

**WOOD TURTLE ECOLOGY AND MANAGEMENT STRATEGIES IN A
LANDSCAPE UNDER ACTIVE AGRICULTURE**

by
Shaylyn Wallace

**Hr BSc Environment and Natural Resources,
University of New Brunswick 2017**

A Thesis Submitted in Partial Fulfillment
of the Requirements for the Degree of

MScEM

in the Graduate Academic Unit of Forestry and Environmental Management

Supervisor: Graham Forbes, PhD, FOREM, Biology

Joseph Nocera, PhD, FOREM

Examining Board: Loic D'Orangeville, PhD, FOREM

Chris Edge, PhD, Canadian Forest Service

This thesis is accepted by the
Dean of Graduate Studies

THE UNIVERSITY OF NEW BRUNSWICK

February, 2020

©Shaylyn Wallace, 2020

ABSTRACT

I investigated the habitat selection of wood turtles (*Glyptemys insculpta*) in a landscape within active agriculture and assessed the risk of agricultural practices. I tracked 23 wood turtles and recorded their habitat use versus availability on a 3rd and 4th order scale. I found that wood turtles preferred fields over the forest and that hay fields are likely an attractant to wood turtles due to high food availability and low canopy cover. Wood turtles used the hayfields during the hay harvest season, and stayed close to field edges. I monitored the movement response of wood turtles as they were approached by agricultural machinery and found that most turtles could not successfully escape the mower. My study shows that agriculture poses a high risk to wood turtles in an agricultural landscape and management strategies are necessary to prevent populations from extirpation.

ACKNOWLEDGMENTS

I would first like to thank my co-supervisors, Dr. Graham Forbes and Dr. Joe Nocera, for all their guidance and help throughout my project. Special thanks to my field staff, Bethany Crossfield and Abbey Greer, for their great note taking, and positive work ethic and to Katie Moore for her work in 2017.

This work would not have been possible without the help of the landowners who let me conduct my field work on their land and use their equipment for my experiments. Thanks to Deanna McCullum for helping me conduct research at Base Gagetown and Jae Ogilvie for his GIS guidance. Thank you to the Department of Natural Resources and Energy Development, particularly Maureen Toner, and the Nature Trust of New Brunswick for their support and help with field work. The work also could not have been possible without the financial support of the Habitat Stewardship Program from Environment & Climate Change Canada.

My biggest support system throughout all of this has been my lab mates in the Nocera and Forbes labs, especially Cole Arsenault, Delaney Brooks, and Douglas Munn. Thank you all for input on statistical analysis, comments on my manuscripts, and keeping me sane with much needed breaks throughout my project. The past two years would have gone by much slower without all your help! Finally, thank you to my family for their love and support throughout these last two years. I would not have been able to do this without you!

Table of Contents

ABSTRACT ii

ACKNOWLEDGMENTS iii

List of Tables vii

List of Figures ix

Chapter 1: General Introduction..... 1

1.1. Literature Cited 13

Chapter 2: Habitat selection, movement, and food availability of wood turtles (*Glyptemys insculpta*) in an agri-forested landscape..... 19

2.1. Abstract 19

2.2. Introduction 20

2.3. Methods..... 22

2.4. Results..... 29

2.5. Discussion..... 39

2.6. Literature Cited..... 45

Chapter 3: Relationship of wood turtle behaviour to agricultural practices 51

3.1 Abstract 51

3.2. Introduction 52

3.3. Methods..... 56

3.4. Results.....	61
3.5. Discussion.....	69
3.6. Management.....	75
3.7. Literature Cited.....	78
Chapter 4: Conclusion	84
4.1 Overview of Thesis	84
4.2 Management.....	85
4.3 Future Study Recommendations.....	90
4.4 Literature Cited.....	91
Appendix A: Experimental Assessment of the Impact of Agricultural Machinery on Wood Turtles (<i>Glyptemys insculpta</i>)	94
A.1. Abstract.....	94
A.2. Introduction.....	95
A.3. Materials and methods	98
A.4. Results	101
A.5. Discussion	103
A.6. Management.....	106
A.7. Literature Cited	108

Appendix B: Habitat selection model outputs for male and female wood turtles 120

Appendix C: Individual home ranges for each radio tagged wood turtle at the study site, using the minimum convex polygon and adaptive kernel method in 2018. 124

Appendix D: Percent of turtle relocations (n=723) within each habitat type compared to the percent of habitat available at the study site in 2018..... 125

Appendix E: Individual wood turtle measurements, notch code, sex and age at the study site. 125

Appendix F: The number of photos captured per predator species at an agricultural (Site A) and forested (Site B) landscape from trail cameras installed along a 2-km stretch of river. Cameras were set up from May 31-October 29, 2018 and a total of 49, 320 hours were recorded..... 128

Curriculum Vitae

List of Tables

Table 2.1. Definitions used to classify habitat types at my study site.	22
Table 2.2. Distance of male and female wood turtle relocations to the main river during May-September, 2018 at the study site. Females moved more than 500m from the main river whereas males stayed within 200m.	30
Table 2.3. The average home range size of male and female wood turtles at my site during the active season. Calculated using minimum convex polygon (MCP) and adaptive kernel (AD), using 50 and 95% of relocations.	31
Table 2.4. Log-ratio differences (numerator habitat in rows, denominator in columns) and ranking of foraging habitat. Numbers in bold represent significant deviation from random at $P < 0.05$	32
Table 2.5. The percent of male (n=209) and female (n = 507) wood turtle relocations at the study site on land or in water.	32
Table 3.1. The number of wood turtles found in each age class in an agricultural site (Site A) and forested site (Site B). Wood turtles were captured opportunistically throughout 2017 and 2018 at Site A. At Site B, a mark and recapture survey was completed in 2012 and 2018 in May for three consecutive days. A total of 50 turtles were found at Site A, and 56 turtles were found at Site B.	62
Table 3.2. Summary of injuries to wood turtles found in agricultural or forested landscapes. A total of 50 turtles were found at Site A in 2017 and 2018. A total of 56 turtles were found at Site B in 2012 and 2018 during the mark and recapture studies.	69
Table 4.1. Potential management recommendations with the percent of turtles that would have been saved at study Site A if implemented and the cost for each. Cost is calculated based on the information given by the STRIDES program (Sherren et al. 2019).	89
Table A.1. The average size and mass of wood turtles (<i>Glyptemys insculpta</i>) in a population close to Fredericton, New Brunswick, Canada. The proxies were separated into five size classes: adult male, adult female, subadult, juvenile, and hatchling. Adults were defined as ≥ 16.4 cm straight carapace length, subadults as ~ 7 -11 years old, juveniles as ~ 3 -6 years old, and hatchlings as ≤ 2 years old.	114
Table A.2. Parameters from logistic regressions modelling injury to proxy wood turtles (<i>Glyptemys insculpta</i>) using cantaloupe (<i>Cucumis melo</i>) for sickle mowers. Model selection was based on minimizing AIC.	115
Table A.3. Parameters from logistic regressions modelling injury to proxy wood turtles (<i>Glyptemys insculpta</i>) using cantaloupe (<i>Cucumis melo</i>) for disc mower. Model selection was based on minimizing AIC.	116
Table B.1. A generalized linear model using penalized quasi-likelihood through backward selection for all 23 tagged wood turtles during the active season (May-October) of 2018 and a r^2 value for the whole model.	120

Table B.2. A generalized linear model using penalized quasi-likelihood through backward selection for females (n=16) during the season (May-October) of 2018 and a r^2 value for the whole model.120

Table B.3. A generalized linear model using penalized quasi-likelihood through backward selection for males (n=6) during the season (May-September) of 2018 and a r^2 value for the whole model.120

Table B.4. A generalized linear model using penalized quasi-likelihood through backward selection for females (n=16) during activity period 1 (May 10 to August 10) of 2018 and a r^2 value for the whole model.....121

Table B.5. A generalized linear model using penalized quasi-likelihood through backward selection for females (n=16) during activity period 2 (August 11 to October 10) of 2018 and a r^2 value for the whole model.121

Table B.6. A generalized linear model using penalized quasi-likelihood through backward selection for males (n=6) during activity period 1 (May 10 to June 20) of 2018 and a r^2 value for the whole model.121

Table B.7. A generalized linear model using penalized quasi-likelihood through backward selection for males (n=6) during activity period 2 (June 21 to July 20) of 2018 and a r^2 value for the whole model.122

Table B.8. A generalized linear model using penalized quasi-likelihood through backward selection for males (n=6) during activity period 3 (July 21 to August 20) of 2018 and a r^2 value for the whole model.....122

Table B.9. A generalized linear model using penalized quasi-likelihood through backward selection for males (n=6) during activity period 4 (August 21 to October 10) of 2018 and a r^2 value for the whole model.122

Table B.10. A generalized linear model using penalized quasi-likelihood through backward selection for wood turtles within the agricultural field in 2018 and a r^2 value for the final model.123

List of Figures

Figure 2.1. The minimal periodic movement for male and female wood turtles in 10-day periods at the study site. The squares represent the significant changes in movement found by the change point analysis. The activity period starts May 11th to October 10th, 2018.	33
Figure 2.2. The weight of slugs (<i>Miax gagates</i>), earthworms (<i>Lumbricina spp.</i>), and snails (<i>Succinea putris</i>) at the site between three habitat types (field, buffer and forest) from the months of June to August of 2018.	37
Figure 2.3. The presence of berries and mushrooms at the site from the months of May to September of 2018, collected from the habitat plots for each turtle relocation.	38
Figure 2.4. The presence of turtles within the field in comparison with the presence of mushrooms and berries throughout wood turtles' active season at the study site in 2018.	39
Figure 3.1. Timing of female and male wood turtles relocated in hayfields in 2018 at Site A. Time is recorded in Julian days starting from June 1 until September 17.	64
Figure 3.2. Percent of adult wood turtle locations in a field per week at Site A, from June 3 to August 31 of 2017 and 2018. A total of 14 turtles were radio-tracked in 2017 and 23 in 2018.	65
Figure 3.3. The percent of adult wood turtle relocations within various buffer widths in hayfields at study Site A in June and July of 2017 and 2018. Solid lines represent distance between the turtle location and any edge of the field; dashed lines are the edge solely closest to the main river.	66
Figure 3.4. Mowing patterns for harvesting hay. The image on the left is a zigzag pattern and on the right is an outside to inside pattern (Hall 2013).	76
Figure A.1. Probability of adult and young wood turtles (<i>Glyptemys insculpta</i>) proxies being damaged during hay harvest using a disc mower in areas with different vegetation height. Cantaloupe halves of similar weight and dimensions of adult and young (hatchling to subadult; Table 1) wood turtles were used as proxies for wood turtles. Rotary blades were raised to 5, 10, and 15 cm heights. "Above" and "Below" are referring to the placement of the proxies in relation of the thatch (accumulation of undecomposed grass). Solid lines represent damaged turtles; dashed lines undamaged.	118
Figure A.2. Probability of adult and young wood turtles (<i>Glyptemys insculpta</i>) proxies being damaged during hay harvest using a sickle mower in areas with different vegetation height. Cantaloupe halves of similar weight and dimensions of adult and young (hatchling to subadult; Table 1) wood turtles were used as proxies for wood turtles. "Above" and "Below" are referring to the placement of the proxies in relation of the thatch (accumulation of undecomposed grass). Sickle blades were raised to 5 and 10 cm heights. Solid lines represent damaged turtles; dashed lines undamaged.	119

Chapter 1: General Introduction

Habitat Alteration and Ecological Traps

Human activities in wildlife habitat has, for some species, resulted in population decline, range retraction, and, local extirpation (Pechmann et al. 1991; González et al. 2017). Habitat loss or alterations can indirectly have negative impacts on a species by creating a population sink or ecological trap. An ecological trap is when a species inadvertently chooses habitat in which an individual has low fitness when other habitat that provides high fitness is available (Kokko and Sutherland 2001). For example, rusty blackbirds (*Euphagus carolinus*) breed in boreal wetlands and establish nest sites in dense young coniferous growth (Powell 2000). Logged areas close to wetlands can be enticing to blackbirds for nesting, but logged areas also have higher predator populations that cause nest failures. High depredation has resulted in a population decline of rusty blackbirds, making logged areas an ecological trap (Powell 2000). Natural selection can help a population avoid poor quality habitat, but for long-lived specie with low juvenile recruitment may go extinct before they can adapt (Kokko and Sutherland 2001).

Agriculture history and impacts on wildlife

Agriculture has existed for millennia, yet it has increasingly become a concern for wildlife managers in the last 50 years (Rider et al. 1993). Agricultural practices strive to decrease cost and maximize yields, which has resulted in new

machinery and earlier harvest seasons (Humbert et al. 2009). The onset of hay harvest in eastern North America has advanced by 14-21 days in the past 50 years as farmers switched to exotic cold-adapted grass species and varieties that can grow quickly and be harvested earlier (Nocera et al. 2007). All graminoids decrease in nutritional quality as they age; thus an earlier harvest contains higher nutritional value, and may allow for a second harvest in the same growing season (Herkert 1997). The earlier hay harvest has a negative influence on some species, including grassland birds. Some species, like the bobolink (*Dolichonyx oryzivorus*), nest in hayfields during June, and their young do not fledge until mid-July (Brown and Nocera 2017). The hay harvest has advanced from the end of June/mid-July to much earlier and young birds are killed by machinery, making it unlikely for broods to survive (Nocera et al. 2007).

In the last 50 years, there has been a shift from using sickle cutterbar mowers to rotary disc mowers (Horrocks and Valentine 1999; Erb and Jones 2011; Dodd 2002; Humbert et al. 2009). Rotary disc mowers are preferred over sickle bars because they can cut on uneven ground, run at a faster speed, and are more durable with a blade tilted on an angle with no blade guards. In comparison, sickle bar blades cut parallel to the ground at lower speeds (Miller and Rotz 1995; Pogue et al. 1996). Due to the different mechanisms between the two mowers, wildlife species that use the fields during harvest with a rotary disc mower have a higher likelihood of being hit by machinery (Licznar 1999; Erb and Jones 2011). For example, mortality rates of some beetle (Blodgett and Denke 1999) and frog (Licznar 1999) species were lower when sickle bar

mowers were used. Any wildlife species that is slow moving or has a defence strategy that relies on camouflage or armour is likely to be at greater risk from farm machinery because they will not move away from the threat.

The wood turtle (*Glyptemys insculpta*) is one species that is known to experience significant mortality rates from agricultural operations (Saumure et al. 2007; Tingley et al. 2009). Wood turtles are more terrestrial than other freshwater turtle species, using a range of landscapes, from forest to farm fields. Mortality from agricultural machinery has been recorded in most of the species' range but relatively limited research has been undertaken on the factors associated with risk. For example, it is not apparent if wood turtles are attracted to fields over other habitat types, or if the field is simply the closest land to the river. Farming activities will continue but it may be that some practices can be altered such that wood turtle mortality is lessened. For such mitigation to work, there needs to be data illustrating the benefits. Basic questions remain unanswered, such as how wood turtles respond to approaching machinery, will they be able to escape to safety, and how likely are turtles to be injured or killed by machinery of different types?

The overall objective of this project is to improve our understanding of wood turtle habitat selection and behaviour in an agri-forested landscape and thereby provide management recommendations to land managers in New Brunswick that will help reduce the mortality of wood turtles.

Wood Turtle

Geographic range

Wood turtles occur in the mid-latitudes of eastern North America. In the United States, they are distributed from eastern Minnesota to south Virginia and in Canada they are distributed from southern Ontario to Nova Scotia. Sub-populations within this broader distribution are often patchily distributed, with apparent gaps between most populations (COSEWIC 2018).

Life History

The wood turtle is a freshwater species that is terrestrial during their active season (May-October). They hibernate within second and third-order streams between October to April, typically in the oxbows or main channel (Harding and Bloomer 1979). Wood turtles can be distinguished by their yellow plastron and yellow, orange, and red throat, and the scalloped scutes on the carapace (Ernst and Lovich 2014). Black markings on the plastron are unique to every individual and can be used for identification purposes, until the shell becomes too worn to identify markings (Ernst and Lovich 2014). Wood turtle exhibit sexual dimorphism, with male wood turtles having a concaved plastron for mating. Males are also generally heavier and larger than female wood turtles (Harding and Bloomer 1979).

The species generally avoids moving at temperatures $< 7^{\circ}\text{C}$ or $> 30^{\circ}\text{C}$ (Ernst 1986). In ideal temperatures, females can travel up to 1km from a stream throughout the active season, whereas males usually stay within 75-333m (Ernst and Lovich 2014). In their northern range, home ranges were calculated to be 24ha (Ontario) and 28ha (Quebec) whereas in the southern portion of their range, (Pennsylvania, Wisconsin and northern Michigan) home ranges were

between 0.4-6.7ha, using the minimum convex polygon method (Quinn and Tate 1991; Ross et al. 1991; Kaufmann 1995; Arvisais et al. 2002; McCoard et al. 2016).

Wood turtle's mate in the spring and nest in June (Farrell and Graham 1991; Wirsing et al. 2012). They can also mate in the fall and store the sperm until the next nesting season (Kauffman 1992). Females can lay up to eight eggs in one clutch, but they do not nest every year, especially at the northern edge of their range (COSEWIC 2018). During and after the nesting season, wood turtles forage during the day and may return to the stream at night (Ernst and Lovich 2014). Nests hatch in late August and September (Harding and Bloomer 1979; Wirsing et al. 2012; Mullin 2019). Wood turtles reach maturity when their carapace length is > 165mm which often is between the ages of 12-16 years in southern range, and up to 22 years of age in northern range. Wood turtles have a long generation period and can live up to 36-47 years of age (Van Dijk and Harding 2011).

Status and Threats

The wood turtle was listed under the Species at Risk Act in 2010 and the Committee on the Status of Endangered Wildlife (COSEWIC) has recommended retaining their threatened status during their 10-year review (COSEWIC 2018). Throughout the wood turtles range in Canada, they are at risk in each province: Quebec (S2), Ontario (S2), Nova Scotia (S2), New Brunswick (S2S3) (NatureServe 2019). Wood turtles face threats such as poaching, the pet trade, all-terrain vehicle usage, road mortality, agricultural machinery, and high predation (Harding and Bloomer 1979; Saumure et al. 2007; Geller 2012; Mullin

2019). Road collisions and agricultural machinery can heavily influence populations by removing adults from a population, and high predation pressures can cause low juvenile recruitment (Quinn and Tate 1991; Saumure et al. 2007; Mullin 2019).

High predation rates on species are associated with disturbed landscapes, usually created by humans (Turgeon et al. 2015). Predator population densities can be extremely high in urban areas and landscapes with agricultural fields (Daigle and Jutras 2005). For turtle species that live close to agricultural fields, predation pressures have negative impacts on their population. Wirsing et al. (2012) found that in a disturbed area, the predation rate on wood turtle nests was 95%, while in undisturbed regions, the predation rate was 60%. In Michigan, wood turtles nesting near agricultural land had 100% of their nests depredated in each of three consecutive years (Harding and Blooming, 1979).

During the hay harvest season, wood turtles use agricultural fields; therefore, they are at high risk of being hit by agricultural machinery (Saumure and Bider 1998; Kaufmann 1992b; Saumure et al. 2007; Tingley et al. 2009; Mullin 2019). Tingley et al. (2009) noted that 14 out of the 27 tagged turtles were found within the field at least once during their active season, and a subset of turtles was within the field during the peak harvest season (June 8-August 19). Saumure et al. (2007) recorded that 20% of their study population died due to agricultural machinery, and in Nova Scotia, five mortalities, out of 27, were observed during the first harvest (Tingley et al. 2009).

Within a turtle population, adult survivorship is important, and threats that result in high adult mortality can cause extirpation (Kaufmann 1992a). Within Ontario, more than half of a wood turtle population was removed, likely collected for the pet trade, and an analysis showed that the population would be extirpated in the near future if no management actions were implemented (Mullin 2019). Annual survivorship of adults usually is high (90-99%) in pristine habitats, but in disturbed landscapes, such as agricultural fields, which host increased predator densities and the risk of mortality from agricultural machinery, these threats have resulted in lower survivorship, causing populations to be unsustainable (Saumure et al. 2007; Ernst and Lovich 2014).

Habitat Selection

Habitat selection studies are essential for understanding a species' life history, identifying critical habitat, mitigating threats within the landscape, and recognizing ecological traps (Mayor et al. 2009). These studies are especially important for species at risk because it provides knowledge for identifying critical habitat. Critical habitat is habitat necessary for the survival and protection of a species at risk (SARA, SC 2002, c 29). Habitat selection studies can be separated into four spatial scales: geographic range, home range, within home range, and how components of habitat are used (Johnson 1980).

Wood turtles can use a wide variety of habitat types but often select areas with a variety of biophysical conditions, such as mixed forest areas near water because such areas offer foraging, open areas for basking, and clear streams with a moderate current for breeding and hibernation (Saumure et al.

2007; Ernst and Lovich 2014). Wood turtles are ectothermic and, they will select habitat features based on temperature (Dubois et al. 2009). Alder (*Alnus spp.*) thickets have been noted to be preferred by wood turtles for the semi-open area they provide, but open forest canopy, abandoned fields, and agricultural fields can also be suitable (Ernst and Lovich 2014). There has been a debate over the degree to which heterogeneity of habitats provide an ideal landscape for wood turtles. Dubois et al. (2009) showed that heterogeneous habitats provided greater opportunities for thermoregulation, but Hughes and Litzgus (2019) found that a less thermal variation on the landscape offers higher thermal quality. Both studies were at different scales (60ha vs 2ha), which likely influenced the results.

Wood turtles use agricultural fields to access basking areas and food (Saumure and Bider 1998). Wood turtles are opportunistic omnivores and will feed on raspberries (*Rubus spp.*), herbs, mushrooms, slugs (*Miag spp.*), and earthworms (*Lumbricina spp.*). Earthworms are often abundant within pastures and fields, which could entice wood turtles (Saumure and Bider 1998; Whalen 2004). Agricultural fields can present an ecological trap for wood turtles, because features such as low canopy cover and high food abundance attract wood turtles into the fields during the hay harvest season, causing individuals to be injured or killed by machinery (Arvisais et al. 2004; Saumure et al. 2007). In Nova Scotia, female wood turtles were found to bask and forage in a hayfield adjacent to the nesting area between nesting attempts (Tingley 2009). Compton et al. (2002) created a model for the habitat selection of wood turtle in Maine, USA. They found that wood turtles make a trade-off between feeding in a

forested area or basking in an open area. It is most likely that turtles are selecting for forested edges, and the edge habitats meet both needs. There have been many habitat selection studies on wood turtles (Arvisais et al.2002; Compton et al. 2002; Dubois et al. 2009; Roy-McDougall 2010), but there is limited information on wood turtle populations in an agricultural landscape. To help reduce wood turtle mortality in agricultural fields, obtaining information on their habitat use within an agricultural landscape is needed. Understanding why and how often they use agricultural fields could help management recommendations.

Management

Several researchers have provided management recommendations to decrease high mortality rates of wood turtles from agricultural machinery. Tingley (2009) recommended raising the blade height to 10cm, and Saumure et al. (2007) advised increasing the blade height to 5-10cm, but noted it would not be realistic for farmers due to a concurrent loss in profit. Saumure et al. (2007) suggested setting a blade height as low as 2.5cm during the second harvest in August because turtles had already retreated to the river. However, Tingley (2009) noted that within Nova Scotia, turtles still occupied the field during the second hay harvest. Although the two studies recommended changing blade heights, they did not conduct blade height experiments. Erb and Jones (2011) completed trials regarding blade heights and mower types. They used four different mowers (sickle cutterbar, rotary, mulching head, and flail) (Figure 1) with three different blade heights (10cm, 15cm, and 19cm) on fake turtles. They

set the sickle cutterbar mower to 10cm, and no (presumed) mortalities were noted. The disc mowers were set at 10cm and resulted in a 50% mortality rate. Due to the high mortality caused by the disc mower, a second experiment was conducted solely with the rotary mower. They tested the mortality rate of proxies when the blade was set at a height of 10 and 15cm. They also did a trial without the mower to calculate the number injured solely by the tires. Between the three treatments they did not find a significant difference. This result could be because tires caused 46% mortality within the three treatments combined. Since there is high mortality of wood turtles due to tires, machinery like wind rowers and balers can also cause harm to the species (Humbert et al. 2009). Even though wood turtles do not use the field as frequently after hay harvest, individuals still bask along the edges and sometimes within the field (Saumure and Bider 1998).



Figure 1. The blade of a rotary disc and sickle cutterbar mower (Case International 2020).

Wood turtles have been recorded to escape the tractor if they had been hit previously (Saumure et al. 2007). Managers have recommended that landowners consider mowing from the inside of the field to the outside to allow

wood turtles time to escape (STRIDES 2016). This technique has not been tested.

Increasing the riparian buffer width from the main river has been another management recommendation. Tingley et al. (2009) noted that a riparian buffer of 235m would include 95% of wood turtles. They recognized, however, that such a wide buffer would cover most existing fields along rivers and as such it may not be a practical management strategy. Delaying the hay harvest has also been recommended as it is a common technique for conserving grassland birds (STRIDES 2016).

Wood turtles in New Brunswick

In New Brunswick (NB), wood turtles occur within many watersheds, except for those in a few southwestern areas, and in the highland plateau in northern NB (McAlpine and Gerriettes 1999). Approximately 94% of the NB watersheds containing wood turtles have agricultural areas within 200m of a watercourse (DERD, unpublished data). Many agricultural practices are a high threat to wood turtles within the province and management strategies are necessary to mitigate threats. There is limited empirical information associated with mitigation strategies in agricultural areas in general, and very little information on wood turtles in NB or eastern Canada. Wood turtles have been studied in a watershed of mainland Nova Scotia (McCurdy 1995). A single habitat selection study (i.e., Roy-McDougall 2010) was completed on a wood turtle population in central NB, but this project was undertaken in a forested

landscape and did not address agricultural issues. No other studies have investigated threats to the species within NB.

Structure of the Thesis

This thesis is presented in journal article format. Chapter 2 is formatted for the *Canadian Journal of Zoology*. In Chapter 2, I investigate wood turtle second and third-order habitat selection in a landscape under active agriculture. Home range and food availability throughout the landscape are included in the analysis. Chapter 3 is also formatted for the *Canadian Journal of Zoology*. In Chapter 3, I focus on the wood turtle's use of hayfields and their behavior in response to hay harvest. Injury and age structure are compared between an agri-forested landscape and a purely forested landscape to obtain an understanding of predation and machinery pressures in disturbed and undisturbed sites. Predation occurrence between the two locations is also analyzed. In Chapter 4, I summarize the knowledge gained from my research and how it relates or disagrees with similar studies. I offer possible management recommendations and future research requirements that would further help us protect the threatened wood turtle. Appendix A is formatted for *Chelonian Conservation and Biology*. In Appendix A, I examine the injury that two common mower types have on proxy wood turtles at various life stages to gain an understanding of how high a risk each mower type is during harvest.

1.1. Literature Cited

- Arvisais, M., Bourgeois, J.-C., Lévesque, E., Daigle, C., Masse, D., and Jutras, J. 2002. Home range and movements of a wood turtle (*Clemmys insculpta*) population at the northern limit of its range. *Can. J. Zool.* **80**(3): 402–408. doi:10.1139/z02-013.
- Arvisais, M., Lévesque, E., Bourgeois, J.-C., Daigle, C., Masse, D., and Jutras, J. 2004. Habitat selection by the wood turtle (*Clemmys insculpta*) at the northern limit of its range. *Can. J. Zool.* **82**(3): 391–398. doi:10.1139/z04-012.
- Blodgett, S.L., and Denke, P.M. 1999. Blister Beetles (Coleoptera: Meloidae) occurring in Montana alfalfa. *J. Entomol. Sci.* **34**(1): 113–118. doi:10.18474/0749-8004-34.1.113.
- Brown, L.J., and Nocera, J.J. 2017. Conservation of breeding grassland birds requires local management strategies when hay maturation and nutritional quality differ among regions. *Agric. Ecosyst. Environ.* **237**: 242–249.
- Case International. 2020. <https://www.caseih.com/northamerica/en-us/products/mowers-conditioners#0>.
- Compton B.W., Rhymer J.M., and McCollough, M. 2002. Habitat selection by wood turtles (*Clemmys insculpta*): an application of paired logistic regression. *Ecology* **83**(3): 833–843. doi:10.1890/0012-9658(2002)083[0833:HSBWTC]2.0.CO;2.
- COSEWIC. 2018. COSEWIC assessment and update status report on the Wood Turtle *Glyptemys insculpta* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. Vii + 51 p.p.
- Daigle, C., and Jutras, J. 2005. Quantitative evidence of decline in a southern Québec wood turtle (*Glyptemys insculpta*) population. *J. Herpetol.* **39**(1): 130–132.
- Dodd, C.K. 2002. North American box turtles: A natural history. University of Oklahoma Press, Norman, Oklahoma. Xvii + 239 p.p.

- Dubois, Y., Blouin-Demers, G., Shipley, B., and Thomas, D. 2009. Thermoregulation and habitat selection in wood turtles *Glyptemys insculpta*: chasing the sun slowly. *J. Anim. Ecol.* **78**(5): 1023–1032. doi:10.1111/j.1365-2656.2009.01555.x.
- Erb, L., and Jones, M.T. 2011. Can turtle mortality be reduced in managed fields? *Northeast. Nat.* **18**(4): 489–496.
- Ernst, C.H., and Lovich, J.E. 2014. *Turtles of the United States and Canada*. Johns Hopkins University Press, Baltimore, United States. 827 p.p.
- Farrell, R.F., and Graham, T.E. 1991. Ecological notes on the turtle *Clemmys insculpta* in northwestern New Jersey. *J. Herpetol.* **25**(1): 1–9. doi:10.2307/1564787.
- Geller, G.A. 2012. Notes on the nest predation dynamics of *Graptemys* at two Wisconsin sites using trail camera monitoring. *Chelon. Conserv. Biol.* **11**(2): 197–205. doi:10.2744/CCB-0992.1.
- González, G.C., Ceballos, G., and Dirzo, R. 2017. Biological annihilation via the ongoing sixth mass extinction signaled by vertebrate population losses and declines. *Proceedings of the National Academy of Sciences of the United States of America*, **114**(30). doi:10.1073/pnas.1704949114.
- Harding, J.H., and Bloomer, T.J. 1979. The wood turtle, *Clemmys insculpta*...a natural history. *Bulletin of the New York Herpetological Society* 15:9-26.
- Herkert, J.R. 1997. Bobolink *Dolichonyx oryzivorus* population decline in agricultural landscapes in the Midwestern USA. *Biol. Conserv.* **80**(1): 107–112. doi:10.1016/S0006-3207(96)00066-3.
- Horrocks, R.D., and Valentine, J.F. 1999. *Harvested forages*. Academic Press. San Diego, California, United States. 426 p.p.
- Hughes, G.N., and Litzgus, J.D. 2019. Impact of natural resource extraction on thermal properties of wood turtle (*Glyptemys insculpta*) habitat. *J. Therm. Biol.* **84**: 469–478. doi:10.1016/j.jtherbio.2019.07.031.
- Humbert, J.-Y., Ghazoul, J., and Walter, T. 2009. Meadow harvesting techniques and their impacts on field fauna. *Agr. Ecosyst. Environ.* **130**(1): 1–8. doi:10.1016/j.agee.2008.11.014.

- Johnson, D.H. 1980. The comparison of usage and availability measurements for evaluating resource preference. *Ecology* **61**(1): 65–71. doi:10.2307/1937156.
- Kaufmann, J.H. 1992a. Habitat use by wood turtle in central Pennsylvania. *J. Herpetol.* **26**: 315-321.
- Kaufmann, J.H. 1992b. The social behavior of Wood Turtles, *Clemmys insculpta*, in central Pennsylvania. *Bulletin Museum of Zoology, University of Florida*.
- Kaufmann, J.H. 1995. Home ranges and movements of wood turtles, *Clemmys insculpta*, in central Pennsylvania. *Copeia*. (1): 22–27. doi:10.2307/1446796.
- Kokko, H., and Sutherland, W.J. 2001. Ecological traps in changing environments: Ecological and evolutionary consequences of a behaviourally mediated allee effect. *Evol. Ecol. Res.* **3**: 537–551.
- Liczner, Y. 1999. Auswirkungen unterschiedlicher Mäh- und Heubearbeitungsmethoden auf die Amphibienfauna in der Narewniederung (Nordostpolen). *Rana – Mitteilungen für Feldherpetologie and Ichthyofaunistik in Norddeutschland – Sonderheft* **3**:67-79.
- Mayor, S.J., Schneider, D.C., Schaefer, J.A., and Mahoney, S.P. 2009. Habitat selection at multiple scales. *Écoscience* **16**(2): 238–247. doi:10.2980/16-2-3238.
- McAlpine, D. F. and S. H. Gerriets. 1999. Using the internet to establish the status of an easily distinguished, vulnerable species, the Wood Turtle (*Clemmys insculpta*) in New Brunswick, Canada. *Herpetol. Rev.* **30**(3):139-140.
- McCoard, K.R.P., Billings, A.A., and Anderson, J.T. 2016. Wood turtle home range and habitat use in the central Appalachians. *Chel. Conserv. Biol.* **15**(2): 173–180. doi:10.2744/CCB-1215.1.

- McCurdy, D.G. 1995. Orientation and movement patterns of reciprocally transplanted wood turtles (*Clemmys insculpta leconte*) in northeastern Nova Scotia. BSc.HR, Acadia University. 102 pp.
- Miller, D.A., and Rotz, C.A. 1995. Harvesting and storage. Pages 163-169 in R.F. Bames, D.A. Miller, and C.J. Nelson. Forages. Volume 1: An Introduction to Grassland Agriculture. Fifth edition. Iowa State University Press, Ames, Iowa, USA.
- Mullin, D.I. 2019. Evaluating the effectiveness of headstarting for wood turtle (*Glyptemys insculpta*) population recovery. M.Sc. Thesis. Laurentian University, Sudbury, Ontario, Canada. 144 pp.
- NatureServe. 2019. NatureServe Explorer. An online encyclopedia of life. Version 7.1. NatureServe, Arlington, Virginia. Available <http://explorer.natureserve.org>
- Nocera, J.J., Forbes, G., and G.R. Milton. 2007. Habitat relationships of three grassland breeding bird species: broadscale comparisons and hayfield management implications. Avian. Conserv. Ecol. 2:7.
- Pechmann, J.H.K., Scott, D.E., Semlitsch, R.D., Caldwell, J.P., Vitt, L.J., and Gibbons, J.W. 1991. Declining amphibian populations: The problem of separating human impacts from natural fluctuations. Science **253**(5022): 892–895.
- Pogue, D.D., Evans, R.R., Ivy, R.L., and Bagley, C.P. 1996. The dollars and sense of hay production. Report No: MAFES Information Bulletin 311 Mississippi Agricultural and Forestry Experiment Station, Mississippi, USA. 26 pp.
- Powell, RA. 2000. Animal home ranges and territories and home range estimators. Pages 65-110 in L. Boitani & T.K. Fuller, editors. Research techniques in animal ecology. Controversies and Consequences. Columbia University Press, New York, New York, USA.
- Quinn, N.W.S., and Tate, D.P. 1991. Seasonal movements and habitat of wood turtles (*Clemmys insculpta*) in Algonquin Park, Canada. J. Herpetol. **25**(2): 217–220. doi:[10.2307/1564654](https://doi.org/10.2307/1564654).

- Rider, A.R., Barr, S.D., and Pauli, A.W. 1993. Hay and Forage Harvesting. Fourth edition. Deere Service Publications, East Moline, United States. 276 pp.
- Ross, D.A., Brewster, K.N., Anderson, R.K., Ratner, N., and Brewster, C.M. 1991. Aspects of the ecology of wood turtles, *Clemmys insculpta*, in Wisconsin. Can. Field-Nat **105**: 363–367.
- Roy-McDougall, V. 2010. Habitat selection by wood turtle in central New Brunswick, Canada. M.Sc.F., University of New Brunswick, Canada. 71 pp.
- SARA (Species At Risk Act). 2002. c 29.
- Saumure, R.A., and Bider, J.R. 1998. Impact of agricultural development on a population of wood turtles (*Clemmys insculpta*) in southern Québec, Canada. Chel. Conserv. Biol. **3**: 37–45.
- Saumure, R.A., Herman, T.B., and Titman, R.D. 2007. Effects of haying and agricultural practices on a declining species: The North American wood turtle, *Glyptemys insculpta*. Biol. Conserv. **135**(4): 565–575. doi:[10.1016/j.biocon.2006.11.003](https://doi.org/10.1016/j.biocon.2006.11.003).
- STRIDES. 2016. Beneficial management practices for wood turtle conservation. 16 pp.
- Tingley, R., McCurdy, D.G., Pulsifer, M.D., and Herman, T.B. 2009. Spatio-temporal differences in the use of agricultural fields by male and female wood turtles (*Glyptemys insculpta*) inhabiting an agri-forest mosaic. Herpetol. Conserv. Biol. **4**: 185-190.
- Turgeon, G., Vander Wal, E., Massé, A., and Pelletier, F. 2015. Born to be wild? Response of an urban exploiter to human-modified environment and fluctuating weather conditions. Can. J. Zool. **93**(4): 315–322. doi:[10.1139/cjz-2014-0263](https://doi.org/10.1139/cjz-2014-0263).
- Van Dijk, P.P., and Harding, J. 2011. *Glyptemys insculpta* (errata version published in 2016). The IUCN red list of threatened species 2011: e.T4965A97416259.

- Whalen, J.K. 2004. Spatial and temporal distribution of earthworm patches in corn field, hayfield and forest systems of southwestern Quebec, Canada. *Appl. Soil Ecol.* **27**(2): 143–151. doi:10.1016/j.apsoil.2004.04.004.
- Wirsing, A.J., Phillips, J.R., Obbard, M.E., and Murray, D.L. 2012. Incidental nest predation in freshwater turtles: inter- and intraspecific differences in vulnerability are explained by relative crypsis. *Oecologia* **168**(4): 977–988. doi:[10.1007/s00442-011-2158-y](https://doi.org/10.1007/s00442-011-2158-y).

Chapter 2: Habitat selection, movement, and food availability of wood turtles (*Glyptemys insculpta*) in an agri-forested landscape

2.1. Abstract

Wood turtles (*Glyptemys insculpta*) are habitat generalists and will change their habitat use depending on their geographic range and available habitat types. The species will use agricultural fields for basking, feeding, and accessing nesting habitat, but the fields can be an ecological trap due to mortality from agricultural machinery. There has been minimal research of wood turtle habitat use in an agricultural landscape and what type of food resources could be influencing their selection. I sought to investigate wood turtle habitat selection in the 3rd and 4th order scale in an agri-forested landscape. To quantify the rate at which such habitat is selected by wood turtles, I radio-tracked 23 adult individuals (6M:17F) from May to November of 2017 and 2018. I measured habitat features, such as food abundance (e.g., berries, fungi) at each wood turtle location and three random sites within 50m of that location. Wood turtles selected for low canopy cover and presence of coarse woody debris. Earthworms were in high abundance within hayfields, and berries and fungi were abundant in forests. Wood turtles left the hayfields at the end of July, likely due to the emergence of berries and fungi within the forest. I found that hayfields provide a food source that entice wood turtles during the prime hay harvest period and that food availability likely influences their habitat use during the season.

Keywords: Agri-forested landscape; food availability; *Glyptemys insculpta*; habitat selection; movement; wood turtle

2.2. Introduction

The wood turtle (*Glyptemys insculpta*) is listed as federally threatened in Canada, and efforts for understanding their ecology, habitat use, and threats have been a primary focus to help protect the species (Arvisais et al. 2002; COSEWIC 2018 Saumure et al. 2007). Wood turtles select for aquatic and terrestrial features in a variety of landscapes for thermoregulation, foraging, and breeding. Much of their third-order (Johnson 1980) habitat use is related to thermoregulation behaviour, as they seek basking sites in openings in forest canopy, exposed parts of fields, and river banks (Compton et al. 2002; Saumure et al. 2007; Dubois et al. 2009; Roy-McDougall 2010). Wood turtles are also food opportunists and have been recorded eating a wide range of food items, from berries, slugs, fruit, to scavenging. As result of this broad diet, wood turtle distribution is not considered to be limited by food (Harding and Bloomer 1979; Saumure and Bider 1998; Compton et al. 2002). Instead, it is likely that landscapes that facilitate survival in winter (a challenging period for poikilotherms) and permit breeding and reproduction will be primarily selected, whereas food would be a secondary habitat feature for such a species than can consume a wide variety of food items. The relative value of different structures in a habitat can make it difficult to discern actual selection. For example, in sites where agriculture is adjacent to river sites, it is unknown whether the use of the field by wood turtles is simply because the field is nearby, or because the field is

attracting wood turtles. Compton et al. (2002) found that wood turtles make a trade-off between feeding in a forested area and basking in an open area. It is most likely that turtles are selecting for forested edges, as the edge habitats meet both needs, making agricultural fields enticing for wood turtles. Since wood turtles can adjust their diet depending on availability, it is also likely to affect their habitat use or movement throughout their active season (Harding and Bloomer 1979; McCurdy 1995; Powell 2000). The use of agricultural fields can result in wood turtles being at risk of being hit by agricultural machinery, which can cause population declines if individuals (especially adults) are consistently killed each year (Saumure et al. 2007; Tingley et al. 2009). Understanding how wood turtles select for habitat within an agricultural landscape is important for protecting the species. There has not been any research on food abundance across a landscape with active agriculture and how that could affect wood turtle habitat selection. Dubois et al. (2009) studied their habitat selection in regard to temperature in an active agriculture landscape, but other habitat features (e.g., ground cover, distance to water), and food availability were not investigated. Throughout the wood turtle's range, agricultural landscapes are abundant and pose risks to population levels, so management action is needed to help protect the species.

I tracked wood turtles in an agri-forest landscape in 2017 and 2018 to investigate the causes of habitat selection (third and fourth-order), movements, and home range. I also measured food availability within the home range to assess differences among habitat types and examine whether habitat use is affected by food availability.

2.3. Methods

Study area - I conducted this study in a 268.9-hectare area (2.69km²), located in central New Brunswick, Canada, along a 3-km stretch of a third-order river that is relatively straight with meandering areas. The exact location cannot be provided due to the potential threat of collection for the pet trade (Garber and Burger 1995). The river is 5-15m wide and 1-200cm deep (spring and summer). The riverbed consisted of 0.35% sand, 0.58% mud, 2.34% boulders (diameter >25cm) and 96.7% cobble (diameter <25cm). The site has various habitat types (Table 2.1) and six hayfields encompass the area and were 1-15 meters away from the main river. The study site is close to property development with the nearest house being 140m away from the river, and the nearest road (paved) is 120m away.

Table 2.1. Definitions used to classify habitat types at my study site.

Habitat Type	Definition	Area in study site (ha)
Forest	Young mixed trees	190.9
Field (uncut)	Agricultural hay field, consisting mainly of timothy and bedstraw. Grass height up to 2 meters	58.4
Cut Field	Agricultural hay field that has been harvested, grass height reaching a maximum of two inches	58.4
Riparian Buffer	Alder dominated vegetation	5.9
Edge	Transition of two habitat types	5.4
River	Flowing water	5.1
Marsh	Periodically floods, no trees and the dominant vegetation is emergent	3.2
Development	Anthropogenic development including housing, barns, roads etc.	2.4
Opened Grassy Areas	Regenerating vegetation, no trees	2.2

Capture and Tagging Methods - I captured wood turtles opportunistically from June to October in 2017, and from May to October of 2018. In May 2018, I captured wood turtles during a two-person visual survey within 10m of the main river; I conducted these surveys for 1h, three times a week, for three weeks (as per Flanagan et al. 2013). Surveys occurred during the day when temperatures were above 7°C with no precipitation. I marked captured turtles for identification using a shell notching system (Cagle 1939). I equipped turtles with transmitters (Model: A1-F2 adults; 33g, Holohil systems Ltd. Ottawa, Canada) attached to the edge of the right posterior scute using epoxy. When a new turtle was found, I recorded sex, age (if <20 years), visible injuries (on shell and limbs), shell wear, carapace length (midline and maximum), maximum carapace width, and carapace height using a tape measure and calipers. I conducted these studies with permits from New Brunswick Energy and Resource Development (SAR18 – 026) and University of New Brunswick Animal Care protocol (18027).

I recorded the location of each wood turtle using a Global Positioning System (Garmin 64) and simultaneously triangulated tagged turtles using a radio receiver (Telonics Tr4 Model Tempe, Arizona) approximately two to three times per week. I located turtles primarily between 0830 and 1700h. Wood turtles are active within this time frame, as determined by an analysis of 24-hour movement patterns (Forbes 2005).

Home range - I calculated home range using two different methods: minimum convex polygon (MCP, 90%) and autocorrelated kernel density

(AKDE, 50% and 90%). I used the MCP using the package “adehabitatHR” (Version 0.4.15, Calenge and Fortmann-Roe 2019), and the kernelUD command to calculate each home range using the package “ctmm” (Version 0.5.2, Fleming et al. 2019) in R Software version 1.1. 463 (R Core Team 2018). AKDE considers where the turtles could roam using the location, date, and time the turtles were found at a certain point. I could not calculate the AKDE for turtles that had <13 relocations (Springer 1982).

Habitat Variables – At each turtle relocation site, I measured habitat variables within a 1m radius circular plot. Habitat type was characterized as shore, forest, riparian buffer, field, marsh, river, and edge.

The canopy was characterized by percent tree cover, and the shrub layer was characterized by average shrub height and percentage cover. The ground layer was characterized by plant height, percent cover, and dominant plant species. The type of substrate, and the presence of coarse woody debris (CWD) was noted. At each plot, the presence of red raspberries (*Rubus idaeus*), bunchberries (*Cornus canadensis*), wild strawberries (*Fragaria virginiana*), blueberries (*Vaccinium sp.*) and mushrooms was recorded. Distance to the nearest river, river pond, or agricultural field was measured in the field (if within 10m) or generated using ArcGIS.

The temperature at ground level (1cm above ground) was recorded using a Mastercraft™ temperature gun, and HOBOware data loggers (Model: UA-001-64). Data loggers were deployed on land and in the water to record hourly temperature during the turtle’s active season (May to October 2018). Within the water, 11 HOBO data loggers were deployed within three different water types:

third-order river (n=5), second-order river (n=3), and backwater connected to the third-order river (n=3). Data loggers in a third-order river were either placed under a bank or in the river channel. On land, 17 data loggers were placed in three different habitat types: forest (n=6), field (n=5), and riparian buffer (n=6). For forest and riparian buffer, half of the loggers were placed in open canopy and the other half in closed canopy areas. Within the fields, three loggers were placed over the thatch (undecomposed layer of debris above the soil layer) and two under the thatch. The two set under the thatch were not placed until the end of June due to little or no presence of thatch. During June, loggers placed in areas of opened canopy had small umbrellas covering the devices to prevent overheating caused by direct sunlight.

To measure 4th order selection, I measured available habitat by recording the same habitat variables as above at three random plots, within 12-50m of each capture location (range of movement between relocations). Random plots were chosen by using a random number generator between 12-50 for distance and a number between 0-360 for direction. I measured random plots immediately following the turtle relocation. By comparing wood turtle relations on the same day to random habitat plots, I effectively compared what was available to a wood turtle within its activity range to habitat used.

When a turtle was relocated in an agricultural field after 12 June 2018 (the time when turtles started using the agricultural fields), I made a detailed measurement of vegetation type to study 4th order selection within hay fields. To measure vegetation, I used a Daubenmire frame, which was placed at each turtle location and was thrown (~5m) in each cardinal direction from the turtle's

location. Inside the frame, I identified, counted (number of stems), height measured, and estimated percent cover for each grass species. The temperature at ground level was also measured for each turtle relocation and the random plots. I identified whether the turtle was under or over the thatch as well as the turtle's behavior (e.g., hiding under or moving on top of vegetation). I measured grass height using the Daubenmire frame, and the distance from the field edge and water was recorded on-site or using ArcGIS.

Habitat Selection and Movement Analyses - Following the methods of Arvisais et al. (2002), I split the active season into three periods of each month (10 days each). The minimum periodic movement (MPM) of turtles was calculated using ArcMap to measure the straight-line distance between the turtle's location to the next location. For each period, the average distance was recorded. Once the data were averaged, I conducted a repeated-measures analysis of variance (ANOVA) to analyze movement in terms of sex and activity period. The data were log-transformed before analysis in an attempt to meet the assumption of normality (Original data: AIC=8074, log-transformed data: AIC=1813). The activity period was the covariate, sex was the fixed factor, and movement was the dependent variable. I used the Shapiro-Wilk test to test normality and found a significant departure from normality ($W = 0.99$, $p=0.0002$). I tested homogeneity of variance using a Mauchly's test of sphericity, and the assumption of homogeneity was met. I used the package "changept" (Version 2.2.2, Killick et al. 2016) in R to find a change in MPM between the activity periods.

To investigate third-order habitat selection I calculated the amount of habitat available by assessing the habitat types using ArcGIS and from ground surveys. I first conducted a classical compositional analysis of habitat use (Aebischer et al. 1993) to determine if habitat use and availability were different using the package `adehabitatHS` (Version 0.4.15, Calenge and Basille 2019).

To investigate fourth-order habitat selection I built generalized linear mixed models (GLMM), fitted using Penalized Quasi-Likelihood (PQL) to determine which predictive variables were most important for habitat selection in each active season using the `MASS` package (version 7.3-50, Ripley et al. 2019). The dependent variable was turtle occurrence, and the random (non-nested) effects were Julian days and turtle ID. The fixed effects were canopy, ground and shrub percentage, presence of CWD, berries and mushrooms, distance to field and water, substrate type, and temperature. Variables were tested for correlation using a chi-square test with a statistical threshold of 0.05 and the variable "Habitat type" was removed due to high correlation with CWD, substrate, mushrooms and berries. To select the best model, I used a reverse stepwise procedure to reduce the number of variables until the best model was identified through inspection of parameter estimates. For the final model, I calculated a pseudo- R^2 (conditional and marginal coefficients of determination) to estimate model strength using the `MuMIn` package (version 1.42.1, Barton 2019).

Food Availability - I estimated the abundance of gastropods/worms in the study area. After a heavy rainfall (>10mm) in June, July, and August, I surveyed a 1x1m plot within four different habitat types (forest, riparian buffer, grown hay

field and cut hay field) for slugs, earthworms, snails, and any other gastropods, above and below ground. For counting gastropods above ground, a surveyor spent six to ten minutes looking through the vegetation and stems for gastropods. If found, they were placed in sealed plastic bags to be weighed and counted. Once completed, the plot was then dug to count the gastropods within the soil up to 30cm deep, the soil was sifted through for worms, and if found, they were placed in a sealed plastic bag to be weighed and counted.

Gastropods of the same genus were placed in the same bags. The soil was returned to the plot after completion. Vegetation type and height, soil type (e.g. soil, sand, cobble), and percent cover were also recorded.

I used a generalized linear model to test whether month, location (above or below ground), substrate type, vegetation and habitat type were important in predicting gastropod/worm abundance. Due to the high amount of zeroes within the data set, I used a GLM with a Poisson error distribution. However, I used a negative binomial error distribution for gastropod/worms based on the low AIC value compared to other tests. I used Vuong's non-nested hypothesis test and found significant levels of zero-inflation (Slugs: $z=18.33$, $p<0.0001$, Snails: $z=3.23$, $p=0.001$, Worms: $z=74.02$, $p<0.0001$). The variables location, month, and habitat type were the fixed effects and the weight of the species was the dependent variable. A GLM with a binary distribution was used to test whether the occurrence of berries or mushrooms (dependent) were linked to different habitat types and months (independent).

2.4. Results

Population structure – I located a total of 50 wood turtles (13 M: 28 F: 10 J) during 2017 - 2018. In 2017, 12 turtles were radio-tagged and tracked throughout the active season, and in 2018, 23 turtles were tagged and tracked throughout the active season. A total of 1,052 locations were recorded during the two study years, including tagged and untagged turtles (2017: 245, 2018: 817). The male to female ratio was 0.46:1 and was significantly different ($X^2=5.45$, $df=1$, $p=0.019$). To reduce the effect of female-catching bias during the nesting season, I removed eight females from the dataset that were found from June 1 to 28, and the sex ratio was found not to be significant ($X^2=1.48$, $df=1$, $p=0.223$). Adult to juvenile ratio (4.1:1) was significant ($X^2=18.83$, $df=1$, $p<0.0001$).

Home range and Movement – During late-winter/early-spring of 2018, many tagged turtles were washed downriver a mean distance of about 1km, due to the high velocity of the river from snowmelt and the spring freshet. Within a month, all turtles had returned to their original location. Males did not travel further than 200m from the river and most stayed within 100m, but females often travelled >500m away from the river. In August, over 20% of the females were > 100m from the river (Table 2.2). During the active season, three female wood turtles were located > 400m from the main river. Two turtles used same area in 2017 and 2018, which was > 400m from the main river. One turtle spent over a month (July and August) 900m away from the main river. Female turtles traveled < 100m to their nesting sites, which were always within their home range.

Table 2.2. Percent of male and female wood turtle relocations distance to the main river during May-September, 2018 at the study site. Females moved more than 500m from the main river whereas males stayed within 200m.

Distance (m)	Active Season		May		June		July		August		September	
	Male (n=163)	Female (n=436)	Male (n=35)	Female (n=78)	Male (n=50)	Female (n=136)	Male (n=50)	Female (n=135)	Male (n=22)	Female (n=65)	Male (n=6)	Female (n=20)
0	22.4	19.7	7.9	11.4	12.3	12.3	15.3	14.0	33.3	22.6	53.8	33.3
1-100	75.7	75.0	92.1	87.5	87.7	85.2	81.4	81.5	60.6	60.7	46.2	56.7
101-200	1.9	2.9	0.0	1.1	0.0	1.3	3.4	2.5	6.1	7.1	0.0	10.0
201-300	0.0	1.3	0.0	0.0	0.0	0.6	0.0	0.6	0.0	6.0	0.0	0.0
301-400	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
401-500	0.0	0.6	0.0	0.0	0.0	0.6	0.0	0.0	0.0	2.4	0.0	0.0
500+	0.0	0.6	0.0	0.0	0.0	0.0	0.0	1.3	0.0	1.2	0.0	0.0

Home range calculations was solely focused on the 2018 field season due to a lack of relocations in 2017. I found that with 95% of relocations, the average home range was 63.0 ha (range, 4.4-238.9ha) for AKDE and 14.5 for MCP (range, 1-37.3ha). With 50% of relocations the AKDE calculated the average home range at 15.2 ha (range, 0.9-55.6ha) (Table 2.3). Average home range size for AKDE or MCP between males and females was not significantly different (MCP: $t=-1.19$, $df=8.02$, $p=0.27$, AKDE50: $t=-0.31$, $df=7.9$, $p=0.76$, AKDE90: $t=-0.29$, $df=7.6$, $p=0.78$) (Table 2.2).

Table 2.3. The average home range size of male and female wood turtles at my site during the active season. Calculated using minimum convex polygon (MCP) and adaptive kernel (AD), using 50 and 95% of relocations.

	MCP (ha)		Adaptive Kernel (ha)			
	95%	SE	50%	SE	95%	SE
Male	20.1	6.0	15.8	7.8	71.3	35.1
Female	12.4	3.2	13.1	4.1	60.0	17.3

Habitat Selection – Based on the compositional analysis, wood turtles selected for specific habitat types within the study site. The most preferred was the edge (17% of relocations), although it had the least availability in the landscape (Table 2.4). Forest was the most abundant habitat type in the landscape, yet it was the least preferred (10% of relocations). The field was chosen over forest but not selected over any other habitat type. The percentage of wood turtles using the field (23% of relocations) as a habitat type in comparison to what was available is relatively similar (Table 2.4). Throughout the active season, turtles were mostly on land from May to August. In May, more males were on land than females, but in September more females were on land than males. By October, most of the turtles were within the water (Table 2.5).

Table 2.4. Log-ratio differences (numerator habitat in rows, denominator in columns) and ranking of foraging habitat. Numbers in bold represent significant deviation from random at $P < 0.05$.

	Forest	Field	Shore	Buffer	River	Edge	Rank
Forest	0.0						0
Field	5.8	0.0					1
Shore	12.7	5.1	0.0				2
Buffer	12.8	7.1	2.0	0.0			3
River	13.0	7.5	2.3	0.04	0.0		4
Edge	12.7	21.0	11.8	9.5	11.3	0.0	5

Table 2.5. The percent of male (n=209) and female (n = 507) wood turtle relocations at the study site on land or in water.

Month	% on Land		% in Water	
	Male	Female	Male	Female
May	91.1	87.1	8.9	12.8
June	87.9	90.0	12.1	10.0
July	87.1	89.2	12.9	10.8
August	67.6	78.8	32.4	21.2
September	23.1	66.7	76.9	33.3
October	9.1	13.3	90.9	86.7
November-April 1	0	0	100	100

MPM's were significantly different between sexes ($\chi^2=11.17$, $p = 0.0008$).

Due to the differences between sexes, I divided the active season differently for each. The change point analysis found one significant change in MPM throughout the active season for females and three for males (Figure 2.1) and the active season was divided accordingly: Females: May 10-August 10 and

August 11-October 10; Males: May 10-June 20, June 21-July 20, July 21-August 20 and August 21- October 10.

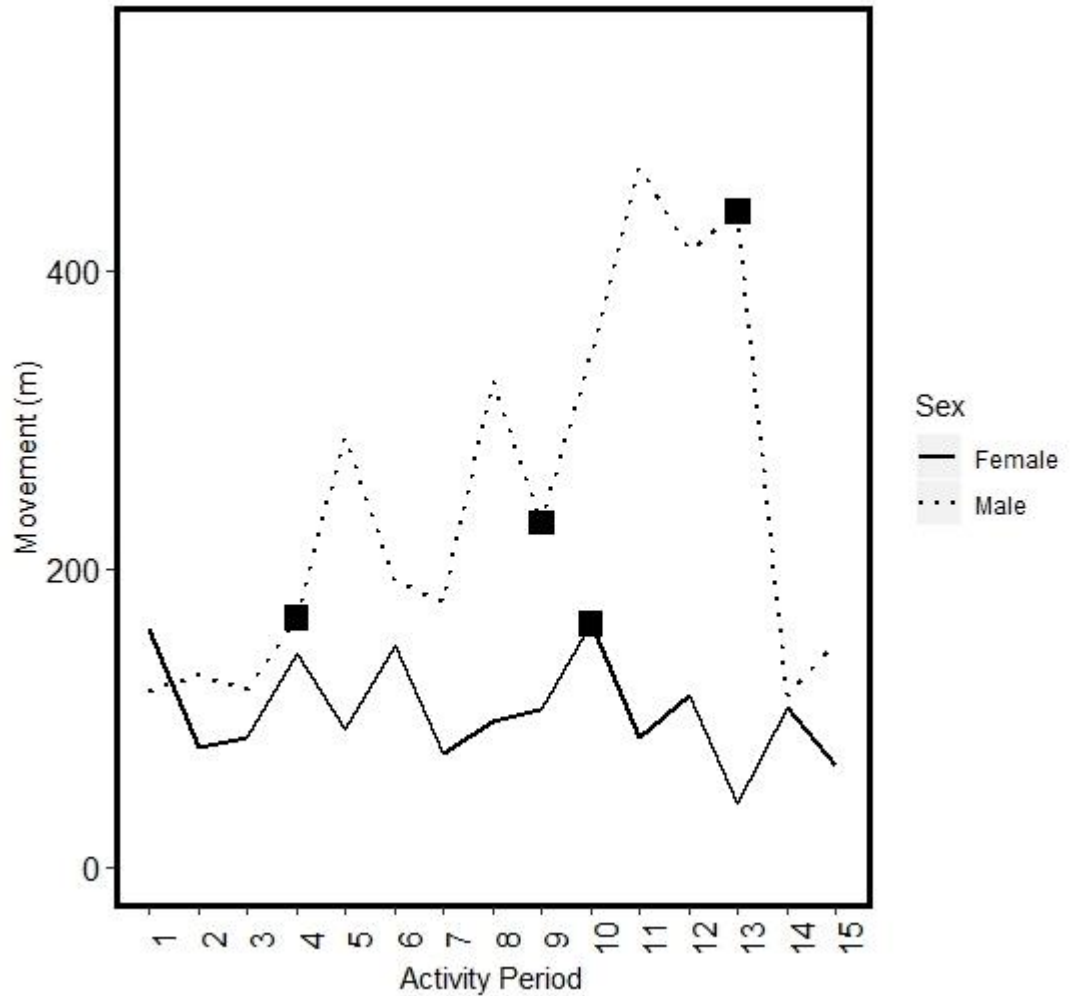


Figure 2.1. The minimal periodic movement for male and female wood turtles in 10-day periods at the study site. The squares represent the significant changes in movement found by the change point analysis. The activity period starts May 11th to October 10th, 2018.

A total of ten models were created to analyze the habitat selection among all turtles throughout the whole season as well as the activity periods based on

the MPM's for male and female wood turtles. Six variables were chosen as important to predict wood turtle occurrence during the active season (May to October), (Appendix B; Table B.1). High temperature ($t = 3.03$, $p = 0.003$), presence of CWD ($t = 5.10$, $p = 0.0001$), presence of berries ($t = 2.31$, $p = 0.02$), high shrub cover ($t = 2.07$, $p = 0.039$), low ground cover ($t = -3.928$, $p < 0.0001$) and low canopy ($t = -8.68$, $p < 0.0001$). But the model was very weak ($mr^2 = 0.079$, $cr^2 = 0.086$).

For females during the active season, low canopy cover ($t = -6.80$, $p < 0.0001$) and presence of CWD ($t = 3.52$, $p = 0.001$) were important variables ($mr^2 = 0.085$, $cr^2 = 0.089$). The female's activity season was split into two periods based on the changepoint analysis. For the first activity period, low canopy cover ($t = -7.28$, $p < 0.0001$), low ground cover ($t = -3.15$, $p = 0.002$), and presence of sand ($t = 3.85$, $p < 0.0001$) and CWD ($t = 3.65$, $p < 0.0001$) were important for presence of females (Appendix B; Table B.4) ($mr^2/cr^2 = 0.17$). For the second activity period, low temperatures ($t = -3.71$, $p < 0.0001$) and distance to field (DTF) ($t = 3.11$, $p = 0.002$) were important ($mr^2/cr^2 = 0.14$) (Appendix B; Table B.5).

For males during the active season, low ground cover ($t = 3.83$, $p < 0.0001$), low canopy cover ($t = -6.08$, $p < 0.0001$) and presence of CWD ($t = 3.46$, $p = 0.001$) were variables found to predict probability of wood turtle presence ($mr^2/mc^2 = 0.109$). The change point analysis calculated four distinct activity periods for males. Their first activity period showed that low canopy ($t = -3.72$, $p < 0.0001$), low ground cover ($t = -2.68$, $p = 0.008$), and presence of CWD ($t = 2.27$, $p = 0.025$) were the most important for wood turtle presence

($mr^2/cr^2 = 0.57$) (Appendix B; Table B.6). Activity period two showed that high temperatures ($t=3.02$, $p=0.003$), low ground cover ($t=-3.27$, $p=0.001$), and occurrence of CWD ($t= 1.75$, $p = 0.083$) were the most important ($mr^2/cr^2 = 0.15$) (Appendix B; Table B.7). During the third period, the presence of CWD ($t=2.28$, $p=0.025$) and the absence of soil ($t=-2.98$, $p=0.004$) were the most important ($mr^2/cr^2 = 0.098$) (Appendix B; Table B.8). For their last period, low canopy ($t=-2.32$, $p=0.024$), low ground cover ($t=-3.30$, $p=0.002$), and closeness to water ($t=2.74$, $p=0.008$) was highly important ($mr^2 = 0.40$, $cr^2 = 0.42$) (Appendix B; Table B.9). Micro-field habitat variables did not predict wood turtle presence (Appendix B; Table B.10).

Food availability- Three main taxa were found within the plots: slugs (mainly *Miagorhina gagates*), earthworms (*Lumbricina spp.*), and snails (mainly *Succinea putris*). For snails and slugs, the final model included the variables month and location as the most important. For the snail model, abundance above ground was significantly higher in comparison to below ground ($z=-3.06$, $p=0.003$) but abundance between months was not (June: $z=1.11$, $p=0.271$, August: $z=-0.22$, $p=0.83$). Snail abundance was high in June for buffer and field but decreased in August (Figure 2.2). For the slug model, abundance was higher above ground compared to below ($z=-5.03$, $p<0.05$) and there were more slugs in the month of July (June: $z=-2.26$, $p=0.02$, August: $z=-2.26$, $p=0.003$). For earthworms, all three variables (location, month, and habitat type) were important. The abundance of earthworms in the forest ($z=-2.46$, $p<0.05$) and a cut field ($z=2.05$, $p<0.05$) were significantly lower in comparison to an uncut field. The month of June, in comparison to July, was also found to affect the

abundance of earthworms ($z = 2.22, p < 0.05$). Earthworm abundance declined within the field between months but increased in the buffer (Figure 2.2).

For mushrooms, the GLM showed that the occurrence was higher in the month of September ($z = 4.8, p < 0.05$) and lower in May ($z = -3.1, p < 0.05$) and July ($z = -4.4, p < 0.05$). There was also a higher occurrence within the forest compared to other habitats ($z = 4.5, p < 0.05$). For berries, the occurrence was lower in July compared to the other months ($z = -2.5, p = 0.01$). Berry occurrence was also positively associated with the forest habitat type ($z = 2.1, p = 0.03$). The occurrence of mushrooms and berries increased as the activity season progressed (Figure 2.2). Turtle presence in the field decrease as

the berry and fungi abundance increased (Figure 2.4).

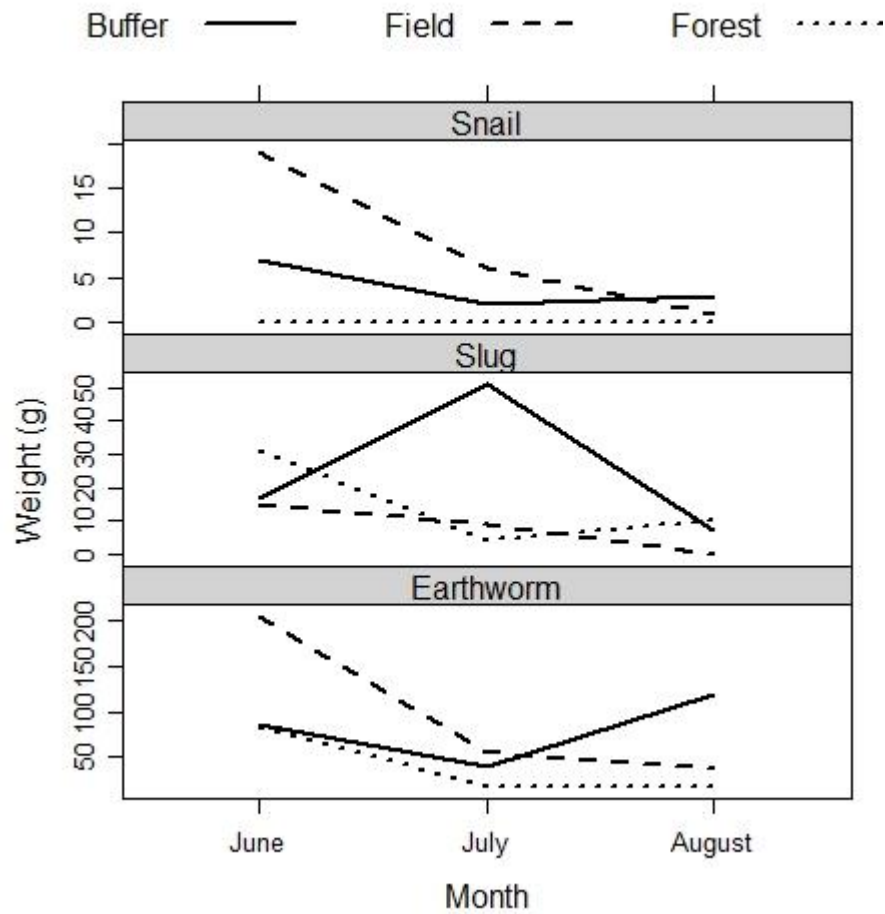


Figure 2.2. The weight of slugs (*Miax gagates*), earthworms (*Lumbricina spp.*), and snails (*Succinea putris*) at the site between three habitat types (field, buffer and forest) from the months of June to August of 2018.

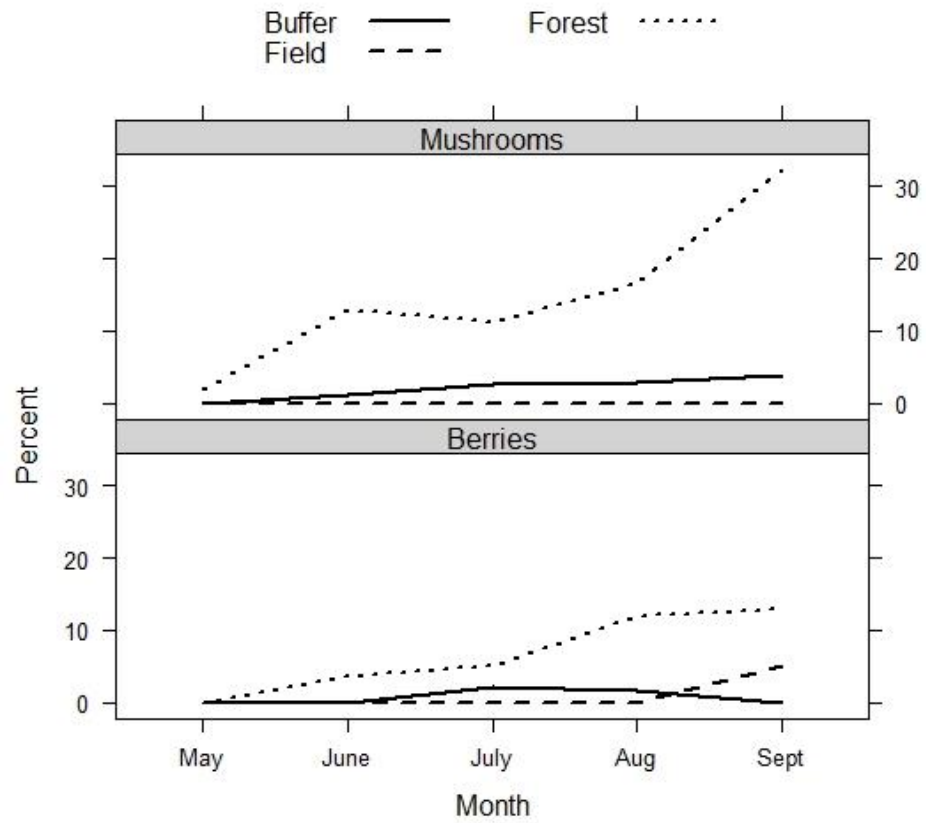


Figure 2.3. The presence of berries and mushrooms at the site from the months of May to September of 2018, collected from the habitat plots for each turtle relocation.

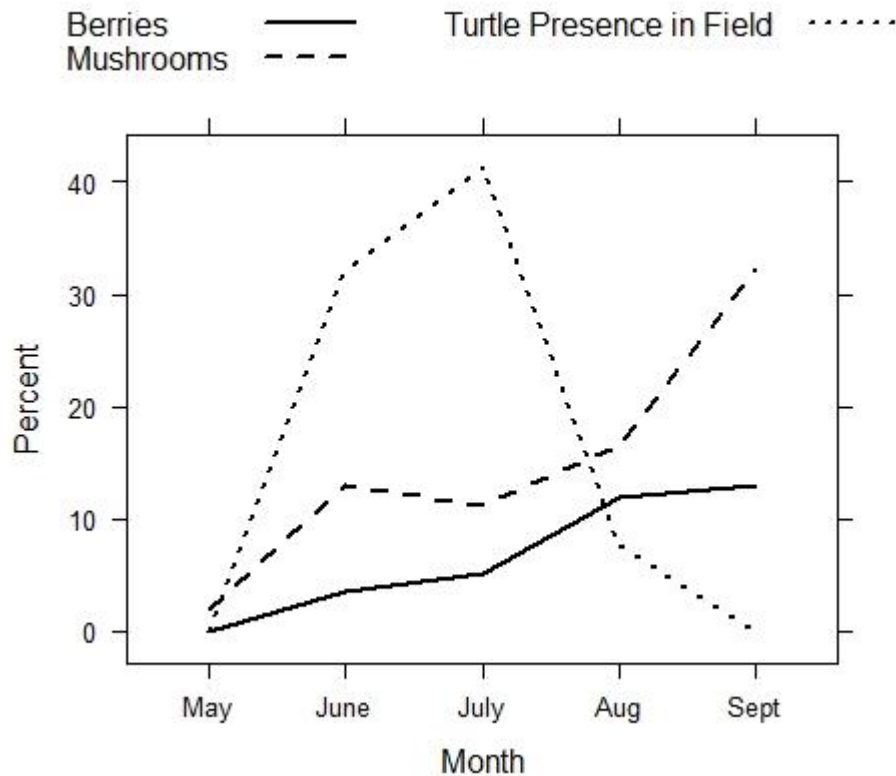


Figure 2.4. The presence of turtles within the field in comparison with the presence of mushrooms and berries throughout wood turtles' active season at the study site in 2018.

2.5. Discussion

Sex Ratio - In my study, I found a significantly skewed sex ratio (1:0.46), but this is likely due to the sampling effort. I caught wood turtles opportunistically, which likely resulted in a catching bias of females during the nesting season (Gibbons 1970; Farrell and Graham 1991; Daigle 1997; Neiderberger and Seidel, 1999; Greaves and Litzgus 2009). Biases can be due to surveyor effort, and if turtles are surveyed within the prime nesting season,

females may be found more frequently. No significant difference was found in the sex ratio when nesting females were removed from analysis.

Flooding Events - At the beginning of the 2018 field season, turtles at my study site emerged from hibernation and were swept downriver due to the strong current for approximately 1km. All turtles returned to their original hibernation area within two to four weeks. Turtles being washed downriver after hibernation is common, but if there are high floods and the turtles are washed more than 2-5.5km away, then they may not be able to return to their original location (Carroll and Ehrenfield 1978; McCurdy 1995; Mullin 2019). High flooding can also result in high levels of mortality due to ice flow, drowning, and log jams, but some populations are unaffected (Norden 1999; Jones and Sivert 2009; Ernst and Lovich 2014; Jergenson et al. 2014; Cross et al. 2018; Mullin 2019). In my study area displacement from the home range was temporary and did not appear to affect habitat use.

Movement and Home Range – During the active season, females moved up to 900m from the main river, whereas males were found to mostly stay within 100m. Many studies have found similar results, with females reaching up to 1km away from the river (Harding and Bloomer 1979; Ernst and Lovich 2014; Thompson et al. 2018). Females that traveled more than 300m from the river were found to use the same area (~5-20m away) between years, likely due to food resources (Powell 2000).

I used two different methods to calculate home range. The adaptive kernel method calculates home range by taking the location points and extrapolating where they could go within their lifetime, making the home ranges

quite large, whereas MCP uses each animal relocation and creates the smallest polygon but can be biased depending on sample size (Boyle et al. 2009). At my site, the average home range was 63ha (range, 4.4-238.9 ha) using a 95% adaptive kernel and 14.5ha (range, 1-37 ha) using a 95% MCP. The adaptive kernel produces a much larger home range than MCP, but Remsberg et al. (2006) also found that adaptive kernel populated a large home range (40.3ha). Home ranges of wood turtles fluctuate depending on the landscape and their location in their breeding range. In the northern part of their breeding range, home ranges were 24.3ha (Ontario) and 28.3ha (Quebec), whereas in the southern portion of their range, (Pennsylvania, Wisconsin, and northern Michigan) home ranges were between 0.4-6.7ha, using the MCP method (Quinn and Tate 1991; Ross et al. 1991; Kaufmann 1995; Arvisais et al. 2002; McCoard et al. 2016). Studies have also noted that landscapes with disturbed habitat result in larger wood turtle home ranges that facilitate access prime habitat and food resources (Quinn and Tate 1991). Saumure (2004) found that the home range was 25.7ha (using MCP) in an agricultural landscape within Quebec. Wood turtles at my site did not need to travel large distances to access ideal nesting (e.g., extensive sandbars) and hibernation locations, which likely resulted in smaller movement patterns in comparison to other study sites (Aresco 2005; Tingley et al. 2009; Parren 2013; Ernst and Lovich 2014).

Habitat Selection and Food Availability – Wood turtles selected certain habitat types, with the edge being the most common and forest being the least common, despite forest being the most available habitat at the site. The wood turtle population at my site selected specific habitats and did not seem to use

habitat based on availability. My findings are consistent with other habitat studies, as wood turtles are known to be “edge” species and avoid areas of thick canopy, likely because canopy limits ideal basking locations (Arvisais et al. 2004; Saumure et al. 2007).

Movement differed significantly between sexes at my site. These results support the idea that movement is generally greater for male wood turtles since they appear to be continually searching for females (Ross et al. 1991; Thompson et al. 2018). But some studies have found that there was no significant difference in movement between sexes (Arvisais et al. 2002). Female movements at my site also may be smaller in comparison to males because they did not have to travel large distances to access nesting and food sources.

Habitat selection differed for the active season and between activity periods. The models for the entire active season were weak, but low canopy cover, and the presence of CWD, were the most important model. Low canopy cover would be preferred due to limited basking areas (Compton et al. 2002). Woody debris is thought to be of particular importance to smaller herptile species, like salamanders and frogs for protection and moisture (Whiles and Grubaugh 1996). For turtles, CWD is used for basking spots, but my study shows that they used CWD for shelter as well. The temperature at ground level was also important for predicting turtle presence. At the beginning of the active season, high temperatures are chosen, but as the season progresses, the turtles use areas with lower temperatures. 2018 had high temperatures during the summer, and since turtles are ectothermic, they were likely trying to escape

to cooler temperatures. CWD seemed to provide these cool temperatures and also provided a place for turtles to hide from predators.

Habitat selection differed slightly between sexes. Females were found to prefer sand, likely because of the nesting season, and the presence of berries whereas males preferred high temperatures. The micro-habitat model for field use did not have any variables important for predicting presence, which could be due to the lack of data associated with temperature or wood turtles could be more selective in other habitats due to features being patchily distributed. Many of the models are weak, which could be due to a small sample size from splitting the data into different activity periods.

Berries were important for wood turtle presence within the female's habitat models. Wood turtles are noted to be food opportunists, and their habitat usage can change depending on availability (Harding and Bloomer 1979; Compton et al. 2002). Berries and mushrooms were the most abundant in forests and occurred in high abundance in August and September. Earthworms were the most abundant in June within the fields. Wood turtles were observed to leave the fields as the worms became least abundant and when the berries and fungi became most abundant. During the active season, most of the wood turtles left the fields after the end of July. At the study site, the fields were not harvested until the end of August, and so the loss of cover would not result in the turtles leaving the fields. Low abundances of earthworms in the fields and the increase of fungi and berries in the forest is likely why the wood turtles left the fields and moved to other habitat types. Saumure (2004) noted that food resources could influence wood turtle home range size, and many studies have

indicated that wood turtles use areas based on the emergence of different food types (Kaufmann 1992; Remley and Rhymer 1997; Compton et al. 2002; Arvisais et al. 2004). Generally, earthworm abundance has been noted to be low in July and August but return in September, likely due to the heat (Whalen et al. 2004). It should be noted that although most of the wood turtles at my study site left the fields at the end of July, other studies have found that wood turtles stay in the fields until end of August, mid-September (Saumure et al. 2007; Tingley et al. 2009). It seems likely that wood turtles may stay in the fields for a longer time if food availability is lacking in other habitat types.

The agricultural fields provide a rich food source, low canopy cover, and a thick thatch for protection, and they are enticing to wood turtles during the prime hay harvest season (June and July). The fields at my site are also encompassing a large portion of the landscape and are within 15m from the main river. The use of agricultural fields by wood turtles is of conservation concern because significant mortality rates from hay harvest have been recorded in numerous studies (Saumure et al. 2007; Tingley et al. 2009). It appears that the fields are being used by wood turtles for food, as opposed to simply using fields adjacent to waterways. Mitigation strategies that lessen mortality are vital to viable wood turtle populations (e.g., raise blade height, delaying hay harvest), but managers may want to consider reducing the prey densities that are attracting wood turtles to the field. Further research on slug and earthworm response to crop harvesting and tilling practices may prove beneficial.

2.6. Literature Cited

- Aebischier, N.J., Robertson, P.A., and Kenwood, R.E. 1993. Compositional analysis of habitat use from animal radio-tracking data. *Ecology* **74**(5): 1313–1325.
- Aresco, M.J. 2005. The effect of sex-specific terrestrial movements and roads on the sex ratio of freshwater turtles. *Biol. Conserv.* **123**(1): 37-44. doi:10.1016/j.biocon.2004.10.006.
- Arvisais, M., Bourgeois, J.-C., Lévesque, E., Daigle, C., Masse, D., and Jutras, J. 2002. Home range and movements of a wood turtle (*Clemmys insculpta*) population at the northern limit of its range. *Can. J. Zool.* **80**(3): 402–408. doi:10.1139/z02-013.
- Arvisais, M., Lévesque, E., Bourgeois, J.-C., Daigle, C., Masse, D., and Jutras, J. 2004. Habitat selection by the wood turtle (*Clemmys insculpta*) at the northern limit of its range. *Can. J. Zool.* **82**(3): 391–398. doi:10.1139/z04-012.
- Barton, K. 2019. MuMIn: Multi-model inference. R package version 1.43.15. <https://cran.r-project.org/web/packages/MuMIn/MuMIn.pdf>
- Boyle, S.A., Lourenço, W.C., da Silva, L.R., and Smith, A.T. 2009. Home range estimates vary with sample size and methods. *Folia Primatol. Int. J. Primatol.* **80**(1): 33–42. doi:10.1159/000201092.
- Cagle, F.R. 1939. A system of marking turtles for future identification. *Copeia* **1939**(3): 170–173. doi:10.2307/1436818.
- Calenge, C., and Basille, M. 2019. adehabitatHS: Analysis of habitat selection by animals. R package version 0.3.14. <https://cran.r-project.org/web/packages/adehabitatHS/adehabitatHS.pdf>
- Calenge, C., and Fortmann-Roe, S. 2019. adehabitatHR: Home range estimation. R package version 0.4.16. <https://cran.r-project.org/web/packages/adehabitatHR/adehabitatHR.pdf>
- Carroll, T.E., and Ehrenfeld, D.W. 1978. Intermediate-range homing in the wood turtle, *Clemmys insculpta*. *Copeia* **1978**(1): 117–126. doi:10.2307/1443831.

- Compton B.W., Rhymer J.M., and McCollough, M. 2002. Habitat selection by wood turtles (*Clemmys insculpta*): an application of paired logistic regression. *Ecology* **83**(3): 833–843. doi:10.1890/0012-9658(2002)083[0833:HSBWTC]2.0.CO;2.
- Congdon, J.D., Tinkle, D.W., Breitenbach, G.L., and Sels, R.C. van L. 1983. Nesting ecology and hatching success in the turtle *Emydoidea blandingi*. *Herpetologica*. **39**(4): 417–429.
- COSEWIC. 2018. COSEWIC assessment and update status report on the Wood Turtle *Glyptemys insculpta* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. Vii + 51 p.p.
- Cross, J., Cross, R., Chartrand, D., and Thompson, D.G. 2018. Characterizing wood turtle (*Glyptemys insculpta*) populations at the Northwestern periphery of the species range in Canada. *Northeastern Naturalist* **25**: 571–586.
- Daigle, C. 1997. Size and characteristics of a wood turtle, *Clemmys insculpta*, population in Southern Quebec. *Can. Field-Nat.* **111**: 440–444.
- Dubois, Y., Blouin-Demers, G., Shipley, B., and Thomas, D. 2009. Thermoregulation and habitat selection in wood turtles *Glyptemys insculpta*: chasing the sun slowly. *J. Anim. Ecol.* **78**(5): 1023–1032. doi:10.1111/j.1365-2656.2009.01555.x.
- Ernst, C.H., and Lovich, J.E. 2014. Turtles of the United States and Canada. In *Second*. Johns Hopkins University Press, Baltimore, United States.
- Farrell, R.F., and Graham, T.E. 1991. Ecological notes on the turtle *Clemmys insculpta* in Northwestern New Jersey. *J. Herpetol.* **25**(1): 1–9. doi:[10.2307/1564787](https://doi.org/10.2307/1564787).
- Flanagan, M., Roy-McDougall, V., and Forbes, G. 2013. Survey methodology for the detection of Wood Turtles (*Glyptemys insculpta*). *Can. Field-Nat.* **127**: 216–223. doi:10.22621/cfn.v127i3.1486.
- Fleming, C.H., Calabrese, J.M., Dong, X., Winner, K., Peron, G., Noonan, M.J., Kranstauber, B., Gurarie, E., Safi, K., Cross, P.C., Mueller, T., Paula, R.C., Akre, T., Drescher-Lehman, J., and Harrison, A. 2019. ctm:

Continuous-time movement modeling. R package version 0.5.8.

<https://cran.r-project.org/web/packages/ctmm/ctmm.pdf>

- Forbes, G. 2005. Diurnal and nocturnal habitat use by Wood Turtle (*Clemmys insculpta*) in New Brunswick, Canada. Undergraduate thesis, University of New Brunswick, Fredericton.
- Garber, S.D., and Burger, J. 1995. A 20-Yr Study documenting the relationship between turtle decline and human recreation. *Ecol. Appl.* **5**(4): 1151–1162. doi:[10.2307/2269362](https://doi.org/10.2307/2269362).
- Gibbons, J.W. 1970. Terrestrial activity and the population dynamics of aquatic turtles. *Am. Midl. Nat.* **83**(2): 404–414. doi:[10.2307/2423953](https://doi.org/10.2307/2423953).
- Greaves, W.F., and Litzgus, J.D. 2009. Variation in life-history characteristics among populations of North American wood turtles: A view from the north. *Journal of Zoology* **279**(3): 298–309. doi:[10.1111/j.1469-7998.2009.00621.x](https://doi.org/10.1111/j.1469-7998.2009.00621.x).
- Harding, J.H., and Bloomer, T.J. 1979. The wood turtle, *Clemmys insculpta*...a natural history. *Bulletin of the New York Herpetological Society* 15:9-26.
- Jergenson, A.M., Miller, D.A.W., Neuman-Lee, L.A., Warner, D.A., and Janzen, F.J. 2014. Swimming against the tide: resilience of a riverine turtle to recurrent extreme environmental events. *Biol. Lett.* **10**(3): 20130782. doi:[10.1098/rsbl.2013.0782](https://doi.org/10.1098/rsbl.2013.0782).
- Johnson, D.H. 1980. The comparison of usage and availability measurements for evaluating resource preference. *Ecology* **61**:65–71.
- Jones, M.T., and Sievert, P.R. 2009. Effects of stochastic flood disturbance on adult wood turtles, *Glyptemys insculpta*, in Massachusetts. *Can Field-Nat.* **123**(4): 313–322. doi:[10.22621/cfn.v123i4.1000](https://doi.org/10.22621/cfn.v123i4.1000).
- Kaufmann, J.H. 1992. Habitat use by wood turtle in central Pennsylvania. *J. Herpetol.* **26**:315-321.
- Kaufmann, J.H. 1995. Home ranges and movements of wood turtles, *Clemmys insculpta*, in Central Pennsylvania. *Copeia*. **1995**(1): 22–27. doi:[10.2307/1446796](https://doi.org/10.2307/1446796).

- Killick, R., Haynes, K., Eckley, I., Fearnhead, P., and Lee, J. 2016. changepoint: Methods for changepoint detection. R package version 2.2.2. <https://cran.r-project.org/web/packages/changepoint/changepoint.pdf>
- McCoard, K.R.P., Billings, A.A., and Anderson, J.T. 2016. Wood turtle home range and habitat use in the central Appalachians. *Chel. Conserv. Biol.* **15**(2): 173–180. doi:[10.2744/CCB-1215.1](https://doi.org/10.2744/CCB-1215.1).
- McCurdy, D.G. 1995. Orientation and movement patterns of reciprocally transplanted wood turtles (*Clemmys insculpta leconte*) in northeastern Nova Scotia. BSc.HR, Acadia University.
- Mullin, D.I. 2019. Evaluating the effectiveness of headstarting for wood turtle (*Glyptemys insculpta*) population recovery. M.Sc. Thesis. Laurentian University, Sudbury, Ontario, Canada. 144 pp.
- Niederberger, A.J., and Seidel, M.E. 1999. Ecology and status of a wood turtle (*Clemmys insculpta*) population in West Virginia. *Chel. Conserv. Biol.* **3**:414-418.
- Norden, A.W. 1999. Flood induced winter mortality of wood turtles (*Clemmys insculpta* Le Conte) in Maryland. *Maryland Nat.* **43**: 3–4.
- Parren, S.G. 2013. A twenty-five year study of the wood turtle (*Glyptemys insculpta*) in Vermont: Movements, behavior, injuries, and death. *Herpetol Conserv. Biol.* **8**:176–190.
- Powell, RA. 2000. Animal home ranges and territories and home range estimators. Pages 65–110 in L. Boitani & T.K. Fuller, editors. *Research Techniques in Animal Ecology. Controversies and Consequences*. Columbia University Press, New York, New York, USA.
- Quinn, N.W.S., and Tate, D.P. 1991. Seasonal movements and habitat of wood turtles (*Clemmys insculpta*) in Algonquin Park, Canada. *J. Herpetol.* **25**(2): 217–220. doi:[10.2307/1564654](https://doi.org/10.2307/1564654).
- R Core Team. 2018. A language and environment for statistical computing. R foundation for statistical computing, Vienna, Austria. URL <http://www.R-project.org/>.

- Remley, M., and Rhymer, J. 1997. Nesting ecology and habitat use of wood turtles in western Maine. University of Maine, Orono.
- Remsberg, A.J., Lewis, T.L., Huber, P.W., and Asmus, K.A. 2006. Home ranges of wood turtles (*Glyptemys insculpta*) in Northern Michigan. *Chel. Conserv. Biol.* **5**(1): 42–47. doi:[10.2744/1071-8443\(2006\)5\[42:HROWTG\]2.0.CO;2](https://doi.org/10.2744/1071-8443(2006)5[42:HROWTG]2.0.CO;2).
- Ripley, B., Venables, B., Bates, D.M., Hornik, K., Gebhardt, A., and Firth, D. 2019. MASS: Support functions and datasets for venables and Ripley's MASS. R package version 7.3-51.5. <https://cran.r-project.org/web/packages/MASS/MASS.pdf>
- Ross, D.A., Brewster, K.N., Anderson, R.K., Brewster, C.M., and Ratner, N. 1991. Aspects of the ecology of wood turtle, *Clemmys insculpta*, in Wisconsin. *Can. Field-Nat.* **105**:363-367.
- Roy-McDougall, V. 2010. Habitat selection by wood turtle in central New Brunswick, Canada. M.Sc.F., University of New Brunswick, Canada.
- Saumure, R.A., AND J.R. Bider. 1998. Impact of agricultural development on a population of wood turtles (*Clemmys insculpta*) in southern Quebec, Canada. *Chel. Conserv. Biol.* **3**:37-45.
- Saumure, R.A. 2004. Spatial ecology and conservation of the north American wood turtle (*Glyptemys insculpta*) in a fragmented agri-forested landscape. PhD, Department of Natural Resource Science, McGill University, Montreal, Quebec, Canada
- Saumure, R.A., Herman, T.B., and Titman, R.D. 2007. Effects of haying and agricultural practices on a declining species: The North American wood turtle, *Glyptemys insculpta*. *Biol Conserv.* **135**(4): 565–575. doi:[10.1016/j.biocon.2006.11.003](https://doi.org/10.1016/j.biocon.2006.11.003).
- Springer, J.T. 1982. Movement patterns of coyotes in south central Washington. *J. Wildl. Manag.* **46**(1): 191–200. doi:[10.2307/3808422](https://doi.org/10.2307/3808422).
- Thompson, D.G., Swystun, T., Cross, J., Cross, R., Chartrand, D., and Edge, C.B. 2018. Fine- and coarse-scale movements and habitat use by wood turtles (*Glyptemys insculpta*) based on probabilistic modeling of

radiotelemetry and GPS-telemetry data. *Can. J. Zool.* **96**(10): 1153–1164. doi:10.1139/cjz-2017-0343

Tingley, R., McCurdy, D.G., Pulsifer, M.D., and Herman, T.B. 2009. Spatio-temporal differences in the use of agricultural fields by male and female wood turtles (*Glyptemys insculpta*) inhabiting an agri-forest mosaic. *Herpetol Conserv. Biol.* **4**:185-190.

Whalen, J.K. 2004. Spatial and temporal distribution of earthworm patches in corn field, hayfield and forest systems of southwestern Quebec, Canada. *Appl. Soil Ecol.* **27**(2): 143–151. doi:10.1016/j.apsoil.2004.04.004.

Whiles, M.R., and J.W. Grubaugh. 1996. Importance of coarse woody debris to southern forest herpetofauna. Pp. 94-100 in *Biodiversity and Coarse Woody Debris in Southern Forests* (J.W. McMinn and D.A. Crossley, Jr., eds.). *Proceedings of the Workshop on Coarse Woody Debris in Southern Forests: Effects on Biodiversity*. USDA Forest Service General Technical Report SE-94.

Chapter 3: Relationship of wood turtle behaviour to agricultural practices

3.1 Abstract

Agricultural land and agricultural machinery present an ecological trap for some species. The threatened wood turtle (*Glyptemys insculpta*) inhabits riparian buffers and forests but will use agricultural fields if close to nesting habitat, as these fields can provide adequate basking temperatures and feeding grounds. In actively farmed fields, agricultural machinery can present a mortality risk for the species. Mitigation of this risk is difficult, as there is limited information on the effects of agricultural practices on wood turtles. I sought to quantify how different agricultural practices affect wood turtles at levels ranging from individual movement behavior to population demographics. From May to October of 2017 and 2018, I studied wood turtles in central New Brunswick, Canada along a third-order stream surrounded by hayfields and forest. I located 50 wood turtles along a 2-km section and radio-tagged 23 (6M:17F) to monitor their habitat use and relative risk from agricultural practices. I recorded a total of 1,057 relocations in 2017 and 2018; during the typical haying season (15 June - 15 July), approximately 35% of relocations were within a hayfield. Females used the fields more often and for a longer period than did males. When in fields, 86% and 80% of the turtles were <30m from the field edge in June and July, respectively. Direction trials (n= 50) involved monitoring movement trials on 13 adult (3M:10F) and 1 juvenile turtle in cut and uncut fields, from 15 - 185m from water, and from 1 - 125m from an alternative choice of forest cover; in 98% of trials, the turtle turned and moved towards water before moving 10m, indicating turtles could move to safety. When they were approached by the tractor, I

observed the response of 24 wood turtles already in the field or those temporarily translocated from nearby rivers; 44% moved towards water, when the tractor was <10m away. However, none moved fast enough to avoid the tractor, suggesting that recommendations for machinery to harvest from the centre of fields outwards, as a strategy to allow turtles to escape will not greatly reduce mortality rates. Therefore, I recommend that, in addition to raised blade height initiatives, managers consider a minimum 30m-wide buffer strip of uncut hay along the edge of the field closest to the river until the Autumn when turtles have most likely returned to the water.

KEYWORDS: Agriculture; behavior; injury; management; predation pressure; wood turtles

3.2. Introduction

Anthropogenic habitat alterations have resulted in ecological traps for many species. An ecological trap occurs when individuals uses habitat that results in low fitness when there is other habitat available that provides high fitness (Robertson and Hutto 2006). Agricultural practices are one form of habitat alteration that has resulted in an ecological trap for insects, birds, and herptile species (Blodgett and Denke 1999; Nocera et al. 2007; Saumure et al. 2007; Humbert et al. 2009). For some species, agricultural fields can provide suitable nesting habitat, ease of travel, and forage areas (Browne and Paszkowski 2014; COSEWIC 2016). Historically, agriculture in eastern North America has increased the population size of species such as bobolink (*Dolichonyx oryzivorus*) and eastern meadowlark (*Sturnella magna*), but in the

last 50 years the change in blade type and a shift to earlier hay harvest has increased mortality rates of juvenile ground-nesting birds (Nocera et al. 2007; Humbert et al. 2009; Walk et al. 2010). Early hay harvest not only affects birds but also herptile species, such as the wood turtle (*Glyptemys insculpta*) (Liczner 1999; Saumure et al. 2007; Tingley et al. 2009).

The wood turtle is a terrestrial, freshwater species that use rivers for hibernation, shores for nesting, and open areas for basking (Compton et al. 2002; Dubois et al. 2009; Saumure et al. 2007; Mui et al. 2015; Thompson et al. 2018). Hayfields that are close to suitable rivers can be enticing to wood turtles because of opened canopy, thick thatch for cover, and abundant food (Compton et al. 2002; Arvisais et al. 2004; Saumure et al. 2007; Dubois et al 2009; Tingley et al. 2009; Ernst and Lovich 2014; Chapter 2.1). During the hay harvest season, wood turtles use agricultural fields and are at high risk of being hit by agricultural machinery (Saumure and Bider 1998; Kaufmann 1992; Mullin 2019). In Nova Scotia, Tingley et al. (2009) recorded 14 out of the 27 tagged adult turtles in fields at least once during the active haying season (June 8-August 19), and five mortalities during the first harvest. Saumure et al. (2007) recorded that 20% of their study population died and survivorship decreased by 10-13% due to impact from agricultural machinery. Wood turtles are sensitive to decreases in adult survival because their populations are not generally density dependent and individuals only become sexually mature between 12-15 years old (COSEWIC 2018; Saumure et al. 2007). Because of their life history strategy, even minor rates of adult mortality strongly impact population viability (Compton 1999). Within Ontario, a population of wood turtles decreased by 65-

75% within a year due to poaching; population viability analysis indicated that the population is predicted to be extirpated within 50 years if no management was implemented (Mitchell et al. 1997; Cameron and Brooks 2002). Such high risk of extirpation has led to an emphasis on mitigation practices that increase the survival of adult turtles (STRIDES 2016; Erb and Jones 2011).

Mitigation strategies in agricultural areas include raising blade height, mowing in a pattern from the inside of the field outwards, establishing a riparian buffer, and delaying hay harvest (Saumure et al. 2007; Tingley et al 2009; Erb and Jones 2011; STRIDES 2016; Wallace et al. 2020 {Appendix A}). Wood turtles will use hayfields, but assessing risk requires data on the frequency and duration of hayfield use by wood turtles that is coincident with farm machinery (Saumure et al. 2007). Another uncertainty is the actual vulnerability to machinery; wood turtles can feel ground vibrations, have excellent hearing, and their learning ability is similar to that of rats, which could help them perceive the tractor as a danger during harvest and thus facilitate escape to safety (Tinklepaugh 1932; Harding and Bloomer 1979). Saumure et al. (2007) noted that wood turtles who were previously hit by a tractor and survived had a learned response and could escape during the next harvest. If a turtle moves during harvest, then their ability to orient towards safety is relevant to any recommendations on altering mowing patterns by farmers. Limited information also exists on movement; it is uncertain whether turtles will seek water for protection when they are far away from it, such as in a field, or if they will escape to the nearest forest edge, regardless of the direction to the nearest water.

The establishment of buffer strips has been recommended as a strategy to reduce the danger of agricultural machinery on wood turtles (Saumure et al. 2007; STRIDES 2016). However, such a buffer would need to be very wide; Tingley et al. (2009) noted that a riparian buffer of 235m would include 95% of female wood turtles at their site. Such a loss of productive land would not be tenable in floodplain farmland, which dominates large parts of agriculture within the wood turtle's range. Also, a forested buffer may not suffice because wood turtles choose edge habitat and are likely to travel through forested buffer strips to find basking sites and food in the hayfields (Compton et al. 2002; Saumure et al. 2007; Section 2.4). Data are lacking on how far wood turtles will enter fields; if most wood turtle locations within a field are close to the edge, then a relatively thin, un-mowed field buffer strip could provide some safety during harvest.

Agricultural areas may also present an indirect threat to wood turtles because such areas often support higher predator populations (Daigle and Jutras 2005), which results in high injury rates of adults and juveniles, as well as increased depredation on nests (Mullin 2019). In agricultural landscapes, the depredation rate was 95%, compared to 60% in a forested landscape (Wirsing et al. 2012). Higher injury rates, which could affect mobility and nest digging by turtles, have been recorded in agricultural landscapes than forested landscapes (Saumure and Bider 1998).

My project focused on a wood turtle population located in New Brunswick in an agri-forested landscape. My goal was to determine the risk that agricultural landscapes pose on wood turtles. I focused on how often wood turtles used the hay fields, their behaviour during hay harvest, their proximity to the edge of the

field, injury rates, and whether predation is a threat to age structure. Based on this information, I provide mitigation recommendations that could be used by landowners, non-for-profit organizations, and government agencies in the management of wood turtle.

3.3. Methods

Study Site – I used two study sites, both located in central New Brunswick, Canada, with Site A as the primary site for telemetry and turtle response to agriculture, and Site B used for a comparison of predation in agricultural versus forested landscapes. The sites are approximately 75km apart; the exact locations of this federally threatened species are not provided due to the potential threat of collection for the pet trade (Garber and Burger, 1995). Site A was a 268.9-hectare area along a 2-km long stretch of a third-order river. The river is 5-15m wide and 0.01-2m deep. The riverbed consisted mainly of small cobble rocks (97%; diameter <25cm) and boulders (2%; diameter >25cm) with a few deposits of sand (0.4%) and mud (0.6%), mainly along meandering sections of the river. Approximately 75% of the study site is *Picea-Acer* forest <50 years old with floodplain shorelines dominated by alder (*Alnus incana*), willow (*Salix* spp.) and other woody vegetation < 1m high, open grassy areas, and cobble beaches. Six hay fields encompass 22% of the study area and exist on both sides of the river but are interspersed among forested sections. The average field dimensions are: 132m long (range, 49–225m) by 322m wide (range, 181–648m) and 120ha (range, 25–343ha). The maximum grass height reached 1.7m. All fields had a layer of thatch (undecomposed plant

material) approximately 2cm high in July and August. Four of the five fields are <15m away from the river, and the sixth field was approximately 40m away. The fields are a mixture of timothy (*Phleum pratense*), bedstraw (*Galium aparine*), brome grass (*Bromus spp.*), and orchard grass (*Dactylis glomerata*), these plants comprise a common field type in much of the intervale landscapes in the Maritimes. The area has been partially developed with housing and has a paved road that is parallel to the river ranging from 117–665m away. Site B was in mixed forest containing spruce (*Picea spp.*) and fir (*Abies balsamea*) and various hardwood species (e.g., *Populus spp.*, *Acer spp.*) along a 2-km long stretch of a fifth order stream and is used as a comparison of agricultural and forest landscapes for some parts of the study. The river is 7–32m wide and 0.05–5m deep with a riverbed of cobble and rock, with sandbanks and grassy shorelines along the meandering sections. There are several small (i.e., <3 ha) abandoned fields, and a gravel road crossing, but much of the immediate area is unmanaged forest 30–60 years old.

Capture Methods – At Site A, I captured wood turtles opportunistically from June to October in 2017, and from May – October, 2018. In May 2018, I captured wood turtles during a two-person visual transect within 10 meters of the main river for 1 hour, three times a week for three weeks (Flanagan et al. 2013). Surveys occurred during the day when temperatures were above 7°C, with no precipitation. I marked captured turtles for identification using a shell notching system (Cagle 1939). I equipped turtles with transmitters (Model: A1-F2 adults; 33g, Holohil Systems Ltd. Ottawa, Canada) attached to the edge of the right posterior scute using J-B Weld ClearWeld Quick-Setting Epoxy. I

conducted these studies with permits from New Brunswick Energy and Resource Development (SAR18 – 026) and University of New Brunswick Animal Care protocol (18027).

At Site A, I recorded the location of each wood turtle using a Global Positioning System (Garmin 64) and simultaneously triangulated tagged turtles using a radio receiver (i.e., Telonics Tr4 Model. Tempe, Arizona) individual turtles were usually found two to three times a week. I located turtles primarily between 0830 and 1700h because wood turtles are mainly active within this time frame, as determined by an analysis of 24-hour movement patterns conducted on one of the sites previously (Forbes 2005). When a wood turtle was found in a hayfield, ArcGIS was used to measure the distance between the turtle to the edge (transition between two habitat types) of the field and the main river.

Mark and recapture studies conducted in 2012 (independently of this study) and in 2018 at Site B were used to document age structure of a population in a non-agricultural landscape. The 2-km stretch of river was surveyed by two people on either side of the river within 10m of the shore. The area was surveyed for three consecutive days in May. At both sites turtles I recorded sex, weight, age (typically only if <20 years old), injuries (on shell and limbs), shell wear, carapace length (midline and maximum), maximum carapace width, and carapace height, using tape measure or caliper. Carapace height was also measured at Site A. A chi-square test was completed to analyze whether the sex ratio and adult versus juveniles differed from 1:1.

Response Trials – I observed the behaviour of wood turtles within agricultural fields during hay harvest at Site A in July and August of 2017 and

2018 to establish whether turtles perceive the machinery as a threat and can escape to safety. A Case International 595 tractor, owned and operated by a private landowner, was used during harvest equipped with a New Idea 5209 rotary disc mower. The farmer cut in a clockwise direction, starting from the outside edge of the field and moving into the centre. On the day of harvest, I tracked turtles to find any individuals within the field. If few turtles were found in the field, then tagged turtles found nearby were temporarily placed into the field. I assumed that turtles which remained in the field for at least 10 minutes were not responding to the observer; turtles that fled when placed in the field were removed from analysis. Observers monitored one turtle each hay harvest and stood at a distance where they could see the turtle but not disturb turtle (i.e., ~5m). During the hay harvest, we recorded whether the turtle reacted to the presence of the tractor (e.g., head lift or retraction), escape movement and direction to either field, forest, or river, rate of movement, and rate of speed according to the proximity of the tractor. If a turtle was within 5 meters of the tractor and at risk of being harmed, the observer moved the turtle to safety.

Direction Trials - In 2017 and 2018, I assessed the ability of wood turtle to detect the direction of water at Site A with 50 trials on 14 individual turtles (3M: 10F:1 juvenile). Surveyors moved tagged individuals into a field (recently cut, or up to 1m high) and recorded the movement and direction of the turtle once positioned. Forty of the trials were conducted when grass was freshly cut, and the horizon was visible. Fifteen of the turtles were placed in a cut field and 26 turtles within an uncut field. Turtles were placed at a range of 15–180m from the river and 1–125m from forest canopy cover at different cardinal directions and at

sites with varying horizontal visibility. Turtles were placed in fields between forest and the river such that they had a choice between moving towards river or forest cover. To detect if the observer influenced direction moved by the turtle, the observer alternated standing between the turtle and river or forest during the trials. Half the trials had an observer between the turtle and the river. The rate of movement and presence of observer between the turtle and the river was also recorded.

Predator Occurrence– Twelve trail cameras were established at Sites A and B to compare the occurrence of egg, hatchling or adult turtle predators during the wood turtle active season in agriculture and forested landscapes I used Trail Cameras TM, with a triggering distance of 25m, a 20m range of IR flash, and an 8MP CMOS sensor. Cameras were installed along a 2-km long stretch of two rivers within 15m of the shore. Six of the cameras were positioned in front of suitable nesting sand bars, and six were placed facing the edge of the river, which was either in grasses, alder, or forest. Cameras were programmed to capture 24 hours a day on a normal trigger sensitivity setting and three photos per event for fast moving animals. Cameras recorded from May 31-October 29, 2018 at Site B and from June 1-July 17 and August 29-October 15 at Site A; the gap in coverage was due to theft of cameras and we accounted for this gap by only comparing the same sampling periods. Predator occurrence was recorded as the number of predators per 100 hours. A two tailed *t-test* was completed to compare the presence of each predator species at the two study locations.

Injury – I used Saumure et al. (2007) carapace mutilation index (CMI) to assess past injuries that wood turtles sustained in a landscape under active

agriculture (Site A). This index focuses on injuries visible on the carapace across the four different quadrants of the shell. The carapace was chosen because it has a large surface area, it displays old injuries, and its primary purpose is to protect the turtle from harm (Achrai and Wagner 2017). Each shell quadrant was assessed for injury and given one of the four values (the highest given for each quadrat): intact = 0, minor = 1; moderate =2; and severe =3 (see Saumure et al. 2007). The four quadrats were summed for each turtle and then divided by 12 (maximum injury possible) to give a value between 0 and 1. A Mann-Whitney U-test was used for pair-wise comparisons, and a Wilcoxon signed rank test was used to test for the non-random distribution of injuries recorded as moderate or severe. I conducted all statistical analyses using the program R Studio version 1.1.463 and the alpha threshold was set at 0.05 (R Core Team 2018).

3.4. Results

Population structure and occurrence in fields - A total of 50 wood turtles (12 M: 27 F: 11 juveniles) were captured at Site A in 2017 - 2018. No turtles under the age of four were found during the two years of study, and the ratio of adults to juveniles was significant ($\chi^2 = 18.8$, $df = 1$, $p = 1.5e-05$). Juveniles accounted for 22%, and turtles over the age of 20 years accounted for 50% (Table 3.1). I observed female turtles attempting to nest, but there was no evidence of depredated or hatched nests in either year. At Site B, with the data combined from 2012 and 2018, there was a total of 56 wood turtles found (7

M:15 F: 34 juveniles) with juveniles accounting for 61% of turtles found and 27% were ≤ 4 years old (Table 3.1). In September 2018, four successfully hatched nests were found along the river at Site B. Adults over the age of 20 accounted for 27% of the population.

Table 3.1. The number of wood turtles found in each age class in an agricultural site (Site A) and forested site (Site B). Wood turtles were captured opportunistically throughout 2017 and 2018 at Site A. At Site B, a mark and recapture survey was completed in 2012 and 2018 in May for three consecutive days. A total of 50 turtles were found at Site A, and 56 turtles were found at Site B.

Age Class (years)	Site A - Agriculture		Site B - Forest	
	<i>n</i>	%	<i>n</i>	%
0–4	0	0	15	27
5–9	10	20	16	29
10–14	4	8	4	7
15–19	11	22	6	11
>20	25	50	15	27

At Site A, 14 turtles were radio-tagged (3M:11F) in 2017, and an additional nine turtles were tagged in 2018 (3M:6F) for a total of 23 individuals and tracked throughout the active season. In 2017, there was a total of 215 relocations for tagged turtles, of which 24% of relocations were in the field. In 2018, 19% of 778 relocations were in the field. Females were found twice as often as males in the fields (2017: F-24%, M-11%; 2018: F-22%, M-12%). I do not include days within the field in 2017 due to irregular sample effort. In 2018,

turtles began using the fields on June 13, and most females stopped using the field by August 2 (Figure 3.1), whereas males left the fields by July 20. In both years, between 38–58% of turtle relocations were within the hayfields between June 17 – July 21, and the first week of July had the highest amount of relocations (Figure 3.2). Although I did not tag juvenile (carapace length <16.5cm) wood turtles, six juveniles were found within the field or along the edge in June of 2017 and 2018. Out of the 23 turtles tagged, 21 individuals had used a hayfield at least once as well as five out of the six fields at the site.

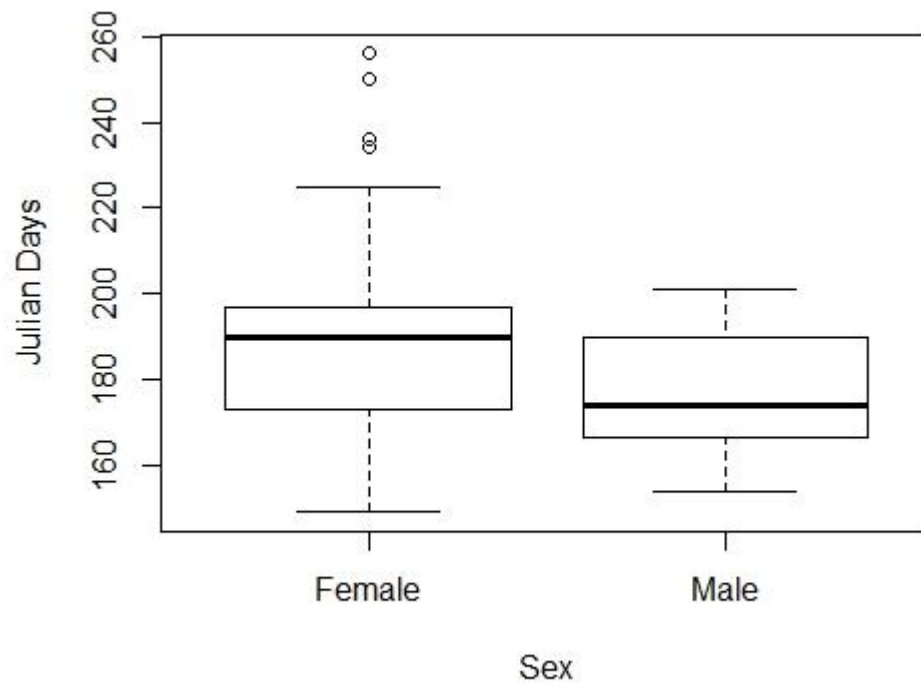


Figure 3.1. Timing of female and male wood turtles relocated in hayfields in 2018 at Site A. Time is recorded in Julian days starting from June 1 until September 17.

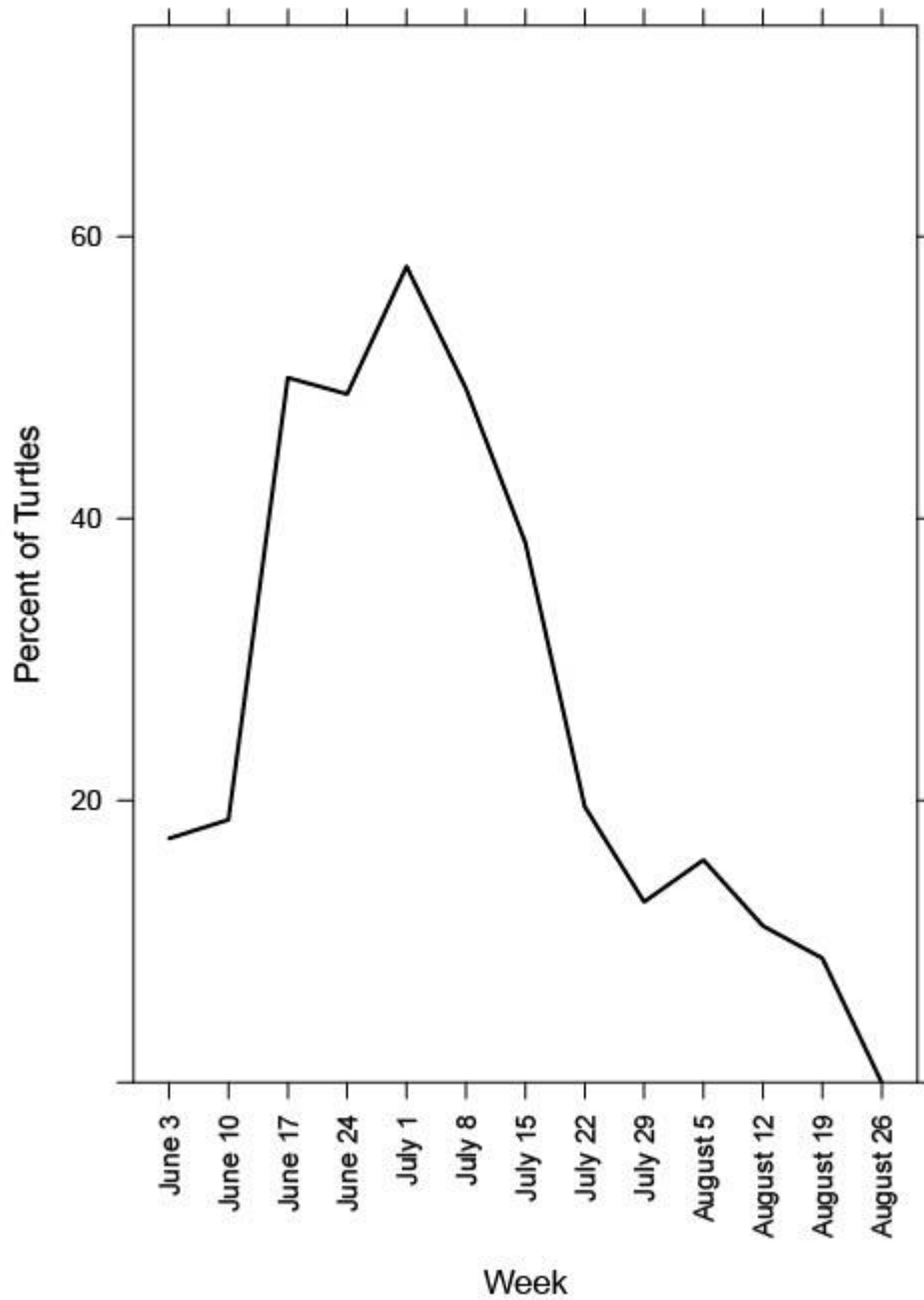


Figure 3.2. Percent of adult wood turtle locations in a field per week at Site A, from June 3 to August 31 of 2017 and 2018. A total of 14 turtles were radio-tracked in 2017 and 23 in 2018.

During June of 2017 and 2018, of the 64 relocations (15M:49F) in a field, most (86%) relocations were ≤ 30 of the field edges, and 47% of relocations were < 10 m from the edge. All wood turtle locations were within 50m of the edge. The edge of the field that was closest to the water had 23% of relocations within 10m, 50% were within 30m, and 77% within 50m (Figure 3.3). During July of each year, of the 83 relocations (9M:74F) in a field, 80% of relocations were ≤ 30 from the field edge, and 36% of relocations were < 10 m from the field edge (Figure 3.3). The edge of the field closest to the water had 34% of relocations < 10 m, 50% within 30m, and 81% within 50m.

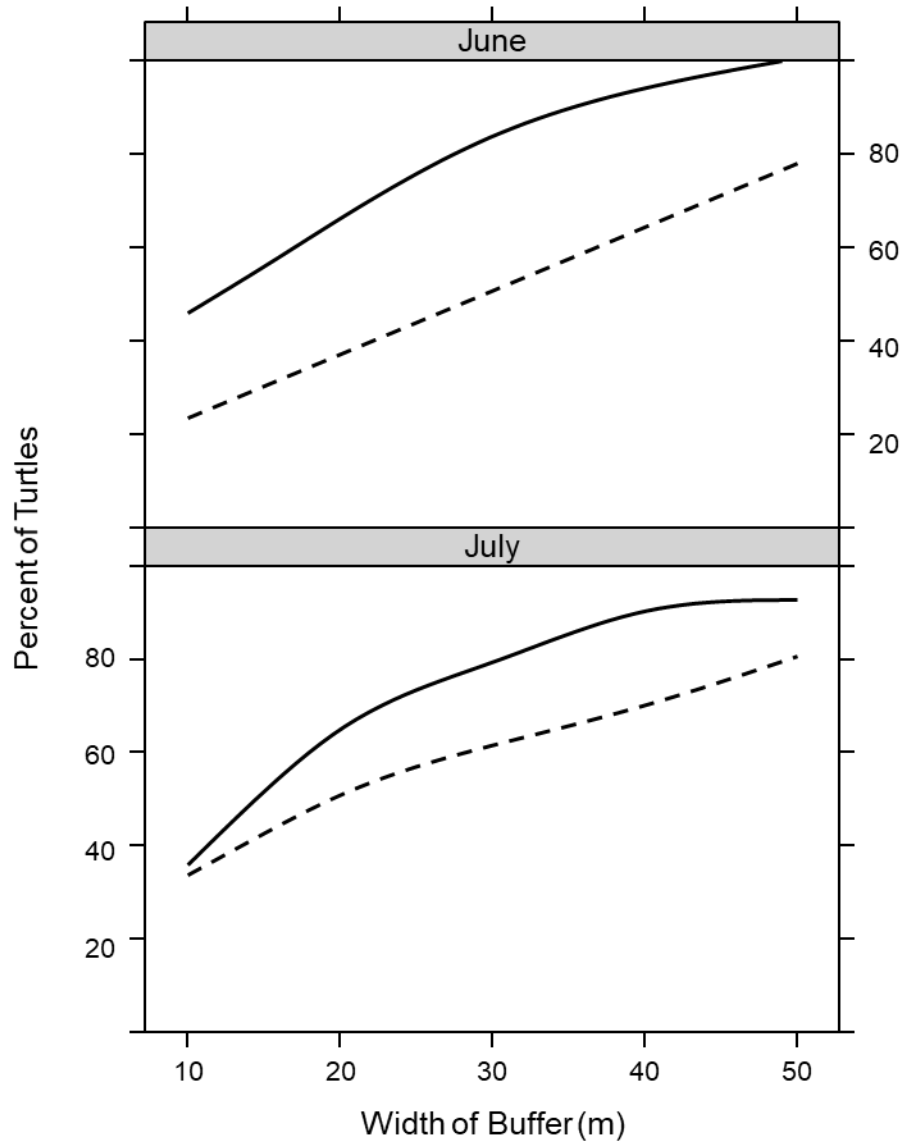


Figure 3.3. The percent of adult wood turtle relocations within various buffer widths in hayfields at study Site A in June and July of 2017 and 2018. Solid lines represent distance between the turtle location and any edge of the field; dashed lines are the edge solely closest to the main river.

Response Trials – Trials were conducted on nine female turtles in 2017, and 15 (3M:12F) turtles in 2018. In 2017, five turtles were already in the field during harvest (under thatch), and we added four turtles one hour before the tractor arrived. In 2018, all trials used turtles added to the field because mowing started July 31 and most tagged turtles had moved to other areas. Out of the five turtles who were originally in the field during harvest in 2017; three did not move, one moved but became immobile when the tractor was near, and the last turtle moved constantly but would have been hit by the tractor.

I found that 69.2% of the turtles who were placed in the field had a behavioural response to the tractor. Almost half of the turtles (44.4%) were noted to slow down when the tractor approached them (~10m away) at the start of harvest but then sped up whenever the tractor came closer after a few swaths of cutting. On average, the rate of the turtles was around 1 meter per minute (range, 0.5–1.5m/minute). Turtles were slowed by thick vegetation, like bedstraw, and would stop frequently. Most (11 of 13) turtles that moved during harvest were moving towards the main river. In both years combined, 30.7% of turtles did not move during harvest, but 90% noticed the tractor entering the field by lifting of their head.

Directional Trials – The behaviour of individual wood turtles was virtually the same between sex, varying horizontal visibility, and grass length. Turtles were able to discern location of the river when grass was 0-1m high, and the horizon was either visible, or obscured by grass. Most turtles (68%) headed towards the water within 3m of moving, and 98% of turtles heading towards the water within 10m of moving. Only one male turtle did not move towards water

after 10m in a field that was uncut. No turtles chose to move to the nearby forest cover, even when it was 1m in front of them, and the river was 180m in the opposite direction.

Predator abundance - A total of 49,320 hours was recorded between the two sites (Site A: 25,392 hrs, Site B: 23,928 hrs). Predator species recorded on the cameras included: American black bear (*Ursus americanus*), eastern coyote (*Canis latrans*), raccoon (*Procyon lotor*), bobcat (*Lynx rufus*), fisher (*Pekania pennanti*), American mink (*Neovison vison*) and domestic dog (*Canis lupus familiaris*)(Appendix D). Raccoon ($t = -2.5$, $df = 12.6$, $p = 0.03$), domestic dog ($t = -2.3$, $df = 11$, $p=0.04$) were significantly more abundant at Site A, while bear ($t = 4.3$, $df = 11.6$, $p < 0.05$) was the only species more abundant at Site B. Fisher was recorded once and was omitted from analyses. All other predator species were not significant (Mink: $t = -0.9$, $df = 15.3$, $p= 0.4$; Bobcat: $t = 2.1$, $df = 11.8$, $p =0.06$).

Injury - Mean carapace height for Site A's adult population (11 M; 24 F) was 70.1mm (range, 6.0–8.1mm). No intersexual differences in adult carapace height were found ($t = -0.9$, $df = 14.4$, $p=0.37$). The average carapace height for juveniles was 43mm (range, 26.0–55mm). During the two field seasons, there were two mortalities, which occurred during winter hibernation. To my knowledge, no radio-tagged turtles were hit during the hay harvest because we monitored and removed turtles, but a wood turtle shell was found at the edge of a field, likely from the previous year. Two turtles at Site A were missing their front feet, but the injuries were healed and thus old, and they could move efficiently. Almost double the amount of the turtles captured during 2017 and

2018 at Site A had injuries on their carapace and tail compared to Site B (Table 3.2). Limb injury was higher at Site A, and plastron injury was 10% at Site A, but 0% at Site B.

Table 3.2. Summary of injuries to wood turtles found in agricultural or forested landscapes. A total of 50 turtles were found at Site A in 2017 and 2018. A total of 56 turtles were found at Site B in 2012 and 2018 during the mark and recapture studies.

Site	Tail (%)	Limb (%)	Carapace (%)	Plastron (%)
Site A- Agriculture	41.0	11.8	45.0	9.8
Site B- Forest	25.5	7.2	18.1	0

There was no significant difference in injury (CMI) between the sexes at Site A ($U = 146$, $p = 0.31$), but there was higher injury on females than juveniles ($U = 198.5$, $p = 0.006$). No significant difference in injury was found between the anterior and posterior of adult wood turtles ($Z = -0.9$, $p = 0.3$), but there was a significantly more injury found on the left side of adults compared to the right ($Z = 2.1$, $p = 0.03$). A CMI could not be completed on turtles captured at Site B due to a lack of data.

3.5. Discussion

Population Structure - Breeding individuals are usually more abundant than juveniles in wood turtle populations (Ernst and Lovich 2014), but my study population may have little to no juvenile recruitment and a skewed age structure of breeding individuals. At Site A, wood turtles above the age of 15 accounted

for 72% of the turtles caught, and 34% at Site B. Saumure and Bider (1998) found that adults over the age of 15 accounted for 61% of the study population in a forested landscape and 73% in an agriculture landscape. In Ontario, turtles above the age of 15 comprised of 49% of the population in an agriculture site (Greaves and Litzgus 2009). The age structure of wood turtle populations can vary by site due to anthropogenic pressures, and predator abundance, but agricultural areas have a skewed age structure towards breeding individuals (Saumure and Bider 1998; Saumure et al. 2007).

I did not find any turtles under the age of four at the agricultural site (Site A). This result could be due to the difficulty of finding smaller turtles, females only nesting every few years, failed nest success due to floods, or high density of predators (Compton 1999; Daigle and Jutras 2005; COSEWIC 2018; Geller 2012). The central region of New Brunswick encountered extremely high-water levels in 2008, and 2018, and the flood could have drowned the nests, as has been recorded elsewhere (e.g. Standing et al. 1999). Saumure and Bider (1998) also did not find any turtles under the age of four at their agricultural site, but at their forested site, 13% (n=31) were under the age of four. They also found that juveniles comprised 12% of the population found at the agricultural site and 36% at the forested site. In our study, similar numbers of adults were residing in similar hydrology and climate and we suspect that the reduction in younger age cohorts in the agricultural site is due to the significantly higher raccoon occurrence at Site A, which likely predate most wood turtle nests (Harding and Bloomer 1979; Saumure and Bider 1998; Wirsing et al. 2012; Mullin 2019).

Occurrence in field - Male and female wood turtles at Site A used agricultural fields for extended periods. Almost half of the tagged turtles, mostly females, used the fields regularly throughout the prime harvest season. In Quebec, at a similar latitude to our study, most turtles were out of the field by the last few days of August or the first week of September (Saumure et al. 2007). In Nova Scotia, males used the field more often and for a longer period than female wood turtles and females seemed to use the fields to access nesting habitat (Tingley et al. 2009). I did not find that females used the fields to access nesting habitat, but they were using the fields to bask and possibly feed on gastropods or worms (refer to section 2.4). Females used the fields longer and more often than males, which could be due to my small sample size of males, but females at my study site used the fields longer than the females at Tingley et al. (2009) site. Wood turtles are habitat generalists, and their home range, behaviour, and habitat selection can change depending on geographic location (Compton et al. 2002). Most of the turtles at Site A stayed close to the edge of the field, which supports similar observations made in other studies (Arvisais et al. 2004; Saumure et al. 2007; Section 2.4).

Response Trials – Only one turtle was observed to escape during the response trials; the remainder either did not move or moved in front of the tractor during mowing. Of turtles already using the field when the tractor arrived, 3 of 5 did not move and the other two would have been hit by machinery. All five of these turtles had been under the thatch, which likely provided some perceived security.

Over half of the turtles who were moved into the field exhibited a behavioural response to the tractor. Harvest in the 13.9ha fields required 5-25 circuits in a clockwise pattern towards the centre of the field. Tractor speed was 9km/hr during the beginning of the harvest, and most turtles either stopped or slowed down when the tractor was 5-15m away, but after the tractor had passed by 3-5 times, turtles would either start to move or move faster whenever the tractor was close. Although wood turtles moved during the harvest, they were not fast enough to escape. The fields had thick bedstraw which made it difficult for the turtles to maneuver and movement often was in a zigzag pattern. Turtles would often stop, every few minutes as the tractor mowed in smaller circuits. However, instead of staying still, they would often increase movement when the tractor was approaching, which often put them in the path of machinery. The maximum speed I recorded a turtle moving was 1.5 meters per minute in the field, and at such speeds, it would take them four minutes to get past the mower and tractor, which is 6m in length. Saumure (2004) found that wood turtles moved in a zigzag pattern within uncut vegetation, but once they moved into a harvested area their movements were relatively straight and long. Turtles could be moving in a zigzag pattern due to avoidance of hay stems, or visual obstruction (Bell 1991; Goodwin and Fahrig 2002).

It is promising for the conservation of turtles that more than half of the turtles moved at the approach of the tractor. These turtles could escape to safety, and any harvest pattern that allowed more time for escape could lower mortality rates. However, most of my sample was translocated turtles, and these animals may have already been primed for a flight response after being picked

up and placed in a nearby field (Cabanac and Bernieri 2000). Although I removed from analysis any turtles that did not stay where they were placed, it is possible that the higher rate of movement in translocated turtles (69%) reflects stress because only 40% of the 'resident' turtles decided to move, rather than hide. A larger sample of trials using 'resident' turtles would improve results but, in my study, I had to rely on the location of our turtles when the tractor arrived.

Direction – Almost all the wood turtles in the direction experiment headed towards the water, even if they were closer to a forest or riparian buffer, and some movement was as far as > 180m from the river. Wood turtles have a homing ability and strong spatial orientation, which can help them orient towards water (Saumure et al. 2007). Wood turtles are also noted to use smell to orient to safety if there is a visual obstruction (Barzilay 1980). McCurdy (1995) found that wood turtles orientated towards water when they perceived danger and if approached from the direction of the water, they exhibited an arc behaviour but eventually redirected themselves towards water. Wood turtles have been noted to move around opened areas instead of through them, but they have also been observed to walk across cut portions of the field despite the presence of a hard edge (McCurdy 1995; Saumure 2004). My study is in agreement with the latter, we observed that wood turtles moved through opened areas towards water despite nearby cover.

Predator occurrence – Occurrence of predator species was significantly different between an agricultural and forested landscape. A significant amount of raccoons and domestic dogs were at the agricultural site compared to the forested site. Coyotes were also frequent at both study sites. Black bears have

been recorded to depredate nests (Lovich et al. 2014) but bears preying on wood turtle nests or eating hatchlings does not seem to have been recorded.

Raccoons and coyotes are significant predators on wood turtles because they depredate nests and eat turtles until the carapace size is larger than their gape, which typically equates to adult-sized turtles (COSEWIC 2018; Wiring et al. 2012). Within New Brunswick, raccoon populations within an agricultural landscape can be as high as 18 raccoons/km², in comparison to forested landscapes with 9 raccoons/km² (Belyea 2018). Raccoons can be a problem for wood turtle recovery within an agricultural landscape in Ontario because they amputated limbs and kill even adult wood turtles (Mullin 2019). Raccoons are a primary predator of turtle nests and can predate up to 100% of their nests (Harding and Bloomer 1979). Although I did not find depredated nests in our study, we found few juveniles and wood turtles with high injury in comparison to the forested site where raccoons and coyote were less abundant.

Injury – Injury rates in the agricultural landscape were double of those recorded in the forested landscape. Injuries in all four categories (tail, limbs, carapace, and plastron) were higher at Site A than in Site B. In an agricultural landscape in Vermont, 89% of females and 52% of males had injuries, and 43.5% of males had missing feet (Parren 2013). In northern Ontario, within a forested landscape area, 48% of the turtles had some form of injury, 7% with limb amputations, and 42% missing a part of their tail (Cross et al. 2018). At Site A, a left-side injury bias on the carapace was significant. Saumure et al. (2007) had found a right-side injury bias and attributed it to the fact that the farmer cut in a counter-clockwise direction, and during harvest, their right side would be

exposed to the mower because they would be headed towards the river for safety. The farmer at Site A mowed in a clockwise direction, which could explain the left-side bias found in our study because the wood turtles left side would be exposed to the mower when headed towards the river.

3.6. Management

Concerns over mortality rates in agricultural landscapes has resulted in a range of mitigation recommendations (Briggs 2019; Megyesy and Doperalski 2019; Sherren 2010). Mitigation strategies in agricultural landscapes include directing machinery to mow from the inside of the field to the outside, instead of vice versa (the most common technique) in order to allow wood turtles a chance to escape (STRIDES 2016). From our research if the pattern was changed from inside to the outside pattern, turtles that are far from the river would likely be hit by agricultural machinery because they crossed large fields to get to water and do not avoid the tractor. A better option would be a zigzag pattern that would start on the side of the field furthest from the main river because it may allow enough time for turtles to move towards the water and escape (Figure 3.4). This pattern might be difficult for farmers to implement since they would be taking sharp turns and likely miss cutting portions of the field. But, even with altered mowing patterns, many turtles remain stationary during the harvest so a buffer, delaying harvest or raising blade height would have a higher likelihood of saving turtles.

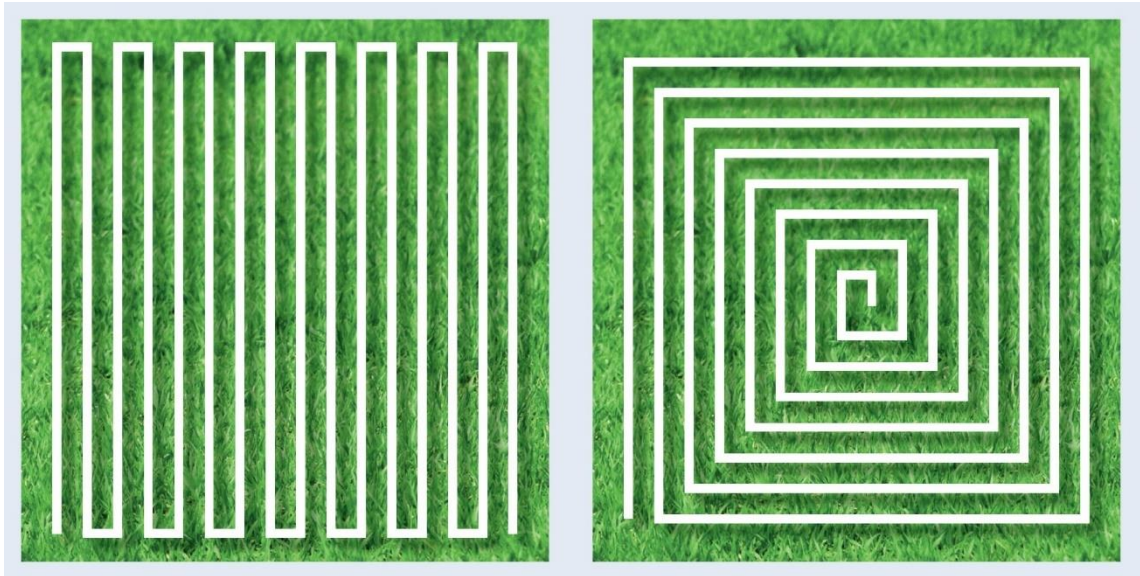


Figure 3.4. Mowing patterns for harvesting hay. The image on the left is a zigzag pattern and on the right is an outside to inside pattern (Hall 2013).

Raising the blade height or changing the mower type has been recommended as a strategy to reduce wood turtle mortality in the fields (Saumure et al. 2007; Erb and Jones 2011; STRIDES 2016; Wallace et al. 2020). The use of a sickle cutterbar mower instead of a rotary disc mower would likely drastically reduce wood turtle injury during harvest (Wallace et al. 2020). If a rotary disc mower is used, then raising the blade height to 17cm was found to save 50% of adult wood turtles within a hayfield. It should be noted that tires still pose a large risk to wood turtles even if the blade height is raised or a different mower type is used (Erb and Jones 2011; Wallace et al. 2020).

I found that wood turtles using hay fields stayed close to the edge and implementing an un-mowed buffer strip within a field in the summer months, or at least until the end of July, would be ideal to save turtles during harvest. Strips would need to be cut at the end of the season, or every couple of years, to

maintain grass and reduce weeds. If strips were left to grow, then it is likely that the wood turtles would stop using the buffer and move further into the field for low canopy cover and potential feeding (section 2.4). At my study site, 100% of wood turtles were within 50m of any field edge. Landowners may not be willing to implement a 50m buffer surrounding the edges of their fields, but another option could be to leave an un-mowed buffer strip along the edge of the field closest to the main river. If a 30m un-mowed buffer strip was applied to the edge closest to the river in June and July, then more than 50% of turtles in my study could be safe from the machinery and a buffer of 50m would save over 75% of turtles. Delaying the hay harvest until the end of July could also be an option and would have resulted in 87% of turtles in my study being safe from machinery. Delaying hay harvest would also help grassland birds who nest at the end of June and fledging's are not able to escape harvest until mid-July (Nocera et al. 2007). Both an uncut or a delayed hay harvest could result in a seasonal loss of hay volume and reduced forage quality; therefore, this management option would also require both willingness on the part of the landowner as well as potential financial incentives. In Nova Scotia, participating farmers are subsidized \$75/acre to leave areas uncut (Sherran et al. 2019).

There is no one technique that will be suitable for every landowner. The amount of agricultural land a landowner has near the river, the type of equipment they own, and the amount and/or quality of hay they are willing to lose will change management recommendations. Programs have been implemented to compensate farmers for implementing management strategies to protect wildlife species (bobolink and wood turtles) and environmentally

sensitive land (Government of Prince Edward Island n.d.; The Bobolink Project n.d.; Sherren 2019), expansion of their program to other regions likely is required as a model for improved viability of wood turtles in agricultural landscapes.

3.7. Literature Cited

- Achrai, B., and Wagner, H.D. 2017. The turtle carapace as an optimized multi-scale biological composite armor – A review. *J. Mech. Behav. Biomed. Mater.* **73**: 50–67.
- Arvisais, M., Levesque, E., Bourgeois, J., Daigle, C., Masses, D., and Jutras, J. 2004. Habitat selection by the wood turtle (*Clemmys insculpta*) at the northern limit of its range. *Can. J. Zool.* **82**: 391–398.
- Barzilay, S. 1980. Orientation and homing of the wood turtle (*Clemmys insculpta*). PhD Thesis, State University of New Jersey, New Brunswick, New Jersey, USA. 176 pages.
- Bell, W.J. 1991. Searching behavior: The Behavioural Ecology of Finding Resources. Chapman and Hall, London, England.
- Belyea, M. 2018. Optimizing control of raccoon rabies in New Brunswick through the study of relative raccoon density. Masters Environmental Management Final Report, University of New Brunswick, Fredericton. 28 pages.
- Blodgett, S.L., and Denke, P.M. 1999. Blister Beetles (Coleoptera: Meloidae) Occurring in Montana Alfalfa. *J. Entomol. Sci.* **34**(1): 113–118. doi:[10.18474/0749-8004-34.1.113](https://doi.org/10.18474/0749-8004-34.1.113).
- Briggs, K. 2019. Achieving turtle conservation on private land, Spotted, Blanding's, and Wood Turtle Conservation Symposium; Berkeley Springs, WV. November 4–5, 2019.
- Browne, C.L., and Paszkowski, C.A. 2014. The influence of habitat composition, season and gender on habitat selection by western toads (*Anaxyrus boreas*). *Herpetol. Conserv. Biol.* **9**: 417–427.

- Cabanac, M., and Bernieri, C. 2000. Behavioural rise in body temperature and tachycardia by handling of a turtle (*Clemmys insculpta*). *BehavProcess* **49**: 61–68.
- Cagle, F.R. 1939. A system of marking turtles for future identification. *Copeia* 1939: 170–173.
- Cameron, M., and Brooks, R.J. 2002. Maitland River Valley wood turtle population analysis. Report to the Ontario Ministry of Natural Resources. 45 pages.
- Compton, B.W. 1999. Ecology and conservation of wood turtle (*Clemmys insculpta*) in Maine. MSc thesis. University of Maine. 91 pp.
- Compton, B.W., Rhymer, J.M., and McCollough, M. 2002. Habitat selection by wood turtles (*Clemmys insculpta*): An application of paired logistic regression. *Ecology* **83**:833–843.
- COSEWIC. 2018. COSEWIC assessment and update status report on the Wood Turtle *Glyptemys insculpta* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. Vii + 51 p.p.
- COSEWIC. 2016. COSEWIC assessment and status report on the Blanding's Turtle *Emydoidea blandingii*, Nova Scotia population and Great Lakes/St. Lawrence population, in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. xix + 110 pp.
- Cross, J., Cross, R., Chartrand, D., and Thompson, D.G. 2018. Characterizing wood turtle (*Glyptemys insculpta*) populations at the Northwestern periphery of the species range in Canada. *Northeast Nat.* **25**: 571–586.
- Daigle, C., and Jutras, J. 2005. Quantitative evidence of decline in a southern Quebec wood turtle (*Glyptemys insculpta*) population. *J. Herpetol.* **39**: 130–132.
- Dubois, Y., Blouin-Demers, G., Shipley, B., and Thomas, D. 2009. Thermoregulation and habitat selection in wood turtles *Glyptemys insculpta*: chasing the sun slowly. *J. Anim. Ecol.* **78**: 1023–1032.
- Erb, L., and Jones, M.T. 2011. Can turtle mortality be reduced in managed fields? *Northeast. Nat.* **18**:489–496.

- Ernst, C.H., and Lovich, J.E. 2014. Turtles of the United States and Canada. Baltimore, Maryland. 827 pp.
- Flanagan, M., Roy-McDougall, V., Forbes, G., and Forbes, G. 2013. Survey methodology for the detection of wood turtles (*Glyptemys insculpta*). *Can. Field-Nat.* **127**: 216–223.
- Forbes, G. 2005. Diurnal and nocturnal habitat use by wood turtle (*Clemmys insculpta*) in New Brunswick, Canada. BScF thesis, University of New Brunswick, Fredericton. 35 pp.
- Garber, S.D., and Burger, J. 1995. A 20-year study documenting the relationship between turtle decline and human recreation. *Ecol. Appl.* **5**:1151–1162.
- Geller, G.A. 2012. Notes on the nest predation dynamics of Graptemys at two Wisconsin sites using trail camera monitoring. *Chelonian Conserv. Biol.* **11**(2): 197–205. doi:[10.2744/CCB-0992.1](https://doi.org/10.2744/CCB-0992.1).
- Goodwin, B.J., and Fahrig, L. 2002. Effects of landscape structure on the movement behavior of a specialized goldenrod beetle, *Trirhabda borealis*. *Can. J. Zool.* **80**: 24–35.
- Government of Prince Edward Island. N.d. Alternative land use services (ALUS) Program. <https://www.princeedwardisland.ca/en/service/alternative-land-use-services-alus-program>
- Greaves, W.F., and Litzgus, J.D. 2009. Variation in life-history characteristics among populations of North American wood turtles: a view from the north. *J. Zool.* **279**: 298–309.
- Hall, R. 2013. Today's winning numbers are. *Turf Magazine*: Retrieved from: <https://www.turfmagazine.com/services/todays-winning-numbers-are/>
- Harding, J.H., and Bloomer, T.J. 1979. The wood turtle, *Clemmys insculpta*...a natural history. *Bulletin of the New York Herpetological Society* **15**: 9–26.
- Humbert, J., Ghazoul, J., and Walter, T. 2009. Meadow harvesting techniques and their impacts on field fauna. *Agr. Ecosyst. Environ.* **130**:1–8.
- Kaufmann, J.H. 1992. Habitat use by wood turtle in central Pennsylvania. *J. Herpetol.* **26**: 315-321.

- Liczner, Y. 1999. Auswirkungen unterschiedlicher Mäh- und Heubearbeitungsmethoden auf die Amphibienfauna in der Narewniederung (Nordostpolen). *Rana – Mitteilungen für Feldherpetologie and Ichthyofaunistik in Norddeutschland – Sonderheft* **3**:67–79.
- Lovich, J., Delaney, D., Briggs, J., Agha, M., and M. Austin. 2014. Black bears (*Ursus americanus*) as a novel potential predator of Agassiz's desert tortoises (*Gopherus agassizii*) at a California wind energy facility. *Bulletin of the Southern California Academy of Sciences* **113**: 34–41.
- McCurdy, D.G. 1995. Orientation and movement patterns of reciprocally transplanted wood turtles (*Clemmys insculpta leconte*) in northeastern Nova Scotia. BSc.HR, Acadia University.
- Megyesy, J., and Doperalski, M. 2019. Working lands for wildlife – Northeast turtles: State conservation area networks and plans help guide on-the-ground change on private working lands in NH, Spotted, Blanding's, and Wood Turtle Conservation Symposium; Berkeley Springs, WV. November 4–5, 2019.
- Mitchell, J., S.R. de Solla, and Brooks, R.J. 1997. Survey and monitoring study for the Wood Turtle (*Clemmys insculpta*) in Ontario: Research project results. Dept. of Zoology, University of Guelph.
- Mui, A.B., Edge, C.B., Paterson, J.E., Caverhill, B., Johnson, B., Litzgus, J.D., and He, Y. 2015. Nesting sites in agricultural landscapes may reduce the reproductive success of populations of Blanding's Turtles (*Emydoidea blandingii*). *Can. J. Zool.* **94**(1): 61–67. doi:[10.1139/cjz-2015-0154](https://doi.org/10.1139/cjz-2015-0154).
- Mullin, D.I. 2019. Evaluating the effectiveness of headstarting for wood turtle (*Glyptemys insculpta*) population recovery. M.Sc. Thesis. Laurentian University, Sudbury, Ontario, Canada. 144 pp.
- Nocera, J.J., Forbes, G., and Milton, G.R. 2007. Habitat relationships of three grassland breeding bird species: broadscale comparisons and hayfield management implications. *Avian. Conserve. Ecol.* **2**: art 7.

- Parren, S.G. 2013. A twenty-five year study of the wood turtle (*Glyptemys insculpta*) in Vermont: Movements, behavior, injuries, and death. *Herpetol. Conserv. Biol.* **8**: 176–190.
- R Core Team. 2018. A language and environment for statistical computing. R foundation for statistical computing, Vienna, Austria. URL <http://www.R-project.org/>.
- Robertson, B.A., and Hutto, R.L. 2006. A framework for understanding ecological traps and an evaluation of existing evidence. *Ecology* **87**: 1075–1085.
- Saumure, R.A., and Bider, J.D. 1998. Impact of agricultural development on a population of wood turtles (*Clemmys insculpta*) in southern Quebec, Canada. *Chelonian Conserv. Biol.* **3**:37–45.
- Saumure, R.A. 2004. Spatial ecology and conservation of the North American wood turtle (*Glyptemys insculpta*) in a fragmented agri-forested landscape. PhD thesis, Department of Natural Resource Science, McGill University, Montreal, Quebec, Canada
- Saumure, R.A., Herman, T.B., and Titman, R.D. 2007. Effects of haying and agricultural practices on a declining species: The North American wood turtle, *Glyptemys insculpta*. *Biol. Conserv.* **135**:565–575.
- Sherren, K., Tourangeau, W., Lamarque, M., and Greenland-Smith, S. 2019. Exploring motivation crowding around farmer incentives for riparian management in Nova Scotia. *Can. Geographer.* 1–16. Doi: 10.11111/cag.12572.
- Standing, K.L., Herman, T.B., and Morrison, I.P. 1999. Nesting ecology of Blanding's turtle (*Emydoidea blandingii*) in Nova Scotia, the northeastern limit of the species' range. *Can. J. Zool.* **77**:1609–1614.
- STRIDES. 2016. Beneficial management practices for wood turtle conservation. 17pp.
- The Bobolink Project. n.d. Helping farmers project grassland birds. <https://www.bobolinkproject.com/farmers.php>

- Thompson, D.G., Swystun, T., Cross, J., Cross, R., Chartrand, D., and Edge, C.B. 2018. Fine- and coarse-scale movements and habitat use by Wood Turtles (*Glyptemys insculpta*) based on probabilistic modeling of radiotelemetry and GPS-telemetry data. *Can. J. Zool.* **96**(10): 1153–1164. doi:[10.1139/cjz-2017-0343](https://doi.org/10.1139/cjz-2017-0343).
- Tingley, R., McCurdy, D.G., Pulsifer, M.D., and Herman, T.B. 2009. Spatio-temporal differences in the use of agricultural fields by male and female wood turtles (*Glyptemys insculpta*) inhabiting an agri-forest mosaic. *Herpetol. Conserv. Biol.* **4**:185–190.
- Tinklepaugh, O.L. 1932. Maze learning of a turtle. *J. Comp. Psychol.* **13**:201-206.
- Walk, J.W., Kershner, E.L., Benson, T.J., and Warner, R.E. 2010. Nesting success of grassland birds in small patches in an agricultural landscape. *Auk*, **127**: 328–334.
- Wallace, S.D., Forbes, G.J., and Nocera, J.J. 2020. Experimental assessment of the impact of agricultural machinery on wood turtles (*Glyptemys insculpta*). *Chelonian Conserv. Biol.* *In Press*.
- Wirsing, A.J., Phillips, J.R., Obbard, M.E., and Murray, D.L. 2012. Incidental nest predation in freshwater turtles: inter- and intraspecific differences in vulnerability are explained by relative crypsis. *Oecologia* **168**: 977–988.

Chapter 4: Conclusion

4.1 Overview of Thesis

In Chapter 2, I quantitatively measured third and fourth order habitat selection of wood turtles in a landscape under active agriculture (Johnson 1980). My models showed that low amounts of canopy cover, and presence of coarse woody debris, berries, and mushrooms were important for wood turtle presence. I found that although forest covered most of my study site, it was the least selected. I found that food types (earthworms, snails, berries and mushrooms) were in different abundances depending on habitat types and that food availability was likely a factor in wood turtle habitat selection. Agricultural fields are likely an attractant for wood turtle in mid-summer because of earthworm prey.

In Chapter 3, I assessed the impact of agricultural practices on wood turtles. I found that wood turtles heavily used the fields during the prime hay harvest season, and they were at high risk of being hit by machinery. During the months of June and July, 50% of wood turtle relocations within the field were found to be 30m from the edge of the fields closest to the main river.

I monitored wood turtle behaviour during hay harvest and expected most wood turtles to move and escape due to their excellent hearing, ability to feel vibrations through their shell, and their learning ability (Tinklepaugh 1932; Saumure et al. 2007). However, more than half of the wood turtles naturally in the field did not move during harvest and for the ones who did move, only one would have escaped without human intervention. More than half of the turtles

placed in the field had behavioural response to the tractor, but they could not escape.

I recorded predator occurrence and injury rates of wood turtles at a forested and agricultural site. I found that raccoon occurrence was significantly higher at the agricultural site as well as wood turtle injury. Many wood turtles within the agricultural site were missing limbs or tails, which is likely attributed to the high abundance of raccoons. No turtles under the age of four were found at the agricultural site, which could also be attributed to predation of nests by raccoons or flooding of nests.

I experimentally tested the injury that two common mower types have on proxy wood turtles at various life stages to gain an understanding of how much of a risk each mower type presents during harvest (Appendix A). The rotary disc mower caused greater injury to all wood turtle proxies in comparison to sickle cutter bar mower. Adults and proxies above thatch were also found to have greater injury. I found that raising the blade height to 17cm on a rotary disc mower would reduce injury of adult wood turtles to 50% and raising a sickle cutterbar mower to 4cm would reduce injury to 60%. Tires still pose a risk during harvest, with turtles have a 20% chance of being struck by a tire. If struck by a tire, there would be a high chance of mortality due to the heavy weight of the machinery.

4.2 Management

Mitigation strategies in agricultural landscapes include directing machinery to mow from the inside of the field to the outside, instead of vice

versa (the most common technique) to allow wood turtles a chance to escape (STRIDES 2016). From my research, if the pattern was changed from inside to the outside pattern, turtles that are far from the river would likely be hit by agricultural machinery because they crossed large fields to get to water and do not successfully avoid the tractor. A better option would be a zigzag pattern that would start on the side of the field furthest from the main river because it may allow enough time for turtles to move towards the water and escape. This pattern would be difficult for farmers to implement since they would be taking sharp turns and likely miss cutting portions of the field. But, even with altered mowing patterns, many turtles remain stationary during the harvest, so providing a buffer, delaying harvest, and/or raising blade height would have a higher likelihood of saving turtles.

Managers and researchers have promoted raising of blade height (5-15cm) to lessen injury and mortality, with the encouragement to farmers that there is little nutritional value in the stems and it would reduce wear on machinery (MacGregor and Elderkin 2003; Saumure et al. 2007; Tingley et al. 2009; Wisconsin Department of Natural Resources 2015). However, based on my study, blade heights would need to be raised to a minimum of 17cm to have at least a 50% probability of an adult turtle remaining safe from the blade. A similar blade height would likely protect 80% of young turtles. Raising the blade to this height would result in landowners losing money as a greater volume of hay will be left growing in the field. Depending on the type of hay, the relevant commodities markets, and time of the year, landowners could lose

approximately \$30 per hectare (based on current markets) if the blade height was raised to 15cm (Lantz 2007; Sherran et al. 2019).

Using a sickle-cutter bar mower instead of a rotary disc mower would be a more suitable option because it would allow farmers to continue to cut hay at low blade heights while reducing the injury rate to adult and young wood turtles. But the use of sickle cutter bar mowers is in decline, and normally only small-scale farmers still use them. Within New Brunswick, approximately 31% of farmers still use sickle cutter bar mowers (Noel et al. 2017).

If the blade height is raised to reduce the injury to wood turtles, the tires still pose a substantial threat. During harvest, tires can contact almost 20% of the field's surface area. Therefore, if a turtle does not move during harvest, then the turtle has a one in five chance of being struck by a tire. Erb and Jones (2011) found that 46% of mortality was due to tires alone and that the rear tires accounted for 37% of the tire width. The width of the tractor and tires used in our experiment were smaller, so the threat of the tractor tires will be dependent on the tractor model and tires sizes used. Since there is a high chance of turtles being killed by tractor tires, implementing a buffer or delaying the hay harvest may be an ideal solution.

I found that wood turtles using hay fields stayed close the edge, and implementing an un-mowed buffer strip within a field during the summer months, or at least until the end of July, would be ideal to save turtles during harvest. Strips would need to be cut at the end of the season, or every couple of years, to keep the field dominated by preferred grasses. If strips were left to grow, then it is likely that wood turtles would stop using the buffer and move back into the

field due to low canopy cover. The wood turtles at my site showed that a field buffer along the edges would be an ideal management strategy to reduce the amount of injury and mortality due to the hay harvest. Landowners may not be willing to implement a 10-50m buffer surrounding the edges of their fields, but another option could be to leave a buffer strip along the field edge closest to the main river. If a 30m buffer was applied to the edge closest to the river in June and July, then more than 50% of turtles could be safe from machinery and a 50m buffer would save over 77% of turtles. If this strategy was implemented it could cost landowners \$75/acre (Sherren et al. 2019). At my study site, implementing a 50m buffer along the edge of the field closest to the water could cost \$1,200 (Table 4.1). High cost is because the agricultural fields at the site are parallel to the river and are larger in length than in width. If a farmer had a field where only a small portion of the field was parallel to the river and the rest was surrounded by woods, then the cost of a field buffer would be greatly reduced. Delaying the hay harvest until the end of July could also be an option to help the turtles who are using the center of the field. Delaying harvest until the end of July at my site would have resulted in 87% being saved, but it would cost around \$2,000 (Table 4.1). Delaying hay harvest would also help grassland birds who nest at the end of June and fledglings are not able to escape harvest until mid-July (Nocera et al. 2007).

If a farmer has multiple fields, throughout the landscape, including pastures, then switching from a hay field to a pasture where there is a wood turtle population could be an ideal solution (STRIDES 2016). High densities of farm animals within a pasture might be problematic because turtles would be at a

high risk of being stepped on and potentially damaging their shells. But if there was smaller farm animals or low densities than the risk would be lower.

There is no one technique that will be suitable for every landowner. The amount of agricultural land a landowner has near the river, the type of equipment they own, and the amount of hay they are willing to lose will change management recommendations. Programs have been implemented to compensate farmers for implementing management strategies to protect wildlife species (bobolink and wood turtles) and environmentally sensitive land (Government of Prince Edward Island n.d.; The Bobolink Project n.d.; Sherran 2019) that could serve as a model for management in NB.

Table 4.1. Potential management recommendations with the percent of turtles that would have been saved at study Site A if implemented and the cost for each. Cost is calculated based on the information given by the STRIDES program (Sherren et al. 2019).

Recommendation	% Saved	Cost (\$)
Raise blade height of rotary mower to 17cm	40	406
Raise blade height of sickle cutterbar mower to 10cm	40	58
Raise blade height with rotary to 17cm along the 50m to the edge to river	30	109
Field buffer of 20m on edge closest to water- no cutting until October	50	638
Field buffer of 50m on edge closest to water- no cutting until October	80	1,223
Delay harvest until end of July	87	2,030

4.3 Future Study Recommendations

Wood turtle habitat selection has been shown to differ depending on geographic location and habitat types within the landscape (Compton et al. 2002; Arvisais et al. 2004). Populations that are within an area under active agricultural use different habitat types to regulate their body temperature, and find suitable nesting habitat and food resources. It is very common for active agriculture to change their crops to improve the soil quality and wood turtle within crop-rotation landscape may change their habitat selection, depending on the type of crop. Certain agricultural crops could have mixed impacts on the species. Wood turtles have been found to use corn fields to bask and nest whereas hay fields are used for basking and feeding (Mullin 2019; refer to Chapter 3). Corn fields also result in a higher predation pressure because of high raccoon populations (Rivest and Bergeron, 1981). Currently there has been no research of the impacts of shifting agricultural crops on wood turtle habitat selection and population ecology.

Another recommendation is to continue monitoring wood turtle habitat use in different agricultural landscapes within New Brunswick. My study provides information on wood turtle habitat use at one study site, but more information is needed to assess the efficacy of management recommendations within the province. Because wood turtles change their home range and habitat use based on location, a larger database of wood turtle ecology is important for management strategies. Gathering information such as distance to edge of field, usage of the field, home range size, food availability within the landscape, number of turtles using a field, and how long they stay in the field would be

beneficial information for management recommendations. Food availability may be an indicator of how long turtles stay within the hayfields, for example, landscapes that have a low abundance of fungi or berries may result in turtles using the hay fields for a longer period.

Often management recommendations are given but they are not tested to see how influential they are at reducing negative effects of agricultural practices on the population. Studying pre- and post-treatment management strategies at multiple sites would be helpful for critiquing recommendations and conservation practices.

4.4 Literature Cited

- Arvais, M., Lévesque, E., Bourgeois, J.-C., Daigle, C., Masse, D., and Jutras, J. 2004. Habitat selection by the wood turtle (*Clemmys insculpta*) at the northern limit of its range. *Can. J. Zool.* **82**(3): 391–398.
doi:[10.1139/z04-012](https://doi.org/10.1139/z04-012).
- Compton B.W., Rhymer J.M., and McCollough, M. 2002. Habitat selection by wood turtles (*Clemmys insculpta*): an application of paired logistic regression. *Ecology* **83**(3): 833–843. doi:10.1890/0012-9658(2002)083[0833:HSBWTC]2.0.CO;2.
- Erb, L., and Jones, M.T. 2011. Can turtle mortality be reduced in managed fields? *Northeast. Nat.* **18**: 489–496.
- Government of Prince Edward Island. N.d. Alternative land use services (ALUS) program. <https://www.princeedwardisland.ca/en/service/alternative-land-use-services-alus-program>
- Johnson, D.H. 1980. The comparison of usage and availability measurements for evaluating resource preference. *Ecology* **61**: 65–71.

- Lantz, V. 2007. Establishing payment rates for ecological goods and services provided by agricultural producers in the Souris and founds watersheds, PEI. Unpublished report to the Souris and Area branch of the PEI Wildlife Federation. Pp. 30.
- MacGregor, M.K., and Elderkin, M.F._2003. Protecting and conserving wood turtles; A stewardship plan for Nova Scotia. Biodiversity program, wildlife division. Nova Scotia Department of Natural Resources.
- Mullin, D.I. 2019. Evaluating the effectiveness of headstarting for wood turtle (*Glyptemys insculpta*) population recovery. M.Sc. Thesis. Laurentian University, Sudbury, Ontario, Canada. 144 pp.
- Nocera, J.J., Forbes, G., and Milton, G.R. 2007. Habitat relationships of three grassland breeding bird species: broadscale comparisons and hayfield management implications. Avian. Conserve. Ecol. 2: art 7.
- Noel, A., Olale, E., and Stuible, S. 2017. New Brunswick Census of Agriculture Report 2016. Department of Agricultures, Aquaculture and Fisheries, Government of New Brunswick, 33 pp.
- Rivest, P., and Bergeron, J.M. 1981 Density, food habits, and nomic importance of raccoons (*Procyon lotor*) in Quebec agrosystems, Can. J. Zool. **59**: 1755–1762.
- Saumure, R.A., Herman, T.B., and Titman, R.D. 2007. Effects of haying and agricultural practices on a declining species: The North American wood turtle, *Glyptemys insculpta*. Biol. Conserv. **135**: 565–575.
- Sherren, K., Tourangeau, W., Lamarque, M., and Greenland-Smith, S. 2019. Exploring motivation crowding around farmer incentives for riparian management in Nova Scotia. Can. Geographer. 1–16. Doi: 10.11111/cag.12572.
- STRIDES. 2016. Beneficial management practices for wood turtle conservation.17 pp.
- The Bobolink Project. n.d. Helping farmers project grassland birds. <https://www.bobolinkproject.com/farmers.php>

- Tingley, R., McCurdy, D.G., Pulsifer, M.D., and Herman, T.B. 2009. Spatio-temporal differences in the use of agricultural fields by male and female wood turtles (*Glyptemys insculpta*) inhabiting an agri-forest mosaic. *Herpetol. Conserv. Biol.* **4**:185–190.
- Tinklepaugh, O.L. 1932. Maze learning of a turtle. *J. Comp. Psychol.* **13**:201–206.
- Wisconsin Department of Natural Resources. 2015. Wisconsin wood turtle species guidance. Bureau of Natural Heritage Conservation, Wisconsin Department of Natural Resources, Madison, Wisconsin. PUB-ER-684.

Appendix A: Experimental Assessment of the Impact of Agricultural Machinery on Wood Turtles (*Glyptemys insculpta*)

A.1. Abstract

The wood turtle (*Glyptemys insculpta*) is a threatened species that uses agricultural fields, in part, to nest, bask, and feed. This use of anthropogenic habitats has resulted in the injury and death of individuals during crop harvest. Turtles have been exposed to hay harvests for over a century but the increased use of rotary disc mowers may have increased mortality rates to unsustainable levels. Mitigation measures have focused on raising blade height to minimize contact with turtles but these measures are based on the dimensions of the largest turtles and the effects of agricultural machinery on subadults, juveniles, and hatchlings have not been quantified. We sought to quantify how different agricultural machinery affects wood turtles at multiple life stages through experimental trials using two mower types. Cantaloupe (*Cucumis melo*) halves were used as turtle proxies to avoid actual harm to turtles. We found that rotary disc mowers resulted in a significantly greater injury to adult (i.e., female, male, and subadult) and young (i.e., juvenile and hatchling age class) proxies at low grass heights (10 to 20 cm) compared to sickle cutter bar mowers. Young proxies were found to be essentially unaffected by the sickle mower, at all grass heights, but they were highly affected by the rotary disc mower at grass heights from 10–18 cm. If blade heights were to be raised to reduce the risk to wood turtles, a minimum blade height of 17 cm would be needed to obtain >50% of adults remaining undamaged during harvest and a minimum height of 15 cm for young turtles.

KEYWORDS – Agriculture; blade height; hay field; injury; management; rotary disc mower; sickle cutter bar mower; wood turtle

A.2. Introduction

The wood turtle (*Glyptemys insculpta*) is a terrestrial freshwater species that is long-lived (>40 yrs) and reaches sexual maturity at 12 to 14 years old in northern populations (Ernst 2001; Walde et al. 2003; Marchand et al. 2018). Female wood turtles nest once per year and the likelihood of hatchlings reaching sexual maturity is low, especially when they face multiple threats (Powell 1967; Harding and Bloomer 1979; Schneider et al. 2018). Throughout their range, the wood turtle is considered at risk (COSEWIC 2018; U.S. Fish and Wildlife 2015; van Dijk and Harding 2011). This status is primarily due to threats such as poaching, road mortality, residential development, destruction of nests by all-terrain vehicles, increased predation, and agricultural machinery (e.g., Harding and Bloomer 1979; Garber and Burger 1995; Daigle and Jutras 2005; Saumure et al. 2007; van Dijk and Harding 2011). Agricultural machinery has become a substantial threat because wood turtles use agricultural fields during the summer months to bask, feed, and nest (e.g., Compton et al. 2002; Saumure et al. 2007; Tingley et al. 2009; McCoard et al. 2018). Wood turtles can be hit by agricultural machinery during crop harvest, causing injury or death; for example, Saumure and Bider (1998) found that carapace injuries were twice as common in agricultural landscapes than in forested landscapes. In Québec, Saumure et al. (2007) recorded that 20% of their study population died due to agricultural machinery within two years and 27% were injured. They noted that adult survivorship declined by 10–13% and juveniles by 18% in a two-year period. In

Nova Scotia, Tingley et al. (2009) recorded five turtle mortalities during the first harvest and that 14 of 27 turtles tagged had been within the field at least once throughout the active harvest season. Low adult survivorship is a common concern for turtle conservation because they are strongly K-selected species with little potential to recover populations quickly (e.g., Brooks et al. 1991; Congdon et al. 1993, 1994; Keevil et al. 2018). For example, in Ontario, river otters (*Lutra canadensis*) killed adult snapping turtles (*Chelydra serpentina*), decreasing the known population from 47 to 16 turtles within three years (Brooks et al. 1991) and 23 years later the population size had not recovered (Keevil et al. 2018). Thus, conservation actions that increase juvenile recruitment may be needed to achieve viability (Congdon et al. 1993; Mullin 2019).

Hay harvest has occurred in parts of wood turtle range for hundreds of years and likely has affected individuals and populations, but the threat is now considered more significant with continually improving machinery (Saumure et al. 2007). Farmers aim to maximize yield and minimize cost and, within the last 50 years, there has been a shift from using sickle cutter bar mowers to rotary disc mowers (Rider et al. 1993; Humbert et al. 2009). Rotary disc mowers are preferred over sickle bars because they can cut on uneven ground, run at a faster speed, and are more durable (Pogue et al. 1996) because the blade is tilted on an angle with no blade guards. In comparison, sickle bar blades cut parallel to the ground at lower speeds (Miller and Rotz 1995). Rotary disc mowers can cause a higher injury rate on adult turtles compared to sickle cutter bar mowers (Erb and Jones 2011). This is likely because the multiple, small

rotary discs cut downwards into each depression, whereas the rigid sickle blades miss some turtles.

Managers require information on strategies to reduce the mortality of wood turtles during hay harvest. Many farmers cut their hay at a blade height of 5 cm. Consequently, it has been recommended to raise the blade height of the mower to 10 or 15 cm to reduce injury to wood turtles using agricultural fields (Saumure et al. 2007; Erb and Jones 2011; Wisconsin Department of Natural Resources 2015). These recommendations are based on the tallest carapace height of a wood turtle in a population. Erb and Jones (2011) tested the possible effects of different mower types (sicklebar mower, rotary mower, mulching head mower, and flail mower) on adult turtles with raised blade heights (10, 15, and 19 cm). They found that there was no injury to proxies using the sicklebar mower but the rotary and mulching head mower caused high levels of injury at a blade height of 10 cm. The rotary mower caused 50% mortality when the blade was set at 10 cm, but they also found that 38% were killed by tires. They noted that their sample size may have been too small to detect trends of injury due to the blade and the tires may have diluted the effect on the proxies. There is, however, no information as to whether different mower types also affect smaller, younger turtles. Smaller turtles (i.e., juveniles and hatchlings) could be severely injured by the blade or thrown due to the suction of the mower (Erb and Jones 2011). Juveniles and hatchlings use hay and corn fields during the summer and could be at equal risk of being injured during harvest (Tuttle and Carroll 2005; Castellano et al. 2008). If all age classes of wood turtles are at high risk during

hay harvest, then future recovery of a population becomes increasingly unlikely. One unknown factor is whether vegetation can protect a turtle during a harvest.

The goal of our study was to refine existing conservation recommendations for wood turtle populations exposed to agricultural mowers. Firstly, we investigated whether injury to wood turtles during haying operations was dependent on one or more of the following variables: size class, mower type, grass height, and location above or below thatch. Secondly, we sought to identify a blade height that could reduce the mortality of wood turtles of all age classes. Lastly, we provided management strategies that consider landowner limitations. Our study used two different mower types (i.e., sickle cutter bar and rotary disc mower) with blade heights ranging from 5 to 15 cm across varying simulated wood turtle body sizes to observe the probability of injury.

A.3. Materials and methods

We conducted our study in July and August of 2018 near Fredericton, New Brunswick (Canada), at three different study sites containing early-successional hayfields. The fields were a mixture of timothy (*Phleum pratense*), bedstraw (*Galium aparine*), brome grass (*Bromus* spp.), and orchard grass (*Dactylis glomerata*), and are the common field type in much of the intervale landscapes in the Maritimes region. The fields were relatively flat with mounds (~2.5 cm) every few meters. The fields are used as sheep pasture, for the production of hay, and/or maintained as early-successional habitat.

We attempted to estimate possible injury of wood turtles as it relates to the following variables: (1) mower types; (2) blade heights; (3) vertical location of the turtle in the field (above or below thatch), and varying subject sizes. Live

wood turtles were not used to avoid harm to this imperiled species. We used cantaloupe (*Cucumis melo*) halves as a proxy for turtles because we could manipulate the size and weight to represent a wood turtle. In addition, the outer casing of unripe cantaloupes has a hard exterior, similar to turtle shells. To characterize the population, we separated the turtle proxies into five size classes: adult male, adult female, subadult, juvenile, and hatchling (Table A.1). Adults were not classified by age because they reach sexual maturity at a certain size, not a certain age (Harding and Bloomer 1979). All other wood turtles were classified by age by counting the annuli on their scutes. Adults were defined as ≥ 16.4 cm straight carapace length, subadults as $\sim 7\text{--}11$ years, juveniles as $\sim 3\text{--}6$ years, and hatchlings as ≤ 2 years old (Farrell and Graham 1991; Mullin 2019). We separated each class based on the average size and weight recorded for a nearby wood turtle population (Wallace, unpubl. data) and used a minimum of five replicates in each treatment (minimum $n = 300$; Table 1). To facilitate relocation of proxies after harvest, we applied food coloring (blue, red, yellow, green, and purple) to each size class. Two mower types were used to compare injury, with three different models. For the sickle cutter bar mower (henceforth “sickle mower”), we used an International Model 1190. For the rotary disc mower (henceforth “disc mower”), we used a New Idea 5209 and a Kubota DM1022. We used two tractor types: a Ford 4000 and a Case International 595. The rear tires of the Ford 4000 measured 37.8 cm in width and the total width of the tractor was 171.5 cm. The Case International 595 rear tires were 37.8 cm wide and the total width of the tractor was 190.5 cm.

We measured vegetation height before and after harvest to account for topography, tractor speed, and mower differences. Before each hay harvest, we laid cantaloupe halves of the same size class in a row within an area that a tractor could pass over in a single swath to allow for ease of injury assessment. We placed proxies above or below the thatch (undecomposed organic matter at the soil surface). After harvest, we assessed the injury of each proxy as undamaged or damaged; damage would include crushed or sliced sections of any single proxy. Assessment of the proxy's injuries was completed immediately after harvest of the field. We completed two to three replicates for each tractor type and blade height within uncut areas of the field. We did not separate mortality from injury on damaged proxies because turtles can sometimes survive with partially damaged shells (e.g., Saumure and Bider 1998; Saumure et al. 2007; Galois and Ouellet 2007; Bennett and Litzgus 2014).

Statistical Analysis. — We used logistic regression to predict the probability of injury (0 = uninjured, 1 = injured) based on increasing grass heights, location of proxy, and size class. Proxies that were damaged by tires were removed from the analysis to obtain an isolated assessment of the damage by the blade. Grass height varied at each site post-harvest, even though the blade height was the same. Due to varying grass heights, we used this measurement (instead of blade height) to infer injury. We merged size classes that did not have a significant difference of injury between grass heights ($p > 0.05$), based on a Students' *t*-test. We compared models using Akaike's Information Criterion (AIC; Akaike 1974) to identify the best candidate model(s).

We conducted all statistical analyses using the program R Studio version 1.1.463 (R Core Team 2018).

A.4. Results

We had a sample size of 398 proxies (cantaloupe halves) among three sites: 181 for the sickle mower and 217 for the disc mower. Blade heights of 5, 10, and 15 cm were used for the disc mower, which resulted in average post-harvest grass heights ranging from 10–25 cm (range 8–40 cm). We used grass height as a proxy for blade height due to the variation in grass height after harvest. Grass height was the height of grass left standing after the mower had harvested. Sickle mower had blade heights set to 5 cm and 10 cm, resulting in grass heights ranging from 10–15 cm. The average area that the tractor tires covered was 22% of each field. The logistic regression populated one top model for each mower type (Tables A.2 and A.3). For both models, grass height, placement of proxy (above or below thatch), and size class were all important in predicting injury. Female, male, and subadult classes had similarly low variability of injury among size classes ($p > 0.05$) and were merged to create an “adult” size class. Juvenile and hatchling were combined to create a “young” size class. Merged classes resulted in four treatments for each mower type: (1) adults above thatch; (2) adults below thatch; (3) young above thatch; and (4) young below thatch.

Disc mowers had a negative impact on the proxies. At the lowest cutting height (10 cm), 99% (95% CI 96.7–99.7) of adult proxies and 95.5% (95% CI 88–98.4) of young proxies were damaged (Fig. A.1). Proxies located above thatch had a higher damage rate on both adult and young proxies, compared to

damage on proxies located below thatch (Fig. A.1). The threshold for most undamaged proxies for adults was at a grass height of 23 cm for above-thatch and 19.7 cm for below-thatch trials. The threshold for young was at 18.5 cm for above-thatch and 15.1 cm for below-thatch trials. At the tallest grass height (25 cm), the younger size class had a 91% (95% CI 80–96.3) probability of being uninjured by the blade, compared to the adults that had a 66% (95% CI 49–80) probability.

For the sickle mower trials, at the lowest grass height (10 cm), 58% (95% CI 37–77) of adults and 21% (95% CI 43–98.7) of young were damaged above thatch (Fig. A.2). Adults below thatch had a 35% (95% CI 21–52) probability of being damaged at 10 cm and young had a 10% (95% CI 4–22) probability. When the grass height increased to 15 cm, damage to adults was reduced to 24% (95% CI 11–45) and young to 6% above thatch (95% CI 2–17) (Fig. A.1). The threshold for adults above thatch was at a grass height of 11.2 cm. All other treatments had more undamaged proxies than damaged for grass heights at and above 10 cm.

At a grass height of 15 cm, adult proxies above thatch had a 95% (95% CI 87–98) probability of being damaged if cut by a disc mower; whereas for the sickle mower, it was only 24% (95% CI 11–45). For young proxies, 78% (95% CI 61–89) had a likelihood of being injured at a grass height of 15 cm for rotary but for sickle they had a damaged probability of 6% (95% CI 2–17). The rotary blade trials revealed that a taller grass height is needed to achieve the threshold compared to sickle mower for all treatments. After harvest, 5% of hatchlings

could not be located if a disc mower had been used; whereas, for sickle mower, 19% of the hatchlings and one subadult could not be located.

There is also a considerable difference of injury rate between the two size classes for each mower type. When the disc mower blade was set to the lowest height (10 cm grass height), adult and young proxies above thatch had a relatively similar injury rate (adults 99.1%, young 95.6%). Whereas for the sickle mower, the adult size classes were twice as likely to be damaged at the lowest grass height compared to young proxies.

A.5. Discussion

We found that all wood turtle sizes are similarly affected by a disc mower if the blade is set to heights between 5 and 10 cm. However, raising the blade higher than 5 cm on a sickle mower can reduce injury significantly for all size classes. Location of the turtle, the equipment used, the blade height, and the size of the turtle can all influence the injury rate of individuals. Our results support other studies which suggest that disc mowers injure more turtles than sickle mowers (Licznar 1999; Humbert et al. 2009; Erb and Jones 2011).

Proxies that we set above the thatch showed a higher injury rate than those set below the thatch, which was likely due to some protection for the proxies under vegetation. The disc mower caused a high injury rate at multiple blades heights and at the tallest grass height more than 30% of proxies were still damaged; whereas, the sickle mower had less than 50% undamaged proxies when the grass height was 11 cm. Erb and Jones (2011) conducted a similar experiment with adult proxies comprised of cabbage and found that sickle mowers did not injure any of their proxies at a blade height of 10 cm. For disc mowers, they

found that 36% of their proxies were injured at a blade height of 15 cm. Our study found a higher rate of injury to the proxies, possibly due to a larger sample size or a difference in agricultural machinery and practices. We could not use blade height as an accurate indicator of injury due to the difference in grass heights post-harvest. Grass height could be variable due to a combination of topography, blade wear, and tractor speed. These variables were not measured in either Erb and Jones (2011) or our study; thus, we are uncertain which of these additional factors could be important for mitigation. Erb and Jones (2011) also noted that the number of “dead” turtles did not significantly decrease when the blade height increased from 10 to 15 cm with the disc mower. They speculated that this could be due to a small sample size or the results were altered by mortality induced by tires. We found similar results but had a larger sample size and tires did not influence our results. This implies that raising the blade height >15 cm for the disc mower barely reduces the injury or mortality of wood turtles.

We found that the younger size class had varying degrees of injury between the two mower types. Young proxies had a relatively high injury rate (95%) at a grass height of 10 cm for disc mower, but for sickle mower they had a 21% probability of being injured. The number of hatchling proxies missing after harvest by disc mower was relatively small (4.5%) but for sickle mowers 20% of the hatchling samples were missing. A missing hatchling may indicate it was thrown too far away to detect, or more likely, was sliced into pieces too small to be found. It is also possible that the proxies were hard to detect due to their color and size. Hatchlings could be lifted by the suction of the mower and hit by

the rotary blade, whereas the sickle mowers may simply displace the individuals, resulting in difficulty finding them. We excluded missing hatchlings from the injury predictions because we were uncertain whether the missing hatchlings were injured; if the missing hatchlings were added to the total damage on young proxies for sickle mower, the percent injured would be 39.5% at 10 cm and still fairly low relative to the disc mower. Although there is large variation in size between age classes, the disc mower caused a relatively high injury rate to all size classes, whereas the sickle mower has a relatively low impact on smaller turtles and even adults at low blade heights. We found that the number of injured young proxies decreased considerably more than the adults when the grass height was 15 cm for sickle mower. If blade heights are not raised for disc mowers, then all classes will have a high probability of being injured or killed. If the shells of young turtles are injured, it is likely that they would die as they cannot sustain the impact (Saumure et al. 2007). The difference in the injury between the two mower types of the size classes could be attributed to the mechanisms of the two mower types (Saumure et al. 2007). Disc mowers cut at an angle with no blade guards; therefore, the size of the turtle would likely not matter if the blade is set low enough.

Our study shows that recent changes in agricultural machinery, such as a move towards greater use of disc mowers over sickle mowers, is likely causing high rates of injury or mortality to all wood turtle age/size classes occupying fields during hay harvest. With no implementation of management strategies, wood turtle population are likely to become extirpated in agricultural areas.

A.6. Management

Managers and researchers have suggested raising blade height by 5–15 cm to lessen injury and mortality. Raising blade height would benefit farmers in that there is little nutritional value in the stems and it would reduce wear on machinery (MacGregor and Elderkin 2003; Saumure et al. 2007; Tingley et al. 2009; Erb and Jones 2011; Wisconsin Department of Natural Resources 2015). However, based on our study, blade heights would need to be raised to a minimum of 17 cm to have at least a 50% probability of an adult turtle remaining safe from the blade. A similar blade height would likely protect 80% of young turtles. Raising the blade to this height would result in decreased profit to landowners, as a greater volume of hay will be left growing in the field. Depending on the type of hay, the relevant commodities markets, and time of the year, landowners could lose approximately \$30 per hectare (based on current markets) if the blade height was raised to 15 cm (Lantz 2007; Wood Turtle STRIDES n.d.). If landowners have large scale operations, this could result in a high profit loss. As such, increasing blade height as a mitigation measure to protect wood turtles would likely need to be accompanied by financial compensation, which would allow farmers to purchase extra forage to make up for the loss of forgoing hay harvested at a lower height. Programs have been implemented in various jurisdictions to compensate farmers for implementing such management strategies for species at risk that use agricultural fields (Kleijn and Sutherland 2003; Government of Prince Edward Island 2018; Wood Turtle STRIDES n.d.).

Using a sickle mower instead of a disc mower would be a more suitable option because it would allow farmers to continue to cut hay at low blade heights, while reducing the injury rate to adult and young wood turtles. However, the use of sickle mowers is in decline, and typically only small-scale farmers still have them in use. Within New Brunswick, approximately 31% of farmers still use sickle mowers (Noel et al. 2017).

If blade height is raised to reduce the injury to wood turtles, mower tires still pose a substantial threat. During harvest, tires can contact almost 20% of the field's surface area. Therefore, if a turtle does not move during harvest, then the turtle has a one in five chance of being struck by a tire. Erb and Jones (2011) found that 46% of mortality was due to tires alone and that the rear tires accounted for 37% of the tire width. The width of the tractor and tires used in our experiment were smaller, so the threat of the tractor tires depends on the tractor model and tires sizes used.

Researchers have also recommended delaying the hay harvest or implementing buffer strips to avoid the mower altogether (Semlitsch and Bodie 2003; Saumure et al. 2007; Tingley et al. 2009). Buffer strips would be ideal, but wood turtle populations vary in the length of time they use the fields and female wood turtles will move up to a kilometer away from the river (Mullin 2019). Management strategies will be dependent on the equipment being used, the type of hay production, willingness of landowners, and any knowledge on the current wood turtle population.

Non-for-profit organizations that want to increase wood turtle populations in landscapes under active agricultural can use these management strategies to

help reduce mortality risk. Outreach to landowners and farmers who have suitable wood turtle habitat will be necessary to implement these strategies and funding programs that can help compensate landowners for hay loss would likely increase public involvement. An assessment of each landowner's property would be helpful to assess which management option would be ideal for each landowner based on the amount of agricultural land, proximity to the main river, time of year harvested, and type of mower used. If jurisdiction can institute policy or regulation, using management options presented would benefit wood turtle populations.

A.7. Literature Cited

AKAIKE, H. 1974. A new look at the statistical model identification. IEEE

Transactions on Automatic Control 19:716–723.

BENNETT, M.B. AND LITZGUS, J.D. 2014. Injury rates of freshwater turtles on a recreational waterway in Ontario, Canada. Journal of Herpetology 48:262–266.

BROOKS, R.J., BROWN, G.P., AND GALBRAITH, D.A. 1991. Effects of a sudden increase in natural mortality of adults on a population of the common snapping turtle (*Chelydra serpentina*). Canadian Journal of Zoology 69:1314–1320.

CASTELLANO, C.M., BEHLER, J.L., AND ULTSCH, G.R. 2008. Terrestrial movements of hatchling wood turtles (*Glyptemys insculpta*) in agricultural fields in New Jersey. Chelonian Conservation and Biology 7:113–118.

- COMPTON, B.W., RHYMER, J.M., AND MCCOLLOUGH, M. 2002. Habitat selection by wood turtles (*Clemmys insculpta*): an application of paired logistic regression. *Ecology* 83:833–843.
- CONGDON, J.D., DUNHAM, A.E., AND VAN LOBEN SELS, R.C. 1993. Delayed sexual maturity and demographics of Blanding's turtles (*Emydoidea blandingii*): implications for conservation and management of long-lived organisms. *Conservation Biology* 7:826–833.
- CONGDON, J.D., DUNHAM, A.E., AND VAN LOBEN SELS, R.C. 1994. Demographics of common snapping turtles (*Chelydra serpentina*): implications for conservation and management of long-lived organisms. *American Zoologist* 34: 397–408.
- COSEWIC. 2007. COSEWIC assessment and update status report on the wood turtle *Glyptemys insculpta* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. vii + 49 pp.
- DAIGLE, C. AND JUTRAS, J. 2005. Quantitative evidence of decline in a southern Québec wood turtle (*Glyptemys insculpta*) population. *Journal of Herpetology* 39:130–132.
- ERB, L. AND JONES, M.T. 2011. Can turtle mortality be reduced in managed fields? *Northeastern Naturalist* 18:489–496.
- ERNST, C.H. 2001. Some ecological parameters of the wood turtle, *Clemmys insculpta*, in southeastern Pennsylvania. *Chelonian Conservation and Biology* 4:94–99.
- FARRELL, R.F. AND GRAHAM, T.E. 1991. Ecological notes on the turtle *Clemmys insculpta* in northwestern New Jersey. *Journal of Herpetology* 25:1–9.

- GALOIS, P. AND OUELLET, M. 2007. Traumatic injuries in eastern spiny softshell turtles (*Apalone spinifera*) due to recreational activities in the northern Lake Champlain Basin. *Chelonian Conservation and Biology* 6:288–293.
- GARBER, S.D. AND BURGER, J. 1995. A 20-year study documenting the relationship between turtle decline and human recreation. *Ecological Applications* 5:1151–1162.
- GOVERNMENT OF PRINCE EDWARD ISLAND. 2018. Alternative land use service program.
https://www.princeedwardisland.ca/sites/default/files/publications/af_alus_guide.pdf
- HARDING, J.H. AND BLOOMER, T.J. 1979. The wood turtle, *Clemmys insculpta*...a natural history. *Bulletin of the New York Herpetological Society* 15:9–26.
- HUMBERT, J., GHAZOUL, J., AND WALTER, T. 2009. Meadow harvesting techniques and their impacts on field fauna. *Agriculture, Ecosystems & Environment* 130:1–8.
- KEEVIL, M.G., BROOKS, R.J., AND LITZGUS, J.D. 2018. Post-catastrophe patterns of abundance and survival reveal no evidence of population recovery in a long-lived animal. *Ecosphere* 9:e02396.10.1002/ecs2.2396.
- KLEIJN, D. AND SUTHERLAND, W.J. 2003. How effective are European agri-environment schemes in conserving and promoting biodiversity? *Journal of Applied Ecology* 40:947–969.
- LANTZ, V. 2007. Establishing payment rates for ecological goods and services provided by agricultural producers in the Souris and founds watersheds,

PEI. Unpublished report to the Souris and Area branch of the PEI Wildlife Federation. 30 pp.

- LICZNER, Y. 1999. Auswirkungen unterschiedlicher Mäh- und Heubearbeitungsmethoden auf die Amphibienfauna in der Narewniederung (Nordostpolen). *Rana – Mitteilungen für Feldherpetologie and Ichthyofaunistik in Norddeutschland – Sonderheft* 3:67–79.
- MACGREGOR, M.K., AND ELDERKIN, M.F. 2003. Protecting and conserving wood turtles; a stewardship plan for Nova Scotia. Biodiversity program, wildlife division. Nova Scotia Department of Natural Resources.
- MARCHAND, K.A., HUGHES, G.N., AND LITZGUS, J.D. 2018. Geographic variation in somatic growth rate of wood turtles (*Glyptemys insculpta*). *Copeia* 106:477–484.
- MCCOARD, K.R.P., MCCOARD, N.S., AND ANDERSON, J.T. 2018. Observation of wood turtle activity, diet, movements, and morphometrics in the central Appalachians. *Northeastern Naturalist* 25:513–531.
- MILLER, D.A. AND ROTZ, C.C. 1995. Harvesting and storage. In: Barnes, R.F., Miller, D.A., and Nelson, C.J. Forages. Volume I: An Introduction to Grassland Agriculture, 5th ed. Ames, IA: Iowa State University Press, pp. 163–169.
- MULLIN, D.I. 2019. Evaluating the effectiveness of headstarting for wood turtle (*Glyptemys insculpta*) population recovery. MS Thesis, Laurentian University, Sudbury, Ontario, Canada.

- NOEL, A., OLALE, E., AND STUIBLE, S. 2017. New Brunswick Census of Agriculture Report 2016. Department of Agriculture, Aquaculture and Fisheries, Government of New Brunswick, 33 pp.
- POGUE, D.E., EVANS, R.R., IVY, R.L., AND BAGLEY, C.P. 1996. The dollars and sense of hay production. Report No: MAFES Information Bulletin 311 Mississippi Agricultural and Forestry Experiment Station, Mississippi, USA.
- POWELL, C.B. 1967. Female sexual cycles of *Chrysemys picta* and *Clemmys insculpta* in Nova Scotia. Canadian Field-Naturalist 18:134–139.
- R CORE TEAM. 2018. A language and environment for statistical computing. R foundation for statistical computing, Vienna, Austria. URL <http://www.R-project.org/>.
- RIDER, A.R., BARR, S.D., PAULIA, A.W, HATHAWAY, L.R., AND KUTHAR, J.E. 1993. Hay and forage harvesting, 4th ed. Deere, Illinois, USA.
- SAUMURE, R.A. AND BIDER, J.R. 1998. Impact of agricultural development on a population of wood turtles (*Clemmys insculpta*) in southern Québec, Canada. Chelonian Conservation and Biology 3:37–45.
- SAUMURE, R.A., HERMAN, T.B., AND TITMAN, R.D. 2007. Effects of haying and agricultural practices on a declining species: the North American wood turtle, *Glyptemys insculpta*. Biological Conservation 135:565–575.
- SCHNEIDER, A.C., ARNOLD, T.W., HUBER, P.W., AND LEWIS, T.L. 2008. An 18-year mark-recapture study of wood turtles (*Glyptemys insculpta*) in Michigan. Journal of Herpetology 52:193–200.

- SEMLITSCH, R.D., AND BODIE, J.R. 2003. Biological criteria for buffer zones around wetlands and riparian habitats for amphibians and reptiles. *Conservation Biology* 17:1219–1228.
- TINGLEY, R., MCCURDY, D.G., PULSIFER, M.D., AND HERMAN, T.B. 2009. Spatio-temporal differences in the use of agricultural fields by male and female wood turtles (*Glyptemys insculpta*) inhabiting an agri-forest mosaic. *Herpetological Conservation and Biology* 4:185–190.
- TUTTLE, S.E., AND CARROLL, D.M. 2005. Movements and behavior of hatchling wood turtles (*Glyptemys insculpta*). *Northeastern Naturalist* 12:331–348.
- U.S. FISH AND WILDLIFE SERVICE. 2015. Endangered and threatened wildlife and plants; 90-day findings on 25 petitions. FWS-R5-ES-2015-0122-0003.
- VAN DIJK, P.P., AND HARDING, J. 2011. *Glyptemys insculpta* (errata version published in 2016). The IUCN red list of threatened species 2011: e.T4965A97416259.
- WALDE, A.A., BIDER, J.R., DAIGLE, C., MASSES, D., BOURGEOIS, J., JUTRAS, J., AND TITMAN, R.D. 2003. Ecological aspects of a wood turtle, *Glyptemys insculpta*, population at the northern limit of its range in Québec. *Canadian Field-Naturalist* 117:377–388.
- WISCONSIN DEPARTMENT OF NATURAL RESOURCES. 2015. Wisconsin wood turtle species guidance. Bureau of Natural Heritage Conservation, Wisconsin Department of Natural Resources, Madison, Wisconsin. PUB-ER-684.
- WOOD TURTLE STRIDES. <http://www.farmbiodiversity.ca/strides/>

Table A.1. The average size and mass of wood turtles (*Glyptemys insculpta*) in a population close to Fredericton, New Brunswick, Canada. The proxies were separated into five size classes: adult male, adult female, subadult, juvenile, and hatchling. Adults were defined as ≥ 16.4 cm straight carapace length, subadults as ~ 7 -11 years old, juveniles as ~ 3 -6 years old, and hatchlings as ≤ 2 years old.

	Male	Female	Sub- Adult	Juvenile	Hatchling
Carapace height (cm)	7.4	7	5	4	1.5
Carapace length (cm)	20	18	14.5	10	4
Carapace width (cm)	15	14	11	9	3
Mass (kg)	1.05	0.95	0.38	~ 0.25	0.1

Table A.2. Parameters from logistic regressions modelling injury to proxy wood turtles (*Glyptemys insculpta*) using cantaloupe (*Cucumis melo*) for sickle mowers. Model selection was based on minimizing AIC.

Coefficients					
Model	K	logLik	AIC	delta	weight
Grass.height + size + location	4	-66.23	140.7	0	0.72
Grass.height + size	3	-68.26	142.7	1.96	0.269
Grass.height + location	3	-72.56	151.12	10.56	0.004
Grass.height	2	-74.53	153.1	12.43	0.001
Size + location	3	-71.91	150	9.26	0.007
Size	2	-74.78	153.6	12.94	0.001
Location	2	-78.5	161.1	20.37	0

Table A.3. Parameters from logistic regressions modelling injury to proxy wood turtles (*Glyptemys insculpta*) using cantaloupe (*Cucumis melo*) for disc mower. Model selection was based on minimizing AIC.

Coefficients					
Model	K	logLik	AIC	delta	weight
Grass.height + size + location	4	-73.38	154.76	0	0.94
Grass.height + size	3	-77.17	160.33	5.49	0.06
Grass.height + location	3	-80.5	167.00	12.16	0.002
Grass height	2	-83.91	171.9	16.92	0
Size + location	3	-145.78	297.57	142.73	0
Size	2	-147.45	298.89	298.9	0
Location	2	-148.24	300.00	145.59	0

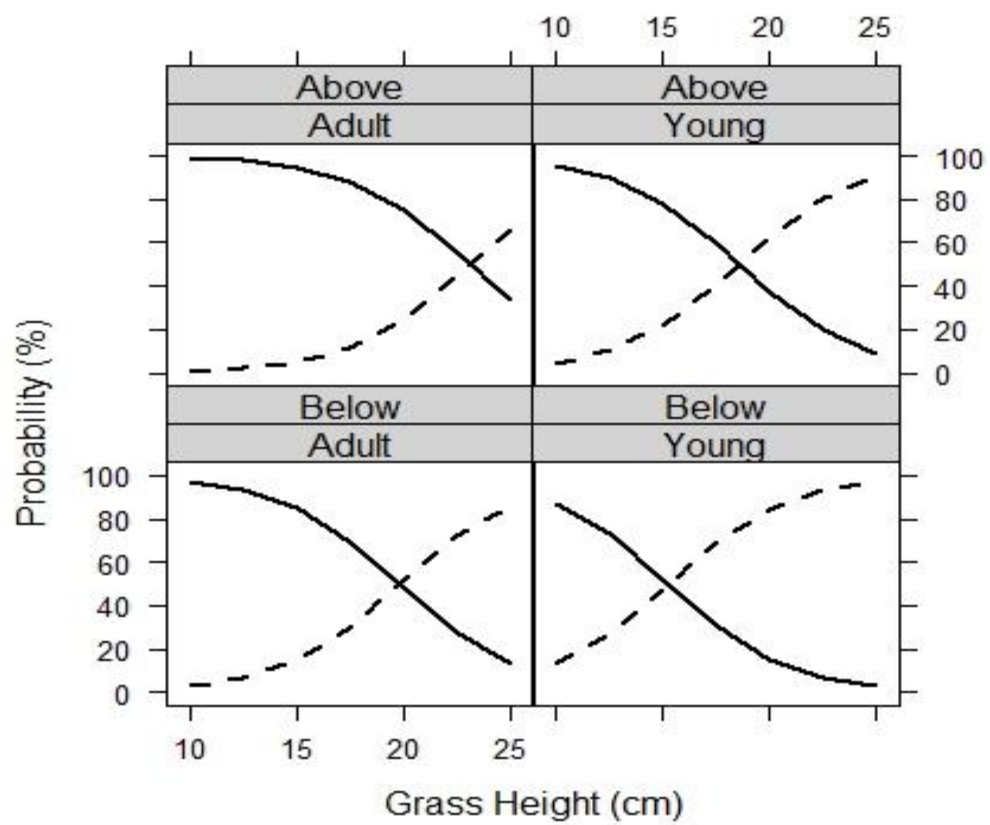


Figure A.1. Probability of adult and young wood turtles (*Glyptemys insculpta*) proxies being damaged during hay harvest using a disc mower in areas with different vegetation height. Cantaloupe halves of similar weight and dimensions of adult and young (hatchling to subadult; Table 1) wood turtles were used as proxies for wood turtles. Rotary blades were raised to 5, 10, and 15 cm heights. “Above” and “Below” are referring to the placement of the proxies in relation of the thatch (accumulation of undecomposed grass). Solid lines represent damaged turtles; dashed lines undamaged.

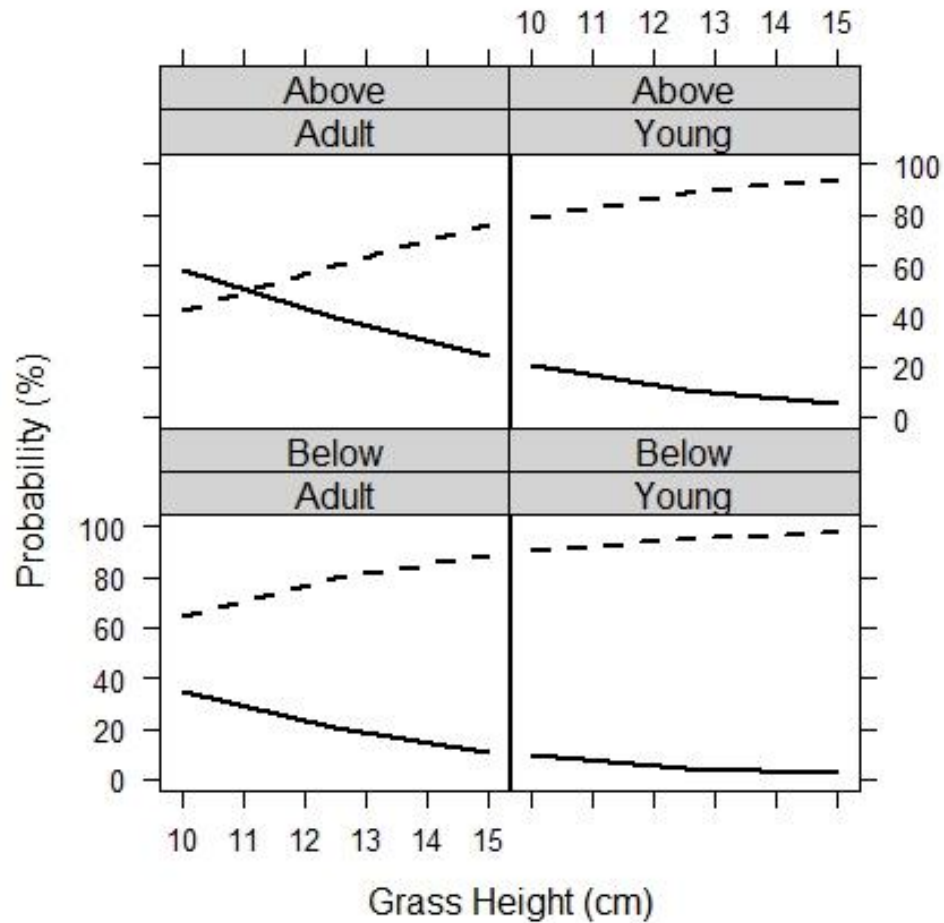


Figure A.2. Probability of adult and young wood turtles (*Glyptemys insculpta*) proxies being damaged during hay harvest using a sickle mower in areas with different vegetation height. Cantaloupe halves of similar weight and dimensions of adult and young (hatchling to subadult; Table 1) wood turtles were used as proxies for wood turtles. “Above” and “Below” are referring to the placement of the proxies in relation of the thatch (accumulation of undecomposed grass). Sickle blades were raised to 5 and 10 cm heights. Solid lines represent damaged turtles; dashed lines undamaged.

Appendix B: Habitat selection model outputs for male and female wood turtles

Table B.1. A generalized linear model using penalized quasi-likelihood through backward selection for all 23 tagged wood turtles during the active season (May-October) of 2018 and a r^2 value for the whole model.

Variable	Coefficient	SE	DF	t	p
<i>Binomial model for the probability of wood turtle presence throughout the active season, $R^2 = 0.079/0.086$</i>					
Fixed effects					
Intercept	-0.957	0.196	1286	-4.893	0.000
Temp at Ground	0.025	0.008	1286	3.026	0.003
Canopy %	-0.022	0.003	1286	-8.677	0.000
Shrub %	0.005	0.002	1286	2.072	0.039
Ground %	-0.006	0.001	1286	-3.928	0.000
Berries (Y)	0.841	0.365	1286	2.307	0.021
CWD (Y)	0.923	0.181	1286	5.102	0.000

Table B.2. A generalized linear model using penalized quasi-likelihood through backward selection for females (n=16) during the season (May-October) of 2018 and a r^2 value for the whole model.

Variable	Coefficient	SE	DF	t	p
<i>Binomial model for the probability of female wood turtle presence throughout the active season, $R^2 = 0.084$</i>					
Fixed effects					
Intercept	-0.786	0.083	1221	-9.429	0.000
Canopy %	-0.021	0.003	1221	-6.800	0.000
DTF	0.001	0.000	1221	2.558	0.035
Berries (Y)	0.906	0.430	1221	2.108	0.035
CWD (Y)	0.672	0.191	1221	3.516	0.001

Table B.3. A generalized linear model using penalized quasi-likelihood through backward selection for males (n=6) during the season (May-September) of 2018 and a r^2 value for the whole model.

Variable	Coefficient	SE	DF	t	p
<i>Binomial model for the probability of male wood turtle presence throughout the active season, $R^2 = 0.109/0.$</i>					
Fixed effects					
Intercept	-0.375	0.137	493	-2.734	0.007
CWD (Y)	1.111	0.321	493	3.462	0.001
Canopy %	-0.026	0.004	493	-6.075	0.000
Ground %	-0.009	0.002	493	-3.829	0.000

Table B.4. A generalized linear model using penalized quasi-likelihood through backward selection for females (n=16) during activity period 1 (May 10 to August 10) of 2018 and a r^2 value for the whole model.

Variable	Coefficient	SE	DF	t	p
<i>Binomial model for the probability of female wood turtle presence during activity period 1, R2 =0.170/0.172</i>					
Fixed effects					
Intercept	-1.309	0.727	695	-4.805	0.000
Temp at Ground	0.032	0.011	695	2.810	0.005
CWD (Y)	0.977	0.268	695	3.652	0.000
Canopy %	-0.037	0.005	695	-7.282	0.000
Ground %	-0.068	0.002	695	-3.150	0.002
Sand	1.291	0.336	695	3.846	0.000
Sand/Cobble	0.589	0.446	695	1.321	0.187
Soil	0.239	0.197	695	1.215	0.225
Soil/Cobble	0.164	0.497	695	0.330	0.741
Soil/Sand	2.215	0.776	695	2.855	0.004
Berries	1.309	0.629	695	2.083	0.038

Table B.5. A generalized linear model using penalized quasi-likelihood through backward selection for females (n=16) during activity period 2 (August 11 to October 10) of 2018 and a r^2 value for the whole model.

Variable	Coefficient	SE	DF	t	p
<i>Binomial model for the probability of female wood turtle presence during activity period 2, R2 =0.139/0.139</i>					
Fixed effects					
Intercept	1.004	0.439	197	2.018	0.045
Temp at Ground	-0.076	0.025	197	-3.709	0.000
Shrooms	1.236	0.487	197	2.580	0.011
Canopy %	-0.015	0.006	197	-2.787	0.006
Berries	1.049	0.641	197	1.638	0.103
DTF	0.003	0.001	197	3.108	0.002

Table B.6. A generalized linear model using penalized quasi-likelihood through backward selection for males (n=6) during activity period 1 (May 10 to June 20) of 2018 and a r^2 value for the whole model.

Variable	Coefficient	SE	DF	t	p
<i>Binomial model for the probability of male wood turtle presence during activity period 1, R2 =0.566/0.566</i>					
Fixed effects					
Intercept	-0.030	0.221	153	-0.137	0.892
CWD	2.032	0.897	153	2.265	0.025
Canopy %	-0.087	0.023	153	-3.723	0.000
Ground %	-0.011	0.004	153	-2.679	0.008

Table B.7. A generalized linear model using penalized quasi-likelihood through backward selection for males (n=6) during activity period 2 (June 21 to July 20) of 2018 and a r^2 value for the whole model.

Variable	Coefficient	SE	DF	t	p
<i>Binomial model for the probability of mle wood turtle presence during activity period 2, R2 =0.153/0.153</i>					
Fixed effects					
Intercept	-2.834	0.831	104	-3.411	0.000
Temp at Ground	0.116	0.038	104	3.023	0.003
CWD	0.956	0.545	104	1.753	0.083
Ground %	-0.018	0.006	104	-3.274	0.001

Table B.8. A generalized linear model using penalized quasi-likelihood through backward selection for males (n=6) during activity period 3 (July 21 to August 20) of 2018 and a r^2 value for the whole model.

Variable	Coefficient	SE	DF	t	p
<i>Binomial model for the probability of male wood turtle presence during activity period 3, R2 =0.098/0.098</i>					
Fixed effects					
Intercept	-0.390	0.328	107	-1.191	0.236
CWD	1.452	0.639	107	2.275	0.025
Berries	1.612	0.875	107	1.842	0.068
Sand	-1.101	0.925	107	-1.190	0.237
Sand/Cobble	-0.996	1.197	107	-0.083	0.407
Soil	-1.346	0.451	107	-2.984	0.004
Soil/Cobble	-0.526	0.921	107	-0.571	0.569
Soil/Sand	-1.220	1.340	107	-0.911	0.365

Table B.9. A generalized linear model using penalized quasi-likelihood through backward selection for males (n=6) during activity period 4 (August 21 to October 10) of 2018 and a r^2 value for the whole model.

Variable	Coefficient	SE	DF	t	p
<i>Binomial model for the probability of wood turtle presence during activity period 4, R2 =0.398/0.419</i>					
Fixed effects					
Intercept	0.160	0.400	51	0.401	0.690
Canopy %	-0.050	0.022	51	-2.320	0.024
Ground %	-0.040	0.012	51	-3.295	0.002
DTW	0.036	0.013	51	2.743	0.008

Table B.10. A generalized linear model using penalized quasi-likelihood through backward selection for wood turtles within the agricultural field in 2018 and a r^2 value for the final model.

Variable	Coefficient	SE	DF	t	p
<i>Binomial model for the probability of wood turtle presence within the hayfields, R2 =0.398/0.419</i>					
Fixed effects					
Intercept	-0.762	0.210	846	-3.632	0.000
Sex	-0.251	0.289	15	-0.867	0.400
DTE	-0.008	0.005	32	-1.586	0.123
Ground cover	-0.002	0.002	32	-0.805	0.427
Number of stems	-0.006	0.006	846	-0.963	0.336
Species cover	-0.005	0.004	846	-1.105	0.270

Appendix C: Individual home ranges for each radio tagged wood turtle at the study site, using the minimum convex polygon and adaptive kernel method in 2018.

Turtle ID	Sex	Number of Locations	MCP (ha)		Adaptive kernel (ha)	
			95%	50%	95%	95%
1	M	38	26.8	17.0	71.4	
2	F	38	10.5	6.8	26.7	
3	F	29	19.7	10.0	111.2	
4	F	37	3.4	2.0	9.0	
5	M	42	3.1	1.3	6.2	
6	F	34	34.8	55.6	225.1	
8	F	40	22.6	26.6	100.7	
9	F	31	2.8	1.1	4.8	
10	F	45	1.5	1.7	9.0	
12	F	22	37.3	41.1	166.5	
14	F	32	2.0	0.87	4.4	
17	F	42	2.3	4.7	22.9	
19	F	30	38.0	29.6	152.8	
20	F	26	9.7	4.7	21.2	
21	M	40	22.2	9.0	36.3	
23	M	30	44.0	53.0	238.9	
24	M	30	19.2	11.6	60.8	
25	F	18	4.8	2.3	10.6	
28	F	18	7.4	4.6	25.1	
29	M	29	7.32	3.1	14.0	
32	F	26	8.9	6.1	22.3	
37	F	31	4.1	12.0	47.3	
38	F	12	1.0	NA	NA	

Appendix D: Percent of turtle relocations (n=723) within each habitat type compared to the percent of habitat available at the study site in 2018.

Habitat Type	% of Available Habitat	% Used
Field	21.7	23.1
Forest	71.0	9.8
Riparian Buffer	2.2	18.5
River	1.9	19.4
Edge	0.2	16.9
Shore	2.1	12.3

Appendix E: Individual wood turtle measurements, notch code, sex and age at the study site.

Turtle ID	Notch Code	Sex	Age	Weight (kg)	Carapace Length (cm)	Carapace Width (cm)	Carapace Height (cm)
1	3-3-0-8,9	M	>20	1.3	21	15.5	NA
2	1-3-0-8,9	F	15	1.1	18.3	14	NA
3	1-3-0-8,10	F	>20	1.1	18.2	14	7.1
4	3-2-0-0,0	F	16	2	20.2	14.8	7.2
5	3-3-0-8,12	M	16	1.3	23	16.5	6.8
6	3-3-0-9,10	F	>20	1.2	19.2	13	7

7	1-3-0- 11,12	J	6	0.3	13.3	10.9	3.1
8	1-2-0-9,10	F	>20	1.5	20.8	14.5	7
9	1-3-0- 10,11	F	17	0.8	19.1	13.4	6.5
10	1-2-0-8,9	F	16	1.1	18.7	14.5	6.8
11	NONE	J	5	0.2	11.5	9	4.1
12	0-0-10-10	F	>20	1.2	18.3	14	7
13	1-3-10,10	F	>20	1.2	18.5	15	6.5
14	1-2-0-8,12	F	>20	1.1	18.3	14	7.1
15	1-3-9-12	F	18	1.4	19.3	14	7.8
16	NONE	J	4	0.7	7.3	6.4	2.6
17	1-3-8,9-0	F	>20	1.1	NA	NA	NA
18	1-2-0- 10,11	F	10	0.4	NA	NA	1.5
19	2-3-0- 11,12	F	19	1.0	19.5	14.5	6.7
20	3-4-0-9,10	F	17	0.9	18.4	14	6.4
21	1-2-0- 10,11	M	>20	1.3	20.7	15.1	6.9
22	1-3-0- 11,12	F	12	0.6	16.8	12.1	6
23	3-3-0- 11,12	M	>20	1.2	20.2	15.5	6.2

24	3-1-0-8,9	M	17	1.3	23	15	7.8
25	3-1-0- 11,12	F	>20	1.3	20.2	15	7.9
26	1-1-0-8,9	J	7	0.4	13.6	11.6	5
27	1-1-0-8,10	J	6	0.3	13.4	10	4.6
28	1-2-0-9,12	F	8	0.7	17	13	6
29	3-3-0-8,10	M	>20	1.0	21.5	14.1	NA
30	1-1-0-8,11	J	6	0.3	14	11.2	5.1
32	1-3-0-8,12	F	17	1.1	NA	16.8	6.5
33	1-3-0-8,11	M	12	1.1	20.5	15.5	7.6
34	1-3-0-9,10	F	>20	1.1	19	14.5	7.5
35	1-3-0-9,12	J	5	0.2	12.5	11.2	NA
36	3-3-0-8,11	M	>20	1.1	22	16	8.1
37	1-3-0-9,11	F	>20	1.2	20.9	15	7.8
38	1-2-0-8,10	F	>20	1.1	19	14.9	7
39	1-3-0- 10,12	F	15	1.2	20.4	14.4	7.3
40	1-2-0-8,11	F	>20	1.2	20	20.6	6.8
41	NONE	F	12	NA	NA	NA	NA
42	1-2-0- 11,12	F	>20	1.1	19.3	13.4	6.6
43	1-2-0-9,11	F	>20	1.0	18.5	14.2	6.7
44	2-1-0-8,12	F	16	1.2	20.5	13.9	7.2
45	1-1-0-8,12	J	6	0.3	12.5	9.5	5.5

46	2-1-0-8,9	J	6	0.4	12.8	10.5	4.4
47	2-1-0-8,10	M	>20	1.3	21.9	15.3	7.2
48	2-1-0-8,11	M	>20	1.2	22.4	15.8	7.9
49	NONE	M	>20	NA	NA	NA	7.9
50	2-1-0-9,10	M	>20	1.2	19.1	15.7	6.1
51	2-1-0-9,11	M	17	NA	NA	NA	6.3

Appendix F: The number of photos captured per predator species at an agricultural (Site A) and forested (Site B) landscape from trail cameras installed along a 2-km stretch of river. Cameras were set up from May 31-October 29, 2018 and a total of 49, 320 hours were recorded.

	Site A		Site B	
	# captured	Occurrence per 100 hours	# captured	Occurrence per 100 hours
Coyote	40	0.16	28	0.12
American Black Bear	17	0.07	226	0.94
Raccoon	40	0.16	9	0.04
Bobcat	2	0.01	15	0.06
Domestic Dog	51	0.2	0	0

Curriculum Vitae

Candidate's full name: Shaylyn Darlene Wallace

Universities attended:

University of New Brunswick, Hr BScENR 2017

Publications:

Wallace, S.D., G.J. Forbes, and J.J. Nocera. 2020. Experimental assessment of the impact of agricultural machinery on wood turtles (*Glyptemys insculpta*). *Chelonian Conservation and Biology*. *In Press*.

Conference Contributions:

Wallace, S.D., G.J. Forbes, and J.J. Nocera. (September 2018). Habitat use and mortality risk of wood turtle in a landscape under active agriculture. Canadian Herpetological Society, Kamloops, British Columbia. Poster presentation.

Wallace, S.D., G.J. Forbes, and J.J. Nocera. (August 2019). Mortality risk of wood turtle in a landscape under active agriculture. Canadian Society for Ecology and Evolution, Fredericton, New Brunswick. Oral presentation.

Wallace, S.D., G.J. Forbes, and J.J. Nocera. (September 2019). Mortality risk to wood turtle in a landscape under active agriculture in New Brunswick. Canadian Herpetological Society, Montreal, Quebec. Oral presentation.

Wallace, S.D., G.J. Forbes, and J.J. Nocera. (October 2019). Mortality risk to wood turtle in a landscape under active agriculture and potential management strategies. Atlantic Society of Fish and Wildlife Biologists, Western Shore, Nova Scotia. Oral presentation.

Wallace, S.D., G.J. Forbes, and J.J. Nocera. (November 2019). Mortality risk to wood turtle in a landscape under active agriculture and potential management strategies. Spotted, Blanding's & Wood Turtle Conservation Symposium, Berkeley Springs, West Virginia. Oral presentation.