Impacts of Air Quality on Breeding Success in House Wrens (*Troglodytes aedon)*

Adrienne Bailey & Willow Zilliox

Student Internship

Beaverhill Bird Observatory

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Abstract

As global temperatures increase, wildfires are becoming more prevalent. Wildfire smoke decreases air quality, which negatively affects both the health and behaviour of wildlife. In this study, we investigated the impacts of air quality on house wren (*Troglodytes aedon*) breeding success while monitoring ninety-nine house wren nest boxes that are maintained by the Beaverhill Bird Observatory in the Beaverhill Natural Area. We hypothesised that poorer air quality would negatively affect nest initiation dates, clutch size, and nest success rates. However, after conducting a series of correlation analyses, we found that there was an insignificant relationship between air quality, nest initiation, clutch size, and nest success.

Introduction

House wrens (*Troglodytes aedon*) are insectivorous, cavity-nesting passerines (Grabarczyk et al., 2022) that are widely distributed between approximately 58°N in North America to 55°S in South America (Kaluthota & Rendall, 2017). With such an expansive range, house wrens are adapted to persist under a variety of environmental conditions (Kaluthota & Rendall, 2017). Most house wren studies, including our own, involve artificial nest boxes that provide protection against predators, wind, and rain (Kaluthota & Rendall, 2017). Consequently, artificial nest boxes are associated with several improved breeding outcomes, such as increased clutch size, greater nestling survival, and higher polygyny rates (Kaluthota & Rendall, 2017). However, artificial nest boxes presumably do not provide additional protection against air pollutants, such as wildfire smoke.

In recent decades, wildfire smoke has been more prevalent in western North America due to climate change-induced changes in precipitation and temperature, which have positively affected both fire ignition and wildfire severity (Overton et al., 2022). Components of wildfire smoke include fine particulate matter, sulphur dioxide, ozone, nitrogen dioxide, and carbon monoxide (Health Canada, 2021).

Bird species are particularly vulnerable to air pollutants due to their lung structure, which facilitates one-directional airflow and enables them to take in air both while inhaling and exhaling (Adams, 2023). Although this lung structure allows birds to obtain twice as much oxygen in hypoxic environments, such as high altitudes, it also makes them vulnerable to air pollutants (Adams, 2023). Previous research shows that air pollution can affect bird species both physiologically and behaviourally (Sanderfoot & Holloway, 2017). Physiologically, exposure to air pollutants increases the likelihood of respiratory disease and illness (Sanderfoot & Holloway, 2017). Furthermore, wildfire smoke can increase avian stress levels and cause immunosuppression (Sanderfoot & Holloway, 2017). Yang et al. (2021) also list air quality, including the presence of nitrogen dioxide, sulphur dioxide, and carbon monoxide, as a major driver affecting migratory bird mortality. Behaviorally, pollution can result in decreased bird presence, availability, and detectability (Sanderfoot & Gardner, 2021). For example, in a study by Sanderfoot and Gardener (2021), wildfire decreased the probability of observing 37% of studied bird species.

Long-term air pollution also has cascading environmental effects, including reduced prey availability, such as arthropods, and foraging success (Brotons et al., 1998). As the house wren diet consists heavily of invertebrates (Grabarczyk et al., 2022), it is possible that increases in air pollution could similarly impact the resident house wrens at the Beaverhill Bird Observatory. While it is not the only factor influencing clutch size (Godfray et al., 1991), an early hypothesis by Lack (1947) suggests that clutch size is impacted by the food availability for future nestlings.

Therefore, a large clutch must also be sustainable to feed (Lack, 1947). If wildfire pollution diminishes food availability for house wrens, the average house wren clutch size would also presumably decrease.

In our study, we compared house wren breeding success over several breeding seasons and analysed the relationship between air quality, the total number of house wren nests, the average clutch size, and the proportion of nestling survival. Because air quality impacts birds behaviourally, physiologically, and may reduce prey availability, we predicted that there would be a greater number of house wren nests, a higher average house wren clutch size, and greater house wren nestling survival when air quality health risks were lower during the early breeding season.

Methods

We conducted our study in the Beaverhill Natural Area (BNA), near Tofield, Alberta, Canada, in the Aspen Parkland ecoregion (Nature Conservancy of Canada, n.d.). Within the BNA, we monitored ninety-nine house wren nest boxes, which are maintained by the Beaverhill Bird Observatory, and which were distributed within four grids, labelled A, B, C, and D. Grids A, C and D contained five rows of five nest boxes, and grid B contained three rows of eight nest boxes. Prior to data collection, the nest boxes were cleaned and repaired as needed. Weekly nest box checks commenced on May 21, 2023, with data collection typically occurring on Sundays. However, nest box checks were not conducted in the rain and were temporarily suspended between mid-July and early August due to flooding.

During nest box checks, nest activity was recorded as active (A) or inactive (I). If the nest box was active, the species present was recorded. Common inhabitants of the nest boxes included both house wrens and tree swallows (*Tachycineta bicolor*), but flying squirrels and bats were also observed. Nest boxes inhabited by house wrens generally contained twigs, leaves, and bark, while nest boxes inhabited by tree swallows generally contained long, dry grasses and feathers. House wren eggs were oval-shaped, dull blush pink, and mottled with a darker shade of brownish pink. Tree swallow eggs were more elliptical and were bright white. Active nest boxes were then differentiated as being built (B), containing eggs (E), or containing nestlings (N). If the nest was in the building stage, the box was differentiated as being lined (L), partially full (P), or full (F). Parental presence was also recorded as absent (A) or present (P). If a parent was present, we recorded whether the parent remained on the nest (R), flushed (F), or remained in the vicinity (V). If the parent remained, no further information for that nest box was recorded on that day to minimise disturbance. If eggs were present, the number of eggs was counted, and the temperature of the eggs was recorded as being warm (W) or cold (C) by gently feeling the eggs with the fingertips or knuckles. If nestlings were present, the number of nestlings was counted, and the age of the nestlings was estimated using a photo reference guide by Brown et al. (2013).

Checks were performed until house wren nestlings reached seven days old and tree swallow nestlings reached ten days old. In order to minimise early fledging, the nest boxes were not rechecked until one week after the oldest fledging age, which is approximately twenty-five days old for house wrens. Nest success was recorded if faecal matter was present and the majority of the nestlings appeared to have fledged. However, nests were recorded as failures if the majority of the nestlings were deceased, the majority of the eggs failed to hatch, or in the absence of faecal matter. The nest boxes were then emptied and cleaned.

Air quality data was obtained from the Air Quality Health Index (AQHI) (Government of Canada, n.d.) for May, June, and July of each respective breeding season. Lower AQHI values indicated better air quality, while higher AQHI values indicated poorer air quality (Government of Alberta, n.d.a). Data regarding house wren breeding success between 2013 and 2022 was collected, recorded, and shared by past interns from the BBO (Beaverhill Bird Observatory, 2022). However, there was no available intern data for 2016; therefore, the 2016 breeding season was omitted from the study. Clutch size data was filtered so that only nests initiated in May or June were included. The nests initiated in July onwards were considered to be second clutches and were omitted from the study, since second clutches tend to be smaller than first clutches (Kennedy & White, 1991). To eliminate the influence of other factors that could limit clutch size, we did not include nests that were parasitized, preyed upon, or otherwise destroyed during the laying period. However, if the clutch size was constant for more than one check prior to the destruction of a nest, the nest was included in the analyses.

Several correlation analyses were performed using Microsoft Excel 2010 (Microsoft Corporation, 2010) and the statistical computation website Vassarstats (Lowry, n.d.). Firstly, using the filtered clutch size data, we performed a correlation analysis between each season's average clutch size and the average air quality for May, June, and July of that year. This correlation analysis examined the clutch size for each breeding season between 2013 and 2023, excluding 2016. Secondly, a correlation analysis was performed between the number of initiated nests and the average air quality for the months of May and June. Nest initiation data from 2013 and 2014 was not included since all four grids had not yet been established prior to 2015. Lastly, a correlation analysis compared the proportion of nest success to the average air quality for May, June, and July. As with clutch size, nests that were initiated in July or were destroyed were not included in the success rate calculations. Any nest that had an uncertain or undetermined status was omitted from the study.

Results

In 2023, a total of thirteen house wren nests at the BBO contained eggs (Figure 3A). There were two nests in grid A, five nests in grid B, three nests in grid C, and three nests in grid D. Eggs were first observed on May 28, 2023, and none of the clutches included in this study were initiated after June 11, 2023. Two nests potentially contained new eggs on July 17 and August 2; however, the eggs may have been from a previous clutch and were assumed to be abandoned. Clutch size ranged from a minimum of five eggs (n=1) to a maximum of eight eggs (n=3). The mean clutch size was 7.1 eggs, and the mode clutch size was seven (n=9).

House wren nestlings were first observed on June 17, 2023. The latest date that new nestlings were observed was July 4, 2023. Brood size was recorded in eleven of the thirteen nest boxes. However, brood size was not recorded for the remaining two nest boxes. In one box, brood size was not recorded due to concerns that the nestlings had already passed fledging age before the nestlings were observed. In the second box, 1-2 day old nestlings were observed; however the brood size was unclear. The age of the nestlings observed during checks ranged from 1 to 7-8 days old. Observed brood size ranged from 1 - 8 nestlings (n=11), with a mean size of 5.8 nestlings. Ultimately, there were nine successful nests, three failed nests, and one nest of uncertain status which was omitted.

The relationship between the average air quality in May, June, and July and house wren clutch size was insignificant ($r(8) = 0.25$, $p = 0.48$; Figure 5A). The relationship between the average air quality in May and June and nest initiation was also insignificant ($r(6) = 0.11$, $p = 0.80$; Figure 5B). However, there were slightly positive trends between the average AQHI value and clutch size and the average AQHI value and nest initiation. The relationship between air quality in May, June and July and nest success was negative but insignificant (r(8) = -0.06, p = 0.86: Figure 5C).

Detailed house wren data from 2023 can be found in Appendix A and the raw air quality and house wren breeding data used in the analyses can be found in Appendix B.

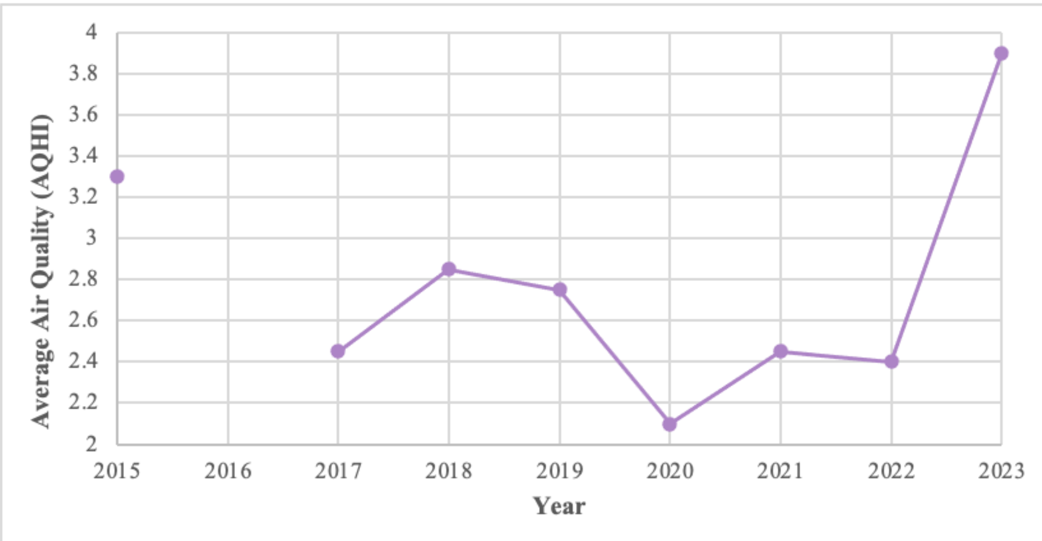

Figure 1A. Average Air Quality for May and June from 2013 to 2023*. The average hourly air quality for each month was used to calculate the mean air quality for the two-month span. *Although air quality data is available for 2016, clutch size data is unavailable, so that year was omitted from this graph.

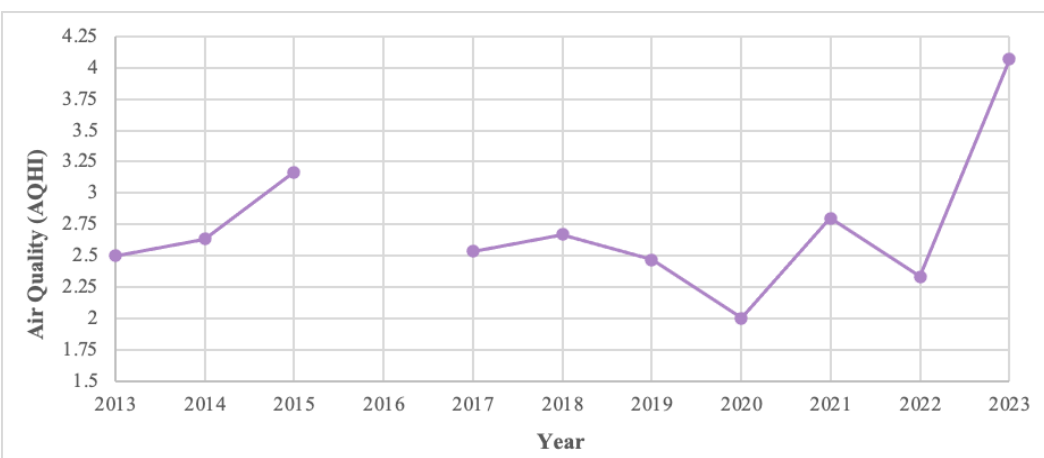

Figure 1B. Average Air Quality for May, June, and July from 2013 to 2023*. The average hourly air quality for each month was used to calculate the mean air quality for the three-month span. *Although air quality data is available for 2016, clutch size data is unavailable, so that year has been omitted from this graph.

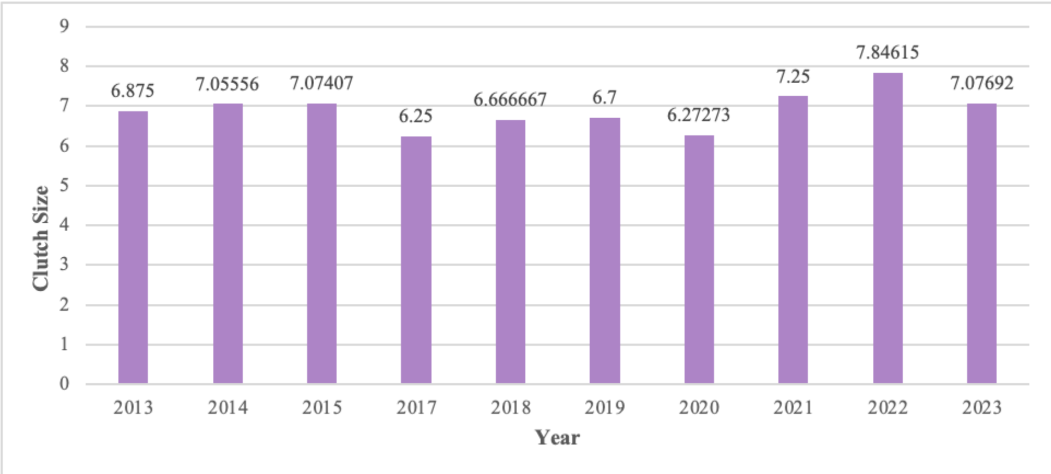

Figure 2A. Mean House Wren Clutch Size from 2013 to 2023*. *Data for 2016 is unavailable.

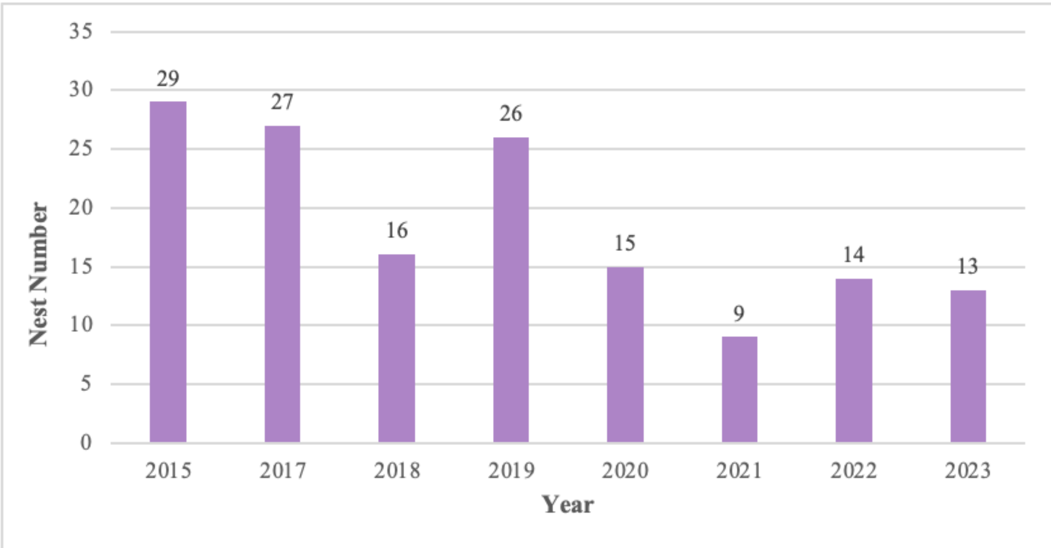

Figure 3A. House Wren Nests Initiated in May or June from 2015 to 2023*. This figure displays the total number of house wren nests initiated in May or June which contained eggs at the Beaverhill Bird Observatory between 2015-2023*. *Data for 2016 is unavailable.

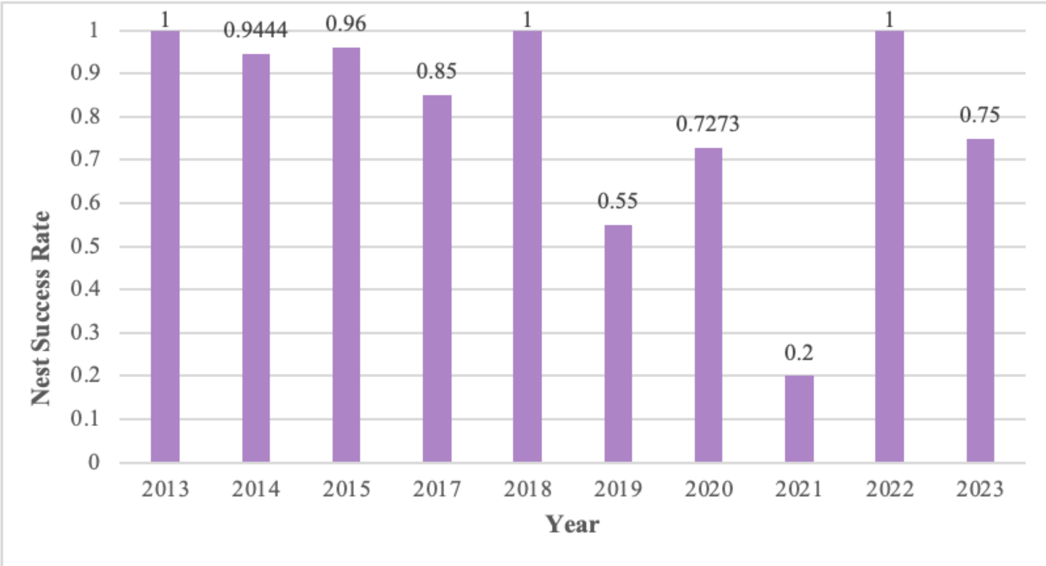

Figure 4A. House Wren Nest Success from 2013 to 2023*. This figure displays the proportion of successful house wren nests initiated in May or June at the Beaverhill Bird Observatory from 2013-2023*. *Data for 2016 is unavailable.

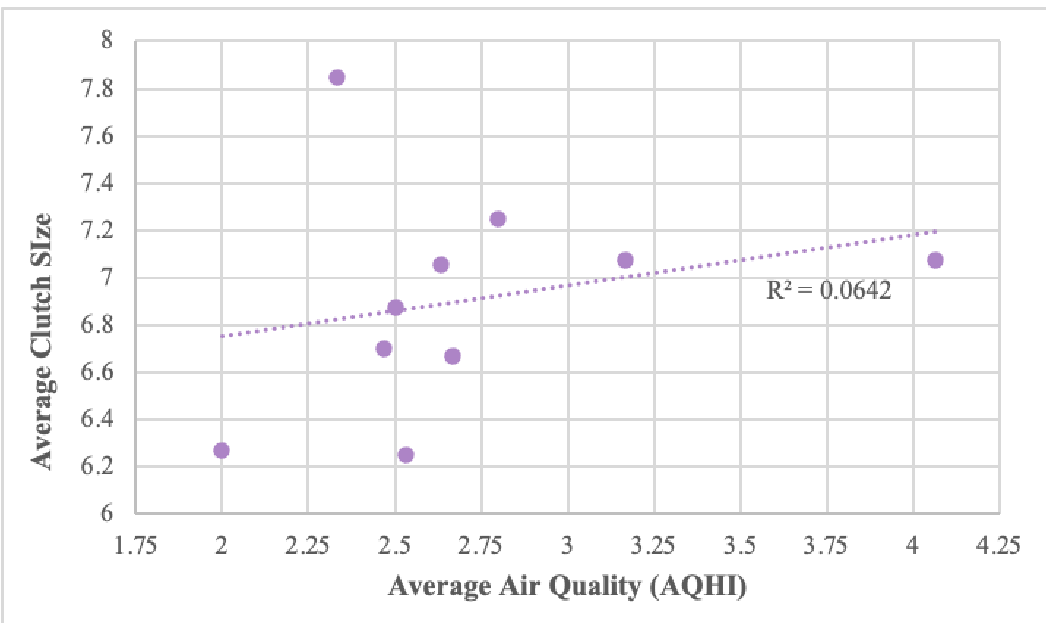

Figure 5A. Air Quality (AQHI) versus House Wren Clutch Size. This figure displays the relationship between air quality (measured using the AQHI) of May, June, and July and the average house wren clutch size.

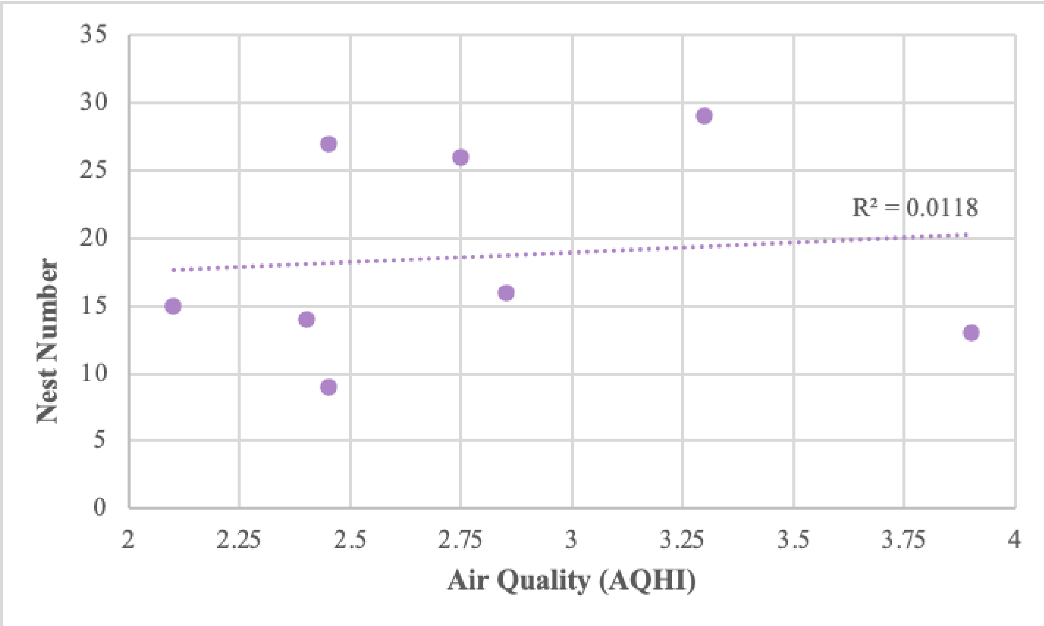

Figure 5B. Air Quality (AQHI) versus House Wren Nest Initiation. This figure displays the relationship between the average air quality (measured using the AQHI) in May and June and the number of house wren nests initiated in May or June.

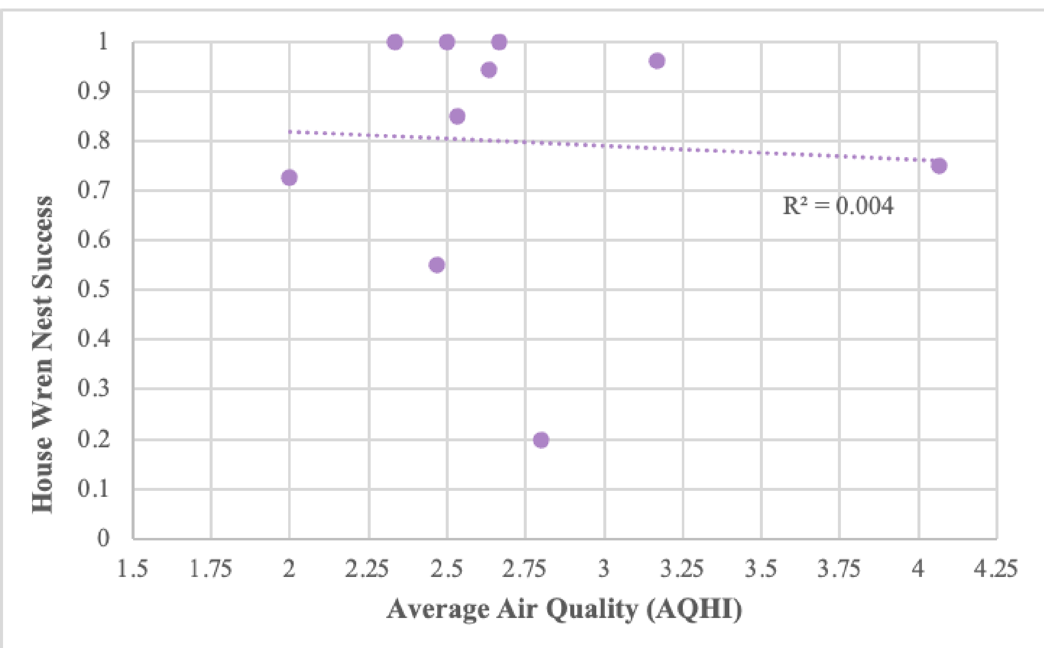

Figure 5C. Air Quality (AQHI) versus House Wren Nest Success. This figure displays the relationship between the average air quality (measured using the AQHI) of May, June, and July and the proportion of successful house wren nests.

Discussion

Contrary to our prediction, air quality did not have a significant impact on clutch size, nest initiation, or breeding success in house wrens. Barton et al. (2023) noted that most studies analysing the effects of pollution on terrestrial birds find at least one trait that is negatively impacted by decreased air quality. Therefore, it is unusual that we did not find at least one factor that was significantly impacted by the AQHI value. However, Barton et al. (2023) explain that the impacts of air pollution are often difficult to observe since air quality is not uniform spatially or temporally. Furthermore, a species' response to decreased air quality is difficult to separate from other environmental stressors (Barton et al., 2023). Therefore, it is possible that the results of the study were influenced by factors which were not accounted for.

There is also a possibility that higher AQHI values may not significantly impact external factors influencing breeding success, such as foraging rates, as we predicted. For example, one study observed greater reproductive success in great tits near emission sources because caterpillars, one of their primary food sources, were more abundant in those areas (Sanderfoot & Holloway, 2017). Therefore, decreased air quality may not necessarily decrease foraging success and breeding success. In order to determine the effects of air quality on foraging success in house wrens, further research would be required.

Furthermore, instead of observing a negative relationship between AQHI values and clutch size as originally predicted, we observed a slightly positive relationship between AQHI values and the average clutch size. This may be explained using a similar theory to the reproductive compensation hypothesis, which states that animals which mate under non-ideal circumstances, specifically with a non-preferred partner, will produce a greater number of offspring in order to improve the chances of offspring survival (Gowaty et al., 2007). During times of decreased air quality, a similar mechanism may encourage house wrens to lay more eggs to increase the likelihood of reproductive success.

Another possible reason why increased AQHI values did not have a significant impact on breeding success is that the nesting sites were not significantly disturbed. Previous research shows that air pollution can have varying impacts on species depending on their nesting habits (Barton et al., 2023). In one study, the nesting sites of ground-nesting birds were significantly disturbed by pollution and declined in frequency near a copper smelter, while bird species with tree-nesting habits were not significantly disturbed and became increasingly dominant near the copper smelter (Barton et al., 2023). Therefore, there may have been an insignificant relationship between the AQHI value, the average clutch size, nest initiation rates, and success rates because the tree-nesting habits of house wrens made them less susceptible to air quality disturbances.

Furthermore, a study by Reif et al. (2023) shows that the effects of ozone exposure on bird populations varied depending on the altitude of the monitoring site. While species at lower altitudes were not significantly impacted by ozone exposure, upland species experienced significant negative population growth due to increased ozone concentrations at higher altitudes (Reif et al., 2023). Therefore, the house wrens at the BBO may not have been significantly impacted by decreased air quality because their nesting sites were located at a sufficiently low altitude.

Finally, the results of our study were limited by a small sample size. In 2023, most of the house wren nest boxes were occupied by tree swallows, while only thirteen of the ninety-nine house wren nest boxes contained house wren clutches. In order to confidently determine the relationship, or lack thereof, between air quality and house wren breeding success, a larger sample size is required.

In future studies, the relationship between air quality and breeding success could be monitored in a variety of bird species in order to determine whether the effects of air quality are common across species. Also, an expanded geographical region of study would aid in identifying whether or not proximity to pollution sources alters the effects of pollution on breeding success.

Conclusion

Anthropogenic climate change has significantly contributed to the drying of landscapes, which has prolonged the wildfire season by twenty-six days between 1979 and 2015 (Abatzoglou & Williams, 2016). In 2023 alone, approximately one thousand wildfires burned 1.8 million hectares of land in Alberta (Government of Alberta, n.d.b). In order to mitigate the effects of climate change, it is important to understand the effects of wildfires and the consequent increases in air pollutants on the health and behaviour of wildlife. Although previous research provides evidence that decreased air quality negatively impacts bird behaviour and health, the results of our study showed an insignificant relationship between AQHI values, nest initiation, clutch size, and nest success rates. Due to the variation in findings, further research is required to better understand the spatial and temporal effects of reduced air quality, both between and within species, and the factors determining the magnitude of these effects. By understanding the effects of air quality on breeding success, we will not only better understand the ecological consequences of climate change, but we will also be able to implement educated conservation efforts to better protect house wren populations.

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Appendix A

Grid	Box	Eggs	Nestlings	Success/Failure
A	B5	7 (June 4), 8 (June 11)	7 (June 25, 7-8 days old)	Success (July 17)
	E4	6 (June 4), 7 (June 11)	1 (June 17)	Success (July 17)
B	A5	3 (May 28), 7 (June 4)	7 (June 17, 5 days old)	Success (July 9)
	B1	3 (May 28), 8 (June 4)	8 (June 17, 3 days old)	Success (July 9), 3C eggs remained*
	B5	7 (June 11)	7 (June 25, 1 day old)	Success (August 2)
	C1	6 (June 11), 7 (June 17)	6 (June 25, 1 day old)	Failure (August 2)
	C6	1 (June 4), 7 (June 11)	5 (June 25, 2-3 days old) Recorded as "~5" in the data.	Success (July 17)
C	B2	3 (June 4), 7 (June 11)	6 (June 25, 4 days old) Recorded as "≥6" in the data.	Failure (July 17)
	D3	4 (June 11), 7 (June 17)	7 (July 4, 7 days old)	Success (August 6)
	E2	7 (June 11)	Unknown**	Success (August 6)
D	B2	7 (June 4), 8 (June 11)	Unknown***	Uncertain****
	D4	2 (June 11), 6 (June 17), 7 (June 25)	7 (July 4, 3 days old) Not checked after this, as they would have been older than 7 days.	Failure (August 6)
	E1	4 (June 4), 5 (June 11)	3 (June 25, 6-7 days old)	Success (July 17). One egg remained.
Summary		Mean clutch size = 7.07692	Mean brood size upon observation = 5.81818	Success rate = 0.75

Appendix A. House Wren Data for the 2023 Season. Detailed data on nest location, clutch size, brood size, and nest success for the thirteen house wren nests during this season of study. *A new nest may have been initiated in this box on August 2 (E3C recorded). On August 6, the eggs were cold and there were spiderwebs in the nest, so it was assumed to be abandoned. It is unclear if these three eggs were from the original nest or if they were new. **The number of nestlings was unknown when the box was checked on June 25 and the nestlings were 1-2 days old. The nest box was not checked after this as they would have been older than 7 days old. There could have only been a maximum of six nestlings, since one unhatched egg remained in the nest after fledging. ***Only eggs were observed in this box. Due to concerns the nestlings would already be too old to check, the box was never checked when nestlings were present. ****Six cold eggs were in the nest on July 17, and it was unclear if they were from a first or second clutch. It was recorded as a “possible failure” in the data sheet. On August 6, the box was rechecked and four of the six eggs had holes in them and were assumed to be abandoned.

Appendix B

Year	Average Air Quality for May and June (AQHI)	Average Air Quality for May, June, and July (AQHI)	Nest Number	Average Clutch Size	Nest Success Rate
2013	*	2.5	*	6.88	1
2014	*	2.63	*	7.06	0.94
2015	3.3	3.17	29	7.07	0.96
2017	2.45	2.53	27	6.25	0.85
2018	2.85	2.67	16	6.67	1
2019	2.75	2.47	26	6.7	0.55
2020	2.1	2	15	6.27	0.73
2021	2.45	2.8	9	7.25	0.2
2022	2.4	2.33	14	7.85	1
2023	3.9	4.07	13	7.08	0.75

Appendix B. Summarised air quality and house wren data used in the statistical analyses. Data for 2016 is unavailable. *In the test pertaining to nest number and air quality in May and June, the 2013 and 2014 breeding seasons were omitted from study since all four grids had not yet been established.