turtles would be swept into the population from upstream. In other words, we hypothesized that we would observe lower survival, recruitment, and lambda in years with flooding if these EEE exert immediate negative effects. Falsification of these hypotheses would suggest these turtles exhibit substantial resiliency to such EEE.

2. MATERIAL AND METHODS

(a) Field methods

We collected nesting data on *C. picta* from late May to late June in 1995-2012 at the Thomson Causeway in Thomson, IL [10]. During this period, seven years (1996-1998, 2001, 2002, 2008, 2011) experienced significantly definable spring floods (any time from 1 March to 31 May; figure 1). A significant flood in that area is defined as water level > 5 m [11]. We captured *C. picta* on the main beach after nesting to assess if they were already marked or, if unmarked, whether they were primiparous or new to the population [10]. We uniquely marked all unmarked turtles that we captured by filing notches into different combinations of marginal scutes [12].

(b) Data analyses

We analyzed capture-mark-recapture records for nesting turtles using a reverse-time estimator [13] in Program Mark [14]. We used this approach to estimate four parameters: annual survival, recruitment (the annual per-capita rate of new individuals entering the population), lambda (the annual growth rate for the adult female segment of the population), and detection (the probability that an adult female was captured given that she was still alive). The analyses included hyper-parameters to account for inter-dependence among individuals within a year [15,16]. We estimated effects for survival and detection using a logit-link function and for recruitment and
lambda using a log-link function. Hence, parameter values were on these scales and credible intervals for flood effects were used to make inferences.

We performed analyses in Program Mark using two classes of flooding. In the first analysis, flood events were indicated when water level ≥ 5 m. The second analysis considered extreme flooding events as water level ≥ 6 m. To evaluate long-term changes in spring flood incidence, we used chi-square tests to compare the frequencies of flood events during our study period (1996-2012) to those during the previous 57 years at our study site. All water level data were collected ~1 km from our study site [11].

3. RESULTS

From 1995 to 2012, we captured an average of 168 unique nesting painted turtles each year (range = 80-301) of which an average of 118 were recaptures of previously marked animals (range = 28-205). The long time period of this study and large samples provided a rich dataset for assessing annual patterns in nesting biology.

Spring floods, which always began in April, lasted 3-35 d. Onset of the nesting season was delayed 11 d on average in flood years, and any turtles swept downriver had 59 d on average to return to the field site to nest before the season ended on 30 June.

Credible intervals for the effects of flooding on all parameters widely overlapped 0. In the case of survival and lambda for both flood levels and of recruitment for the 5-m flood level, the mean posterior values for a flood effect were, in fact, positive (Table 1). The nesting population generally increased during the study, with lambda > 1 in 12 of the years and overall high survival and steady recruitment (figure 2). The only episode of steady decline occurred between 2003 and 2008, a time during which no extreme flooding events were observed.
During the 16-year study period, our site experienced four extreme spring flooding events (25%), whereas only eight extreme spring floods occurred during the previous 57 years (14%). Although this result suggests an increase in the frequency of extreme floods over time, these patterns did not differ significantly ($\chi^2 = 1.59, p = 0.207$). Less extreme floods also did not occur more frequently in recent years than in the past ($\chi^2 = 0.25, p = 0.621$).

4. DISCUSSION
Our long-term field study reveals a notable resiliency of adult female painted turtles to EEE. The population of nesting turtles was repeatedly unchanged even after major floods just prior to the nesting season. Since aquatic displacement of adult female painted turtles > 3 km reduces successful homing behavior by > 75% [9], our results suggest that most turtles probably took refuge in low-current locations during floods to avoid substantive displacement.

Aquatic turtles appear resilient in harsh environments (e.g. [17]). Although events such as freezing [18] can induce significant mortality, the iconic individual longevity of turtles could help buffer their populations from adverse effects of such EEE [19]. Since first appearing in the Triassic, turtles as a lineage have repeatedly survived numerous global cataclysms, yet most extant turtle species appear on the IUCN Red List [20] and EEE are expected to increase in frequency with climate change [7], which will challenge their historical resiliency.

This study addresses the influence of a particular short-lived EEE---flooding---and may not reflect the biological impact of another type of EEE on these or other turtle populations. For example, extreme heat can reduce hatching success and fully skew offspring sex ratio [21], which subsequently impact population size and structure [10]. In addition, flooding events during other times of the year (e.g. egg-incubation season) dramatically affect population recruitment.
Flooding effects on turtles

(e.g. [21,22]) by reducing egg survival. The work reported here is observational and we do not know how these floods affect juveniles and males, energy expenditure during increased flow rates, turtle predators and prey, or organisms that are not as well adapted to an aquatic environment. Nevertheless, the multiple spring flooding events that occurred during our long-term study provided a rare and unmatched opportunity to rigorously evaluate how this EEE might contribute to population dynamics. Indeed, other types of major weather events can substantially affect migration in other taxa [23].

Our findings offer hope that chelonians may be more resistant to at least some environmental and anthropogenic changes than traditionally feared. A growing body of research suggests that many turtle populations may express phenotypic plasticity or heritable variation in particular traits that permits co-existence with a range of human activities in altered environments (e.g. [12,24,25]). Even so, no population can endure when habitats are rapidly and thoroughly destroyed, which is perhaps the gravest threat to the long-term persistence of these venerable creatures and other organisms.

We thank the Janzen Lab and Turtle Camp crews who gathered these data over the past two decades. We also thank the U.S. Army Corps of Engineers and Illinois Department of Natural Resources for permission to work at the field site and the Iowa State University Committee on Animal Care for permission to study the turtles. The research was funded by NSF LTREB grants DEB-0089680 and DEB-0640932.


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Flooding effects on turtles


Flooding effects on turtles


Table 1. Estimates of parameters for a riverine population of adult female painted turtles in the context of definable spring flood events, 1995-2012. Data were analyzed using reverse-time capture-mark-recapture estimators fit using MCMC methods. Effects for survival and detection are on a logit scale and for recruitment and lambda are on a log scale. Positive estimates indicate that the parameter was greater in flood years than in non-flood years.

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Figure 1. Water level and flow rate of the Mississippi River at the study site, 1996-2012. Water level (solid line) is the maximum height reached during 1 March to 31 May. Flow rate (dotted line) is the average measured during a flood event or the average during April and May in non-flood years. The horizontal line represents the water level at flooding (5 m) in this area [11].

Figure 2. Annual estimates of survival, recruitment, lambda, and detection for a riverine population of adult female painted turtles, 1995-2012. Plotted results represent mean posterior values and 95% credible intervals obtained from a model in which 5-m flooding was included as an effect. Years with flooding >5 m (but <6 m) are denoted by * and those with >6 m by +.
Water level and flow rate of the Mississippi River at the study site, 1996-2012. Water level (solid line) is the maximum height reached during 1 March to 31 May. Flow rate (dotted line) is the average measured during a flood event or the average during April and May in non-flood years. The horizontal line represents the water level at flooding (5 m) in this area [11].

215x279mm (300 x 300 DPI)