

**Impacts of a windfarm and wildfire on the spatial ecology and
habitat selection of an endangered freshwater turtle**

by

Stéphanie J Delay

A thesis submitted in partial fulfillment
of the requirement for the degree of
Master of Science (MSc) in Biology

The Faculty of Graduate Studies
Laurentian University
Sudbury, Ontario, Canada

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THESIS DEFENCE COMMITTEE/COMITÉ DE SOUTENANCE DE THÈSE
Laurentian University/Université Laurentienne
Faculty of Graduate Studies/Faculté des études supérieures

Title of Thesis Titre de la thèse	Impacts of a windfarm and wildfire on the spatial ecology and habitat selection of an endangered freshwater turtle (<i>Clemmys guttata</i>)
Name of Candidate Nom du candidat	Delay, Stéphanie
Degree Diplôme	Master of Science
Department/Program Département/Programme	Biology
Date of Defence Date de la soutenance	August 26, 2022

APPROVED/APPROUVÉ

Thesis Examiners/Examineurs de thèse:

Dr. Jackie Litzgus
(Supervisor/Directeur(trice) de thèse)

Dr. John Urquhart
(Committee member/Membre du comité)

Dr. Yves Alaire
(Committee member/Membre du comité)

Dr. Jeffrey Lovich
(External Examiner/Examineur externe)

Approved for the Office of Graduate Studies
Approuvé pour le Bureau des études supérieures
Tammy Eger, PhD
Vice-President Research (Office of Graduate Studies)
Vice-rectrice à la recherche (Bureau des études supérieures)
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Abstract

Wind is a source of renewable energy, and its use is projected to increase as governments look for solutions to reduce carbon emissions. Although wind energy presents many advantages, windfarms can pose risks to wildlife. I used a *post-hoc* design to investigate whether body condition, spatial ecology, and multiscale habitat selection by spotted turtles (*Clemmys guttata*) differed among three treatment sites in central Ontario: Control, windfarm (Wind), and combined post-wildfire and windfarm (Windburn). I outfitted 9-10 turtles per treatment with VHF radio transmitters and tracked them approximately twice per week throughout the active season. Body condition, home range size and minimum daily distances moved by turtles did not differ among treatments, but it is possible that I did not detect acute responses to the habitat modification because turtles may have had sufficient time to adapt their behaviours as my study was conducted 2 years post-construction and 2.5 years post-wildfire. Turtles did not avoid habitats near turbines or roads but also did not cross roads unless a semi-aquatic culvert was present, highlighting the need to maintain habitat connectivity. In Windburn, turtles used wet depressions on rock barrens while Control and Wind turtles did not, possibly because Windburn turtles were exploiting new early successional macrohabitat resulting from the wildfire; however, pre-wildfire movement data would be required to confirm cause. In all treatments, turtles selected microhabitat based on temperature, water depth, available cover, and hummock presence, suggesting that turtles were able to find suitable microsites in the modified landscapes of my study area. My study is one of the first to assess the impacts of windfarms on semi-aquatic turtles, an at-risk and understudied taxon on windfarms, but more research is required to understand the acute and long-term impacts of windfarms and wildfires on turtles to inform data-driven mitigation strategies.

Keywords: windfarm; renewable energy; wildfire; turtle; *Clemmys guttata*; spatial ecology; habitat selection

Résumé

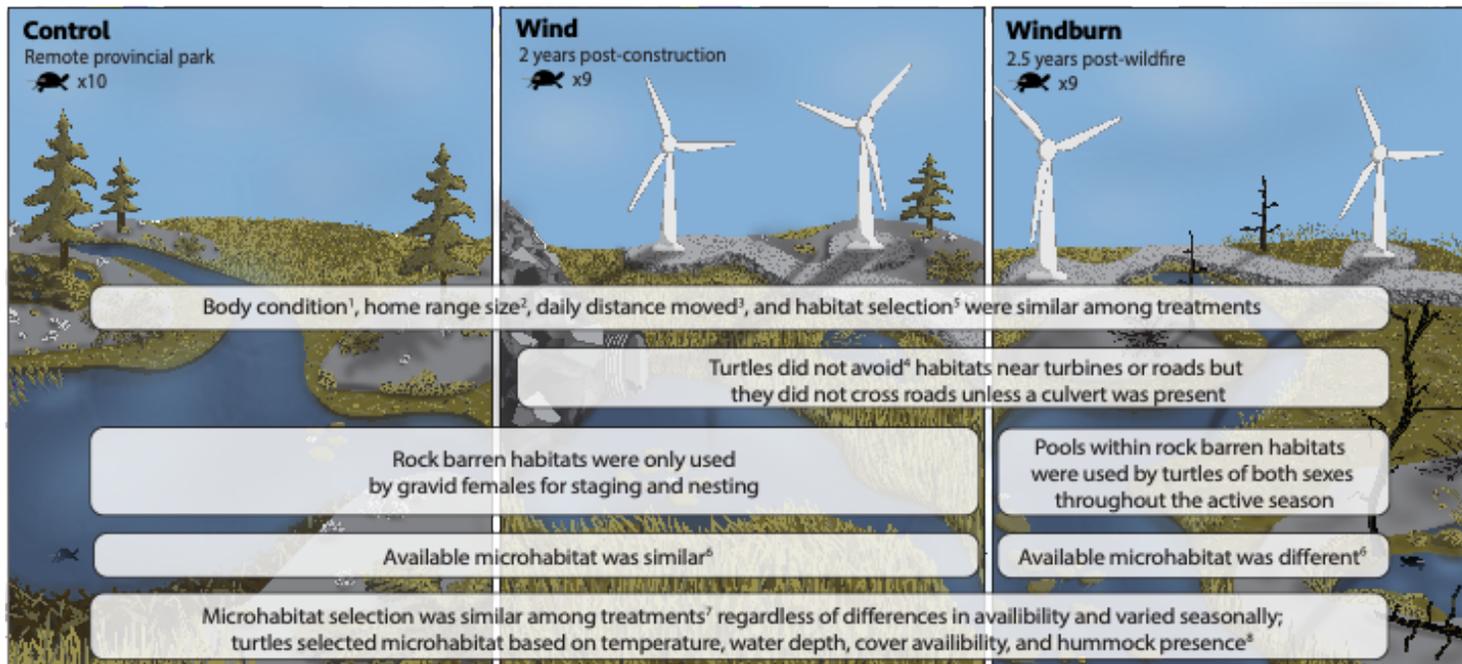
L'énergie éolienne est une source d'énergie renouvelable qui accroît rapidement et qui continuera d'accroître comme les gouvernements cherchent à réduire nos émissions de carbone. L'énergie éolienne a plusieurs avantages, cependant les parcs éoliens peuvent poser des risques pour la faune. J'ai utilisé trois traitements *post-hoc* pour déterminer si l'état corporel, l'écologie spatiale, et la sélection d'habitat des tortues ponctuées (*Clemmys guttata*) étaient différents entre trois sites-traitements en Ontario : un site Contrôle, un site dans un parc éolien (Éolien), et un site avec impact combiné de parc éolien et feu de forêt (Éolien-incendié). J'ai affixé des émetteurs radios de très haute fréquence (VHF) sur 9 à 10 tortues ponctuées par traitement et je les ai localisés environ deux fois par semaine durant la saison active. Je n'ai pas trouvé de différences significatives entre l'état corporel, la grandeur du domaine vital ou la distance parcourue par jour entre les traitements, mais c'est possible que je n'aie pas pu détecter une réponse aiguë à la modification d'habitat en raison de l'espace de temps depuis la construction et le feu de forêt (2 et 2.5 ans respectivement). Les tortues n'ont pas évité les habitats proximaux aux éoliennes ou aux chemins, mais ils ont aussi seulement croisé les rues lorsqu'un ponceau semi-aquatique était présent, soulignant l'importance de maintenir la connectivité d'habitats. Au site Éolien-incendié, les tortues ont utilisé des dépressions humides sur les zones rocheuses tandis que les tortues au sites Contrôle et Éolien n'ont jamais utilisé ces dépressions. Il se peut que le feu de forêt a créé des espaces pionnières sur les zones rocheuses que les tortues ont préféré, mais il faudrait des données prédatant le feu de forêt afin de mieux supporter une relation de causalité. Dans tous les traitements, les tortues ont sélectionné leurs micro-habitats selon la température, la profondeur d'eau, la disponibilité d'abris, et la présence d'une butte (hummock), indiquant que les tortues ont pu trouver des microsites convenables, même dans les sites modifiés par le parc-éolien et le feu de forêt. Mon étude est une des premières à déterminer les impacts des parcs-éoliens sur des tortues semi-aquatiques, un taxon en péril et peu étudié dans le contexte éolien, mais des recherches plus approfondies sont requises pour mieux comprendre les répercussions immédiates et à long-terme de parcs éoliens et des feux de forêts sur les tortues afin d'informer des stratégies d'atténuation basées sur des données scientifiques.

Mots clés : éoliennes, énergie renouvelable, feux de forêt, tortue, *Clemmys guttata*, écologie spatiale, sélection d'habitats

Graphical Abstract

Impacts of a windfarm and wildfire on the spatial ecology and habitat selection of an endangered freshwater turtle

Stéphanie J. Delay, Supervised by Dr. Jacqueline D. Litzgus, School of Natural Sciences, Laurentian University, 2022





Pre-construction planning and road passages like culverts may help mitigate impacts of windfarms on wildlife

Wildfires help maintain early successional habitats which may offer novel active season habitats for spotted turtles



Wildfires appear to have more pronounced impacts on turtle habitats than windfarms but turtles found suitable microsites in both landscapes

My study is one of the first to examine the impacts of windfarms on semi-aquatic turtles, but further investigation is required to inform data-driven mitigation strategies



VHF radio telemetry was conducted 1-2x / week during the active season, methodology is indicated by superscript; 1: scaled mass index, 2: MCP home range, 3: euclidean distances, 4: telemetry locations vs randomly generated locations, 5: KDE home range and compositional analysis, 6: 1 m² plots and GLM, 7: model selection (AIC and BIC) determine if treatment is a predictor, 8: paired logistic regression (1 m² plot use vs non-use)

Notice of data sensitivity

Turtles are poached both for the pet and food trades, with North American turtle species regularly found in both online and physical markets (Mali et al. 2014, Sung *et al.* 2021). Collection of turtles from wild populations can lead to population declines (e.g., Mullin et al. 2021), as turtle population persistence relies on high adult survivorship (Congdon et al. 1993, Heppell 1998, Enneson and Litzgus 2008). The collection of wild turtles is illegal in many jurisdictions, though enforcement of illegal trade is insufficient (Harrison et al. 2016). Illegal collection for the pet trade has been identified as a major threat for spotted turtles (COSEWIC 2014) especially during spring and fall aggregations (Ernst 1976). Poachers may use scientific manuscripts, theses, and reports to obtain species location information (Lindenmayer and Scheele 2017), so self-censorship of location data for high-risk populations is required (Lowe et al. 2017)

As per Lowe et al.'s (2017) recommendations, I will publish openly but responsibly. Specific locations have not been presented in my thesis to reduce the risk of illegal poaching. Anti-poaching protocols are in place at the study site, including electronic gated access and random wildlife checks.

Literature cited

- Congdon, J. D., A. E. Dunham, and R. C. Van Loben Sels. 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.
- COSEWIC. 2014. COSEWIC assessment and status report on the Spotted Turtle *Clemmys guttata* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. xiv + 74 pp. <www.registrelep-sararegistry.gc.ca/default_e.cfm>.
- Enneson, J. J., and J. D. Litzgus. 2009. Stochastic and spatially explicit population viability analyses for an endangered freshwater turtle, *Clemmys guttata*. *Canadian Journal of Zoology* 87:1241–1254.
- Ernst, C. H. 1967. A mating aggregation of the turtle *Clemmys guttata*. *Copeia* 1967:473–474.
- Harrison, J. R., D. L. Roberts, and J. Hernandez-Castro. 2016. Assessing the extent and nature of wildlife trade on the dark web. *Conservation Biology* 30:900–904.
- Heppell, S. 1998. Application of life-history theory and population model analysis to turtle conservation. *Copeia* 1998:367-375.

- Lindenmayer, D., and B. Scheele. 2017. Do not publish. *Science* 356:800–801.
- Lowe, A. J., A. K. Smyth, K. Atkins, R. Avery, L. Belbin, N. Brown, A. E. Budden, P. Gioia, S. Guru, M. Hardie, T. Hirsch, D. Hobern, J. La Salle, S. R. Loarie, M. Miles, D. Milne, M. Nicholls, M. Rossetto, J. Smits, B. Sparrow, G. Terrill, D. Turner, and G. M. Wardle. 2017. Publish openly but responsibly. *Science* 357:141–142.
- Mali, I., M. W. Vandewege, S. K. Davis, and M. R. J. Forstner. 2014. Magnitude of the freshwater turtle exports from the US: Long term trends and early effects of newly implemented harvest management regimes. *PLoS ONE* 9(1): e86478.
- Mullin, D. I., R. C. White, A. M. Lentini, R. J. Brooks, K. R. Bériault, and J. D. Litzgus. 2020. Predation and disease limit population recovery following 15 years of headstarting an endangered freshwater turtle. *Biological Conservation* 245:108496.
- Sung, Y. H., W. H. Lee, F. K. W. Leung, and J. J. Fong. 2021. Prevalence of illegal turtle trade on social media and implications for wildlife trade monitoring. *Biological Conservation* 261:109245.

Acknowledgements

This thesis would not have been possible without the support and mentorship of many including,

Dr. Jackie Litzgus: Your enthusiasm, dedication, and forethought make you an amazing supervisor. I appreciate all the time that you spent checking-in on my field escapades and editing document after document. I loved teaching frog calls and herp ID to keen undergraduate students with you; your passion for teaching the next generation of biologists is inspiring. Your thoughtful advice throughout my graduate experience has made me a better biologist and person. Thank you for being an incredible role model.

John Urquhart, MSc: This project would not exist without you. Thank you for taking a chance on me and supporting me as I expanded my skills. I have learned so much from you and from your team of amazing biologists.

Dr. Yves Alarie: Your outside perspective encouraged and challenged me to consider the wider context in which my research exists. Merci!

Dr. Jeffrey Lovich: I could not think of a more suited external examiner. You have a wealth of knowledge regarding chelonians and windfarms that is unmatched, and I am honoured that you accepted to review my work.

Partner First Nation: I am humbled to have conducted research on your lands. I will continue to educate myself and to participate in reconciliation to ensure that the past and ongoing wrongs are not forgotten and are remediated.

Blazing Star Environmental: Especially **Monique Aarts** who always kept our ship afloat – I have no words to express my gratitude for all that you did for me and our team, **Kaitlyn Hall** and **Siobhan Galway** for helping me learn the ropes of this massive project and being the best trailer park lot mates, **Briar Hunter** for your unmatched enthusiasm during our above-average 12-hour field days, **Aidan Maloney** for our scientific discussions in the field and camp chats, and everyone who helped me in the field over the two years including **Jason Ashawasegei**, **Mike Ashawasegei**, **Kelly Rintoul**, **Adam Solomon**, **Stacey Kinder**, **Taylor North**, **Sarantia Katsaras**, and **Michelle Hill**.

Litzgus Labbers: our experience was not the same as it may have been in non-pandemic times, but our bi-weekly zoom meetings made things feel a little normal. Thank you especially to **Jenna Kentel** and **Kyle Vincent** for our lab hangouts and **Matt Keevil** for listening and advising when I rambled on about stats.

Family and friends: Especially **Chantal Sarrazin-Delay** for nurturing a love for all critters from the time I could walk and your willingness to come in the field anytime I needed someone or just wanted your company, **Dominique Delay** for being my stay-at-home, make your own graduate experience buddy, **Daniel Delay** for all your time and knowledge working on my trailer to make it the best home I could have asked for, **Sara Machum** for your enduring friendship even when I was up to my ears in turtles with little time for anything else, and **Damien Mullin** for your unfaltering support and our weekly stress birding that kept me sane through the long winter.

This research was supported by the Canada Graduate Scholarship Master's program (NSERC CGS-M), Ontario Graduate Scholarship (OGS) Program, Natural Sciences and Engineering Research Council (NSERC; Discovery Grant to JDL), and Ganawenim Meshkiki. In kind support was provided by Anna Sheppard, Ontario Parks, and Laurentian University. All work involving animals was carried out under approved Laurentian University animal care protocols (AUPs 2017-02-01 and 2021-03-14). Work was authorized by Endangered Species Act (ESA) permit number M-102-2300390045, Species at Risk Act (SARA) permit number SARA-OR-2020-0538, and Wildlife Scientific Collector's authorization number 1100178.

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General Introduction

Renewable energy and windfarms

Currently, the world relies heavily on fossil fuels for energy production. In 2018, over 80% of the world's global energy was generated from fossil fuels (IEA 2020), but as the threat of greenhouse gas-induced climate change mounts, governments are increasingly turning to renewable energy sources to reduce fossil fuel emissions (GWEC 2019). If renewable energies are to replace fossil fuels, they must be cost-effective, reliable, and highly available to meet demands, and they should avoid worsening the current biodiversity crisis (Barnosky et al. 2011). Over the past few years, the sustainability and viability of various types of renewable energy including wind, solar, hydro, nuclear, and geothermal energy have been reviewed (Evans et al. 2009, Panwar et al. 2011, Ellabban et al 2014, Brook and Bradshaw 2015, Gibson et al. 2017). Wind energy has been suggested as one of the most appealing types of renewable energy due to the low lifetime carbon emissions, an almost negligible water consumption per kwh, and a relatively high energy generation efficiency; however, high land-use requirements have been described as a downfall of wind energy centers (Evans et al. 2009).

Wind energy centers (i.e., windfarms) require large amounts of land, although only a relatively small percentage of the land (1-10%) is directly altered (Denholm et al. 2009, Fthenakis and Kim 2009). The directly impacted area consists of the infrastructure needed to support the installation and maintenance of turbines and the transport of electricity. Windfarm infrastructure generally includes (1) service roads wide enough for the transport of turbine blades and towers, (2) permanent clearings at the base of turbines to allow for maneuvering of installation and maintenance machinery, (3) concrete foundations to support the base of each turbine, (4) powerlines to transport electricity, (5) electrical substations where the electricity generated from

the wind turbines is transformed for long distance transmission, (6) laydowns for machinery storage, and (7) service buildings. These infrastructure requirements result in fragmentation and alteration of the landscape which has been described as a major concern for wildlife residing in windfarms (Lovich and Ennen 2013).

Wildlife and windfarms

Windfarms have been shown to present significant risks to wildlife both from the turbines themselves and their related infrastructure. The mortality of birds and bats due to turbine blade collisions has been extensively studied (Kuvlesky et al. 2007, Hayes 2013, Smallwood 2013, Wang and Wang 2015, Allison et al. 2019) and is of significant concern, as both local and distant populations can be affected by the direct mortality of individuals (Gibson et al. 2017). It is worth noting that much of the research does not put the mortality of birds and bats in context; one review found that fossil fuel power stations were responsible for approximately 5.2 bird fatalities per GWh compared to only 0.3-0.4 bird fatalities per GWh on windfarms (Sovacool 2013). Another hypothesized cause of direct mortality for bats on windfarms is the change in pressure caused by the spinning blades of wind turbines, but it is unlikely that this turbulence is responsible for a significant number of deaths directly related to turbines (Lawson et al. 2020). Turbulence caused by turbine blades can, however, directly alter the surrounding microclimate (Roy and Traiteur 2010, Zhou et al. 2012, Armstrong et al. 2016) which could affect wildlife, particularly ectotherms or those animals that exhibit temperature sex determination (TSD), although the specific effects have not been quantified (Lovich and Ennen 2013). Noise, vibrations, and shadow flicker from the turbines (Barber et al. 2010, Zwart et al. 2016) could also have effects on wildlife but these are again relatively understudied in a wildlife context (Lovich and Ennen 2013, but see Rabin et al. 2006, Trowbridge and Litzgus 2022).

Windfarm infrastructure causes fragmentation, alteration, and destruction of habitat (Kuvlesky et al. 2007, Diffendorfer et al. 2019), threats which have been identified as globally significant causes of terrestrial biodiversity loss (Newbold et al. 2015, WWF 2020). Road mortality is another specific threat to terrestrial vertebrates (Steen and Gibbs 2004, Galista et al 2008, Fahrig and Rytwinski 2009) and has been reported as a source of animal mortality on windfarms (e.g., Lovich et al. 2011*c*). Finally, a lesser-known impact of windfarms is the ignition of wildfires (Lovich and Ennen 2013, Uadiale et al. 2014, Lovich et al. 2018*a*).

Fires and windfarms

As with most types of energy generation, fire is a concern on windfarms, but the risk has not been quantitatively reviewed in the scientific literature. It is difficult to assess the risk of turbine fires or operation-related fires because many fires go unreported, making alternate sources of information (grey literature, i.e., reports and media publications) biased, incomplete or unavailable (Uadiale et al. 2014). FireTrace International, a fire suppression system seller, estimates that there is a 1 in 100 chance of a turbine catching fire over its lifespan (FireTrace 2021*a*) which could be a significant risk when Canada alone has over 6,771 operational turbines (CanWea 2019). A report from the SP Technical Research Institute of Sweden compiled various sources of information and found that there was an average of 0.3 turbine fires per 1000 onshore turbines, but they acknowledge that this number may be an underestimation (Dederichs et al. 2016). The risk of fire in turbines is attributable to the three basic elements of fire – fuel (oil and polymers), oxygen (wind), and ignition (electrical connections, mechanical parts, or lighting) – being present in the nacelle of the turbines (Uadiale et al. 2014). The height of the turbines also means that once a fire has been ignited, little can be done to extinguish the fire; this presents a significant concern for wildfire ignition as falling debris could ignite the vegetation below (Uadiale et al. 2014).

Installation and maintenance operations on windfarms can also ignite wildfires. Both turbine and operation-related fires have resulted in multiple wildfires at the Mesa wind energy facility northwest of Palm Springs, CA, USA (Lovich et al. 2011b, 2018a). Other wildfires in the United States have been attributed to windfarms including the 152 ha View Fire in 2012 and the 100 ha Juniper Fire in 2019, both of which put infrastructure, and residential areas at risk (FireTrace 2021b). As mentioned previously, there are no regulations mandating the reporting of windfarm operation-related fires, making it difficult to quantitatively assess the combined risks of windfarms and wildfires to communities of plants and animals. Wildfires are unlikely to be the main issue for biological communities on windfarms (see other threats above) but with the number of wind turbines increasing rapidly (IRENA 2020) and climate change increasing the frequency, size, and duration of wildfires (Gillett et al. 2004, Stephens et al. 2014), it is possible that the combined impacts of wildfires and windfarms could soon become commonplace.

Research and rationale

To understand windfarm (post-construction) and post-wildfire effects on freshwater turtles, I investigated the spatial ecology and habitat selection of spotted turtles (*Clemmys guttata*) in Central Ontario where a wildfire originated on a windfarm when an all-terrain vehicle caught fire (Reference redacted). I used a *post-hoc* design with three treatments – Control, Wind (windfarm impacted), and Windburn (combined windfarm and wildfire impacted) – to investigate whether body condition, movements, and habitat selection of spotted turtles differed among treatments. Specifically, I determined and compared body condition, home range size, and daily distance moved, established if turtles demonstrated avoidance of windfarm infrastructure, and described and compared habitat selection at three spatial scales. By comparing the movement patterns and habitat selection of turtles in impacted and control sites, I gained an understanding of how land

impacts from the windfarm and the wildfire, including fragmentation (Kuvlesky et al. 2007, Diffendorfer et al. 2019) and altered resource availability (Markle et al. 2020*b*, Wilkinson et al. 2020), affected spotted turtle land use.

Study System: Spotted turtles

Spotted turtles are a relatively small (max. carapace length 14.25 cm, Haxton and Berrill 1999) freshwater turtle, identifiable by their smooth black carapace with yellow-orange spots. Their range is restricted to Eastern North America where disjunct populations occur from eastern Illinois, through southern Ontario and into New York, as well as along the Atlantic coast from Maine to northern Florida (Ernst and Lovich 2009). Spotted turtles are semi-aquatic; they generally inhabit shallow wetlands including fens, ponds, and sphagnum swamps where aquatic vegetation and substrate are available for cover, but they also use upland habitats for nesting and overland movements (Litzgus and Brooks 2000, Rasmussen and Litzgus 2010, O’Bryan et al. 2016). Spotted turtles are listed as ‘Endangered’ globally (van Dijk 2011), federally (Canada; COSEWIC 2014), and provincially (Ontario; COSSARO 2015). Habitat destruction and alteration, road mortality, and poaching for the pet trade represent major threats to this species (Ernst and Lovich 2009, COSEWIC 2014).

Spotted turtles are a good study system for my research as windfarm developments are on the rise within their range in both Canada and the United States (IRENA 2020) and their critical habitats for reproduction and winter survival have been previously described in Ontario (Litzgus et al. 1999, Litzgus and Brooks 2000, Markle et al. 2020*a*, 2020*b*) allowing for comparisons to the literature. Spotted turtles were also less likely to undertake between-treatment movements as they have generally smaller home ranges (0.2 ha to 10 ha; COSEWIC 2014) compared to other turtle species in the study area (e.g., Blanding’s turtle, *Emydoidea blandingii*: HR size 10 ha to 60 ha;

COSEWIC 2016). Additionally, the windfarm was constructed in known spotted turtle habitat, so impact offsetting, monitoring, and reporting for the Species-at-Risk Act (SARA) was required; my study contributes to these requirements by monitoring spotted turtle movements post-construction.

Data sensitivity

Spotted turtles aggregate in the spring and fall for mating and overwintering respectively (Ernst 1967), making them vulnerable to large scale poaching events. The removal of only 1-3% of reproducing adult turtles from a subpopulation can lead to decline or extirpation due to low juvenile recruitment, low fecundity, and late age at maturity (Brooks et al. 1991, Congdon et al. 1993, 1994, Enneson and Litzgus 2009, COSEWIC 2014, Keevil et al. 2018). With spotted turtles being one of the most popular turtle species in the illegal pet trade (COSEWIC 2014), precautions must be taken to protect the exact locations of animals.

Literature cited

- Allison, T. D., J. E. Diffendorfer, E. F. Baerwald, J. A. Beston, D. Drake, A. M. Hale, C. D. Hein, M. M. Huso, S. R. Loss, J. E. Lovich, M. D. Strickland, K. A. Williams, and V. L. Winder. 2019. Impacts to wildlife of wind energy siting and operation in the United States. *Issues in Ecology* 2019:1–23.
- Armstrong, A., R. R. Burton, S. E. Lee, S. Mobbs, N. Ostle, V. Smith, S. Waldron, and J. Whitaker. 2016. Ground-level climate at a peatland wind farm in Scotland is affected by wind turbine operation. *Environmental Research Letters* 11(4), 044024.
- Barber, J. R., K. R. Crooks, and K. M. Fristrup. 2010. The costs of chronic noise exposure for terrestrial organisms. *Trends in Ecology and Evolution* 25:180–189.
- Barnosky, A. D., N. Matzke, S. Tomiya, G. O. U. Wogan, B. Swartz, T. B. Quental, C. Marshall, J. L. McGuire, E. L. Lindsey, K. C. Maguire, B. Mersey, and E. A. Ferrer. 2011. Has the Earth's sixth mass extinction already arrived? *Nature* 471:51–57.
- Brook, B. W., and C. J. A. Bradshaw. 2015. Key role for nuclear energy in global biodiversity conservation. *Conservation Biology* 29:702–712.
- Brooks, R. J., G. P. Brown, and D. A. Galbraith. 1991. Effects of a sudden increase in natural mortality of adults on a population of the common snapping turtle (*Chelydra serpentina*).

- CanWea. 2019. Wind energy in Canada: Installed capacity. <<https://canwea.ca/wind-energy/installed-capacity/>>.
- Congdon, J. D., and D. W. Tinkle. 1982. Reproductive energetics of the painted turtle (*Chrysemys picta*). *Herpetologica* 38:228–237.
- COSEWIC. 2014. COSEWIC assessment and status report on the Spotted turtle *Clemmys guttata* in Canada. 74. Ottawa. <www.sararegistry.gc.ca/status/status_e.cfm>.
- 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. <<http://www.registrelep-sararegistry.gc.ca/default.asp?lang=en&n=24F7211B-1>>.
- COSSARO. 2015. Ontario Species at Risk Evaluation Report for Spotted Turtle (*Clemmys guttata*). Committee on the Status of Species at Risk in Ontario.
- Dederichs, A., G. Baker, D. Lange, B. Krause, D. Winberg, and J. Gehandler. 2016. Fire safety in offshore wind turbines. SP Technical Research Institute of Sweden, Borås.
- Denholm, P., M. Hand, M. Jackson, and S. Ong. 2009. Land use requirements of modern wind power plants in the United States. Ellabban, O., H. Abu-Rub, and F. Blaabjerg. 2014. Renewable energy resources: Current status, future prospects and their enabling technology. *Renewable and Sustainable Energy Reviews* 39:748–764. <<https://www.nrel.gov/docs/fy09osti/45834.pdf>>
- Diffendorfer, J. E., M. A. Dorning, J. R. Keen, L. A. Kramer, and R. V Taylor. 2019. Geographic context affects the landscape change and fragmentation caused by wind energy facilities. *PeerJ* 7:1–23.
- van Dijk, P. P. 2011. *Clemmys guttata*. The IUCN Red List of Threatened Species 2011: e.T4968A97411228. <<http://dx.doi.org/10.2305/IUCN.UK.2011-1.RLTS.T4968A11103766.en%0ACopyright>>. Accessed 29 Oct 2020.
- Enneson, J. J., and J. D. Litzgus. 2009. Stochastic and spatially explicit population viability analyses for an endangered freshwater turtle, *Clemmys guttata*. *Canadian Journal of Zoology* 87:1241–1254.
- Ernst, C. H. 1967. A mating aggregation of the turtle *Clemmys guttata*. *Copeia* 1967:473–474.
- Ernst, C. H., and J. E. Lovich. 2009. Turtles of the United States and Canada. Second Edi. The John Hopkins University Press, Baltimore.
- Evans, A., V. Strezov, and T. J. Evans. 2009. Assessment of sustainability indicators for renewable energy technologies. *Renewable and Sustainable Energy Reviews* 13:1082–1088.
- Fahrig, L., and T. Rytwinski. 2009. Effects of roads on animal abundance: An empirical review and synthesis. *Ecology and Society* 14.

- FireTrace. 2021a. Wind turbine fire suppression systems. <<https://www.firetrace.com/wind-turbine-fire-suppression-systems>>. Accessed 11 Mar 2021.
- FireTrace. 2021b. An overview of wind turbine fires. <<https://www.firetrace.com/wind-turbine-fire>>. Accessed 11 Mar 2021.
- Fthenakis, V., H. C. Kim. 2009. Land use and electricity generation: A life-cycle analysis. *Renewable and Sustainable Energy Reviews* 13:1465-1474.
- Gibson, L., E. N. Wilman, and W. F. Laurance. 2017. How green is ‘green’ energy? *Trends in Ecology and Evolution* 32:922–935.
- Gillett, N. P., A. J. Weaver, F. W. Zwiers, and M. D. Flannigan. 2004. Detecting the effect of climate change on Canadian forest fires. *Geophysical Research Letters* 31:1–4.
- Glista, D. J., T. L. DeVault, and J. A. DeWoody. 2008. Vertebrate road mortality predominantly impacts amphibians. *Herpetological Conservation and Biology* 3:77–87.
- GWEC. 2019. Global wind report 2018. Brussels. <<https://gwec.net/global-wind-report-2018>>.
- Hayes, M. A. 2013. Bats killed in large numbers at United States wind energy facilities. *BioScience* 63:975–979.
- Haxton, T., and M. Berrill. 1999. Habitat selectivity of *Clemmys guttata* in central Ontario. *Canadian Journal of Zoology* 77:593–599.
- IEA. 2020. Key world energy statistics. Paris. <<https://www.iea.org/reports/key-world-energy-statistics-2020>>.
- Keevil, M. G., R. J. Brooks, and J. D. Litzgus. 2018. Post-catastrophe patterns of abundance and survival reveal no evidence of population recovery in a long-lived animal. *Ecosphere* 9.
- Kuvlesky, W. P., L. A. Brennan, M. L. Morrison, K. K. Boydston, B. M. Ballard, and F. C. Bryant. 2007. Wind energy development and wildlife conservation: challenges and opportunities. *Journal of Wildlife Management* 71:2487–2498.
- Lawson, M., D. Jenne, R. Thresher, D. Houck, J. Wimsatt, and B. Straw. 2020. An investigation into the potential for wind turbines to cause barotrauma in bats. *PLoS ONE* 15:1–24.
- Litzgus, J. D., and R. J. Brooks. 2000. Habitat and temperature selection of *Clemmys guttata* in a northern population. *Journal of Herpetology* 34:178–185.
- Litzgus, J. D., J. P. Costanzo, R. J. Brooks, and R. E. J. Lee. 1999. Phenology and ecology of hibernation in spotted turtles (*Clemmys guttata*) near the northern limit of their range. *Canadian Journal of Zoology* 77:1348–1357.
- Lovich, J. E., M. Agha, J. R. Ennen, T. R. Arundel, and M. Austin. 2018a. Agassiz’s desert tortoise (*Gopherus agassizii*) activity areas are little changed after wind turbine induced

- fires in California. *International Journal of Wildland Fire* 27:856.
- Lovich, J. E., and J. R. Ennen. 2013. Assessing the state of knowledge of utility-scale wind energy development and operation on non-volant terrestrial and marine wildlife. *Applied Energy* 103:52–60.
- Lovich, J. E., J. R. Ennen, S. Madrak, and B. Grover. 2011a. Turtles and culverts, and alternative energy development: An unreported but potentially significant mortality threat to the desert tortoise (*Gopherus agassizii*). *Chelonian Conservation and Biology* 10:124–129.
- Lovich, J. E., J. R. Ennen, S. V Madrak, C. L. Loughran, K. P. Meyer, T. R. Arundel, and C. D. Bjurlin. 2011b. Long-term post-fire effects on spatial ecology and reproductive output of female Agassiz's desert tortoises (*Gopherus agassizii*) at a wind energy facility near Palm Springs, California, USA. *Fire Ecology* 7:75–87.
- Lovich, J. E., J. R. Ennen, S. V Madrak, K. P. Meyer, C. L. Loughran, C. D. Bjurlin, T. R. Arundel, W. Turner, C. Jones, and G. Groenendaal. 2011c. Effects of wind energy production on growth, demography, and survivorship of a desert tortoise (*Gopherus agassizii*) population in Southern California with comparisons to natural populations. *Herpetological Conservation and Biology* 6:161–174.
- Markle, C. E., P. A. Moore, and J. M. Waddington. 2020a. Primary drivers of reptile overwintering habitat suitability: Integrating wetland ecohydrology and spatial complexity. *BioScience* 70:597–609.
- Markle, C. E., S. L. Wilkinson, and J. M. Waddington. 2020b. Initial effects of wildfire on freshwater turtle nesting habitat. *The Journal of Wildlife Management* 84:1373–1383.
- Newbold, T., L. N. Hudson, S. L. Hill, S. Contu, I. Lysenko, R. A. Senior, L. Börger, D. J. Bennett, A. Choimes, B. Collen, J. Day, A. De Palma, S. Díaz, S. Echeverria-Londoño, M. J. Edgar, A. Feldman, M. Garon, M. L. K. Harrison, T. Alhusseini, D. J. Ingram, Y. Itescu, J. Kattge, V. Kemp, L. Kirkpatrick, M. Kleyer, D. L. P. Correia, C. D. Martin, S. Meiri, M. Novosolov, Y. Pan, H. R. P. Phillips, D. W. Purves, A. Robinson, J. Simpson, S. L. Tuck, E. Weiher, H. J. White, R. M. Ewers, G. M. MacE, J. P. W. Scharlemann, and A. Purvis. 2015. Global effects of land use on local terrestrial biodiversity. *Nature* 520:45–50.
- O'Bryan, C. J., J. A. Homyack, R. F. Baldwin, Y. Kanno, and A. L. Harrison. 2016. Novel habitat use supports population maintenance in a reconfigured landscape. *Ecosphere* 7: e01228.
- Panwar, N. L., S. C. Kaushik, and S. Kothari. 2011. Role of renewable energy sources in environmental protection: A review. *Renewable and Sustainable Energy Reviews* 15:1513–1524.
- Rabin, L., R. Coss, D.H. Owings. 2006. The effects of wind turbines on antipredator behavior in California ground squirrels (*Spermophilus beecheyi*). *Biological conservation* 131:410-420.
- Rasmussen, M. L., J. E. Paterson, and J. D. Litzgus. 2009. Foraging ecology of spotted turtles

- (*Clemmys guttata*) in Ontario, Canada. *Herpetological Review* 40:286–288.
- Roy, S. B., and J. J. Traiteur. 2010. Impacts of wind farms on surface air temperatures. *Proceedings of the National Academy of Sciences of the United States of America* 107:17899–17904.
- Smallwood, K. S. 2013. Comparing bird and bat fatality-rate estimates among North American wind-energy projects. *Wildlife Society Bulletin* 37:19–33.
- Sovacool, B. K. 2013. The avian benefits of wind energy : A 2009 update. *Renewable Energy* 49:19–24.
- Steen, D. A., and J. P. Gibbs. 2004. Effects of roads on the structure of freshwater turtle populations. *Conservation Biology* 18:1143–1148.
- Stephens, S. L., N. Burrows, A. Buyantuyev, R. W. Gray, R. E. Keane, R. Kubian, S. Liu, F. Seijo, L. Shu, K. G. Tolhurst, and J. W. Van Wagtenonk. 2014. Temperate and boreal forest mega-fires: Characteristics and challenges. *Frontiers in Ecology and the Environment* 12:115–122.
- Trowbridge, C. M., and J. D. Litzgus. 2022. Wind farms alter amphibian community diversity and chorusing behavior. *Herpetologica* 78:75–85.
- Uadiale, S., É. Urbán, R. Carvel, D. Lange, and G. Rein. 2014. Overview of problems and solutions in fire protection engineering of wind turbines. *Fire Safety Science* 11:983–995.
- Wang, Shifeng, and Sicong Wang. 2015. Impacts of wind energy on environment: A review. *Renewable and Sustainable Energy Reviews* 49:437–443.
- Wilkinson, S. L., A. M. Tekatch, C. E. Markle, P. A. Moore, and J. M. Waddington. 2020. Shallow peat is most vulnerable to high peat burn severity during wildfire. *Environmental Research Letters* 15: 104032.
- WWF. 2020. Living Planet Report 2020 - Bending the curve of biodiversity loss. R. E. A. Almond, M. Grooten, and T. Petersen, editors. WWF, Gland, Switzerland. <<http://www.ecoguinea.org/papers-development.html>>.
- Zhou, L., Y. Tian, S. B. Roy, C. Thorncroft, L. F. Bosart, and Y. Hu. 2012. Impacts of wind farms on land surface temperature. *Nature Climate Change* 2:539–543.
- Zwart, M. C., J. C. Dunn, P. J. K. McGowan, and M. J. Whittingham. 2016. Wind farm noise suppresses territorial defense behavior in a songbird. *Behavioral Ecology* 27:101–108.

Manuscript

Impacts of a windfarm and wildfire on the spatial ecology and habitat selection of an endangered freshwater turtle

Introduction

Wind energy is a renewable energy source that more than tripled in global capacity from 2010 to 2019 (IRENA 2020) and is projected to continue to increase as governments look for ways to reduce carbon emissions (GWEC 2019). Windfarms are highly appealing due to the low lifetime carbon emissions, relatively low cost per MW/h, and an electricity generation efficiency comparable to coal or gas (Evans et al. 2009); however, it has become clear that windfarms are not without risks for wildlife. The mortality of birds and bats from turbine collisions have been extensively studied and reviewed (Kuvlesky et al. 2007, Hayes 2013, Smallwood 2013, Sovacool 2013, Wang and Wang 2015, Allison et al. 2019). Other impacts of windfarms on wildlife include habitat loss, modification, and fragmentation (Kuvlesky et al. 2007, Diffendorfer et al. 2019), road mortality (Lovich et al. 2011c), noise, vibrations, and shadow flicker from turbine blades (Rabin et al. 2006, Barber et al. 2010, Lovich and Ennen 2013, Zwart et al. 2016, Trowbridge and Litzgus 2022), microclimate alteration from turbine turbulence (Roy and Traiteur 2010, Zhou et al. 2012, Armstrong et al. 2016), and a wildfire ignition risk (Lovich and Ennen 2013, Lovich et al. 2018a). These impacts have been studied and described in various taxa, but turtles have largely been excluded from this research.

Turtles are one of the most at-risk taxa worldwide (Lovich et al. 2018b, Stanford et al. 2020), yet they have been consistently underrepresented in wildlife research on windfarms. Desert tortoises (*Gopherus agassizii*) have been comprehensively studied on a California windfarm where parts of the windfarm were burned by turbine-induced and other wildfires (Lovich et al. 2011c, b,

a, 2018a, Agha et al. 2015). These studies found that (1) Desert tortoise activity-center sizes did not differ between the windfarm and a nearby wilderness area (Agha et al. 2015), (2) tortoises on windfarms had higher survivorship than in a nearby wildland area although some operation-related mortality was recorded (Agha et al. 2015), (3) the wildfire killed one tortoise and five others had burn scarring (Lovich et al. 2011b), and (4) after the fires, the activity center size of tortoises on the windfarm remained similar despite the risk of lower quality habitat (Lovich et al. 2011b, 2018a). Unfortunately, the mostly terrestrial behaviour of desert tortoises may limit the transferability of these findings to freshwater turtles. The only existing study of freshwater turtles on a windfarm found that painted turtles (*Chrysemys picta marginata*) had shorter daily movements, displayed some avoidance of turbine roads, and had marginally smaller home ranges than those in nearby control sites (Trowbridge 2020) but this study remains unpublished. The effects of windfarms on movements and habitat selection by freshwater turtles still represent a significant gap in knowledge.

I used a *post-hoc* design with three treatments to investigate if body condition, movement patterns, and multiscale habitat selection by spotted turtles (*Clemmys guttata*) differed among a control site, a post-construction windfarm site (Wind), and a combined post-wildfire and post-construction windfarm site (Windburn). My objectives were to determine and compare (1) body condition, (2) home range size, and (3) daily distance moved among treatments, (4) establish if turtles demonstrate avoidance of windfarm infrastructure, (5) determine if habitat availability and selection differed among treatments, and (6) describe habitat selection at multiple scales. If windfarms and wildfires cause a decline in habitat quality and food resources, then I expected to see lower body condition in the impacted sites. If landscape fragmentation by windfarm infrastructure is affecting spotted turtles, then I expected to see smaller home ranges in the Wind

and Windburn sites compared to the control site, as turtle movements may be restricted by infrastructure. If critical habitats were destroyed or habitat quality was reduced by the windfarm and wildfire, then I expected to see larger home ranges and longer movements in the Wind and Windburn sites, as turtles may need to travel further to access essential resources. If turbines or roads are a significant disturbance to spotted turtles, then I expected that turtle locations would be significantly further from infrastructure than a random distribution of locations, indicating avoidance. If the windfarm and the wildfire affected hydrology, vegetation, microclimate, and/or landscape, then I expected habitat availability to differ among treatments and to observe significantly different habitat selection by spotted turtles at all spatial scales in the Wind and Windburn sites compared to the Control site.

Methods

Study area

My study area is located in Central Ontario, Canada, near the northern range limit of spotted turtles (Ernst and Lovich 2009). The landscape is characterized by granite bedrock ridges and valleys resulting in a mosaic of rock outcrops and wetlands. The rock outcrops are sparsely vegetated by juniper (*Juniperus communis*), jack pine (*Pinus banksiana*), white pine (*Pinus strobus*), and lichens. The wetlands are numerous and highly variable in class and form.

Construction of the windfarm began in August 2017 and the windfarm became fully operational in July 2019. The windfarm has an installed power capacity of 300 MW (87 Vestas turbines V136-3.45 MW[®]) and a total area of 9,000 ha where 7.7% (690 ha) of this area has been directly altered for infrastructure (i.e., roads, turbine pads, transmission lines, laydowns, and substations). During construction, a wildfire originated on the windfarm when an all-terrain vehicle caught fire (Reference redacted). The resulting wildfire burned a total of 11,300 ha: 1,900

ha of the windfarm and 9,400 ha of nearby public lands. The fire was declared extinguished 105 days later (Reference redacted). Both the area that was burned and the footprint of the windfarm are known to support populations of federally endangered spotted turtles (COSEWIC 2014).

I used three treatments to investigate the effects of the windfarm and the wildfire on spotted turtle body condition, spatial ecology, and habitat selection: (1; Control - C) a control site located on relatively pristine public lands, (2; Wind - W) a windfarm site, and (3; Windburn - WB) a burned windfarm site. All three sites were greater than 5 km apart and separated by natural physical barriers, so there was no risk of turtles moving between treatments. Due to the significant threat of illegal poaching of spotted turtles for the pet trade (COSEWIC 2014), site locations will not be further described (Lowe et al. 2017).

Capture and Radiotelemetry

I hand-captured turtles during visual encounter surveys. Captured turtles were sexed using secondary sex characteristics (Ernst and Lovich 2009), weighed using spring scales (± 1 g, Pesola, Präzisionswaagen, AG, Switzerland), measured using calipers (± 0.05 cm, Wondersunm), individually marked using marginal scute notching (Cagle 1939) and photographed for future reference. I recorded capture location (longitude, latitude) using Google Maps (Google, Mountain View, CA, USA) on an iPhone Xs (accuracy ± 5 m; Apple, Cupertino, CA, USA).

In 2021, I outfitted 28 turtles ($n_{\text{Control}} = 10$ (5 ♀ / 5 ♂), $n_{\text{Wind}} = 9$ (4 ♀ / 5 ♂), $n_{\text{Windburn}} = 9$ (4 ♀ / 5 ♂)) with very high frequency (VHF) radio transmitters (Model R1680, 3.6 g, Advanced Telemetry Systems, Isanti, MN, USA). I affixed transmitters to the posterior carapace using fast setting liquid epoxy (J-B Weld MinuteWeld™, Sulfur Springs, TX, USA) and epoxy putty (J-B Weld WaterWeld™, Sulfur Springs, TX, USA). The total mass of the transmitter and epoxy did not exceed 6% of the turtle's (non-gravid) body mass. I tracked turtles at regular intervals with

tracking frequency depending on seasonal activity levels (Haxton and Berrill 2001; Table 1): twice per week during the active season (May-Aug), once per week during the fall (Sept-Oct) and once during the inactive season (Nov-Apr) for turtles in Wind and Windburn only; turtles in the Control treatment could not be tracked in the winter due to accessibility issues. At each radiolocation, I recorded coordinates, habitat type, and environmental parameters (see below).

Body condition

I used scaled mass index (SMI; Peig and Green 2009) to approximate body condition where a higher SMI suggests an accumulation of energy capital and by extension the individual is assumed to have better health (Peig and Green 2009). I used SMI because unlike ordinary least square (OLS) regressions, SMI can be used to compare body condition across different populations (Peig and Green 2009). I calculated scaled mass index for each individual (\hat{M}_i) using $\hat{M}_i = M_i \left(\frac{L_0}{L_i}\right)^{b_{sma}}$ where M_i is the mass of individual i (± 1 g; mass at emergence in April 2021), L_0 is the mean midline carapace length (± 0.05 cm) of all individuals with no missing limbs ($n = 25$), L_i is the midline carapace length (± 0.05 cm) of each individual, and b_{sma} is the scaling exponent calculated from the slope of the log length vs. log mass OLS regression (b_{ols}) divided by Pearson's correlation coefficient r (Peig and Green 2009). I excluded any individuals with missing limbs ($n = 3$; 1 Wind, 2 Windburn) prior to this analysis to remove the impact of limb loss on overall mass. I compared SMI among treatments and sexes using a type III two-way ANOVA ($\alpha = 0.05$) to account for the unequal number of turtles per treatment. Residuals were normally distributed so SMI was not transformed before proceeding to the ANOVA. SMI computation and statistical analyses were conducted in RStudio (R Core Team, 2019).

Home range size

I calculated the annual home range size for each individual ($n = 28$; mean of 28 ± 2 radiolocations per individual) using 100% minimum convex polygons (MCP; Hayne 1949) and 95% kernel density estimators (KDE; Worton 1989) where the smoothing factor (h) resulted in the KDE area being equal to the area of the 100% MCP (Row and Blouin-Demers 2006). Although both methods result in identical home range sizes, they provide different information. KDEs provide information about activity centers, though these may exclude movement corridors as they are disjointed. Conversely, MCPs include all possible movement corridors, including those not detected as a result of intermittent tracking (number of days between tracking events: mode = 3 days, mean = 5 days), as MCPs are not disjointed. MCPs are recommended for comparisons of herpetofauna home range sizes, as MCPs accurately represent the home range size if sampling occurs every few days throughout the active season (Row and Blouin-Demers 2006). I compared 100% MCP home range sizes among treatments and sexes using a type III two-way ANOVA ($\alpha = 0.05$) to account for the unequal number of turtles per treatment. Residuals were not normally distributed so home range data were log transformed before proceeding to the ANOVA. Home range computation (package `adehabitatHR`; Calenge 2006) and statistical analyses were conducted in RStudio (R Core Team, 2019).

Daily distance moved

I calculated the minimum daily distance moved (DDM; m/day) by each individual in RStudio (R Core Team, 2019) using package `adehabitatLT` (Calenge 2006). Straight line distances were generated between tracking events, then divided by the number of days between sequential pairs of tracking events to obtain the minimum distance moved by an individual per day. This method has been widely used in spatial ecology studies of turtles (e.g. Haxton and Berrill 2001,

O'Bryan et al. 2016, Zagorski et al. 2019). I compared minimum DDM among treatments, sexes, and seasons (seasons delineated based on turtle activity patterns;

Table 1) using a type III repeated measures ANOVA to account for the unequal number of turtles per treatment. I used pairwise comparisons with Bonferroni correction to examine any differences. Residuals of the seasonal data were not normally distributed so DDMs were square root transformed before proceeding to the ANOVA. A sphericity correction was required before interpretation. Statistical analyses were conducted in RStudio (R Core Team, 2019).

Avoidance of windfarm infrastructure

To determine if turtles avoided windfarm infrastructure, I generated random locations (RLs) within each individual turtle's KDE annual home range equal to the number of turtle locations (TLs) collected for each individual (mean of 28 ± 2 radiolocations per individual) using 'create random points' tool in ArcGIS Pro 2.9.2 (ERSI, 2021). I also generated RLs within turtle MCP home ranges to ensure that my conclusions were not a result of methodology. Random locations (RLs) were restricted to wetlands and uplands (rock barrens) in the same proportion as the TLs to reflect that spotted turtles are semi-aquatic and that individual preferences for use of wetlands and uplands may exist. I measured the distance of each TL and RL to the nearest turbine and the nearest road using the 'near' tool in ArcGIS Pro 2.9.2 (ERSI, 2021). I compared the distances of TLs and RLs to turbines and of TLs and RLs to roads using Kruskal-Wallis's rank sum tests ($\alpha = 0.05$) as residuals were not normally distributed and did not meet parametric test assumptions. If TLs were significantly further from infrastructure than randomly generated points (RL), this indicated an avoidance of infrastructure (Lavery et al. 2016).

Macrohabitat

I used compositional analyses to determine macrohabitat selection (Aebischer et al. 1993) where selection is inferred if available habitat is used disproportionately. I considered two scales of selection (Johnson 1980): the selection of the individual's home range within the population range (second order) and the selection of specific locations within the individual's home range (third order). Individual's home ranges (HRs) were delineated using 95% KDEs where the smoothing factor (h) was adjusted until the area was equal to the area of the 100% MCP. These KDE HRs are recommended for habitat selection studies of herpetofauna as they provide weighted information on activity centers, contrary to MCPs that encompass all used areas (Row and Blouin-Demers 2006); but it is worth noting that disjointed KDEs could result in important movement corridors being excluded from the home range. The population range was delineated in each treatment using a MCP (encompassing all radiolocations for all individuals) with a 100 m buffer to ensure that all boundaries of individual KDE home ranges were fully included in the population range.

I classified available habitat at both scales of selection based on the hierarchical Ecological Land Classification System (Banton et al. 2008, Wester et al. 2011) using a combination of satellite imagery and field ground truthing. I collapsed the 12 identified ecosites into 5 habitat types (Table 2), as compositional analyses require that most individuals encounter all available habitat types in the population range within their home range to determine if selection occurs. I drew boundaries for each habitat type in ArcGIS Pro 2.9.2 (ERSI, 2021) then used the 'tabulate intersection' tool to calculate (1) the total area of each habitat type available in each treatment's population range, (2) the total area of each habitat type available in each turtle's home range, and (3) the number of radiolocations in each habitat type for each turtle. In RStudio (R Core Team, 2019), I first confirmed that macrohabitat was similarly available among treatments by fitting zero inflated beta

regressions (proportions data (%) and zeros present (no constructed habitat in Control), Ferrari and Cribari-Neto 2004; R package ‘gamlss’, Stasinopoulos and Rigby 2007) with and without treatment as a predictor of proportions and compared both models using Akaike’s information criterion (AIC; Akaike 1974) values and a likelihood ratio test (LRT; $\alpha = 0.05$). I then used the function ‘compana’ within the package ‘adhabitatHS’ (Calenge 2006) to execute compositional analyses (Aebischer et al. 1993) separately for each treatment. A ranking matrix was created for each treatment where a ‘+++’ indicates significant selection of one habitat type over another. To compare macrohabitat selection among treatments, I created a summary table with each treatment’s top-ranking habitat types to qualitatively compare differences. I did not test for seasonal or sex differences in macrohabitat selection because splitting the data would result in an insufficient number of turtles encountering all available habitat types to tabulate selection.

Microhabitat

At each turtle location, I recorded habitat variables in a 1m-by-1m square plot (1 m²) at paired sites: one centered on the turtle location (turtle plot; TP), and one centered on a nearby random location within the same macrohabitat (paired plot; PP). I determined the random plot location (PP) using a random number generator to obtain a random distance (2 - 30 m; Ernst 1976; data support this distance as mean DDM = 15 m per day) and direction (0° - 360°) from the turtle location plot. If I encountered a macrohabitat boundary during the random location transect, I reflected off the boundary to remain in the same macrohabitat; this allowed me to keep spatial scales of interest separate. I measured habitat variables in both plots based on potential importance to spotted turtle biology (Ward et al. 1976, Rasmussen and Litzgus 2010, O’Bryan et al. 2016) including thermoregulation and predator avoidance (Table 3). Air, basking, water, and substrate temperatures were measured with a waterproof thermometer (± 2 °C, Cooper-Atkins Model

DPP400W-0-8, Middlefield, CT, USA). Water depth and substrate depth were measured using a graduated probe (cm, ± 1 cm) made from PVC pipe (3 cm diameter); to measure substrate depth, a 2 kg weight was placed on the PVC pipe to represent a standard force. The percentage of available basking and cover area within the plot were estimated visually. Distance from the plot to the nearest upland area (shore) was measured using the PVC graduated probe (m, ± 1 m). The presence or absence of hummocks as well as the dominant vegetation type were noted. Connectivity of open water was estimated visually and deemed 'true' if open surface water could be observed for an area of at least 20 m² in any direction from the plot.

Selection: To investigate the selection of resources by spotted turtles (Johnson 1980; 4th order selection), I used paired logistic regressions with a binary response of used (1) or available but not used (0) approximating a case-control design (Compton et al. 2002). Paired logistic regressions are advantageous as they allow comparisons of available habitats at the same moment in time as the used habitat, and available habitat can be quantified within the reasonable range of movement for the species resulting in a more realistic model of the choices that low mobility animals, like turtles, are making compared to other methods (Compton et al. 2002). Additionally, categorical variables can be incorporated into the model and there is no assumption of multivariate normality for paired logistic regressions, which can be hard to meet with these types of data (North and Reynolds 1996).

I first tested for and removed any colinear microhabitat variables ($r > 0.5$) using a Spearman's non-parametric rank-correlation coefficient matrix (Appendix A), then fit a fixed model with the remaining 7 microhabitat variables; temperature (water temperature or substrate temperature if no water was present), water depth, cover percentage, distance to shore, hummock presence, continuous open water (connectivity), and dominant vegetation type. Mixed effect

models with random slopes for individual animal identification (Turtle ID) are recommended for matched-pair habitat selection studies, as fixed effect models can lead to errors in interpretation when inter-individual heterogeneity in habitat selection is present (Duchesne et al. 2010, Muff et al. 2020); however, based on parsimony principles, random effects should only be included if they improve the fit of the model to the data. I used a likelihood ratio test (LRT; $\alpha = 0.05$) to determine if the addition of Turtle ID as a random slope for each microhabitat variable significantly improved the fit of the fixed model to the data (Appendix B). Based on the LRT result, random slopes were either included ($p < 0.05$; heterogeneous habitat selection among individuals) or excluded ($p > 0.05$; relatively homogenous habitat selection among individuals) for all subsequent analyses.

Next, I fit nested paired logistic models with interaction terms for each microhabitat variable (Appendix C) to examine if treatment, sex, season, or any of their interactions had a significant influence (variable retained and significant; $\alpha = 0.05$) on spotted turtle microhabitat selection. I used both Akaike's information criterion (AIC; Akaike 1974) and Bayesian Information Criterion (BIC; Schwarz 1978) backwards stepwise regressions on all proposed models, then compared the reduced models using AIC and BIC respectively, as well as log likelihood. AIC and BIC provide different information; AIC models generally retain more variables and offer better predictive power while BIC generally retains fewer variables as BIC assumes that there is a true model (Aho et al. 2014). BIC is best suited if we expect the model complexity to stabilize with an increasing n , consistency is of interest, and we have accurately determined all predictors that may impact microhabitat selection (Aho et al. 2014). As my analyses are exploratory and are unlikely to meet the aforementioned assumptions of BIC, AIC was theoretically more suited to my analyses. However, AIC's goal of increasing prediction accuracy may be undesirable in my study as my goal was not to determine all differences in selection but to

determine if significant, and biologically relevant, differences existed (Martínez-Abraín 2007); BIC offered an alternative perspective by presenting only the most important trends in selection. I used a Tukey post-hoc test (R package ‘emmeans’; Lenth 2022) as needed to further assess any detected differences in the best AIC and BIC models.

To describe selection of microhabitat by spotted turtles, I subdivided data by treatments, sexes, and/or seasons based on the model that best explained selection and fit these data using the best model. I then created a summary table with odds ratios for each set of subdivided data to qualitatively compare selection. Odds ratios (OR) are proportional to the unit-change (i.e., 1 %, 1 m...) and can therefore be examined across models fitted with different data (e.g., subsets), while coefficients could not be compared this way. Generally, odds ratios would be examined without subdividing data, but the use of reference categories during regressions (treatment: control, season: fall) resulted in interpretations of selection that were not biologically relevant (e.g., turtles selected plots with less continuous open water during the summer in Wind than during the fall in Control).

Availability: As habitat selection from paired logistic regressions is interpreted as a difference between available and used habitats (Compton et al. 2002), I assessed if available microhabitat differed among treatments and seasons to determine if selection could be compared without caveats. I pooled all turtle location plots (TP) and paired plots (PP) to represent all available habitat (1536 plots) then fit a separate generalized mixed effect model (GLMM) for each non-collinear microhabitat variable with treatment and season as fixed effects, and pairs (related TP and PP) and ‘day of year’ as a random effects. If treatment or season were significant predictors of availability, then a Tukey post-hoc test was conducted with R package ‘emmeans’ (Lenth 2022) to further examine differences. All microhabitat analyses were completed in RStudio (R Core Team, 2019).

Pilot year

The initial aim for my thesis was to have two field seasons (2020 and 2021) with 10 radio-tagged turtles per treatment. The official declaration of the COVID-19 pandemic on 11 March 2020 (WHO 2020) delayed permit acquisitions and field work commencement for the 2020 field season. Due to this delay, the cryptic nature of spotted turtles, and the nearly 12 000 ha study area with few confirmed spotted turtle habitat locations, not enough turtles were captured in the spring of 2020 which resulted in limited 2020 radio telemetry data. Therefore, the 2020 field season was deemed a pilot year and used to identify spotted turtle-occupied areas within the study area. In 2020, I outfitted a total of thirteen turtles ($n_{\text{Control}} = 2$ (1 ♀ / 1 ♂), $n_{\text{Wind}} = 4$ (3 ♀ / 1 ♂), $n_{\text{Windburn}} = 7$ (5 ♀ / 2 ♂)) with VHF radio transmitters (Model R1680, ATS, Isanti, MN). Due to the small and uneven sample sizes, only home range size (HR) and minimum daily distance moved (DDM) were calculated for 2020, though caution during interpretation was used as home ranges may be incomplete for some individuals (12-26 radiolocations per individual). Eleven turtles that were tracked in 2020 were also tracked in 2021. I compared HR and DDM among years and treatments using a type III two-way ANOVA ($\alpha = 0.05$) to account for the unequal number of turtles per treatment. Residuals were not normally distributed for home range size, so data were log transformed before proceeding to the ANOVA. HR and minimum DDM were calculated using package *adehabitat* (Calenge 2006) in RStudio (R Core Team, 2019). Statistical analyses were also conducted in RStudio (R Core Team, 2019).

Results

Body condition

Scaled mass index (SMI, Appendix D) did not differ among treatments (mean \pm SD (n)): C = 210 ± 16 g (10), W = 214 ± 29 g (8), WB = 205 ± 33 g (7), $F_{(2,19)} = 0.48$, $p = 0.63$). Females had

higher SMI than males in all treatments (mean \pm SD (n): ♀ = 229 \pm 25 g (15), ♂ = 188 \pm 22 g (10); $F_{(1,19)} = 25.99$ $p = 7.98e-05$) but the interaction between treatment and sex was not significant ($F_{(2,19)} = 1.61$, $p = 0.23$). One turtle in Wind and two turtles in Windburn were excluded prior to analyses due to missing limbs. Spotted turtles had a mean carapace length of 11.5 \pm 0.9 cm and an average body mass of 209 \pm 40 g. Females had significantly shorter carapace lengths than males (mean \pm SD (n): ♀ = 11.0 \pm 0.8 cm (15), ♂ = 12.1 \pm 0.7 cm (10); $F_{(1,23)} = 16.30$ $p < 0.001$) but body mass did not differ between sexes (mean \pm SD (n): ♀ = 205 \pm 42 g (15), ♂ = 213 \pm 38 g (10); $F_{(1,23)} = 0.73$ $p = 0.41$).

Home range size

Annual home range size (HR; Appendix E) did not differ significantly among treatments (mean \pm SD (n): C = 6.0 \pm 4.7 ha (10), W = 7.8 \pm 8.9 ha (9), WB = 9.0 \pm 6.5 ha (9); $F_{(2,22)} = 0.05$, $p = 0.95$) or between sexes (mean \pm SD (n): ♀ = 6.1 \pm 5.0 ha (13), ♂ = 9.8 \pm 8.4 ha (15); $F_{(1,22)} = 0.05$, $p = 0.83$) and the interaction of treatment and sex was not significant ($F_{(2,22)} = 0.58$, $p = 0.57$). Annual home range size for all turtles ranged from 0.4 ha to 23.9 ha with a mean of 7.5 ha.

Daily distance moved

Annual minimum daily distance moved (DDM; Appendix F) was not significantly different among treatments (mean \pm SD (n): C = 15.1 \pm 5.7 m/day (10), W = 13.8 \pm 5.9 m/day (9), WB = 15.0 \pm 6.6 m/day (9); $F_{(2,21)} = 1.51$, $p = 0.24$) or between sexes (mean \pm SD (n): ♀ = 13.3 \pm 5.8 m/day (13), ♂ = 16.7 \pm 5.8 m/day (15); $F_{(1,21)} = 0.52$, $p = 0.48$) but DDMs were significantly different among seasons in all treatments (mean \pm SD (n): spring = 21.3 \pm 12.4 m/day (27), summer = 17.6 \pm 8.5 m/day (28), fall = 4.8 \pm 4.2 m/day (28), $F_{(2,42)} = 38.38$, $p = 3.32e-10$). Pairwise tests indicated that minimum DDMs in the fall were significantly shorter than those in the spring

($p_{\text{adjusted}} = 1.79\text{e-}11$) and summer ($p_{\text{adjusted}} = 1.78\text{e-}09$). There were no significant interactions among treatment, sex, and season.

Avoidance of windfarm infrastructure

Spotted turtles did not avoid habitats near infrastructure (Appendix G). Turtle locations (TL) were not significantly further than random location (RL) from turbines in Wind (mean \pm SD (n): TL = 224 ± 108 m, RL = 220 ± 101 m; $X^2 = 0.01$, df = 1, $p = 0.91$) or Windburn (TL = 333 ± 143 m, RL = 355 ± 143 m; $X^2 = 3.57$, df = 1, $p = 0.06$). Turtle locations were also not significantly further from roads in Wind (TL = 115 ± 100 m, RL = 119 ± 95 m; $X^2 = 1.41$, df = 1, $p = 0.23$) or Windburn (TL = 269 ± 155 m, RL = 289 ± 157 m; $X^2 = 1.89$, df = 1, $p = 0.17$). Avoidance of habitats near infrastructure was also not detected when MCPs were used to constrain random locations instead of KDE.

No spotted turtles with or without radio transmitters were detected on roads during my two-year study; however, I directly observed 3 turtles with radio transmitters and 1 turtle without a radio transmitter using a semi aquatic 1-m-diameter corrugated metal pipe culvert (Appendix H) under a road, to move between wetlands. All three confirmed overwintering wetlands in Wind were less than 50 m from a road and were 45 m, 130 m, and 260 m away from a turbine, respectively. All confirmed overwintering wetlands in Wind were used equally by radiotelemetry turtles (3 turtles per wetland) regardless of distance to roads or turbines. Three of the four confirmed overwintering wetlands in Windburn were less than 100 m from a road and two of the four were less than 100 m from a turbine. The wetland in Windburn that was furthest from all infrastructure (400 m) did not appear to be used more frequently for overwintering (3 of 9 radio telemetry turtles) than the overwintering wetlands that were less than 100 m to infrastructure (6 of 9 radio telemetry turtles). All turtles tracked for two consecutive years showed fidelity to their

overwintering wetland except for one turtle in Windburn who overwintered in a different wetland in 2021 than it did in 2020. Both overwintering wetlands used by this individual were within 100 m of a turbine (87 m, 96 m) and 50 m of an access road (27 m, 42 m). All 4 confirmed spotted turtle nest locations in 2020 and 2021 were within 70 m of a road or turbine pad (10 m, 24 m, 44 m, 70 m) and all were within 250 m of a turbine (50 m, 150 m, 200 m, 250 m). No radiotelemetry turtles nested on the infrastructure footprint (roads, turbine pads); all gravid females nested on rock barrens.

Macrohabitat

Available macrohabitat did not differ significantly among treatments (model without treatment: $df = 8$, $AIC = -17.0$; model with treatment: $df = 10$, $AIC = -13.8$; LRT $p = 0.69$; Figure 1). I detected significant habitat selection at both the second and third orders in the Control and Wind, but only second order selection was significant in the Windburn (Table 4), though some individual habitat types were still significantly selected (Appendix I).

Second order macrohabitat selection was similar among treatments (Table 4). Fen was the habitat type most often included within individual home ranges in all three treatments. Rock barrens were the second most included habitat type in Control and Wind, but slightly less included in Windburn. Constructed habitat types were least included in both treatments where constructed habitats were present (Wind and Windburn).

Third order selection differed slightly among treatments (Table 4). Fens and meadow marshes were the top two used habitat types in all treatments with meadow marshes narrowly outranking fens in the Control and Wind sites. Rock barrens were the least used habitat type in Control and Wind with respectively only 1 and 2 radiolocations ($< 1\%$) occurring on rock barrens, but in Windburn, rock barrens ranked third with 18% of all Windburn radiolocations occurring on

rock barrens. Constructed habitats were not used in Windburn (0% of radiolocations) but were the third most used macrohabitat type in Wind in relation to the available area (though only 1% of radiolocations). All turtle locations within the constructed habitat type were recorded in culverts (3 radiolocations, see above); no radiolocations occurred on roads or turbine pads. Turtles in Wind also used powerline rights-of-way throughout the year (4 radiolocations).

Microhabitat

Availability: All non-colinear microhabitat variables except for temperature were statistically different among treatments and all variables except for cover were statistically different among seasons (Appendix J, Appendix K). Control (C) and Wind (W) had relatively similar available habitat to each other while Windburn (WB) had significantly different available habitat; however, differences among treatment means were often relatively small (Appendix L). Annually, Windburn had shallower water by 3.5 cm (mean \pm SD: C = 17 \pm 18 cm, W=16 \pm 15 cm, WB=13 \pm 17 cm), 15% less cover (mean \pm SD: C = 80 \pm 31 %, W = 81 \pm 33 %, WB=65 \pm 39 %;), 15% fewer plots with hummocks (percent of plots with hummocks present: C = 27 %, W = 26 %, WB = 13 %), and 10% fewer plots with continuous open water greater than 20 m² (percent of plots where continuous open water is more than 20 m²: C= 60 %, W= 66 %, WB= 50 %), noting that plots in Windburn were also 3 m closer to shore (mean \pm SD: C = 11 \pm 9 m, W = 10 \pm 7 m, WB = 7 \pm 6 m). For all variables that varied seasonally, fall was significantly different while summer and spring were relatively similar to each other except for temperature where spring and fall were similar, and summer was significantly different. The interaction of season and treatment was significant for temperature, cover, distance to shore, and dominant vegetation.

Selection: The addition of Turtle ID as a random slope for each habitat variable did not significantly improve the fit of the fixed model (AIC_{with random slope} = 12844; AIC_{without random slope} =

12841; LRT, $X^2 = 17.04$, $df = 10$, $p = 0.07$; Appendix B) so Turtle ID was not included in subsequent analyses. The nested model that best fit the data using AIC stepwise regression was the model with both season and treatment as interaction terms to microhabitat variables (AIC = 2766, $\Delta AIC = 6$; Appendix C) but a Tukey post-hoc test following the AIC model revealed that the only significant interaction including treatment was between Windburn, summer, and water connectivity ($p < 0.05$). The nested model that best fit the data using BIC stepwise regression was the model with only season as an interaction term to microhabitat variables (BIC = 2848, $\Delta BIC = 64$, Appendix C); treatment was an uninformative parameter in this case (Arnold 2010, Leroux 2019). In both the best AIC and BIC stepwise models, temperature, water depth, cover percent, and hummock presence were significant in distinguishing turtle location plots from paired plots regardless of season or treatment (Appendix M & Appendix N). Connectivity (continuous open water) and distance to shore were only retained in the AIC stepwise regression (Appendix M). Dominant vegetation type was not significant nor retained in either stepwise model.

To examine habitat selection, I subdivided data only by season and not by treatment based on the best fit model (BIC recommended, Appendix C). The odds ratios (OR) resulting from data subdivided by season (Table 5; Appendix O) reiterated that microhabitat selection varied seasonally for temperature and water depth (Appendix N). Turtles selected microhabitat plots with significantly warmer than available temperatures in the spring (mean TP= 19 °C, PP= 18 °C) and fall (but mean TP= 17 °C, PP= 17 °C), deeper than available water in the summer (mean TP= 22 cm, PP= 10 cm) and fall (mean TP= 16 cm, PP= 8 cm). Turtles preferred plots with hummocks year-round but only significantly selected plots with hummocks over plots without hummocks in the summer (mean TP= 20 %, PP= 11 %) and fall (mean TP= 64 %, PP= 22 %). Turtles also

selected habitats with more cover than what was available regardless of season (mean TP= 85 %, PP= 66 %).

Pilot year

Home range sizes in 2020 (n=13, 13-28 radiolocations per individual) did not differ among treatments (mean \pm SD (n): C = 5.9 \pm 3.1 ha (2), W = 4.1 \pm 5.8 ha (4), WB = 3.4 \pm 2.5 ha (7); $F_{(2,7)} = 0.73$, $p = 0.51$) or between sexes (mean \pm SD (n): ♀ = 4.1 \pm 4.0 ha (9), ♂ = 3.8 \pm 3.2 ha (4); $F_{(1,7)} = 0.31$, $p = 0.59$), and their interaction was not significant ($F_{(2,7)} = 1.41$, $p = 0.31$). Minimum daily distances moved in 2020 also did not differ among treatments (mean \pm SD (n): C = 9.3 \pm 1.1 m/day (2), W = 15.4 \pm 3.1 m/day (4), WB = 16.5 \pm 8.1 m/day (7); $F_{(2,7)} = 0.35$, $p = 0.72$) or between sexes (mean \pm SD (n): ♀ = 13.7 \pm 4.9 m/day (9), ♂ = 17.2 \pm 8.6 m/day (4); $F_{(1,7)} = 0.04$, $p = 0.86$) and their interaction was not significant ($F_{(2,7)} = 1.48$, $p = 0.29$). Not enough turtles were tracked year-round in 2020, so seasonal differences in DDMs could not be calculated and compared. Home range size (mean \pm SD (n): 2020 = 4.0 \pm 3.6 ha (13), 2021 = 7.5 \pm 6.7 ha (28)) and daily distance moved (mean \pm SD (n): 2020 = 15.0 \pm 6.4 m/day (13), 2021 = 14.7 \pm 5.9 m/day (28)) did not differ between years (HR: $F_{(1,35)} = 0.14$, $p = 0.70$, DDM: $F_{(1,35)} = 1.45$, $p = 0.24$) or among treatments (HR: $F_{(2,35)} = 0.67$, $p = 0.52$, DDM: $F_{(2,35)} = 1.04$, $p = 0.36$), and their interaction was not significant (HR: $F_{(2,35)} = 0.80$, $p = 0.45$, DDM: $F_{(2,35)} = 0.92$, $p = 0.41$; Appendix P).

Discussion

I found that body condition, home range size, and daily distance moved were not significantly different among treatments, and that turtles did not avoid habitats surrounding windfarm infrastructure, though they did not cross roads unless a culvert was present. Macrohabitat availability and selection were similar among treatments, but turtles in Windburn used rock barrens more frequently. Microhabitat availability differed statistically in Windburn compared to Wind

and Control, but differences were small and selection was similar among treatments with turtles selecting habitat based on temperature, water depth, available cover, and hummock presence with some seasonal influence on selection.

Body condition

My findings do not support my hypothesis that post-windfarm construction and post-wildfire landscapes may have reduced habitat quality and food resources resulting in lower body condition in the impacted treatments. Spotted turtles in Wind and Windburn were not in poorer body condition than turtles in Control. Females were in better condition than males in all three treatments and this could be attributable to differences in shell shape between the sexes, with females having a flat plastron allowing for more body mass, and males having a concave plastron allowing for less body mass, regardless of treatment. Spotted turtles have a varied diet but mostly feed on aquatic macroinvertebrates (Rasmussen et al. 2009, Environment and Climate Change Canada 2018). If windfarms and wildfires do not deleteriously impact aquatic invertebrate communities in wetlands, this could explain why I did not find lower body condition in the impacted sites (Wind and Windburn) compared to the Control site. The effects of windfarms on aquatic invertebrates are understudied, especially in wetlands. A Before-After-Control-Impact (BACI) study of an upland stream in Scotland found no effect of the construction of a windfarm on the invertebrate community structure 2 years post-construction, even though the water quality was negatively impacted by the construction runoff (Millidine et al. 2015). Previous studies (Hochkirch and Adorf 2007, Beganyi and Batzer 2011, Verkaik et al. 2015) examining the impacts of wildfires on aquatic invertebrates appear to converge on one theme: abundance of macroinvertebrates is unlikely to significantly change post-fire, but there may be effects on certain species and community composition. Spotted turtles consume a variety of aquatic macroinvertebrate species (Rasmussen

et al. 2009) and should therefore have an adequate food source regardless of shifting macroinvertebrate communities post-windfarm construction and post-wildfire. I recommend that future studies assess macroinvertebrate abundance and community at windfarm and wildfire impacted sites, especially in hilly terrain where wind energy development would result in higher rates of erosion (Wilshire and Prose 1987), to test this hypothesis.

Alternatively, it is possible that I did not detect differences in body condition among treatments because of limited sampling duration. A study of tuataras (*Sphenodon punctatus*), a long lived species, found that declining body condition within the population was only detectable after a minimum of 22 years of monitoring (Moore et al. 2007). My study approximated body condition based on only one measurement at emergence, but Moore et al. (2007) recommend at least 30 years of monitoring to detect overall trends in body condition for long lived organisms. It is also possible that it could take more time before the effects of the windfarm and wildfire negatively affect spotted turtle body condition. For example, a study of superb large fan-throated lizards (*Sarada superba*) on an established (16-20 years post-construction) windfarm in India found that the windfarm had lower predatory bird abundance, which increased lizard abundance, and resulted in a density dependent reduction of body condition for individual lizards (Thaker et al. 2018). My study was conducted 2.5 years post-fire and 2 years post windfarm construction, but cascading effects, like those in the Thaker et al. (2018), could take many years to be detected in the taxa of interest, as other taxa must first be impacted. Conversely, spotted turtle body condition could remain unimpacted in the long-term. Desert tortoises were found to have consistent body condition up to 15 years post fire on a California windfarm, though no pre-fire data exist (Lovich et al. 2011b). My study is part of a planned 5-year mark recapture study with the possibility of extension to 20 years. Revisiting the data at the end of the 20-year study and expanding the sample to include

all captured turtles over the 20 years could reveal trends in body condition that were not yet apparent in my dataset.

Home range size and daily distance moved

Spotted turtle spatial ecology was not different in the post-windfarm construction and post-wildfire sites compared to the control site. That is, I did not detect a significant effect of treatment on spotted turtle home range size (HR) or daily distance moved (DDM). I hypothesized that fragmentation of habitat due to windfarm infrastructure might restrict movements of turtles resulting in smaller home ranges and shorter DDMs on windfarm impacted sites, similarly to painted turtles on a Sault Ste. Marie (ON, Canada) windfarm (Trowbridge 2020), but my results do not support this. It is possible that the anticipated effects of fragmentation on the windfarm were mitigated by pre-construction planning at the windfarm. During the pre-construction phase, the windfarm decreased the number of turbines it planned to install (from 91 to 87 turbines) and instead installed turbines with larger rotor diameters (from 126 m rotor diameter to 136 m rotor diameter) maintaining the planned windfarm capacity of 300 MW (Reference redacted) but minimizing the permanent footprint as fewer turbine pads were built. Though the effects of larger turbines on wildlife requires further investigation, minimizing the permanent footprint may be a beneficial mitigation strategy, especially in areas with high biodiversity (Keehn and Feldman 2018) like my study site (Reference redacted). The installation of culverts to maintain connectivity where roads bisected wetlands also likely contributed to reducing the possible effects of fragmentation on turtle movements. A semi-aquatic corrugated metal pipe culvert in Wind (Appendix H) allowed turtles to move between wetlands that would have otherwise been fragmented by infrastructure. My results support the importance of pre-construction planning to reduce the impacts of windfarms on wildlife, but it is important to note that species specific effects

and habitat quality may also explain the lack of fragmentation impacts on movement of spotted turtles. Spotted turtles generally have smaller home ranges than other, more mobile semi-aquatic turtle species (e.g., Blanding's turtle: *Emydoidea blandingii*: HR size 10 ha to 60 ha; COSEWIC 2016) and my study site offers high quality habitat so it is important to consider that in a lower quality habitat or with a different study species, the impacts of fragmentation may have been more pronounced.

I hypothesized that the possible reduction of habitat quality and destruction of critical habitats (i.e., nesting, overwintering) during the windfarm construction and the wildfire might cause spotted turtles to have significantly larger home ranges and longer DDMs to access necessary resources. The time frame of my study likely explains why I did not observe these expected increases in movement patterns. Immediately post-wildfire and post-construction, turtles would likely need to engage in exploratory movements to find new suitable or critical habitats as habitat destruction or alteration would be most pronounced immediately post-impact, but 2 years post-construction and 2.5 years post-wildfire, turtles have likely already found new habitats and the habitat has had a chance to recover from the impacts, especially the wildfire (Watts and Kobziar 2015), possibly explaining the lack of differences in movement patterns among treatments in my study. I especially expected to see the increase in movement patterns in gravid females during the spring as the wildfire reduced the availability of nesting sites (Markle et al. 2020b). A future study should specifically focus on the impacts of wildfires on turtle nesting movements and energetic investment. It is also possible that fewer habitats were destroyed or altered post-construction and post-wildfire than I expected. Windfarm infrastructure was mostly built on rock barrens, avoiding wetlands except for occasional road crossings, and the wildfire generally spared wetlands with high water tables (ex: marshes, used for foraging) and with deep peat (ex: fens, used for

overwintering); this pre-construction planning and patchy burn could have reduced the expected impacts on spotted turtles. Based on these observations, the impacts of the windfarm and wildfire on critical habitats may have been insufficient to drive turtles to increase their HR or DDM in search of new critical habitat though they may exploit novel early successional habitats (see macrohabitat discussion).

My findings are consistent with the findings for desert tortoises on a California (US) windfarm where parts of the windfarm were burned by turbine-induced wildfires. Desert tortoise activity center sizes did not differ between a windfarm and wilderness area (Agha et al. 2015). Post-wildfire, the activity center of the tortoises on the windfarm remained similar despite the risk of lower quality habitat (Lovich et al. 2011*b*, 2018*a*), possibly indicating site fidelity. Spotted turtles are long-lived (max 110 years for females, 65 years for males; Litzgus 2006) and tend to exhibit home range and site fidelity (Litzgus and Mousseau 2004, Litzgus 2006, Buchanan et al. 2017) but spotted turtles can also shift their home ranges when habitat changes (Yagi and Litzgus 2012, Buchanan et al. 2017) or becomes inhabitable (O'Dell et al. 2021). A single year of data without a BACI design does not allow me to observe possible shifts in HR caused by windfarm construction and operation, hence the need for more BACI studies of windfarms (Agha et al. 2020).

Home range sizes and daily distances moved were similar in 2020 (pilot year) and 2021, and most of my calculated HR and DDM were similar to those of spotted turtles in other studies in Ontario, Canada (Litzgus 1996, Haxton and Berrill 1999, Rasmussen and Litzgus 2010, Yagi and Litzgus 2012). A few of my home range sizes are larger than generally reported in Ontario (0.4 ha – 10.9 ha) but similar to those of spotted turtles at more southern latitudes (Litzgus and Mousseau 2004, O'Bryan et al. 2016). There was no discernible trend in the distribution of larger home range sizes among treatments; two turtles in Control, two in Wind and three in Windburn had home

ranges greater than 11 ha, implying that treatment is unlikely to be responsible. Consistent with other studies on spotted turtles, I did not detect differences in HR or DDM between sexes (Litzgus 1996, Rasmussen and Litzgus 2010, Yagi and Litzgus 2012, O'Bryan et al. 2016), though a few other studies have found sex differences (Haxton and Berrill 1999, Litzgus and Mousseau 2004, O'Bryan et al. 2016). I found seasonal differences in minimum DDMs regardless of sex or treatment with fall having significantly shorter DDMs than spring and summer. Seasonal differences in movements patterns are well documented in the spotted turtle literature, though seasons are often defined slightly differently depending on the study. Generally, pre-nesting and nesting movements (spring) are longer than post-nesting movements (summer), and pre-overwintering (fall) has the shortest movements (Haxton and Berrill 2001, Litzgus and Mousseau 2004, Rasmussen and Litzgus 2010, O'Bryan et al. 2016).

Avoidance of windfarm infrastructure

Spotted turtles did not avoid habitats near infrastructure insofar that turtle locations (TL) were not further from turbines or roads than random location (RL); however, turtles were never observed or tracked on turbine pads or roads. I expected that turtles would avoid the habitats near turbines because of the noise, vibrations, and shadow flicker from turbine blades (Barber et al. 2010, Lovich and Ennen 2013, Zwart et al. 2016, Trowbridge and Litzgus 2022), as well as the possible changes to microclimate from turbine turbulence (Roy and Traiteur 2010, Zhou et al. 2012, Armstrong et al. 2016). Instead, turtles used habitats regardless of proximity to infrastructure, and turtles regularly basked in the shadow flicker of the turbine blades. Avoidance of turbines, or lack thereof, may be influenced by the mobility and ecology of a species. Birds have been documented avoiding windfarms during migrations (path deviations of up to 3 km;) and avoiding areas near turbines (generally 100 – 200 m, up to 800 m from a turbine) with the presence

and degree of avoidance largely depending on the species and study site (Drewitt and Langston 2006, Pearce-Higgins et al. 2009). Few studies (but see Rabin et al. 2006, Agha et al. 2017) have assessed avoidance of turbines by non-volant species; Lopucki et al. (2017) found that avoidance response was species-specific, likely related to species ecology. As mentioned previously, spotted turtles have relatively low mobility and often exhibit home range and overwintering site fidelity (Litzgus and Mousseau 2004, Litzgus 2006, Buchanan et al. 2017) but they can also shift their home ranges when habitat becomes unsuitable (Yagi and Litzgus 2012, Buchanan et al. 2017, O'Dell et al. 2021). It is unlikely that the expected impacts from turbines including temperature changes of up to 0.25°C when in proximity to a turbine (Armstrong et al. 2016) would be sufficient to deter turtles from using otherwise suitable habitats, likely explaining the observed lack of avoidance at my study site.

While I did not detect avoidance of habitats near roads, I did not observe any spotted turtles moving across a road at any time during my 2 years of study, even if suitable habitat existed on the other side. My findings are consistent with Seburn (2012) who reported that radio-tracked spotted turtles in Ontario came within 30 m of a paved road bisecting suitable habitat but never crossed the road. Paterson et al. (2019) also found that turtles (*Emydoidea blandingii*) did not avoid roads, yet they avoided road crossings. As previously mentioned, turtles in my study only crossed roads where culverts were present. Evidence of culvert use by spotted turtles and other semi-aquatic turtle species to move across roads has been well documented in the literature (Kaye et al. 2005, Markle et al. 2017, Heaven et al. 2019). If culvert presence is essential for spotted turtle habitat connectivity across roads, as observed in my study, then poor culvert planning during the pre-construction phase of a windfarm could exclude spotted turtles, and other turtle species, from

critical habitats, reiterating the importance of maintaining wetland connectivity using purpose-built semi-aquatic culverts (Woltz et al. 2008, Lovich et al. 2011a).

The only other study of semi-aquatic turtles on windfarms found conflicting evidence of avoidance of roads and turbines (Trowbridge 2020). Painted turtles appeared to avoid service roads on windfarms but turtles in the control site did not avoid municipal roads; the cause of this incongruity was unclear. Trowbridge (2020) observed painted turtles crossing roads at both the windfarm and control sites whereas I observed no road crossings by spotted turtles. This supports that different species have different tolerances to human-induced degradation (DeCatanzaro and Chow-Fraser 2010), including roads, so species-specific studies should be conducted, even though some mitigation measures like culverts are likely to benefit multiple species. Trowbridge (2020) did not find conclusive evidence of turtles avoiding turbines, as turtles at one turbine site showed avoidance while those at the other site did not. Trowbridge postulated that turtles at the site where no avoidance was detected may have been either far enough from turbines so turbines were not a significant disturbance, or that turtles were not able to avoid turbines due to the landscape disposition. The Wind site in my study was surrounded by turbines and roads, so it may have also not been possible for spotted turtles to avoid turbines while finding appropriate critical habitat. In contrast, the Windburn site offered more opportunities for movement away from roads and turbines, yet spotted turtles still did not display avoidance. One turtle used a different overwintering wetland in 2021 than in 2020 but both wetlands were similar distances from turbines and roads, so it is unlikely that this change was an effort by the individual to avoid infrastructure.

Macrohabitat

I detected significant habitat selection at the second and third orders by spotted turtles in all treatments, such that at least one habitat type was selected over another though the use of rock

barrens in Windburn likely resulted in weaker global selection within that treatment. Selection of the home range within the population range (second order) was similar among treatments but selection of locations within the home range (third order) was slightly different among treatments, offering partial support for my hypothesis. Rock barrens were frequently used by spotted turtles in the post-wildfire landscape (Windburn), but barrens were never used in Control or Wind except by gravid females for staging and nesting. Though a few rock barren radiolocations in Windburn were overland movements, most locations were in wet depressions (pools) on the rock barrens where spotted turtles spent time throughout the active season. These pools had variable hydroperiods with some fluctuating dramatically with rain events while others persisted through the year. The variable hydroperiods made mapping these features impossible for my study, but I estimate that the availability of these rock barren pools among treatments was similar. What differed among treatments was the vegetation structure, peat depth, and the amount of open standing water in these pools (Figure 2) which may explain the differences in use. Control and Wind pools were highly vegetated, sometimes had shallow peat accumulations, and had little or no free-standing water. In contrast, the Windburn rock barren pools had very little (<10 cm) to no organic substrate (directly on rock barren), had standing water generally less than 30 cm, and had sparse vegetation. Burned trees were common in and around the pools, and the increased openness of the Windburn pools is likely the result of the wildfire. Significant soil losses on rock barrens were documented post-wildfire (Markle et al. 2020b, Wilkinson et al. 2020). The destabilized shallow soils post-wildfire also resulted in burned trees falling over which resembled hurricane tip ups (uprooted trees following a hurricane). Spotted turtles prefer early successional habitats (Ernst 1967, Litzgus and Mousseau 2004, Buchanan et al. 2017) including hurricane tip ups (Litzgus and Mousseau 2004) and the natural disturbance caused by wildfires can help create or maintain early

successional habitats. Future studies should employ a BACI design to examine the impacts of wildfires on rock barren pools and determine support for the resulting altered macrohabitat selection. The selection of constructed habitats was also different among treatments, but this was solely attributable to differences in availability of sub-types of constructed habitats among treatments. Windburn only had roads and turbine pads as constructed habitat, which were never used by any turtles, while Wind also had culverts and powerlines which represented all of the radiolocations in the constructed habitat type.

My macrohabitat selection findings are similar to previously reported habitat selection by spotted turtles. Spotted turtles have been well documented in the literature using both fens and meadow marshes during the active season and crucially for overwintering (Haxton and Berrill 1999, Litzgus and Brooks 2000, Joyal et al. 2001, Milam and Melvin 2001, Rasmussen and Litzgus 2010). Marshes in my study were not highly ranked in any treatment, possibly because of water depth; spotted turtles tend to prefer shallower water (Ernst and Lovich 2009, Rasmussen and Litzgus 2010) which was better offered by other wetland types, though marshes offered suitable habitats during dryer months. The high degree of rock barren inclusion within home ranges across treatments is also supported in the literature, as spotted turtles often use a network of wetlands with upland habitats serving as travel corridors (Joyal et al. 2001, Milam and Melvin 2001). Turtles in my study used a network of wetlands though overland movements were only made in Windburn.

Microhabitat

Availability: Available microhabitat in Windburn differed statistically from microhabitat in Control and Wind while Control and Wind had very similar available microhabitat. I thought that the possible alteration of microclimate by turbines (Roy and Traiteur 2010, Zhou et al. 2012, Armstrong et al. 2016) would result in altered available habitat in the windfarm (Wind and

Windburn) compared to Control, but I did not detect such differences. If an impact was present, it may have been too small to detect (e.g., Armstrong et al. 2016 only found a differences of up to 0.25°C temperature in proximity to turbines) and whether such a small, predicted change in microclimate from wind turbines would be biologically relevant to an adult spotted turtle is unknown. The impacts of microhabitat alteration by operational wind turbines on turtles requires further investigation. Available microhabitat in Windburn had statistically shallower water, less cover, more plots with hummocks, fewer plots with continuous open water, and shorter distances to shore than Control and Wind. Wildfires can alter microhabitat conditions relevant to spotted turtles including thermal environments (Hossack et al. 2009, Elzer et al. 2013, Wagner et al. 2014, David et al. 2018), hydrological characteristics (Thompson and Waddington 2013, Kettridge et al. 2014, Niemeyer et al. 2020), and vegetation cover (Cochrane and Schulze 1999), though the direction and magnitude of these effects varies depending on landscape pre-wildfire and time since wildfire (Ireland and Petropoulos 2015, Watts and Kobziar 2015, Spence et al. 2020, Wolf et al. 2021). It is possible that the detected differences in microhabitat availability in Windburn were directly related to the wildfire and indicate that the wildfire had a more pronounced impact on the microhabitat than the windfarm, but pre-existing landscape differences and turtle macrohabitat use differences may also be responsible for these differences. Microhabitat plot locations were chosen based on the presence of a radio tracked turtle (TP) and the proximity (within 30 m and in the same macrohabitat) to a turtle (PP). This could introduce bias, as all locations were determined by turtles, and turtles showed variation in macrohabitat selection (see above). The increased selection of rock barren macrohabitats in Windburn could explain the shallower water, differences in dominant vegetation types, less cover, shorter distances to shore, less continuous open water, and fewer hummocks in Windburn, as barrens offered different microhabitats compared to wetlands.

Selection: I hypothesized that microhabitat selection would differ among treatments if the windfarm and wildfire had significant impacts on microhabitat availability. Contrary to my hypothesis, microhabitat selection was similar among treatments despite statistically significant differences in availability among treatments. As availability was similar in Control and Wind, the lack of differences in selection are expected, but selection did not differ in Windburn which is unexpected. Selection may have been similar because differences in available habitat in Windburn were too small to alter habitat selection of adult spotted turtles. I would only expect a statistically significant difference in habitat availability to impact selection if this difference was also biologically relevant. Boreal toads (*Bufo boreas*) were recorded preferentially using severely burned habitats over unburned and partially burned habitats (Guscio et al. 2008), as burned habitats offered warmer temperatures in all microhabitat types (1-3°C) and were more often within the preferred temperature range for the toads (Hossack et al. 2009). Though the difference in temperature was only 1-3 °C, this increased the thermal advantage of habitats resulting in increased selection. In my study, the small differences in availability detected in Windburn regarding water depth, cover, distance to shore, hummock presence, and water connectivity are unlikely to have significant implications for adult spotted turtle fitness or survival, so selection was similar among treatments.

My study took place 2.5 years post-wildfire and the expected impacts of wildfire on microclimate, like increased temperature, can be less pronounced as early as 2 years post-fire due to vegetation regeneration (Watts and Kobziar 2015). It is possible that if my study had taken place immediately post-wildfire, the acute impact on available habitat would have resulted in altered selection. Then again, it is possible that the wildfire, even immediately post-fire, would not have resulted in altered selection. Rock barren landscapes, like the one in my study, may be less

vulnerable to microclimate impacts of wildfires than cool-wet forests (Wolf et al. 2021) and wetlands, where spotted turtles spend time year-round, may be less vulnerable to wildfire than other landscape types due to the higher water table (Wilkinson et al. 2020). I recommend that future studies use static habitat plot monitoring in a BACI context to assess the impacts of wildfires and windfarms on habitat availability in tandem with habitat selection studies to better understand the biologically relevant impacts of wildfires and windfarms on animals.

Spotted turtles displayed seasonal variation in microhabitat selection. Few other studies have quantitatively compared seasonal shifts in microhabitat variables for spotted turtles (but see Litzgus and Brooks 2000), though shifts in macrohabitat selection have been widely recognized (Litzgus and Brooks 2000, Haxton and Berrill 2001, Milam and Melvin 2001, Litzgus and Mousseau 2004, Rasmussen and Litzgus 2010, Yagi and Litzgus 2012). Observed seasonal shifts in selection for temperature and water depth may be related to seasonally limiting factors. Spotted turtles selected warmer than available temperatures in the spring and fall when available temperatures were cooler, likely as turtles needed to achieve minimum body temperatures to engage in activities like mating and foraging (Ernst 1982, Litzgus and Brooks 2000). Deeper than available, but still shallow water, was selected in the summer and fall when water depths were shallower and may have been limiting as spotted turtles forage and mate aquatically (Ernst 1967, 1976). Hummocks offer cover and thermoregulatory opportunities (i.e., aestivation and basking locations; Haxton and Berrill 2001) for spotted turtles throughout the year and also provide suitable overwintering habitat for spotted turtles (Haxton and Berrill 1999, Litzgus et al. 1999, Markle et al. 2020a; this study). Turtles also selected plots with more cover year-round which supports that spotted turtles select habitat based on predator avoidance (Ward et al. 1976), as their small body size makes them vulnerable to depredation (Tucker et al. 1999) even as adults. Similarly to my

study, Rasmussen and Litzgus (2010) and O'Bryan et al. (2016) found that spotted turtles selected warmer temperatures, shallow water, and high cover availability in non-windfarm or wildfire contexts, further supporting that the impacts of the post-construction windfarm and post-wildfire landscape on microhabitat selection may be negligible, but further studies are needed to determine if this is the case immediately post-impact and in the long term.

Conclusion

The goal of my study was to assess the impacts of a post-construction windfarm and a wildfire on a semi-aquatic turtle species. I did not detect any significant effects of the windfarm on the body condition, spatial ecology, or habitat selection of spotted turtles. I found support for mitigation measures like culverts to maintain habitat connectivity, but more research is required to determine if any negative population or reproductive effects exist on windfarms at all stages of operation (i.e., construction, post-construction, decommissioning). The combined windfarm and post-wildfire impact (Windburn) did not appear to impact body condition, spatial ecology, or microhabitat selection of spotted turtles but macrohabitat selection differed slightly. Wet depressions on rock barrens were only used by turtles in Windburn, which may indicate that turtles preferred the early successional habitats created by wildfire but, a before-after-control-impact (BACI) study would be required to test this hypothesis. My study is one of the first to assess the impacts of windfarms on freshwater turtles, an at-risk (Lovich et al. 2018b, Stanford et al. 2020) and understudied group on windfarms, but more research is required to understand the immediate and long-term impacts of windfarm construction and wildfire on turtles to inform data-driven mitigation strategies.

Literature cited

- Aebischer, N. J., P. A. Robertson, and R. E. Kenward. 1993. Compositional analysis of habitat use from animal radio-tracking data. *Ecology* 74:1313–1325.
- Agha, M., J. E. Lovich, J. R. Ennen, B. Augustine, T. R. Arundel, M. O. Murphy, K. Meyer-Wilkins, C. D. Bjurlin, D. K. Delaney, J. Briggs, M. Austin, S. V Madrak, and S. J. Price. 2015. Turbines and terrestrial vertebrates: variation in tortoise survivorship between a wind energy facility and an adjacent undisturbed wildland area in the desert southwest (USA). *Environmental Management* 56:332–341.
- Agha, M., J. E. Lovich, J. R. Ennen, and B. D. Todd. 2020. Wind, sun, and wildlife: Do wind and solar energy development “short-circuit” conservation in the western United States? *Environmental Research Letters* 15.
- Agha, M., A. L. Smith, J. E. Lovich, D. Delaney, J. R. Ennen, J. Briggs, L. J. Fleckenstein, L. A. Tennant, S. R. Puffer, A. Walde, T. R. Arundel, S. J. Price, and B. D. Todd. 2017. Mammalian mesocarnivore visitation at tortoise burrows in a wind farm. *Journal of Wildlife Management* 81:1117–1124.
- Aho, K., D. Derryberry, and T. Peterson. 2014. Model selection for ecologists : the worldviews of AIC and BIC. *Ecology* 95:631–636.
- Akaike, H. 1974. A new look at the statistical model identification. *IEEE Transactions on Automatic Control* 19:716–723.
- Allison, T. D., J. E. Diffendorfer, E. F. Baerwald, J. A. Beston, D. Drake, A. M. Hale, C. D. Hein, M. M. Huso, S. R. Loss, J. E. Lovich, M. D. Strickland, K. A. Williams, and V. L. Winder. 2019. Impacts to wildlife of wind energy siting and operation in the United States. *Issues in Ecology* 2019:1–23.
- Armstrong, A., R. R. Burton, S. E. Lee, S. Mobbs, N. Ostle, V. Smith, S. Waldron, and J. Whitaker. 2016. Ground-level climate at a peatland wind farm in Scotland is affected by wind turbine operation. *Environmental Research Letters* 11:044024.
- Arnold, T. W. 2010. Uninformative parameters and model selection using Akaike’s Information Criterion. *Journal of Wildlife Management* 74:1175–1178.
- Banton, E., H. Lee, G. Racey, P. Uhlig, and M. Wester. 2008. *Ecosystems of Ontario: Provincial Ecosites*.
- Barber, J. R., K. R. Crooks, and K. M. Fristrup. 2010. The costs of chronic noise exposure for terrestrial organisms. *Trends in Ecology and Evolution* 25:180–189.
- Beganyi, S. R., and D. P. Batzer. 2011. Wildfire induced changes in aquatic invertebrate communities and mercury bioaccumulation in the Okefenokee Swamp. *Hydrobiologia* 669:237–247.

- Buchanan, S. W., B. Buffum, and N. E. Karraker. 2017. Responses of a Spotted Turtle (*Clemmys guttata*) population to creation of early-successional habitat. *Herpetological Conservation and Biology* 12:688–700.
- Cagle, F. R. 1939. A system of marking turtles for future identification. *Copeia* 1939:170–173.
- Calenge, C. 2006. The package “adehabitat” for the R software: A tool for the analysis of space and habitat use by animals. *Ecological Modelling* 197:516–519.
- Cochrane, M. A., and M. D. Schulze. 1999. Fire as a recurrent event in tropical forests of the eastern Amazon: Effects on forest structure, biomass, and species composition. *Biotropica* 31:2–16.
- Compton, B. W., J. M. Rhymer, and M. McCollough. 2002. Habitat selection by Wood turtles (*Clemmys insculpta*): an application of paired logistic regression. *Ecology* 83:833–843.
- COSEWIC. 2014. COSEWIC assessment and status report on the Spotted Turtle *Clemmys guttata* in Canada. Ottawa. <www.sararegistry.gc.ca/status/status_e.cfm>.
- David, A. T., J. E. Asarian, and F. K. Lake. 2018. Wildfire smoke cools summer river and stream water temperatures. *Water Resources Research* 54:7273–7290.
- DeCatanzaro, R., and P. Chow-Fraser. 2010. Relationship of road density and marsh condition to turtle assemblage characteristics in the Laurentian Great Lakes. *Journal of Great Lakes Research* 36:357–365.
- Diffendorfer, J. E., M. A. Dorning, J. R. Keen, L. A. Kramer, and R. V Taylor. 2019. Geographic context affects the landscape change and fragmentation caused by wind energy facilities. *PeerJ* 7:1–23.
- Drewitt, A. L., and R. H. Langston. 2006. Assessing the impacts of wind farms on birds. *Ibis* 148:29–42.
- Duchesne, T., D. Fortin, and N. Courbin. 2010. Mixed conditional logistic regression for habitat selection studies. *Journal of Animal Ecology* 79:548–555.
- Elzer, A. L., D. A. Pike, J. K. Webb, K. Hammill, R. A. Bradstock, and R. Shine. 2013. Forest-fire regimes affect thermoregulatory opportunities for terrestrial ectotherms. *Austral Ecology* 38:190–198.
- Environment and Climate Change Canada. 2018. Recovery Strategy for the Spotted Turtle (*Clemmys guttata*) in Canada. Species at Risk Act Recovery Strategy Series. Ottawa. <<https://www.canada.ca/en/environment-climate-change/services/species-risk-public-registry/recovery-strategies/spotted-turtle-2018.html#toc7>>.
- Ernst, C. H. 1967. A mating aggregation of the turtle *Clemmys guttata*. *Copeia* 1967:473–474.
- Ernst, C. H. 1976. Ecology of the Spotted turtle, *Clemmys guttata* (Reptilia, Testudines,

- Testudinidae), in Southeastern Pennsylvania. *Journal of Herpetology* 10:25–33.
- Ernst, C. H. 1982. Environmental temperatures and activities in wild spotted turtles, *Clemmys guttata*. *Journal of Herpetology* 16:112–120.
- Ernst, C. H., and J. E. Lovich. 2009. *Turtles of the United States and Canada*. Second Edi. The John Hopkins University Press, Baltimore.
- Evans, A., V. Strezov, and T. J. Evans. 2009. Assessment of sustainability indicators for renewable energy technologies. *Renewable and Sustainable Energy Reviews* 13:1082–1088.
- Ferrari, S. L. P., and F. Cribari-Neto. 2004. Beta regression for modelling rates and proportions. *Journal of Applied Statistics* 31:799–815.
- Guscio, C. G., B. R. Hossack, L. A. Eby, and P. S. Corn. 2008. Post-breeding habitat use by adult boreal toads (*Bufo boreas*) after wildfire in Glacier National Park, USA. *Herpetological Conservation and Biology* 3:55–62.
- GWEC. 2019. Global wind report 2018. Brussels. <<https://gwec.net/global-wind-report-2018>>.
- Haxton, T., and M. Berrill. 1999. Habitat selectivity of *Clemmys guttata* in central Ontario. *Canadian Journal of Zoology* 77:593–599.
- Haxton, T., and M. Berrill. 2001. Seasonal activity of spotted turtles (*Clemmys guttata*) at the northern limit of their range. *Journal of Herpetology* 35:606–614.
- Hayes, M. A. 2013. Bats killed in large numbers at United States wind energy facilities. *BioScience* 63:975–979.
- Hayne, D. W. 1949. Calculation of size of home range. *Journal of Mammalogy* 30:18. Oxford University Press (OUP).
- Heaven, P. C., J. D. Litzgus, and M. T. Tinker. 2019. A Unique Barrier Wall and Underpass to Reduce Road Mortality of Three Freshwater Turtle Species. *Copeia* 107:92–99.
- Hochkirch, A., and F. Adorf. 2007. Effects of prescribed burning and wildfires on Orthoptera in Central European peat bogs. *Environmental Conservation* 34:225–235.
- Hossack, B. R., L. A. Eby, C. G. Guscio, and P. S. Corn. 2009. Thermal characteristics of amphibian microhabitats in a fire-disturbed landscape. *Forest Ecology and Management* 258:1414–1421.
- Ireland, G., and G. P. Petropoulos. 2015. Exploring the relationships between post-fire vegetation regeneration dynamics, topography and burn severity: A case study from the Montane Cordillera Ecozones of Western Canada. *Applied Geography* 56:232–248.
- IRENA. 2020. Renewable capacity statistics 2020. Abu Dhabi. <<https://www.irena.org/publications/2020/Mar/Renewable-Capacity-Statistics-2020>>.

- Johnson, D. H. 1980. The comparison of usage and availability measurements for evaluating resource preference. *Ecology* 61:65–71.
- Joyal, L. A., M. McCollough, and M. L. Hunter. 2001. Landscape ecology approaches to wetland species conservation: a case study of two Turtle species in southern Maine. *Conservation Biology* 15:1755–1762.
- Kaye, D. R. J., K. M. Walsh, E. L. Rulison, and C. C. Ross. 2005. Spotted turtle use of a culvert under relocated Route 44 in Carver, Massachusetts. Pages 426–432 *in*. Proceedings of the 2005 International Conference on Ecology and Transportation. Center for Transportation and the Environment, North Carolina State University, Raleigh, NC. <<https://escholarship.org/uc/item/0qz725t8>>.
- Keehn, J. E., and C. R. Feldman. 2018. Disturbance affects biotic community composition at desert wind farms. *Wildlife Research* 45:383–396.
- Kettridge, N., R. E. Humphrey, J. Smith, M. C. Lukenbach, K. J. Devito, R. M. Petrone, and J. M. Waddington. 2014. Burned and unburned peat water repellency: Implications for peatland evaporation following wildfire. *Journal of Hydrology* 513:335–341.
- Kuvlesky, W. P., L. A. Brennan, M. L. Morrison, K. K. Boydston, B. M. Ballard, and F. C. Bryant. 2007. Wind energy development and wildlife conservation: challenges and opportunities. *Journal of Wildlife Management* 71:2487–2498.
- Laverty, J. F., B. Korol, and J. D. Litzgus. 2016. Measuring the effects of water-based recreation on the spatial ecology of Eastern Musk Turtles (*Sternotherus odoratus*) in a provincial park in Ontario, Canada. *Copeia* 104:440–447.
- Lenth, R. V. 2022. “emmeans”: Estimated Marginal Means, aka Least-Squares Means. R package version 1.7.2.
- Leroux, S. J. 2019. On the prevalence of uninformative parameters in statistical models applying model selection in applied ecology. *PLoS ONE* 14:1–12.
- Litzgus, J. D. 1996. (Thesis) Life-history and demography of a northern population of Spotted turtles, *Clemmys Guttata*. University of Guelph.
- Litzgus, J. D. 2006. Sex differences in longevity in the spotted turtle (*Clemmys guttata*). *Copeia* 2006:281–288.
- Litzgus, J. D., and R. J. Brooks. 2000. Habitat and temperature selection of *Clemmys guttata* in a northern population. *Journal of Herpetology* 34:178–185.
- Litzgus, J. D., J. P. Costanzo, R. J. Brooks, and R. E. J. Lee. 1999. Phenology and ecology of hibernation in spotted turtles (*Clemmys guttata*) near the northern limit of their range. *Canadian Journal of Zoology* 77:1348–1357.
- Litzgus, J. D., and T. A. Mousseau. 2004. Home range and seasonal activity of southern spotted

- turtles (*Clemmys Guttata*): Implications for management. *Copeia* 2004:804–817.
- Łopucki, R., D. Klich, and S. Gielarek. 2017. Do terrestrial animals avoid areas close to turbines in functioning wind farms in agricultural landscapes? *Environmental Monitoring and Assessment* 189.
- Lovich, J. E., M. Agha, J. R. Ennen, T. R. Arundel, and M. Austin. 2018a. Agassiz's desert tortoise (*Gopherus agassizii*) activity areas are little changed after wind turbine induced fires in California. *International Journal of Wildland Fire* 27:856.
- Lovich, J. E., and J. R. Ennen. 2013. Assessing the state of knowledge of utility-scale wind energy development and operation on non-volant terrestrial and marine wildlife. *Applied Energy* 103:52–60.
- Lovich, J. E., J. R. Ennen, M. Agha, and J. W. Gibbons. 2018b. Where have all the turtles gone, and why does it matter? *BioScience* 68:771–781.
- Lovich, J. E., J. R. Ennen, S. Madrak, and B. Grover. 2011a. Turtles and culverts, and alternative energy development: An unreported but potentially significant mortality threat to the desert tortoise (*Gopherus agassizii*). *Chelonian Conservation and Biology* 10:124–129.
- Lovich, J. E., J. R. Ennen, S. V Madrak, C. L. Loughran, K. P. Meyer, T. R. Arundel, and C. D. Bjurlin. 2011b. Long-term post-fire effects on spatial ecology and reproductive output of female Agassiz's desert tortoises (*Gopherus agassizii*) at a wind energy facility near Palm Springs, California, USA. *Fire Ecology* 7:75–87.
- Lovich, J. E., J. R. Ennen, S. V Madrak, K. P. Meyer, C. L. Loughran, C. D. Bjurlin, T. R. Arundel, W. Turner, C. Jones, and G. Groenendaal. 2011c. Effects of wind energy production on growth, demography, and survivorship of a desert tortoise (*Gopherus agassizii*) population in Southern California with comparisons to natural populations. *Herpetological Conservation and Biology* 6:161–174.
- Lowe, A. J., A. K. Smyth, K. Atkins, R. Avery, L. Belbin, N. Brown, A. E. Budden, P. Gioia, S. Guru, M. Hardie, T. Hirsch, D. Hobern, J. La Salle, S. R. Loarie, M. Miles, D. Milne, M. Nicholls, M. Rossetto, J. Smits, B. Sparrow, G. Terrill, D. Turner, and G. M. Wardle. 2017. Publish openly but responsibly. *Science* 357:141–142.
- Markle, C. E., S. D. Gillingwater, R. Levick, and P. Chow-Fraser. 2017. The true cost of partial fencing: Evaluating strategies to reduce reptile road mortality. *Wildlife Society Bulletin* 41:342–350.
- Markle, C. E., P. A. Moore, and J. M. Waddington. 2020a. Primary drivers of reptile overwintering habitat suitability: Integrating wetland ecohydrology and spatial complexity. *BioScience* 70:597–609.
- Markle, C. E., S. L. Wilkinson, and J. M. Waddington. 2020b. Initial effects of wildfire on freshwater turtle nesting habitat. *The Journal of Wildlife Management* 84:1373–1383.

- Martínez-Abraín, A. 2007. Are there any differences? A non-sensical question in ecology. *Acta Oecologica* 32:203–206.
- Milam, J. C., and S. M. Melvin. 2001. Density, habitat use, movements, and conservation of Spotted Turtles (*Clemmys guttata*) in Massachusetts. *Society for the Study of Amphibians and Reptiles* 35:418–427.
- Millidine, K. J., I. A. Malcolm, A. McCartney, R. Laughton, C. N. Gibbins, and R. J. Fryer. 2015. The influence of wind farm development on the hydrochemistry and ecology of an upland stream. *Environmental Monitoring and Assessment* 187:518.
- Moore, J. A., J. M. Hoare, C. H. Daugherty, and N. J. Nelson. 2007. Waiting reveals waning weight: Monitoring over 54 years shows a decline in body condition of a long-lived reptile (tuatara, *Sphenodon punctatus*). *Biological Conservation* 135:181–188.
- Muff, S., J. Signer, and J. Fieberg. 2020. Accounting for individual-specific variation in habitat-selection studies: Efficient estimation of mixed-effects models using Bayesian or frequentist computation. *Journal of Animal Ecology* 89:80–92.
- Niemeyer, R. J., K. D. Bladon, and R. D. Woodsmith. 2020. Long-term hydrologic recovery after wildfire and post-fire forest management in the interior Pacific Northwest. *Hydrological Processes* 34:1182–1197.
- North, M. P., and J. H. Reynolds. 1996. Microhabitat analysis using radiotelemetry locations and polytomous logistic regression. *The Journal of Wildlife Management* 60:639–653.
- O’Bryan, C. J., J. A. Homyack, R. F. Baldwin, Y. Kanno, and A. L. Harrison. 2016. Novel habitat use supports population maintenance in a reconfigured landscape. *Ecosphere* 7:e01228.
- O’Dell, D. I., J. M. Karberg, K. C. Beattie, K. A. Omand, and E. C. Buck. 2021. Changes to spotted turtle (*Clemmys guttata*) habitat selection in response to a salt marsh restoration. *Wetlands Ecology and Management* 29:301–313.
- Paterson, J. E., J. Baxter-Gilbert, F. Beaudry, S. Carstairs, P. Chow-Fraser, C. B. Edge, A. M. Lentini, J. D. Litzgus, C. E. Markle, K. McKeown, J. A. Moore, J. M. Refsnider, J. L. Riley, J. D. Rouse, D. C. Seburn, J. R. Zimmerling, and C. M. Davy. 2019. Road avoidance and its energetic consequences for reptiles. *Ecology and Evolution* 9:9794–9803.
- Pearce-Higgins, J. W., L. Stephen, R. H. W. Langston, I. P. Bainbridge, and R. Bullman. 2009. The distribution of breeding birds around upland wind farms. *Journal of Applied Ecology* 46:1323–1331.
- Peig, J., and A. J. Green. 2009. New perspectives for estimating body condition from mass/length data: The scaled mass index as an alternative method. *Oikos* 118:1883–1891.
- Rabin, L. A., R. G. Coss, and D. H. Owings. 2006. The effects of wind turbines on antipredator behavior in California ground squirrels (*Spermophilus beecheyi*). *Biological Conservation*

131:410–420. Elsevier.

- Rasmussen, M. L., and J. D. Litzgus. 2010. Habitat selection and movement patterns of spotted turtles (*Clemmys guttata*): Effects of spatial and temporal scales of analyses. *Copeia* 2010:86–96.
- Rasmussen, M. L., J. E. Paterson, and J. D. Litzgus. 2009. Foraging ecology of spotted turtles (*Clemmys guttata*) in Ontario, Canada. *Herpetological Review* 40:286–288.
- Row, J. R., and G. Blouin-Demers. 2006. Kernels are not accurate estimators of home-range size for herpetofauna. *Copeia* 2006:797–802.
- Roy, S. B., and J. J. Traiteur. 2010. Impacts of wind farms on surface air temperatures. *Proceedings of the National Academy of Sciences of the United States of America* 107:17899–17904.
- Schwarz, G. 1978. Estimating the dimension of a model. *The Annals of Statistics* 6:461–464.
- Seburn, D. C. 2012. Why didn't the Spotted Turtle (*Clemmys guttata*) cross the road? *Herpetology Notes* 5:527–530.
- Smallwood, K. S. 2013. Comparing bird and bat fatality-rate estimates among North American wind-energy projects. *Wildlife Society Bulletin* 37:19–33.
- Sovacool, B. K. 2013. The avian benefits of wind energy : A 2009 update. *Renewable Energy* 49:19–24.
- Spence, C., N. Hedstrom, S. E. Tank, W. L. Quinton, D. Olefeldt, S. Goodman, and N. Dion. 2020. Hydrological resilience to forest fire in the subarctic Canadian shield. *Hydrological Processes* 34:4940–4958.
- Stanford, C. B., J. B. Iverson, A. G. J. Rhodin, P. Paul van Dijk, R. A. Mittermeier, G. Kuchling, K. H. Berry, A. Bertolero, K. A. Bjorndal, T. E. G. Blanck, K. A. Buhlmann, R. L. Burke, J. D. Congdon, T. Diagne, T. Edwards, C. C. Eisemberg, J. R. Ennen, G. Forero-Medina, M. G. Frankel, U. Fritz, N. Gallego-García, A. Georges, J. W. Gibbons, S. Gong, E. V Goode, H. T. Shi, H. Hoang, M. D. Hofmeyr, B. D. Horne, R. Hudson, J. O. Juvik, A. R. Kiester, P. Koval, M. Le, P. V Lindeman, J. E. Lovich, L. Luiselli, T. E. M. McCormack, G. A. Meyer, V. P. Páez, K. Platt, S. G. Platt, P. C. H. Pritchard, H. R. Quinn, W. M. Roosenburg, J. A. Seminoff, H. B. Shaffer, R. Spencer, J. U. Van Dyke, R. C. Vogt, and A. D. Walde. 2020. Turtles and tortoises are in trouble. *Current Biology* 30:R721–R735.
- Stasinopoulos, D. M., and R. A. Rigby. 2007. Generalized Additive Models for Location Scale and Shape (GAMLSS) in R. *Journal of Statistical Software* 23:1–46.
- Thaker, M., A. Zambre, and H. Bhosale. 2018. Wind farms have cascading impacts on ecosystems across trophic levels. *Nature Ecology and Evolution* 2:1854–1858. <<https://www.nature.com/articles/s41559-018-0707-z>>. Accessed 16 Oct 2020.

- Thompson, D. K., and J. M. Waddington. 2013. Peat properties and water retention in boreal forested peatlands subject to wildfire. *Water Resources Research* 49:3651–3658.
- Trowbridge, C. 2020. Herps in the wind: The ecology of herpetofauna in windfarms. Laurentian University, Sudbury, ON.
- Trowbridge, C. M., and J. D. Litzgus. 2022. Wind farms alter amphibian community diversity and chorusing behavior. *Herpetologica* 78:75–85.
- Tucker, J. K., N. I. Filoramo, and F. J. Janzen. 1999. Notes and discussion: Size-biased mortality due to predation in a nesting freshwater turtle, *Trachemys scripta*. *American Midland Naturalist* 141:198–203.
- Verkaik, I., M. Vila-Escalé, M. Rieradevall, C. V Baxter, P. S. Lake, G. W. Minshall, P. Reich, and N. Prat. 2015. Stream macroinvertebrate community responses to fire: Are they the same in different fire-prone biogeographic regions? *Freshwater Science* 34:1527–1541.
- Wagner, M. J., K. D. Bladon, U. Silins, C. H. S. Williams, A. M. Martens, S. Boon, R. J. MacDonald, M. Stone, M. B. Emelko, and A. Anderson. 2014. Catchment-scale stream temperature response to land disturbance by wildfire governed by surface-subsurface energy exchange and atmospheric controls. *Journal of Hydrology* 517:328–338.
- Wang, Shifeng, and Sicong Wang. 2015. Impacts of wind energy on environment: A review. *Renewable and Sustainable Energy Reviews* 49:437–443.
- Ward, F. P., C. J. Hohmann, J. F. Ulrich, and S. E. Hill. 1976. Seasonal microhabitat selections of spotted turtles (*Clemmys guttata*) in Maryland elucidated by radioisotope tracking. *Herpetologica* 32:60–64.
- Watts, A. C., and L. N. Kobziar. 2015. Hydrology and fire regulate edge influence on microclimate in wetland forest patches. *Freshwater Science* 34:1383–1393.
- Wester, M., P. Uhlig, W. Bakowsky, and E. Banton. 2011. Great Lakes-St.Laurence ecosite fact sheets.
- WHO. 2020. WHO Director-General’s opening remarks at the media briefing on COVID-19 - 11 March 2020. WHO Director General’s speeches. <<https://www.who.int/director-general/speeches/detail/who-director-general-s-opening-remarks-at-the-media-briefing-on-covid-19---11-march-2020>%0Ahttps://www.who.int/dg/speeches/detail/who-director-general-s-opening-remarks-at-the-media-briefing-on-covid-19>. Accessed 10 Apr 2022.
- Wilkinson, S. L., A. M. Tekatch, C. E. Markle, P. A. Moore, and J. M. Waddington. 2020. Shallow peat is most vulnerable to high peat burn severity during wildfire. *Environmental Research Letters* 15:104032.
- Wilshire, H., and D. Prose. 1987. Wind energy development in California, USA. *Environmental Management* 11:13–20.

- Wolf, K. D., P. E. Higuera, K. T. Davis, and S. Z. Dobrowski. 2021. Wildfire impacts on forest microclimate vary with biophysical context. *Ecosphere* 12:e03467.
- Woltz, H. W., J. P. Gibbs, and P. K. Ducey. 2008. Road crossing structures for amphibians and reptiles: Informing design through behavioral analysis. *Biological Conservation* 141:2745–2750.
- Worton, B. J. 1989. Kernel methods for estimating the utilization distribution in home-range studies. *Ecology* 70:164–168.
- Yagi, K. T., and J. D. Litzgus. 2012. The effects of flooding on the spatial ecology of spotted turtles (*Clemmys guttata*) in a partially mined peatland. *Copeia* 2012:179–190.
- Zagorski, G. M., D. R. Boreham, and J. D. Litzgus. 2019. Endangered species protection and evidence-based decision-making: Case study of a quarry proposal in endangered turtle habitat. *Global Ecology and Conservation* 20:e00751.
- Zhou, L., Y. Tian, S. B. Roy, C. Thorncroft, L. F. Bosart, and Y. Hu. 2012. Impacts of wind farms on land surface temperature. *Nature Climate Change* 2:539–543.
- Zwart, M. C., J. C. Dunn, P. J. K. McGowan, and M. J. Whittingham. 2016. Wind farm noise suppresses territorial defense behavior in a songbird. *Behavioral Ecology* 27:101–108.

General Conclusion

Limitations of study

My study explored differences in body condition, spatial ecology, and habitat selection by spotted turtles in relatively pristine, windfarm, and wildfire landscapes. I did not detect any differences among treatments except for increased use of rock barren habitats in the combined wildfire and windfarm-impacted landscape (Windburn), but there are some limitations to my conclusions. First, my study was a post-hoc design with space as replacement for time which can be effective in detecting differences but using a before-after-control-impact (BACI) design is crucial to establish causal relationships between impacts and wildlife. A BACI design would also allow control over landscape differences which would have been beneficial in my study of spatial ecology and habitat selection. Additionally, my study did not have site replicates within treatments, resulting in uncertainty when distinguishing site variation from treatment variation. Site replication and an addition of a burn only treatment would have been ideal, but the realities of radiotelemetry are that it is very resource intensive (person-hours and money), and this was simply not logistically possible. Moreover, the sample sizes in my study were relatively small (n=28), though I believe that 9-10 spotted turtles per treatment was a representative sample of individuals at each site. Species-at-risk research, especially research involving telemetry, is often published with relatively few individuals (Joyal et al. 2001, Milam and Melvin 2001, Litzgus and Mousseau 2004, Rasmussen and Litzgus 2010, Yagi and Litzgus 2012, Angoh et al. 2021), as telemetry provides crucial evidence-based movement and habitat use data that can inform conservation even with relatively few individuals. Finally, my study took place post windfarm construction, 2.5 years post wildfire, and spanned only 2 years. The timeframe may have been insufficient to detect immediate (during windfarm construction and immediately post-wildfire) and long-term impacts. I

recommend that other studies aim for immediate and long-term monitoring of impacts on wildlife and that my study be repeated in 5 – 10 years to explore the long-term impacts of windfarms on long-lived spotted turtles.

My study fills a gap in knowledge about the spatial ecology of semi-aquatic turtles on windfarms, but my study is not a comprehensive assessment of the effect of windfarms on turtles. I did not quantify population size or viability for spotted turtles. Nest hatching success and survivorship at various life stages should be assessed on and off the windfarm. A small number of adult mortalities can lead to catastrophic population declines (Congdon et al. 1993, Keevil et al. 2018) so if mortality is high during the windfarm construction phase, windfarm construction within spotted turtle habitats may be unsustainable even if spatial ecology and habitat selection post-construction appear relatively unimpacted. Additionally, more continuous environmental monitoring with standardized plots is required to better understand the impacts of windfarms on wildlife microhabitat. The impacts of windfarms and wildfires on wetland water quality and invertebrate abundance should be quantified, as these could possibly have cascading effects on spotted turtles.

My study focused on only one species of semi-aquatic turtle. My findings can be used to inform future research on other turtle species, but management decisions should be cautiously based on my findings as there is variation in habitat needs among species and even among conspecific populations. For example, spotted turtles have smaller home ranges and generally do not travel as far as Blanding's turtles (*Emydoidea blandingii*, Ernst and Lovich 2009). Fragmentation of the landscape by infrastructure may impact Blanding's turtles even though spotted turtles do not appear to be impacted, as Blanding's turtles require more land to meet the same needs (spotted turtle HR size 0.2 – 10 ha (COSEWIC 2014) vs Blanding's turtle HR size 10

– 60 ha (COSEWIC 2016)). Species-specific research should therefore be conducted before making management decisions. Nonetheless, some policies could be applicable to many species including the recommendation based on my data to maintain connectivity of wetlands using semi-aquatic culverts; this would likely benefit multiple semi-aquatic turtles as many species have been previously documented using culverts to cross roads (Kaye et al. 2005, Markle et al. 2017, Heaven et al. 2019). Based on observations from this and other studies, culverts should be purpose-built to offer a safe passage (Lovich et al. 2011a) and have a minimum diameter of 0.5 m (Woltz et al. 2008), though a minimum diameter of 1 m is best (OMNRF, 2016) to reduce the possibility of blockage (Lovich et al. 2011a) and allow larger turtles (ex. snapping turtles, *Chelydra serpentina*) to cross. More studies are required to determine the impacts of windfarms on semi-aquatic turtles and to inform data-driven mitigation strategies, but my study provides crucial preliminary data if turtles are to coexist with windfarms.

Literature cited

- Angoh, S. Y. J., J. Freeland, J. E. Paterson, P. A. Rupasinghe, and C. M. Davy. 2021. Effects of invasive wetland macrophytes on habitat selection and movement by freshwater turtles. *Biological Invasions* 23:2271–2288.
- COSEWIC. 2014. COSEWIC assessment and status report on the Spotted Turtle *Clemmys guttata* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. xiv + 74 pp. <www.sararegistry.gc.ca/status/status_e.cfm>.
- 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. <<http://www.registrelep-sararegistry.gc.ca/default.asp?lang=en&n=24F7211B-1>>.
- Congdon, J. D., A. E. Dunham, and R. C. Van Loben Sels. 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.
- Ernst, C. H., and J. E. Lovich. 2009. Turtles of the United States and Canada. Second Edi. The John Hopkins University Press, Baltimore.

- Joyal, L. A., M. McCollough, and M. L. Hunter. 2001. Landscape ecology approaches to wetland species conservation: a case study of two Turtle species in southern Maine. *Conservation Biology* 15:1755–1762.
- Kaye, D. R. J., K. M. Walsh, E. L. Rulison, and C. C. Ross. 2005. Spotted turtle use of a culvert under relocated Route 44 in Carver, Massachusetts. Pages 426–432 in C. L. Irwin, P. Garrett, and K. P. McDermott, editors. *Proceedings of the 2005 International Conference on Ecology and Transportation*. Center for Transportation and the Environment, North Carolina State University, Raleigh, NC. <<https://escholarship.org/uc/item/0qz725t8>>.
- Keevil, M. G., R. J. Brooks, and J. D. Litzgus. 2018. Post-catastrophe patterns of abundance and survival reveal no evidence of population recovery in a long-lived animal. *Ecosphere* 9(9): e02396.
- Litzgus, J. D., and T. A. Mousseau. 2004. Home range and seasonal activity of southern spotted turtles (*Clemmys Guttata*): Implications for management. *Copeia* 2004:804–817.
- Lovich, J. E., J. R. Ennen, S. Madrak, and B. Grover. 2011a. Turtles and culverts, and alternative energy development: An unreported but potentially significant mortality threat to the desert tortoise (*Gopherus agassizii*). *Chelonian Conservation and Biology* 10:124–129.
- Markle, C. E., S. D. Gillingwater, R. Levick, and P. Chow-Fraser. 2017. The true cost of partial fencing: Evaluating strategies to reduce reptile road mortality. *Wildlife Society Bulletin* 41:342–350.
- Milam, J. C., and S. M. Melvin. 2001. Density, habitat use, movements, and conservation of Spotted Turtles (*Clemmys guttata*) in Massachusetts. *Society for the Study of Amphibians and Reptiles* 35:418–427.
- OMNRF (Ontario Ministry of Natural Resources and Forestry). 2016. *Best Management Practices for Mitigating the Effects of Roads on Amphibians and Reptile Species at Risk in Ontario*. Queen’s Printer for Ontario. 112 pp.
- Rasmussen, M. L., and J. D. Litzgus. 2010. Habitat selection and movement patterns of spotted turtles (*Clemmys guttata*): Effects of spatial and temporal scales of analyses. *Copeia* 2010:86–96.
- Woltz, H. W., J. P. Gibbs, and P. K. Ducey. 2008. Road crossing structures for amphibians and reptiles: Informing design through behavioral analysis. *Biological Conservation* 141:2745–2750. Elsevier Ltd. <<http://dx.doi.org/10.1016/j.biocon.2008.08.010>>.
- Yagi, K. T., and J. D. Litzgus. 2012. The effects of flooding on the spatial ecology of spotted turtles (*Clemmys guttata*) in a partially mined peatland. *Copeia* 2012(2): 179–190.

Figures and Tables

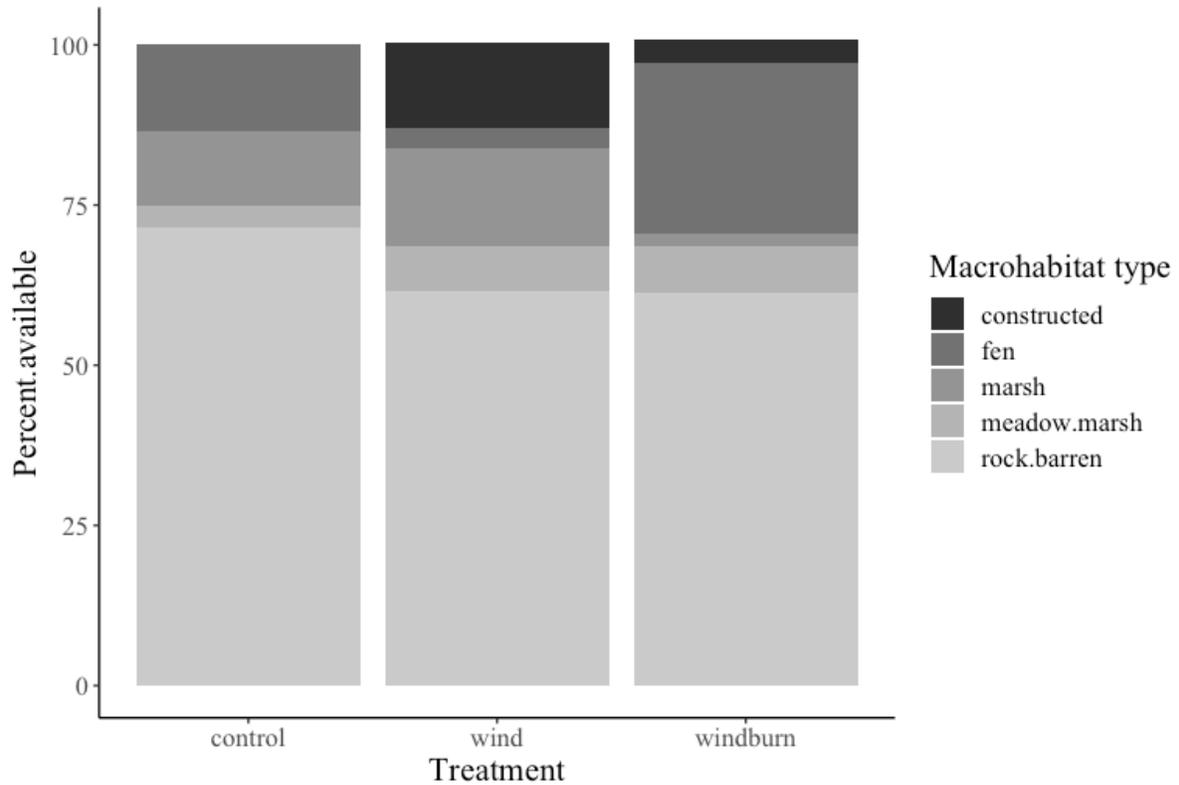


Figure 1: Proportion (%) of each macrohabitat type available within each treatment's (Control, Wind, Windburn) population range (minimum convex polygon (MCP) including all radiolocations + 100 m buffer) for 28 spotted turtles (*Clemmys guttata*) in a windfarm and wildfire impacted landscape in Central Ontario, Canada in 2021.



Figure 2: Example photos of rock pools in the Control (a) and Windburn (b) treatments in Central Ontario, Canada. Spotted turtles (*Clemmys guttata*) frequently used pools in Windburn while spotted turtles were never detected using pools in Control.

Table 1. Delineation of seasons based on spotted turtle (*Clemmys guttata*) activity patterns in Central Ontario, Canada.

Season	Definition	Dates 2021 (start)	Dates 2021 (end)	Number of days	Tracking frequency	Total # micro-habitat radio- locations	Avg # microhabitat radio- locations per individual (/28)
Spring	Active season 1: Emergence from overwintering locations to oviposition of last gravid female. Includes emergence and nesting.	2021-05-15 ⁰	2021-06-12	28	2x/week	186	7
Summer	Active season 2: Oviposition of last gravid female to return of majority of turtles to overwintering wetlands.	2021-06-13	2021-08-17	65	2x/week	350	13
Fall	Active season 3: Movements restricted to overwintering wetlands	2021-08-18	2021-10-05	48	1-2x/week	233	8
Winter	Inactive season: Movements restricted to overwintering wetlands to emergence from overwintering locations.	2021-10-06	2022-05-14	220	1x in Dec ¹	19	1

⁰ Turtles were active prior to this date (active on 2021-04-12) but consistent radiotelemetry did not begin until this date

¹ Telemetry in December was only conducted in Wind and Windburn as Control could not be accessed during the winter

Table 2. Habitat types used to classify available and used macrohabitat for spotted turtles (*Clemmys guttata*) in Central Ontario, Canada, 2021. Habitat types are based on the hierarchical Ecological Land Classification System (ELC; Banton et al. 2008, Wester et al. 2011); all ELC community classes and ecosites that were present at the field site are listed for each habitat type. The unique feature of each habitat type with possible biological relevance to turtles is underlined in the description of the habitat type; these were used to justify combining or splitting of habitat types.

Habitat type	Short description	ELC community classes	ELC ecosites
Constructed	<u>Human made</u> . Includes all windfarm infrastructure: roads, turbine pads, powerlines, substations, and culverts	Constructed, Fills and Deposits	Compact mineral surface (G199) Coarse clean fill (G194)
Fen	<u>Fen indicator species present</u> , tree cover < 25 %	Fens, Shore Fens, Sparse Treed Fens	Poor fen (G139), Open moderately rich fen (G140) Open shore fen (G146) Sparse treed fen (G136)
Meadow marsh	<u>Seasonal water fluctuations</u> , herbaceous cover >50% anchored to substrate	Meadow Marshes	Mineral meadow marsh (G142) Organic meadow marsh (G144)
Marsh	<u>Permanently flooded</u> , emergent vegetation present, water table drawdowns limited or rare	Shallow Marshes Open Water Marshes	Organic shallow marsh (G149) Open water marsh: organic (G149) Open water marsh: floating leaved (G150)
Rock barren	Mostly <u>exposed non-calcareous bedrock</u> , vascular vegetative cover ≤ 25%, some water pooling present	Rock Barrens	Open rock barren (G165) Rock barren (G164)

Table 3. Microhabitat variables measured in 1m² quadrats at both spotted turtle (*Clemmys guttata*) radiolocations (TP) and random paired locations (PP) in Central Ontario, Canada.

Habitat feature	Description	Categorical or Continuous
Air temperature	Shaded temperature 10 cm above the water surface or substrate	Continuous (°C)
Basking temperature	Temperature 10 cm above exposed substrate, generally not shaded	Continuous (°C)
Water temperature	Mid-column water temperature	Continuous (°C)
Substrate temperature	Temperature of aquatic or terrestrial substrate 5cm below the surface	Continuous (°C)
Water depth	Depth of water in the center of the quadrat	Continuous (cm)
Substrate depth	Maximum penetration depth of PVC piping (3cm diameter) into the substrate with a 2kg standardized weight	Continuous (cm)
Cover percentage	Area within quadrat where an adult turtle could conceal at least ¾ of the body	Continuous: recorded in bounds of 5%
Basking percentage	Area within quadrat where an adult turtle could expose at least ¾ of the body to full or partial sun	Continuous: recorded in bounds of 5%
Distance to shore	Pace distance to nearest upland area (i.e., rock barren)	Continuous (m)
Connectivity of open water	True or false that continuous open water at the surface extends more than 20 m ² in any direction from the plot. Indicator of connectivity.	Binary (1/0)
Hummock	Presence or absence of hummocks, a raised vegetated mound (usually mossy), often at the base of shrubs or trees in wetlands.	Binary (1/0)
Dominant vegetation types	Dominant: most proportionally abundant vegetation type within the 1m ² quadrat. Present: all vegetation types present in the m ² quadrat.	Categorical: woody (conifer, shrub), aquatic (submergent, floating, emergent), herbaceous (fern, herb), graminoid (sedge, rush, grass), non-vascular (moss, lichen), none

Table 4: Ranking of macrohabitat selection of 28 spotted turtles (*Clemmys guttata*) in three treatments (Control, Wind, Windburn) in Central Ontario, Canada, 2021. Selection was determined using compositional analyses (Aebischer et al. 1993) and habitat types were based on ELC (Banton et al. 2008, Wester et al. 2011) but lumped into 5 habitat types (Table 2). An asterisk indicates that there is an overall significant selection of habitats by turtles. Habitat types are ranked in decreasing order of selection where 1 is the most selected habitat type and 5 is the least selected.

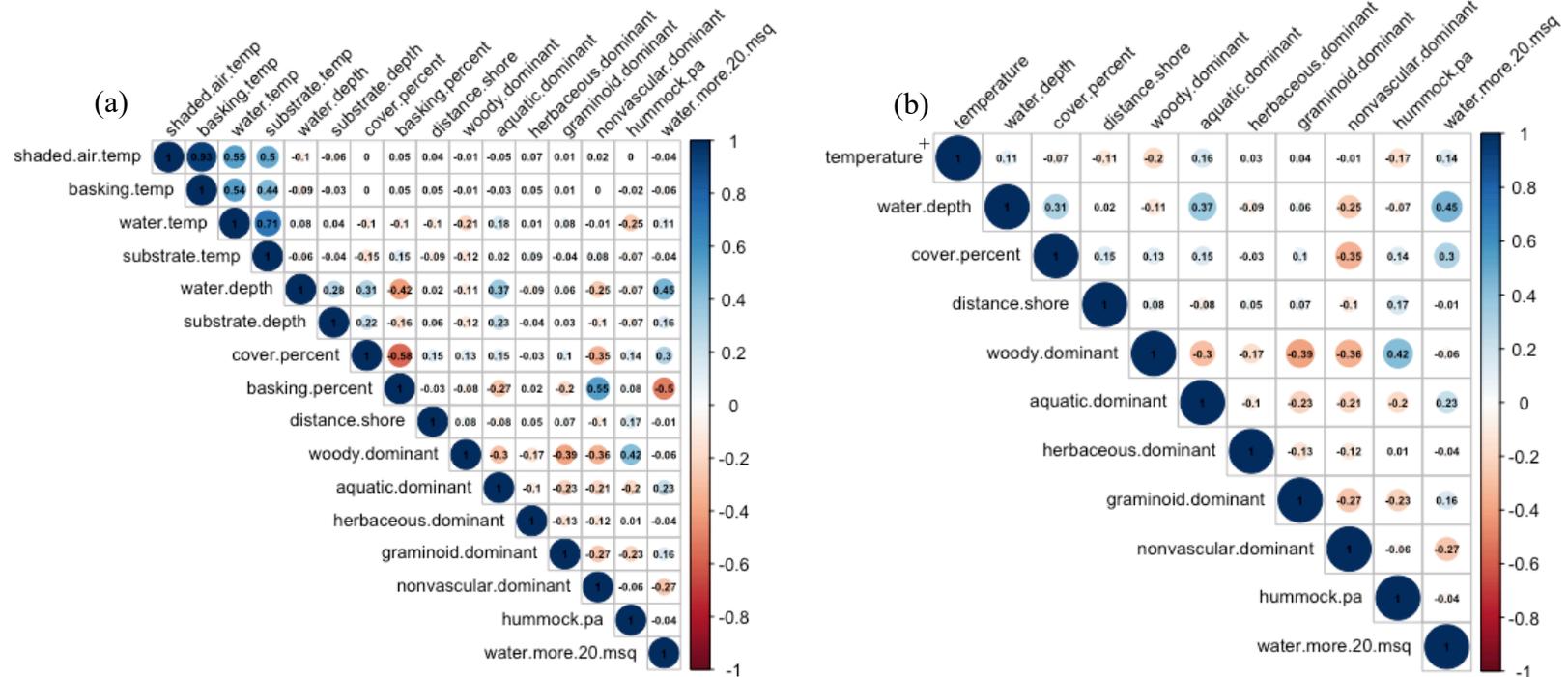
Treatment	Second order (selection of home range in population range)			Third order (selection of locations in home range)		
	Control	Wind	Windburn	Control	Wind	Windburn
N° of turtles	10	9	9	10	9	9
N° of habitat types	4	5	5	4	5	5
Statistic type	Parametric	Parametric	Parametric	Randomization ⁰	Randomization ⁰	Randomization ⁰
Lambda (λ)	0.15	0.074	0.25	0.0022	0.019	0.12
Degrees of freedom	3	4	4	na	na	na
p-value	0.00026*	0.00011*	0.015*	0.0020*	0.008*	0.11
Fen	1	1	1	2	2	1
Meadow marsh	4	3	2	1	1	2
Marsh	3	4	4	3	4	4
Rock barrens	2	2	3	4	5	3
Constructed	Not available	5	5	Not available	3	5

⁰ Randomization test used in place of parametric test when one habitat type was not available within the home range of one or more animal

Table 5: Odds ratios for spotted turtle (*Clemmys guttata*) microhabitat selection in Central Ontario, Canada, after data were split by season (spring, summer, fall) as recommended by the best AIC model (Appendix C); only variables retained in the model (Appendix N) were included. An asterisk indicates a significant (OR does not overlap 1; Appendix O) effect of the microhabitat variable on the outcome (turtle plot (TP) or paired plot (PP)) within the given season. Odds ratios are interpreted as 1 being a null effect of the variables on the outcome (TP vs PP), > 1 is a positive effect (a 1-unit change increases the likelihood of a turtle), < 1 is a negative effect (a 1-unit change decreases the likelihood of a turtle).

Microhabitat variable	Unit change	Spring	Summer	Fall
Temperature	1 °C	1.15*	0.99	1.06*
Water depth	1 cm	1.00	1.02*	1.02*
Cover percentage	1 %	1.01*	1.00*	1.01*
Hummock	TRUE	1.17	1.31*	2.11*

Appendix



+ water and substrate temperatures were merged into one variable where substrate temperature is used if no water was present (similar to O'Bryan et al. 2016) as all temperature metrics were colinear

Appendix A: Spearman's non-parametric rank-correlation coefficient matrix for microhabitat variables measured in 1m² quadrats at both spotted turtle (*Clemmys guttata*) radiolocations (TP) and random paired locations (PP) in Central Ontario, Canada. At the intersection of each pair of variables, an r value is displayed. An r value approaching 1 indicates high correlation; positive r values indicate a positive relationship (blue) while negative r values indicate a negative relationship (red). (a) Correlation matrix with all measured microhabitat variables. (b) Correlation matrix after the removal of highly correlated ($r > 0.5$) variables for microhabitat selection analyses.

Appendix B: Determining if individual turtle ID is a significant predictor of microhabitat selection

Fixed model: (TL.PP ~ temperature + water.depth + cover.percent + distance.shore + hummock.pa + water.more.20.msq + woody.dominant + aquatic.dominant + herbaceous.dominant + graminoid.dominant + nonvascular.dominant + (1|str_ID)

Random slope model: (TL.PP ~ -1 + temperature + water.depth + cover.percent + distance.shore + hummock.pa + water.more.20.msq + woody.dominant + aquatic.dominant + herbaceous.dominant + graminoid.dominant + nonvascular.dominant + (1|str_ID) + (0 + temperature | ANIMAL_ID) + (0 + water.depth | ANIMAL_ID) + (0 + cover.percent | ANIMAL_ID) + (0 + hummock.pa | ANIMAL_ID) + (0 + water.more.20.msq | ANIMAL_ID) + (0 + woody.dominant | ANIMAL_ID) + (0 + aquatic.dominant | ANIMAL_ID) + (0 + herbaceous.dominant | ANIMAL_ID) + (0 + graminoid.dominant | ANIMAL_ID) + (0 + nonvascular.dominant | ANIMAL_ID)

Random slope of individual ID: not needed

	AIC	BIC	logLik	deviance	df.resid
Fixed:	12841	12905	-6409	12817	1524
Random slope:	12844	12962	-6400	12800	1514

Likelihood ratio test (LRT) comparing fixed effect model to random effect model:

	Df	LogLik	Df	Chisq	Pr(>Chisq)
Fixed	12	-6409			
Random	22	-6400	10	17.04	0.074 = fixed and random are not significantly different

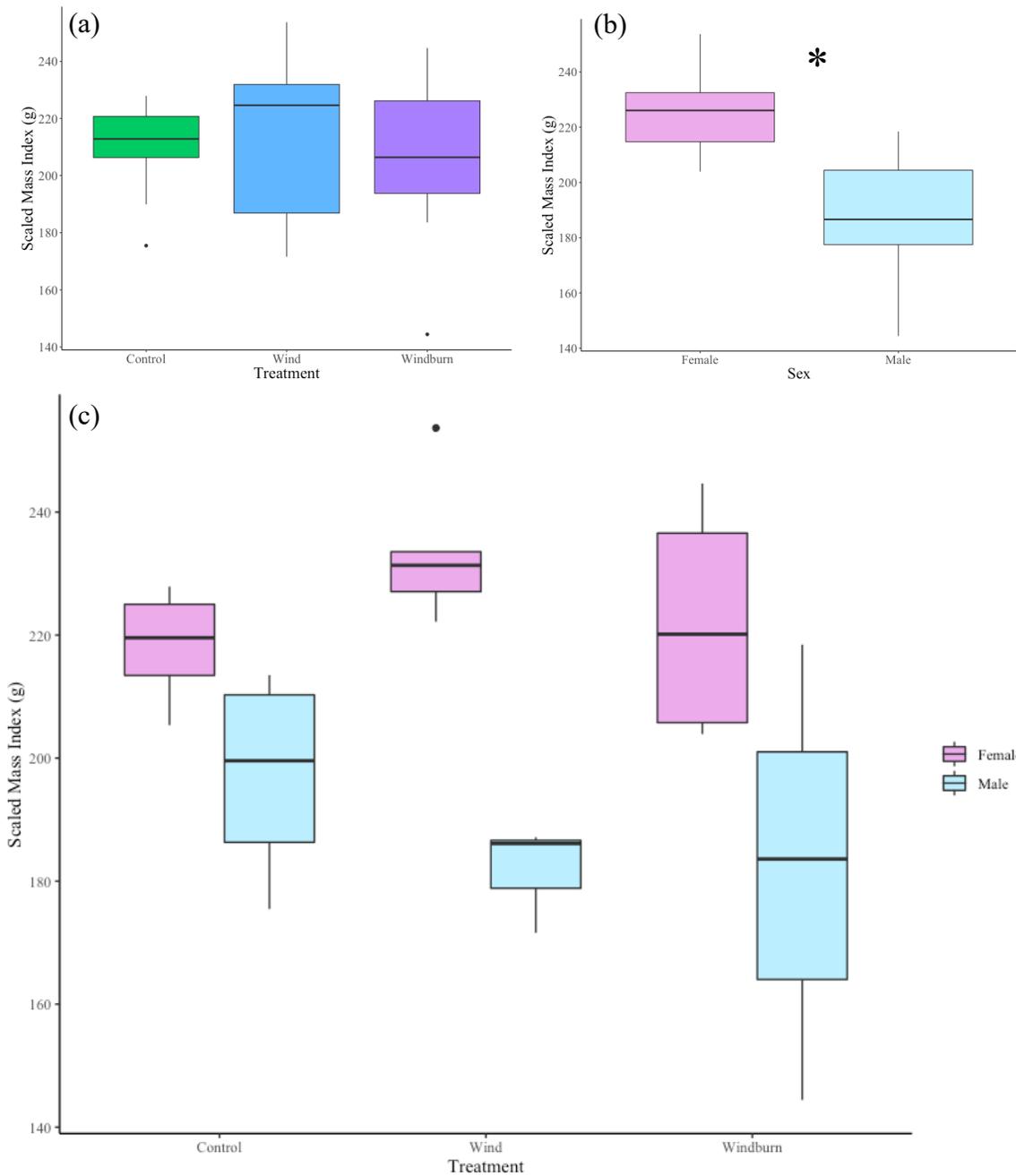
- Also investigated on subsets of data and never better with random slopes

Appendix C: Results of microhabitat selection models after AIC and BIC stepwise backward regression for spotted turtles (*Clemmys guttata*) in Central Ontario, Canada, 2021. The models with the lowest AIC and BIC (i.e., the best fitting models) are indicated in bold font.

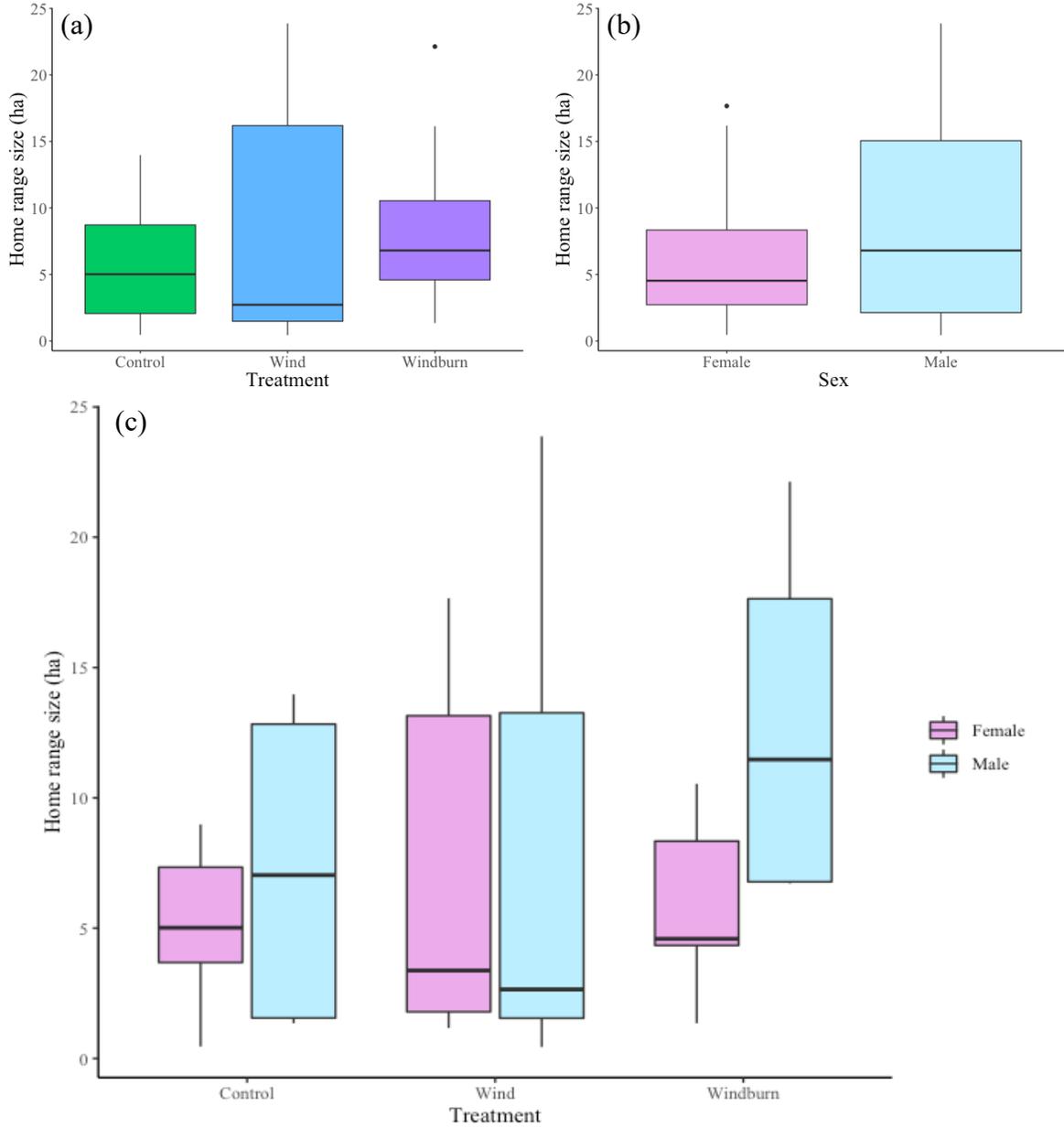
Model name	Variables before regression ⁰	Interpretation if top model after stepwise	AIC backward regression			BIC backward regression		
			df	AIC	LogLik	df	BIC	LogLik
mod.nointer.step	Habitat.vars _i ¹	No effect	8	2880	-1432	6	2912	-1434
mod.intert.step	Habitat.vars _i *treatment	Treatment effect only	15	2868	-1419	6	2912	-1434
mod.inters.step	Habitat.vars_i *season	Seasonal effect only	18	2779	-1371	11	2848	-1383
mod.intersx.step	Habitat.vars _i *sex	Sex effect only	12	2876	-1426	6	2912	-1434
mod.inters.t.step	Habitat.vars _i *treatment + Habitat.vars _i *season	Treatment and season effects exist but not dependent on each other	20	2775	-1368	11	2848	-1383
mod.intersx.t.step	Habitat.vars _i *treatment + Habitat.vars _i *sex	Treatment and sex effects exist but not dependent on each other	22	2866	-1411	6	2912	-1434
mod.interst.step	Habitat.vars_i *treatment*season	Treatment has effect in certain seasons	37	2769	-1347	11	2848	-1383
mod.intersxt.step	Habitat.vars _i *treatment*sex	Treatment has effect for one sex	22	2866	-1411	6	2912	-1434

- ⁰ Representation of variables included prior to the backward stepwise regression. Some variables and interactions were not retained post stepwise regression.

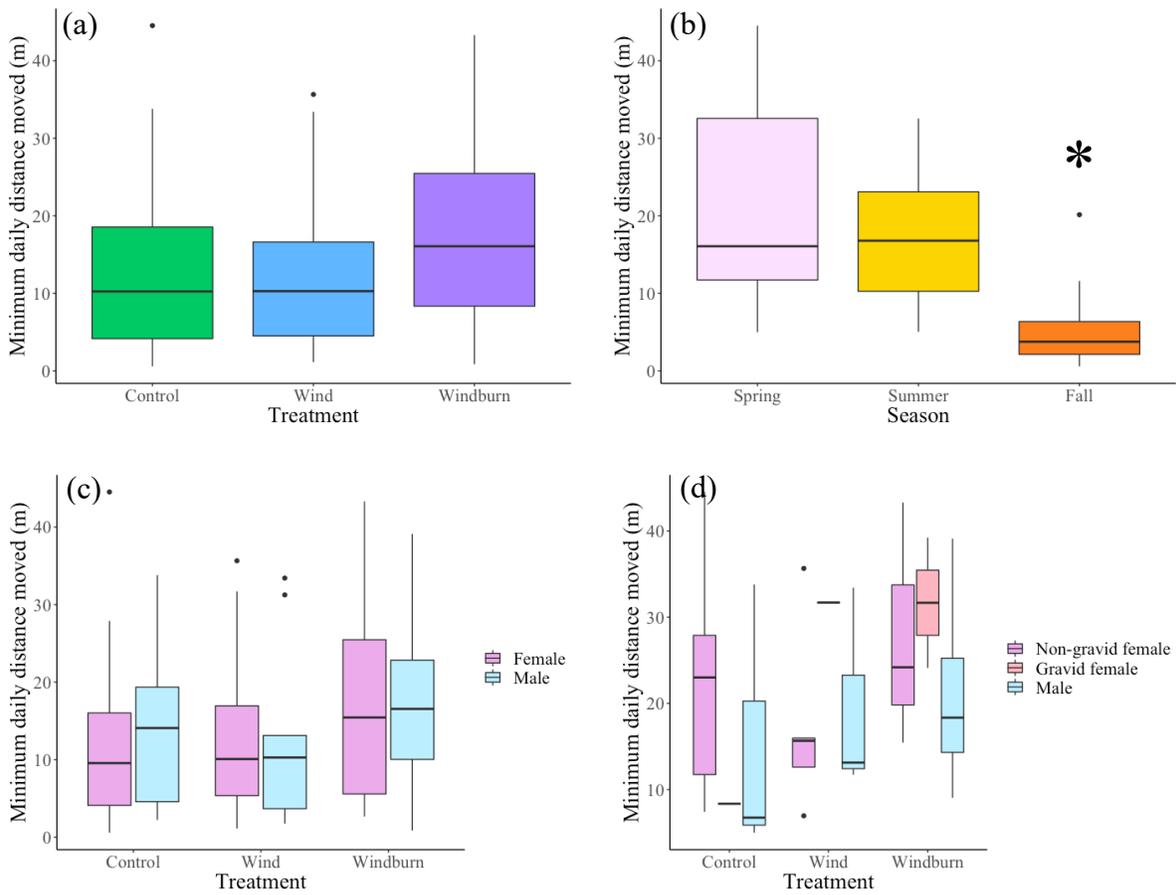
- ¹ Habitat.vars_i includes all non colinear variables (7 variables). Each variable is included with the interaction terms prior to stepwise regression (e.g., model mod.intert.step: water depth*treatment +cover percentage*treatment + ... + (Habitat.vars_i)*treatment.



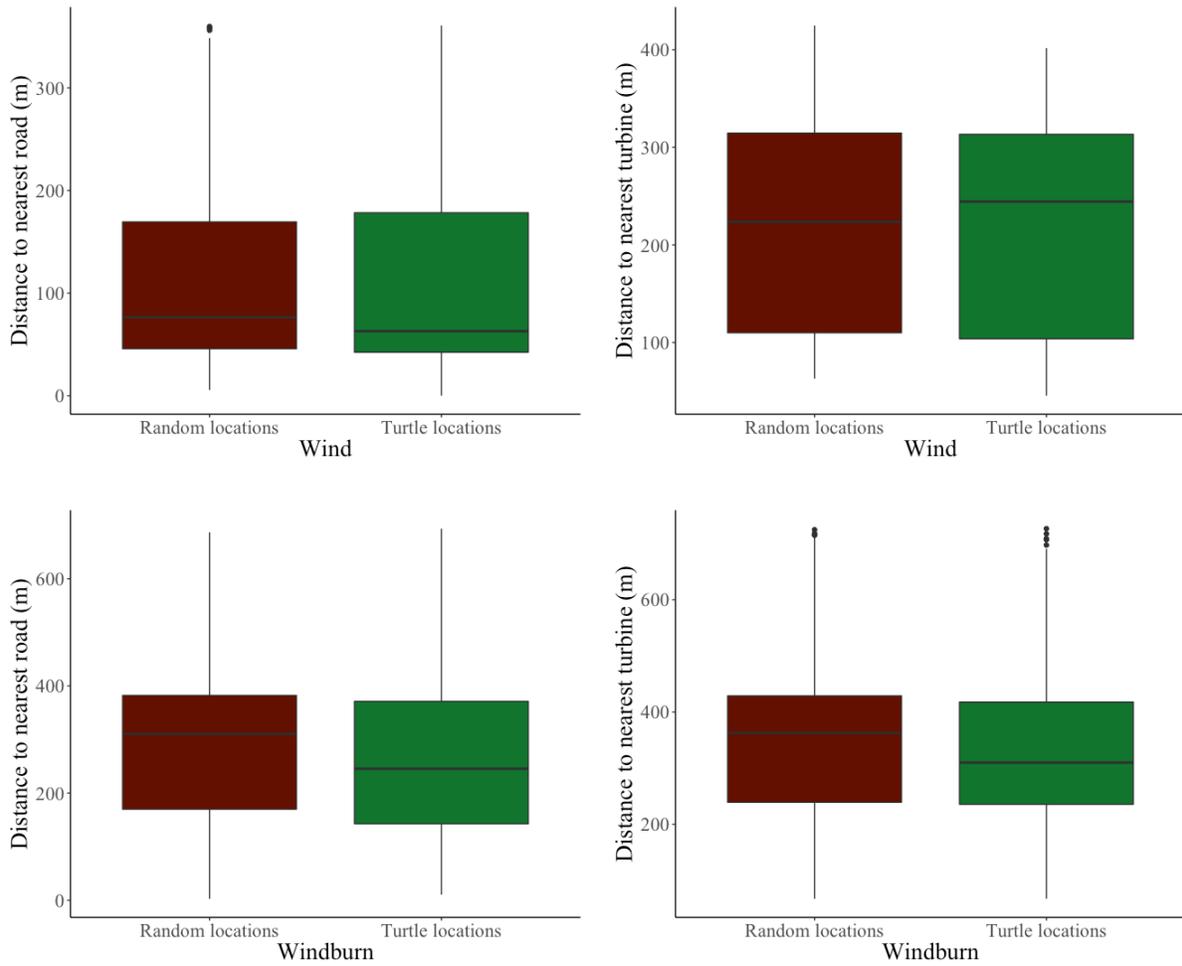
Appendix D: Scaled mass index (SMI) for spotted turtles (*Clemmys guttata*; n = 25) in Central Ontario, Canada in 2021 (a) by treatment (Control, Wind, Windburn), (b) by sex (Male, Female), and (c) by sex and treatment. The asterisks indicate significant differences ($\alpha=0.05$).



Appendix E: Home range size (HR) for spotted turtles (*Clemmys guttata*; n = 28) in Central Ontario, Canada in 2021 (a) by treatment (Control, Wind, Windburn), (b) by sex (Male, Female), and (c) by sex and treatment.



Appendix F: Minimum daily distance moved (DDM) for spotted turtles (*Clemmys guttata*; n = 28) in Central Ontario, Canada in 2021 (a) by treatment (Control, Wind, Windburn), (b) by sex (Female, Male) and treatment (Control, Wind, Windburn), (c) by season (Spring, Summer, Fall), and (d) in the spring only by reproductive class (non-gravid female, gravid female, male). The asterisks indicate a significant difference ($\alpha=0.05$).



Appendix G: Distance of random locations or turtle locations to nearest road or turbine for spotted turtles (*Clemmys guttata*) on an operational windfarm at two sites (Wind and Windburn) in Central Ontario, Canada, 2021. Random locations were generated within the kernel density estimator (KDE) home range of each individual and include the same proportion of barren to wetland locations as the turtle locations.



Appendix H: Semi aquatic culvert used by spotted turtles (*Clemmys guttata*) on an operational windfarm in Central Ontario, Canada. (a) 6 May 2021, north opening of culvert, (b) 6 May 2021, north opening of culvert with a spotted turtle, (c) 17 July 2021, south opening of culvert, measuring water depth.

Appendix I: Second and third order (Johnson 1980) macrohabitat selection ranking matrices using compositional analyses (Aebischer et al. 1993) for spotted turtles (*Clemmys guttata*) in three treatments (Control, Wind, Windburn) in Central Ontario, Canada, 2021. A triple plus sign “+++” indicates significant selection of one habitat type over another.

2 nd order: Control	Fen	Marsh	Meadow marsh	Rock barren
Fen	0	+	+++	+++
Marsh	-	0	+	-
Meadow marsh	---	-	0	-
Rock barren	---	+	+	0

2 nd order: Wind	Constructed	Fen	Marsh	Meadow marsh	Rock barren
Constructed	0	---	-	---	---
Fen	+++	0	+++	+	+++
Marsh	+	---	0	-	-
Meadow marsh	+++	-	+	0	-
Rock barren	+++	---	+	+	0

2 nd order: Windburn	Constructed	Fen	Marsh	Meadow marsh	Rock barren
Constructed	0	---	-	---	---
Fen	+++	0	+++	+	+++
Marsh	+	---	0	---	---
Meadow marsh	+++	-	+++	0	+
Rock barren	+++	---	+++	-	0

3 rd order: Control	Fen	Marsh	Meadow marsh	Rock barren
Fen	0	+++	-	+++
Marsh	---	0	---	+++
Meadow marsh	+	+++	0	+++
Rock barren	---	---	---	0

3 rd order: Wind	Constructed	Fen	Marsh	Meadow marsh	Rock barren
Constructed	0	---	+	---	+
Fen	+++	0	+	-	+++
Marsh	-	-	0	---	+
Meadow marsh	+++	+	+++	0	+++
Rock barren	-	---	-	-	0

3 rd order: Windburn	Constructed	Fen	Marsh	Meadow marsh	Rock barren
Constructed	0	---	-	-	-
Fen	+++	0	+	+	+++
Marsh	+	-	0	-	-
Meadow marsh	+	-	+	0	+
Rock barren	+	---	+	-	0

Appendix J: Results of Tukey post-hoc tests following generalized linear models to compare available (pooled turtle plots (TP) and paired plots (PP); 1536 plots) microhabitat for spotted turtles (*Clemmys guttata*) among treatments (Control, Wind, Windburn) and seasons (spring, summer, fall; defined in Table 1) in Central Ontario, Canada, 2021. Post-hoc tests were conducted only if significant ($\alpha = 0.05$) interactions of treatment or season or their interaction were found for the given microhabitat variable. When a variable had a significant interaction of season and treatment, the post hoc test was controlled for season before assessing the differences among treatments.

Microhabitat variable	Controlled	Contrast	Odds ratio	SE	df	t ratio	p value	Significant
temperature	n/a	fall / spring	-1.19*	0.58	1524	-2.05	0.10	
temperature	n/a	fall / summer	-3.15*	0.51	1524	-6.19	0.00	*
temperature	n/a	spring / summer	-1.96*	0.53	1524	-3.72	0.00	*
water depth	n/a	fall / spring	0.61	0.07	1525	-4.42	0.00	*
water depth	n/a	fall / summer	0.68	0.07	1525	-4.01	0.00	*
water depth	n/a	spring / summer	1.11	0.11	1525	1.03	0.56	
water depth	n/a	control / wind	1.03	0.10	1525	0.29	0.95	
water depth	n/a	control / windburn	1.44	0.15	1525	3.60	0.00	*
water depth	n/a	wind / windburn	1.40	0.14	1525	3.30	0.00	*
cover percent	n/a	fall / spring	1.25	0.07	1525	4.19	0.00	*
cover percent	n/a	fall / summer	1.17	0.05	1525	3.43	0.00	*
cover percent	n/a	spring / summer	0.94	0.05	1525	-1.35	0.37	
cover percent	fall	control / wind	0.90	0.08	1525	-1.23	0.43	
cover percent	fall	control / windburn	1.13	0.10	1525	1.40	0.34	
cover percent	fall	wind / windburn	1.25	0.11	1525	2.61	0.02	*
cover percent	spring	control / wind	1.22	0.12	1525	2.10	0.09	
cover percent	spring	control / windburn	1.42	0.13	1525	3.68	0.00	*
cover percent	spring	wind / windburn	1.16	0.11	1525	1.53	0.28	
cover percent	summer	control / wind	1.00	0.07	1525	-0.02	1.00	
cover percent	summer	control / windburn	1.60	0.11	1525	6.84	0.00	*

cover percent	summer	wind / windburn	1.61	0.12	1525	6.60	0.00	*
distance shore	n/a	fall / spring	1.47	0.11	1525	5.23	0.00	*
distance shore	n/a	fall / summer	1.34	0.08	1525	4.67	0.00	*
distance shore	n/a	spring / summer	0.91	0.06	1525	-1.32	0.39	
distance shore	n/a	control / wind	1.13	0.08	1525	1.86	0.15	
distance shore	n/a	control / windburn	1.45	0.10	1525	5.50	0.00	*
distance shore	n/a	wind / windburn	1.28	0.09	1525	3.61	0.00	*
distance shore	fall	control / wind	0.92	0.10	1525	-0.72	0.75	
distance shore	fall	control / windburn	1.31	0.16	1525	2.29	0.06	*
distance shore	fall	wind / windburn	1.42	0.17	1525	2.99	0.01	*
distance shore	spring	control / wind	1.31	0.18	1525	1.99	0.12	
distance shore	spring	control / windburn	1.13	0.15	1525	0.94	0.62	
distance shore	spring	wind / windburn	0.87	0.12	1525	-1.05	0.55	
distance shore	summer	control / wind	1.20	0.12	1525	1.93	0.13	
distance shore	summer	control / windburn	2.05	0.20	1525	7.41	0.00	*
distance shore	summer	wind / windburn	1.71	0.17	1525	5.28	0.00	*
hummock	n/a	fall / spring	9.15	2.40	1525	8.43	0.00	*
hummock	n/a	fall / summer	4.82	0.89	1525	8.54	0.00	*
hummock	n/a	spring / summer	0.53	0.14	1525	-2.41	0.04	*
hummock	n/a	control / wind	0.97	0.19	1525	-0.17	0.98	
hummock	n/a	control / windburn	3.10	0.80	1525	4.38	0.00	*
hummock	n/a	wind / windburn	3.21	0.82	1525	4.59	0.00	*
connectivity	n/a	control / wind	0.57	0.19	1525	-1.68	0.21	
connectivity	n/a	control / windburn	1.51	0.52	1525	1.20	0.45	
connectivity	n/a	wind / windburn	2.66	0.94	1525	2.77	0.02	*
connectivity	n/a	fall / spring	0.28	0.11	1525	-3.30	0.00	*
connectivity	n/a	fall / summer	0.15	0.05	1525	-5.43	0.00	*

connectivity	n/a	spring / summer	0.54	0.18	1525	-1.82	0.16	
woody dominant	n/a	fall / spring	3.42	0.70	1525	5.98	0.00	*
woody dominant	n/a	fall / summer	2.50	0.43	1525	5.39	0.00	*
woody dominant	n/a	spring / summer	0.73	0.14	1525	-1.66	0.22	
woody dominant	n/a	control / wind	1.06	0.19	1525	0.35	0.93	
woody dominant	n/a	control / windburn	2.19	0.42	1525	4.07	0.00	*
woody dominant	n/a	wind / windburn	2.05	0.38	1525	3.85	0.00	*
woody dominant	fall	control / wind	4.37	1.32	1525	4.88	0.00	*
woody dominant	fall	control / windburn	3.43	1.08	1525	3.92	0.00	*
woody dominant	fall	wind / windburn	0.78	0.24	1525	-0.80	0.70	
woody dominant	spring	control / wind	0.30	0.11	1525	-3.32	0.00	*
woody dominant	spring	control / windburn	1.30	0.52	1525	0.65	0.79	
woody dominant	spring	wind / windburn	4.36	1.66	1525	3.86	0.00	*
woody dominant	summer	control / wind	0.93	0.23	1525	-0.29	0.95	
woody dominant	summer	control / windburn	2.35	0.63	1525	3.22	0.00	*
woody dominant	summer	wind / windburn	2.53	0.69	1525	3.39	0.00	*
graminoid dominant	n/a	fall / spring	0.32	0.10	1525	-3.63	0.00	*
graminoid dominant	n/a	fall / summer	0.33	0.10	1525	-3.73	0.00	*
graminoid dominant	n/a	spring / summer	1.04	0.21	1525	0.21	0.98	
graminoid dominant	n/a	control / wind	0.93	0.18	1525	-0.35	0.94	
graminoid dominant	n/a	control / windburn	4.94	1.52	1525	5.20	0.00	*
graminoid dominant	n/a	wind / windburn	5.29	1.63	1525	5.39	0.00	*
graminoid dominant	fall	control / wind	0.32	0.11	1525	-3.27	0.00	*
graminoid dominant	fall	control / windburn	15.14	11.74	1525	3.51	0.00	*
graminoid dominant	fall	wind / windburn	47.80	36.64	1525	5.05	0.00	*
graminoid dominant	spring	control / wind	3.09	1.19	1525	2.92	0.01	*
graminoid dominant	spring	control / windburn	3.63	1.41	1525	3.31	0.00	*

graminoid dominant	spring	wind / windburn	1.17	0.48	1525	0.39	0.92	
graminoid dominant	summer	control / wind	0.83	0.23	1525	-0.66	0.78	
graminoid dominant	summer	control / windburn	2.20	0.65	1525	2.69	0.02	*
graminoid dominant	summer	wind / windburn	2.64	0.80	1525	3.21	0.00	*
nonvascular dominant	n/a	control / wind	0.93	0.20	1525	-0.32	0.95	
nonvascular dominant	n/a	control / windburn	0.23	0.05	1525	-7.17	0.00	*
nonvascular dominant	n/a	wind / windburn	0.24	0.05	1525	-6.87	0.00	*
aquatic dominant	n/a	fall / spring	0.11	0.03	1525	-7.00	0.00	*
aquatic dominant	n/a	fall / summer	0.21	0.06	1525	-5.13	0.00	*
aquatic dominant	n/a	spring / summer	1.95	0.37	1525	3.53	0.00	*
aquatic dominant	n/a	control / wind	0.79	0.21	1525	-0.88	0.65	
aquatic dominant	n/a	control / windburn	1.05	0.32	1525	0.17	0.98	
aquatic dominant	n/a	wind / windburn	1.33	0.34	1525	1.13	0.49	
aquatic dominant	fall	control / wind	0.16	0.10	1525	-2.80	0.01	*
aquatic dominant	fall	control / windburn	0.67	0.53	1525	-0.51	0.87	
aquatic dominant	fall	wind / windburn	4.20	2.49	1525	2.43	0.04	*
aquatic dominant	spring	control / wind	1.79	0.63	1525	1.65	0.23	
aquatic dominant	spring	control / windburn	1.24	0.42	1525	0.65	0.80	
aquatic dominant	spring	wind / windburn	0.70	0.25	1525	-1.01	0.57	
aquatic dominant	summer	control / wind	1.74	0.51	1525	1.89	0.14	
aquatic dominant	summer	control / windburn	1.41	0.39	1525	1.23	0.44	
aquatic dominant	summer	wind / windburn	0.81	0.25	1525	-0.69	0.77	

* Generalized linear model had a gaussian family link (data are normally distributed) so output is estimate and not odds ratio

Appendix K: Summary of microhabitat variables that were significantly different among treatments (T), seasons (S), their interaction (T:S), or neither (N) for both microhabitat availability (Appendix J) and selection (Appendix M, Appendix N). An ‘X’ represents a significant difference in availability, an ‘A’ represents a significant difference in selection in the AIC model (Appendix M) while an ‘a’ is nearly significant in the AIC model, and a ‘B’ represents a significant difference in selection in the BIC model (Appendix N) while an ‘b’ is nearly significant in the BIC model. Significant pairwise differences are presented with abbreviations where Sp is spring, Su is summer, Fa is fall, C is Control, W is Wind, and WB is Windburn. If a pairwise description is in parentheses, it indicates that the season prior to the parentheses is controlled for prior to the comparison (significant interaction detected). The interpretation of selection is based only on seasonal differences in availability (Table 5) as differences in selection among treatments were negligible (see text for details).

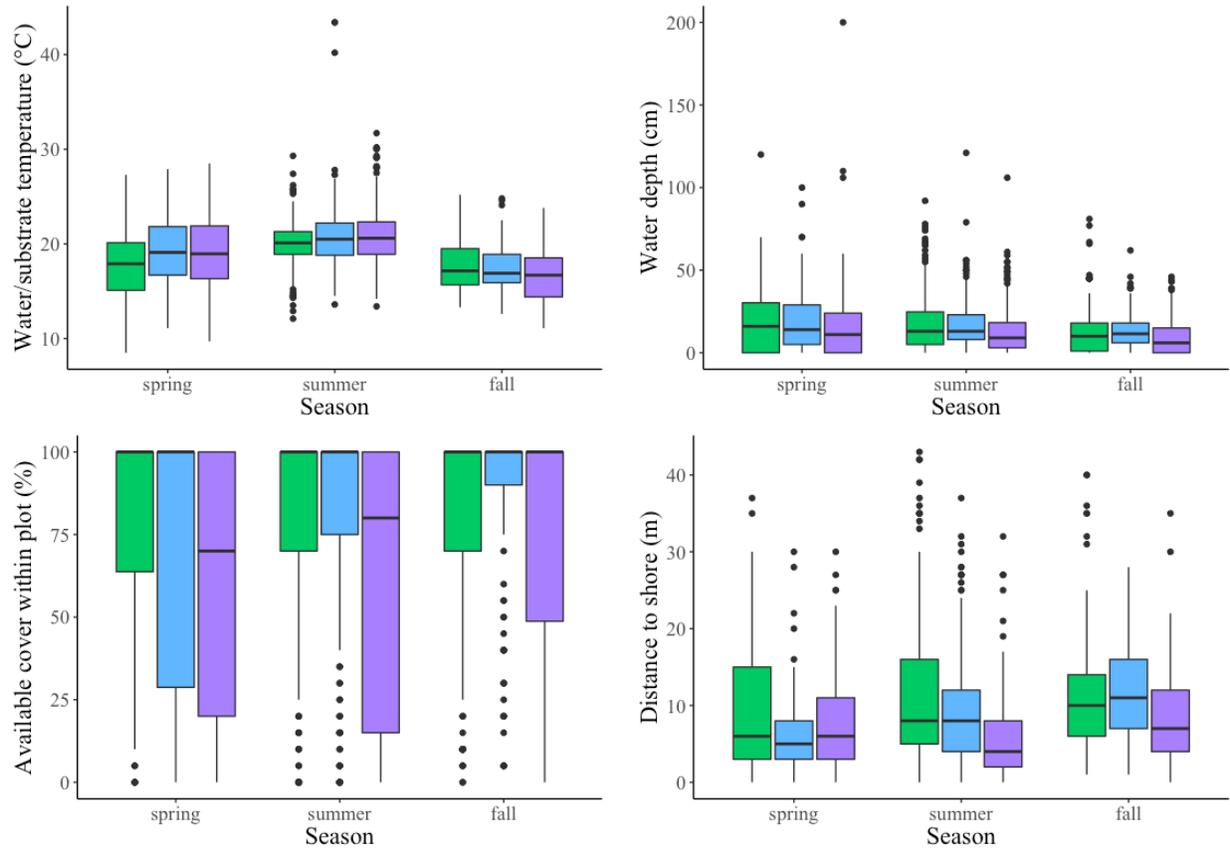
Microhabitat variable	Availability				Selection				
	T	S	T:S	Pairwise	N	T	S	T:S	Interpretation based on odds ratios (Table 5)
Temperature*		X		Su > Sp & Fa	A b		A B		Turtles select warmer water or substrate than available in the spring and fall
Water depth	X	X		Fa < Sp & Su WB < C & W	A B		A B	a	Turtles select deeper water than available in the summer and fall
Cover	X		X	WB < C & W Sp (WB < C) Su (WB < C & W) Fa (WB < W)	A B				Turtles select more cover than available year-round
Hummock	X	X		Fa > Sp & Su WB < C & W	A B		A		Turtles prefer plots with hummocks year-round, significantly selecting plots with hummocks in the summer and fall
Distance to shore	X	X	X	Fa > Sp & Su WB < C & W Su (WB < C & W) Fa (WB < W)		a			
Water connectivity	X	X		Fa < Sp & Su WB < C & W			A	A	
Dominant vegetation type**	X	X	X						n/a
Woody	X	X	X	Fa > Sp & Su WB < C & W					

				Sp (W > WB)
				Sp (W > C)
				Su (WB < C & W)
				Fa (C > W & WB)
Graminoid	X	X	X	Fa < Sp & Su
				WB < C & W
				Sp (W > C > WB)
				Su (C > W & WB)
				Fa (WB < C & W)
Nonvascular	X			WB > C & W
Herbaceous ^{***}				n/a
Aquatic		X	X	Fa < Sp < Su
				Fa (W > C & WB)
None				n/a

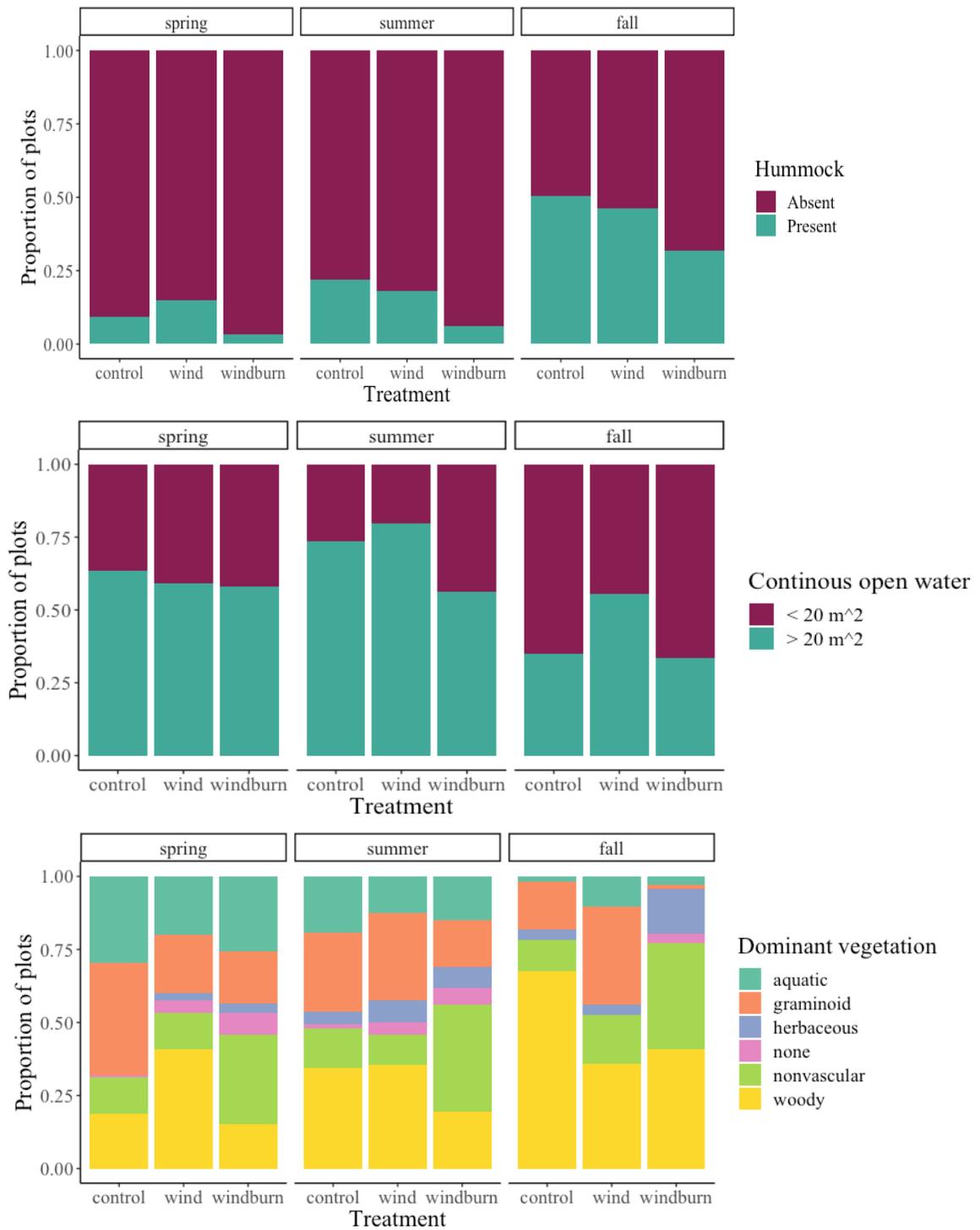
* Temperature is either water temperature mid-column or substrate temperature (5 cm below the surface) if not water was available.

** Dominant vegetation type availability was calculated separately for each vegetation type and summarized in this column. Dominant vegetation type was not retained or significant in either microhabitat selection model.

*** Herbaceous had convergence issue with day of year so day of year removed prior to availability analysis.



Appendix L: Differences in available (pooled paired plots (PP) and turtle location plots (TP)) microhabitat features among treatments (Control: green, Wind: blue, Windburn: purple) for spotted turtles (*Clemmys guttata*) in Central Ontario, Canada in 2021.



Appendix L (continued): Differences in available (pooled paired plots (PP) and turtle location plots (TP)) microhabitat features among treatments (Control: green, Wind: blue, Windburn: purple) for spotted turtles (*Clemmys guttata*) in Central Ontario, Canada in 2021.

Appendix M: Retained variables in best AIC model after stepwise backward regression of spotted turtle (*Clemmys guttata*) microhabitat in Central Ontario, Canada, 2021. A significant P-value (*) indicates that a microhabitat variable can significantly differentiate a turtle location from a paired plot.

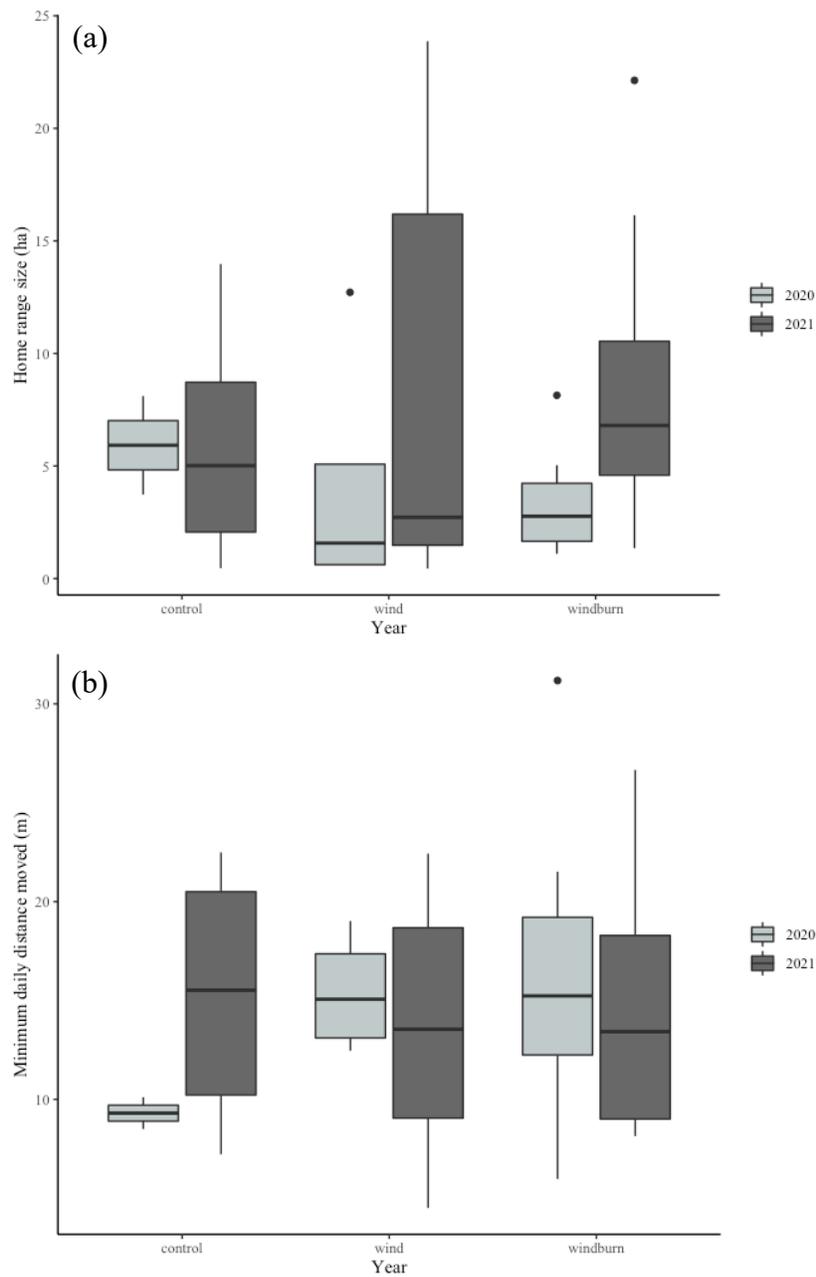
Variable and interaction	Chisq	df	Pr(>Chisq)	Significant
water.depth	4.47	1	0.03	*
season	3.59	2	0.17	
treatment	3.58	2	0.17	
temperature	5.31	1	0.02	*
cover.percent	14.57	1	0.00	*
hummock.pa	36.83	1	0.00	*
distance.shore	1.15	1	0.28	
water.more.20.msq	0.15	1	0.70	
water.depth:season	0.14	2	0.93	
water.depth:treatment	0.15	2	0.92	
season:treatment	15.27	4	0.00	*
season:temperature	26.01	2	0.00	*
season:hummock.pa	12.04	2	0.00	*
treatment:distance.shore	5.42	2	0.07	.
season:water.more.20.msq	13.07	2	0.00	*
treatment:water.more.20.msq	0.18	2	0.91	
water.depth:season:treatment	9.06	4	0.06	.
season:treatment: water.more.20.msq	26.98	4	0.00	*

Appendix N: Retained variables in best BIC model after stepwise backward regression of spotted turtle (*Clemmys guttata*) microhabitat in Central Ontario, Canada, 2021. A significant P-value (*) indicates that a microhabitat variable can significantly differentiate a turtle location from a paired plot.

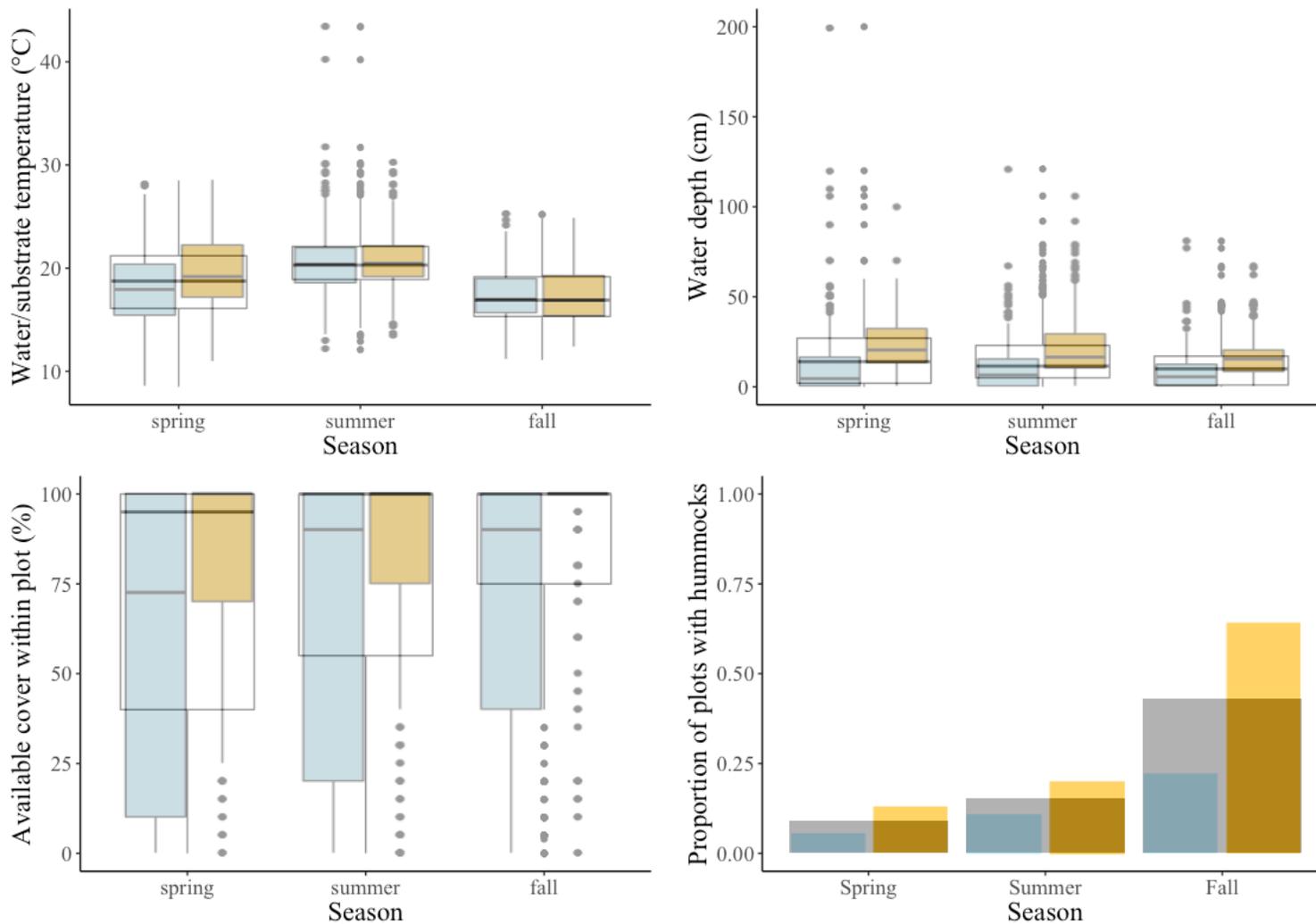
Variable and interaction	Chisq	Degrees	Pr(>Chisq)	Significant
water.depth	10.76	1	0.00	*
season	14.63	2	0.00	*
temperature	3.50	1	0.06	.
cover.percent	28.98	1	0.00	*
hummock.pa	27.25	1	0.00	*
water.depth:season	17.36	2	0.00	*
seasonspring:temperature	25.17	2	0.00	*

Appendix O: Coefficients, standard errors (SE), odds ratios (OR), and confidence intervals (CI) for spotted turtle (*Clemmys guttata*) microhabitat data after data were split by season (spring, summer, fall) as recommended by the best BIC model (Appendix N). Separate models were fit for each season so coefficients cannot be compared, but odds ratios can as ORs are presented based on a one-unit change. A significant P-value (*) indicates that a microhabitat variable can significantly differentiate a turtle location from a paired plot within the given season in Central Ontario, Canada, 2021.

Season	Microhabitat variable	Unit change	Coefficients	SE	OR	CI 2.5%	CI 97.5%	P-Value	Significant
Spring	temperature	1 °C	0.14	0.02	1.15	1.10	1.19	0.00	*
Spring	water.depth	1 cm	0.00	0.00	1.00	1.00	1.01	0.46	
Spring	cover.percent	1%	0.01	0.00	1.01	1.00	1.01	0.00	*
Spring	hummock.pa	TRUE	0.16	0.22	1.17	0.74	1.78	0.47	
Summer	temperature	1 °C	-0.01	0.02	0.99	0.95	1.03	0.71	
Summer	water.depth	1 cm	0.02	0.00	1.02	1.01	1.03	0.00	*
Summer	cover.percent	1%	0.00	0.00	1.00	1.00	1.01	0.04	*
Summer	hummock.pa	TRUE	0.27	0.14	1.31	1.00	1.70	0.05	*
Fall	temperature	1 °C	0.06	0.03	1.06	1.01	1.11	0.03	*
Fall	water.depth	1 cm	0.02	0.00	1.02	1.01	1.02	0.00	*
Fall	cover.percent	1%	0.01	0.00	1.01	1.00	1.02	0.00	*
Fall	hummock.pa	TRUE	0.75	0.14	2.11	1.60	2.80	0.00	*



Appendix P: Home range size (a) and daily distance moved (b) among treatments (Control, Wind, Windburn) and years (2020 and 2021) for spotted turtles (*Clemmys guttata*) in Central Ontario, Canada.



Supplementary figure: Paired plots (PP; blue) and turtle plots (TP; yellow) overlaid over seasonal availability (black and white boxplot or gray bar) for variables that were significant in distinguishing paired plots from turtle plots in the BIC model (Appendix N). Habitat selection from paired logistic regressions (PP vs TP) is interpreted as a difference between available and used habitats (Compton et al. 2002) so availability must be considered when interpreting selection.