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SOURCES OF MORTALITY IN THE ENDANGERED EASTERN MASSASAUGA (*SISTRURUS CATENATUS*) IN ILLINOIS

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***Abstract.*—The identification and management of threats to endangered species are imperative for conservation. Reptile populations are declining globally, yet their secretive nature and a lack of demographic data often make the implementation of conservation strategies difficult. The Eastern Massasauga (*Sistrurus catenatus*) has been recommended for listing as threatened under the federal endangered species act and listed in Illinois as endangered since 1994. As part of a long-term population monitoring project, we quantified sources of mortality in a population of the Eastern Massasauga using data collected from 2000–2011. Using mortality data amassed during both observational and radio-telemetry studies (2001–2003 and 2009–2011), we classified each mortality event into one of eleven categories. We used Poisson regression to evaluate the impacts of sex, stage-class, season, and study type on mortality. Our results indicate automobiles and predation are the leading sources of mortality, together accounting for over 50% of observed mortalities. We found season and mortality category significantly affected the number of observed mortalities. Most mortalities occur in the summer and fall when snakes are most active. Observational studies detected nearly all the automobile mortality while radio-telemetric studies detected nearly all the predation events. We offer conservation and management recommendations to reduce Eastern Massasauga mortality at Carlyle Lake, which are applicable throughout the range.**

Key Words.—conservation; management; rattlesnake; reptile

INTRODUCTION

Conservation of endangered species relies heavily on our ability to identify causes of population decline, past, present, and future, and effectively manage threats (Norris 2004). In the case of worldwide reptile populations, six significant threats have been identified: habitat loss and degradation, introduced invasive species, environmental pollution, disease, unsustainable use, and global climate change (Gibbons et al. 2000). For snakes, habitat loss and fragmentation have been cited as the most significant population threats (Dodd 2001). Human-induced changes in the landscape can impact mortality rates directly but may also have other effects. Rattlesnakes living in disturbed habitats (such as those altered for human use) have been found to display poorer body condition than those living in less disturbed areas (Jenkins et al. 2009). Poor body condition can lead to decreased fecundity, increased susceptibility to disease, and mortality (Naulleau and Bonnet 1996; Metcalfe and Monaghan 2001; Beldomenico et al. 2008). Thus, when managing individual populations of a single species, it is necessary to determine the exact mechanisms by which mortality is occurring to combat significant threats most effectively.

Mortality risk may differ between sexes, may change ontogenetically, or may vary seasonally (Plummer 1990; Mushinsky and Miller 1993). If mortality is biased toward one sex or age class it could reduce recruitment and impact population dynamics (Mushinsky and Miller 1993). Seasonal mortality differences in temperate reptiles may be expected because of differing threats during the active/inactive seasons (Sperry et al. 2010). Venomous snakes may be subject to further anthropogenic mortality sources given the high degree of ophiophobia in the general public (Burghardt et al. 2009).

The Eastern Massasauga (*Sistrurus catenatus*) is a small rattlesnake which ranges from Ontario, Canada, to southern Illinois, USA, and extends east to northwestern Pennsylvania and New York, USA. It occurs primarily in wet prairie or marsh/bog habitat (Ernst and Ernst 2003). The Eastern Massasauga was added to the Illinois state endangered species list in 1994 (Herkert 1994) and has been recommended for listing as threatened under the federal Endangered Species Act (US Fish and Wildlife Service [USFWS] 2015). The largest remaining Illinois population occurs on a small area of highly fragmented habitat surrounding Carlyle Lake, Clinton County (see Dreslik 2005 for a detailed description of study site). We have been monitoring the population continuously since 1999, and using the resulting long-term data set, we identified the most significant sources of mortality and tested for significant differences due to sex, stage-class, season, and study design. This information can be used when making management decisions to allocate limited time and money toward reducing the most significant threats.

TABLE 1. Mortality categories used when documenting Eastern Massasauga (*Sistrurus catenatus*) mortality events at Carlyle Lake, Clinton County, Illinois, USA.

Mortality Category	Description
Automobile	Individuals found dead on roads with obvious evidence of vehicular trauma
Predation	Individuals found whole or in pieces with signs of predator activity (bite/claw marks, partially eaten, radio transmitter found in scat or inside predator)
Died in Captivity	Individuals that died of natural causes while housed in a captive setting
Euthanized	Sick or injured animals brought into captivity and humanely euthanized by a veterinarian
Illness	Individuals that died of disease (determined by a wildlife veterinarian)
Management	Individuals killed inadvertently during habitat management activities (mowing grass, controlled burns), and found by or reported to the authors
Other	Cause of death was something other than the listed categories
Persecution	Individuals killed purposely by humans
Stillborn	Individuals dead at birth born to females held in captivity
Surgical Complications	Individuals that died post-surgical implantation or removal of a radio-transmitter
Unknown	Individuals whose cause of death could not be determined

MATERIALS AND METHODS

We collected dead snakes from the Carlyle Lake population in Clinton County, Illinois, from 2000–2011 while conducting visual encounter surveys (VES), radio-telemetry (2001–2003 and 2009–2011), and while driving on roads. We classified study type as telemetry for mortality of individuals implanted with radio-transmitters and observational for mortalities encountered during VES and while driving on roads. For each dead individual, we recorded date, GPS coordinates, stage (adult or juvenile), sex (when possible), and determined if it was an individual we had captured previously. We determined sex by subcaudal scale count, cloacal probing, or by the presence of visible everted hemipenes. Stage-class was categorized as either adult or juvenile based on the minimum size of reproduction for males (49.7cm; Jellen et al. 2007) and females (48.4cm; Dreslik et al., In press). We classified season by periods of biological significance rather than calendar seasons. Thus, we considered the spring egress period (March to April) as Spring; end of egress to end of birthing season as Summer (May to August); post birthing season to ingress as Fall (September to November); and Winter we considered as December to February, the months most snakes are typically hibernating. We classified each mortality as one of 11 types (Table 1). All salvaged individuals were deposited in the Illinois Natural History Survey Amphibian and Reptile Collection.

To determine what factors influenced the number of observed mortalities, we collapsed our original 11 categories into five based on similarity. The five simplified categories are Automobile, Predation, Illness (combined died in captivity, euthanized, illness), Human (combined management and persecution), and Other (combined other and unknown). We omitted stillborn and surgical complications from analysis because they are unique to specific stage classes. We used Poisson regression in R (R Core Team 2015) to determine if sex, stage-class, season, or study type (telemetry or observational) significantly impacted observed mortality. We evaluated candidate models using AIC (Burnham and Anderson 2002) and included a null model (intercept only), a global model (all main effects), all single effects models, and all two effects models.

RESULTS

We recorded 156 instances of mortality over 11 y. Of these, 68 could be positively identified as males and 65 as females. We were able to classify 79 individuals as adults and 70 as juveniles. We encountered 70 mortalities during radio-telemetric studies and 85 during observational studies. There were 27 mortalities observed in the Spring, 64 during the Summer, 54 during the Fall, and nine during the Winter (Table 2). Overall, automobiles were the leading cause of mortality, accounting for 32% of all observed mortalities. Predation was the second greatest threat, accounting for 22% of observed mortality. All other categories each contributed < 15% to overall mortality (Table 2; Fig. 1). Although observed mortalities from automobiles and predation were overall numerically similar, they were detected disproportionally depending on study type. Automobile mortality accounted for only 1% observed during telemetry studies, and predation accounted for only 1% of mortalities observed during observational studies (Fig. 1). Of the 17 candidate models evaluated, the top model included terms for season and mortality type and carried an Akaike weight of 0.77 (Table 3; model parameter estimates Appendix). Seasonally, mortality is more likely to occur in the summer and fall, and automobiles cause the highest number of mortalities (Table 2). However, adults and juveniles die in equal numbers, as do males and females. Type of study being conducted does not change the number of mortalities detected, but it does change the type of mortality most likely to be observed (Fig. 1).

TABLE 2. All Eastern Massasauga (*Sistrurus catenatus*) mortalities observed from 2000–2011 at Carlyle Lake, Clinton County, Illinois, USA, by group type. Not all classifications of sex (M = male, F = female) or stage (Adult, Juvenile) sum to overall total due to difficulty determining sex or stage in some cases. The abbreviations Observ = observational.

Type of Mortality	Overall	M	F	Adult	Juvenile	Telemetry	Observ	Spring	Summer	Fall	Winter
Automobile	49	28	17	28	18	1	48	3	26	20	0
Predation	34	20	12	18	15	33	1	5	10	19	0
Died in Captivity	1	0	1	0	1	0	1	0	0	1	0
Euthanized	5	2	3	5	0	3	2	1	2	1	1
Illness	10	3	7	8	2	7	3	3	4	0	2
Management	9	3	3	4	3	2	7	5	2	2	0
Other	19	5	10	5	14	11	8	2	8	4	5
Persecution	1	1	0	0	1	0	1	0	0	1	0
Stillborn	8	0	1	0	8	0	8	0	8	0	0
Surgical Complication	6	2	3	6	0	6	0	2	2	2	0
Unknown	13	4	7	5	8	7	6	6	2	4	1
Total	155	68	64	79	70	70	85	27	64	54	9

DISCUSSION

Sources of mortality.—Our study shows automobiles are a significant threat to the Eastern Massasauga population at Carlyle Lake. Snakes may be found on roads either because they are using them to thermoregulate or crossing them to move between habitat areas. Roads may be tempting basking sites for snakes because the pavement absorbs heat quickly and retains it longer than the surrounding environment (Shine et al. 2004). Experiments using Timber Rattlesnakes (*Crotalus horridus*) have found venomous snakes cross roads more slowly than non-venomous species and also become immobile when vehicles approach (Andrews and Gibbons 2005). Additionally, the number of roads present at Carlyle Lake and the high traffic volume (the area receives 700,000 to 1,000,000 visitors annually) likely contribute to the number of automobile deaths. Snakes are abhorred by much of the general public, and a study using model snakes placed on roads found most people will go out of their way to purposely run over snakes when they encounter them (Langley et al. 1989; Ashley et al. 2007).

The high degree of habitat fragmentation created by roads around Carlyle Lake means snakes are either forced to cross roads when searching for mates, suitable foraging, and hibernation sites or remain restricted to one habitat patch. Crossing roads could result in mortality while staying in one habitat patch restricts gene flow between patches, which may reduce population viability (Epps et al. 2005; Shepard et al. 2008b). Studies of reptile road mortality around Carlyle Lake found road mortality of Eastern Massasaugas was biased towards males, the highest mortality rates coincided with the mating season (Aldridge et al. 2008; Shepard et al. 2008a), and Eastern Massasaugas crossed roads less frequently than expected by chance (Shepard et al. 2008b). Roads also increase the amount of edge habitat present at a site. The density of mesopredators, such as Raccoons (*Procyon lotor*) and Long-tailed Weasels (*Mustela frenata*), has been shown to be positively correlated with the amount of edge habitat (Gehring and Swihart 2003).

Predation was the second most common cause of mortality in all groups, although predation is likely underrepresented in our data. In the case of radio-implanted individuals, if the predator eats the entire snake and moves out of range, we cannot confirm the fate, and for non-telemetered animals, evidence of predation is not available. It is also difficult to locate partially consumed animals in grassland habitat during VES surveys, and clearly, we do not find the majority of carcasses. Potential predators present at Carlyle Lake include small mammals, birds of prey, and other snakes. Mammals, including Coyotes (*Canis latrans*) and feral House Cats (*Felis catus*), have been positively identified as predators of snakes (Whitaker and Shine 2000; Kapfer et al. 2008), and while other small carnivores also likely consume snakes, they could be difficult to identify unless the predation event is witnessed. Four confirmed cases of predation of Eastern Massasaugas by other snake species have been observed at Carlyle Lake, indicating other snakes present at the site may represent a significant threat to Eastern Massasaugas (Sarah Baker and Daniel Wylie, pers. obs.). Predation by other snakes has also been observed in Green Snakes (*Opheodrys aestivus*; Plummer 1990), and was suggested as a possible factor in the documented decline of the Eastern Kingsnake (*Lampropeltis getula*) at a protected site in South Carolina (Winne et al. 2007), indicating intra-guild predation may play a more significant role in population dynamics than previously known. We have one confirmed case of avian predation (Eastern Screech Owl, *Megascops asio*) at Carlyle Lake, although many other avian species capable of killing Eastern Massasaugas inhabit the site. Predation by American

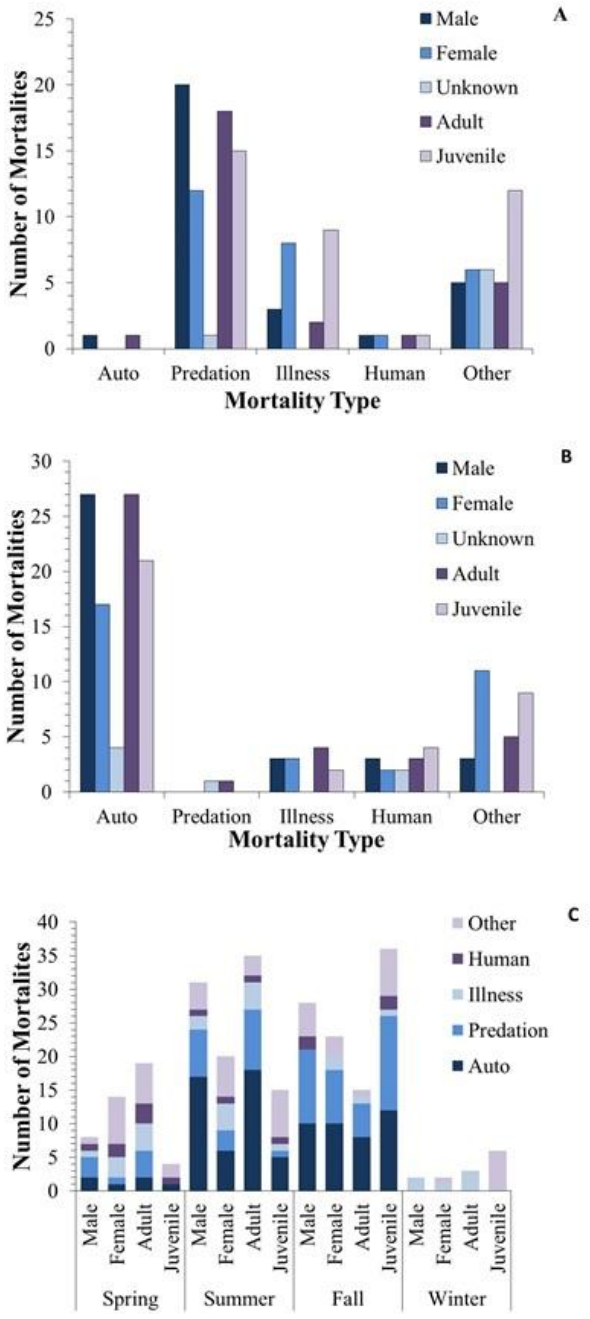

FIGURE 1. Eastern Massasauga (*Sistrurus catenatus*) mortality at Carlyle Lake, Clinton County, Illinois, USA, by sex (male, female, or unknown) and stage (adult or juvenile) for mortality documented during telemetry studies (A); mortality documented during observational studies (B); and mortality documented during each season (C).

Crows (*Corvus brachyrhynchos*) has been identified as the largest source of mortality in a population of Red-sided Gartersnakes (*Thamnophis sirtalis parietalis*) in Manitoba, and predation by hawks has also been observed at the same site (Shine et al. 2001).

TABLE 3. Candidate models tested to explain mortality in the Eastern Massasauga (*Sistrurus catenatus*) at Carlyle Lake, Clinton County, Illinois, USA, from 2000–2011.

Model	K	AICc	ΔAICc	w_i
Season+MortType	8	413.83	0	0.77
Global	11	416.26	2.42	0.23
Stage+Season	5	443.22	29.38	0.00
Season	4	443.75	29.92	0.00
Season+StudyType	5	444.27	30.44	0.00
Sex+Season	5	445.75	31.92	0.00
Stage+MortType	6	458.49	44.65	0.00
MortType	5	458.99	45.16	0.00
StudyType+MortType	6	459.54	45.71	0.00
Sex+MortType	6	461.02	47.19	0.00
Stage	2	488.63	74.79	0.00
Stage+StudyType	3	489.09	75.26	0.00
Null	1	489.24	75.41	0.00
StudyType	2	489.68	75.85	0.00
Sex+Stage	3	490.57	76.74	0.00
Sex	2	491.16	77.33	0.00
Sex+StudyType	3	491.63	77.79	0.00

Management related activities around Carlyle Lake include mowing along roadsides and other man-made structures, prescribed burns for woody vegetation control, and chemical and mechanical treatments of invasive plant species. These activities are necessary to maintain habitat suitable for the Eastern Massasauga but can also pose significant risks. Direct mortality from exposure to fire, contact with mower blades, and crushing under implement tires have been documented in an Eastern Massasauga population in Missouri (Durbian 2006). These activities have also been found to increase predation risk, specifically by reducing cover sites and attracting avian predators (Durbian 2006). It has been suggested Eastern Massasaugas inhabiting prairie/grassland habitats, such as that found at Carlyle Lake, are more vulnerable to management mortality (especially from fire) than those in wetland/bog habitats further north in their range (Cross et al. 2015).

Disease documented in Carlyle Lake Eastern Massasaugas is primarily attributed to infection by the fungus *Ophidiomyces ophidiicola* (snake fungal disease; SFD). Snake fungal disease was first recognized in the population in 2008, but retrospective investigation of museum specimens has indicated its presence in the population at least since 2000 (Allender et al. 2011; Allender et al. 2016). Snake fungal disease has been confirmed in both venomous and non-venomous snake species in the eastern United States (Guthrie et al. 2016) and causes primary mortality in the Eastern Massasauga

(Allender et al. 2011). Other less frequently encountered diseases in the population include tumors and bacterial infections.

Factors explaining mortality.—Season and study type were both included in the top model. Fewer mortalities are observed in the spring and winter when snakes are less active due to colder temperatures. Minimum active body temperatures recorded for Eastern Massasaugas at Carlyle Lake range from 4.1–8.8° C (Dreslik 2005). Movement is restricted at these temperatures and individuals are usually associated with refugia (Dreslik 2005), making them less vulnerable to predators. However, we have recorded cases of neonate Eastern Massasaugas failing to enter burrows for hibernation and succumbing to the elements, as well as failing to emerge from hibernation during egress.

Type of study also influenced recorded sources of mortality. The majority of our observational automobile mortalities were encountered concurrently with a radio-telemetry study (see Shepard et al. 2008a for methods). Although only one radio-implanted individual was killed crossing a road, 48 non-radioed individuals were killed on roads during the study. In contrast, only a single predation mortality was reported from observational data, the remaining 33 coming from radio-telemetry. These data suggest a potential bias in which observational studies under-detect cases of predation and radio-telemetric studies under-detect automobile caused mortality. Road mortality could also be impacted by unknown biases in the individuals chosen for transmitter implantation as some are behaviorally more inclined to move or cross roads (Fraser et al. 2001; Sih et al. 2004). Alternatively, it could indicate an aversion to roads in which the low proportion of radio-implanted snakes killed crossing roads is representative of the population (Shepard et al. 2008b). Similar results were reported for Eastern Massasaugas in Michigan in which radio-telemetry recorded only one mortality (depredation), but three automobile deaths of non-telemetered snakes were reported to researchers over a short time frame (Bailey et al. 2011). Thus, both methods of study are required to obtain the most accurate mortality data for a population. This is especially important for species in need of conservation.

Conservation/management recommendations.—It is important to quantify mortality in species in need of conservation so significant threats can be identified and managed. We suggest several management actions to reduce mortality, applicable not just at Carlyle Lake but throughout the range of the species. Automobiles: To manage these threats, we echo the conservation recommendations made by Shepard et al. (2008a) to create unfragmented habitat and use seasonal closure of non-essential roads to reduce the impact of vehicle traffic. The precedent for road closures exists as seasonal road closures are used in Southern Illinois to protect snakes moving between hibernation sites and foraging areas in the La-Rue/Pine Hills Ecological Area (Ballard 1994). For essential roads that cannot be closed, road mortality hotspots can be identified (Langen et al. 2009). Ecopassages under roadways or informational signage have shown some potential to reduce reptile road mortality in Canada (Baxter-Gilbert 2014), and their evaluation for use elsewhere is warranted.

Predation: While predation will never be eliminated, steps can be taken to reduce the number of predators. Mesocarnivore release has resulted in an increase in populations of predators such as Raccoons (Ritchie and Johnson 2009). Because the Eastern Massasauga population is located mainly on state and federal land, existing furbearer hunting/trapping programs could be expanded to include these areas. Hunting programs for White-tailed Deer (*Odocoileus virginianus*), Turkey (*Meleagris gallopavo*), and Ring-necked Pheasant (*Phasianus colchicus*) already occur at Carlyle Lake and have not resulted in any known negative interactions between hunters and rattlesnakes.

Disease: Wildlife disease is becoming an increasingly challenging problem in conservation biology. Previously, Eastern Massasaugas in Illinois have tested negative for West Nile Virus but seropositive for ophidian paramyxovirus (OMPV; Allender et al. 2006). No known mortality has resulted from OPMV (Allender et al. 2006), but SFD has been documented to cause mortality and occurs at a prevalence rate of 14–22% (Allender et al. 2016). Investigations into treatment options for SFD-positive individuals are ongoing (Mathew Allender, pers. comm.), and land managers should report any individual Eastern Massasaugas displaying unusual behaviors (basking on roads, remaining on the surface during typical hibernation times, etc) or with clinical signs so they may be tested for SFD and treated when possible. To limit the potential of human-mediated spread of SFD, individuals involved in land management activities or research should disinfect footwear and equipment when moving between sites. Continued monitoring for SFD and other emerging diseases should be included in conservation planning.

Management: Management related mortalities, while only accounting for a small percentage of overall mortality, are easily preventable. At Carlyle Lake, management activities such as prescribed fire and mowing have resulted in Eastern Massasauga mortalities. To eliminate management mortality, we recommend burns be conducted prior to spring emergence on cold, cloudy, winter mornings when snakes are hibernating (Dreslik 2005; Durbian 2006; Cross et al. 2015). Mowing of roadsides and recreation

areas should be done frequently to keep the grass short and discourage snakes from occupying these areas. Traditional mowers can create a slight vacuum effect injuring snakes below the blade height; thus any mowing that must be done directly through Eastern Massasauga habitat should use a sickle bar or disk mower which does not create a vacuum (Durbian 2006). Additionally, mowers with a wide wheel base will require fewer passes and reduce the probability of crushing snakes under implement tires (Durbian 2006).

Persecution: Snakes, especially venomous species, are typically despised and feared by the general public (Burghardt et al. 2009), and while we have documented only one known mortality resulting from human persecution, this category is likely under-reported. It is unknown how many people find and kill Eastern Massasaugas on private property, but local residents often boast about these activities. Education and outreach programs are the most effective means of changing attitudes to reduce persecution related mortality (Burghardt et al. 2009).

Surgical complications: This category is caused solely by research activities associated with radio-transmitter implantation. At Carlyle Lake, we have discontinued all research involving surgical implantation of radio-transmitters to eliminate such mortalities. Annual survival rates for Illinois Eastern Massasaugas calculated using radio-telemetry data were low (0.35; Jones et al. 2012) when compared to adult survival calculated with mark/recapture data (0.809–0.995; Michael Dreslik et al., unpubl. data). We recommend the need for any future radio-telemetry projects on the Eastern Massasauga be carefully weighed against the risk of mortality, or use less invasive methods such as externally attached transmitters. As many threatened and endangered species persist in small isolated populations vulnerable to environmental and demographic stochasticity, the identification and mitigation of threats is critical for their conservation. Long-term data sets for the Eastern Massasauga are invaluable and serve as a guide for targeted conservation actions range-wide.

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APPENDIX. Parameter estimates for the top model explaining mortality in the Eastern Massasauga (*Sistrurus catenatus*) at Carlyle Lake, Clinton County, Illinois, USA.

	Estimate	Std Error	z-value	*P*	Lower confidence limit	Upper confidence limit
Intercept	0.77	0.19	4.12	0.00	0.39	1.13
Season:Spring	-0.76	0.26	-2.94	0.00	-1.28	-0.27
Season:Summer	0.02	0.21	0.10	0.92	-0.38	0.42
Season:Winter	-2.24	0.47	-4.76	0.00	-3.30	-1.42
Mort type:Predation	-0.34	0.23	-1.47	0.14	-0.80	0.11
Mort type:Human	-1.86	0.41	-4.58	0.00	-2.75	-1.13
Mort type:Illness	-1.17	0.31	-3.82	0.00	-1.80	-0.59
Mort type:Other	-0.63	0.25	-2.49	0.01	-1.14	-0.14

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