# Ruling the Root: Developing Thermally Optimal Roosts to Enhance Microbat Population Biodiversity

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BIOLOGICAL SCIENCES TECHNOLOGY – RENEWABLE RESOURCES

ALTERNATIVE ENERGY TECHNOLOGY

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## Abstract

Our research objective was to design a thermally-optimal bat roosting box to increase microbat survival of two federally-endangered species in North America: the Little Brown *Myotis* (MYLU) and the Northern *Myotis* (MYSE); our research project was based at the Lehigh Hanson Cadomin Limestone Quarry. We designed three prototypes, each improving from the last, and compared their thermal-stabilization potential to classic bat box designs. The data were recorded within an environmental chamber calibrated with ambient temperatures based upon conditions from previous roosting research in the testing area; internal temperature and relative humidity data were also collected in the field on domestic land outside of Edmonton with HOBO H8 data loggers. Our analysis compared the recorded internal temperatures of the boxes within the environmental chamber to a reference point of 29.2℃ and concluded that our latest prototype was more efficient at stabilizing its internal temperature, due to it never exceeding the reference point. In comparison, the classic bat box designs exceeded the reference point 60% of the time, and our version two prototype exceeded that temperature 30% of the time. For the preliminary field testing, the PCM prototype (our latest prototype) was the most efficient with internal temperatures exceeding 29.2℃ 0.17% of the time, while the classic design boxes exceeded the reference temperature 14% of the time, and 8.7% for the version two prototype. We have concluded that our PCM prototype is the most efficient at stabilizing its ambient internal temperature. Field-testing is currently underway at the Lehigh Hanson Cadomin Limestone Quarry site and will be retrieved and analyzed in spring of 2019, since we will be monitoring the boxes annually.

## Introduction

Bats are enigmatic microfauna that evoke fear and disdain, swayed by cultural superstition and myth. Their voracious appetite for insect pests enhances agriculture and forest productivity, saving billions of dollars per year [4]. This is significant when considering the long lifespan and low fecundity of MYLU [7]. Bats are increasingly threatened by habitat alteration, direct mortalities, persecution, disease, and climatic changes [4]. White Nose Syndrome (WNS) is a disease with a catastrophic impact on the hibernating species of bats in eastern Canada and the United States. It is caused by an introduced pathogenic fungus, *Pseudogymnoascus destructans*, growing on the hibernating bats' wings and bodies; this causes frequent arousals while hibernating, resulting in emaciation and death [11]. The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) reported Canada as representing ~50% of the global range of MYLU before the arrival of WNS [5] and, since its arrival in North America, COSEWIC cites a >90% decline of MYLU, suggesting a loss of 5.7-6.7 million bats in eastern Canada [5]. Since WNS was recorded in Washington State in 2016, and recently confirmed in South Dakota and Manitoba during 2018, the disease is at our proverbial doorstep and action plans are essential to support the survival of these economically-vital species. With the optimal growth range of *Pseudogymnoascus destructans* being between 12.5-15.8℃, we aim to control and stabilize the internal microclimate of the roost in such a way that it could impede the growth of the fungus using our thermally-optimized bat roosting box. Using a biologically suitable target of 29.2℃ within the prototype bat roosts, pre-hibernation fat storage will maintain or increase in bat species; thus, increasing the probability of survival from WNS.

Various roost conditions are required post-emergence from the hibernacula [8 & 10]; although the specific requirements remain unclear, they are presumed to depend on gender, reproductive state, forage availability, ambient conditions, species, and individuals [10]. A substantial amount of previous research related to anthropogenic structures, such as the bat box, is based on warmer southern habitats leaving a quantifiable data void in northern communities [9]. Artificial roosting locations that reduce the amplitude of daily thermal cycling in northern fringe populations may be key in ensuring survivorship. With roosting locations that stabilize thermal cycling throughout the roosting period, behavioral thermoregulation (repositioning and shivering) may lessen, resulting in healthier, heavier bats that may survive additional waking periods linked to WNS. Provision of artificial roosts is a critical step towards ensuring the stability of these bat species. However, merging suitable roost placement with site habitat enhancements, including onsite pond creation that provides foraging opportunities, and incorporation of geophysical attributes, may provide a successful blend with legislated quarry end-use planning initiatives in the future.

The Lehigh Hanson Cadomin Quarry is in an ideal location to provide measurable species recovery support. It is located in the Montane and Foothill subregions of Alberta and was selected as the location of our project due to its close proximity to a known hibernacula in the Cadomin Caves [1 & 2]; thus, species within this given area exhibit cavernicolous behaviors, meaning they hibernate or inhabit caverns. Enhanced species and biodiversity management in and near the quarry site are recommended due to the presence of MYLU and MYSE, both federally-endangered species. Additionally, bats also exhibit talus roosting, which is roosting in crevices of large rocks and debris. Since the quarry creates those spaces for bat roosting amidst overburden, it could be another good opportunity to increase microbat biodiversity when reclaiming the site. Lastly, further understanding is required regarding maternal and day-roosting microclimates in order to combat the devastating effects of WNS on hibernating colonies. Healthy maternal and day roosts support population recovery and are the first defense that promote building adequate lipid (fat) reserves, which assist in the winter survival of the species, with or without WNS impacts.

This project was run by a team of volunteers, consisting of students and alumni from the Northern Alberta Institute of Technology (NAIT), and was supported by many of our partners (Appendix 2). Some of the work involved with this project included the construction of boxes from classic designs, prototype design and development, Thermotron testing, field testing, public speaking, field placements, sensor development, and written aspects.

A two-stage research design was used with the objective of creating bat boxes that will bolster the survivorship of the *Myotis* species within the Lehigh Hanson - Cadomin operation. Stage one included the design and development of our thermally optimal bat roosting box prototype. Our prototype was also tested against classic bat box designs. While stage two included the establishment of our prototype on the quarry site; both stages have been successfully completed.

## Stage One

The first stage included the design, engineering, and controlled testing of bat boxes with microclimatic designs to optimize spring and summer thermal-regulation. While some sources prefer the term bat house, others prefer the term bat box as a real and representative term of the structures often created. While both terms can be synonymous, we opted for the term bat box as we believe that this has a better representation of its purpose in augmenting a bat's roosting behaviors. It should also be noted that our prototypes and the classic bat box designs are not a replacement for natural bat habitat, but rather a mitigation for declining bat populations and lipid preservation in shoulder seasons.

→ Classic box designs were tested against the prototypes in an environmental chamber using ambient thermal temperatures measured near the quarry site to approximate the conditions expected throughout the roosting period. An environmental chamber was used to reduce confounding variables field-testing may record and increases the potential testing scope facilitating suitability assessment for *Myotis* boxes across the Heidelberg Cement group quarries.

Stage Two

The second stage established bat boxes on the quarry and plant site to field-test the microclimatic conditions and attempted to capture the start and end of the hibernation period due to its variable timeline.

→ As there are more than 12 significant forage sites within 0.1 and 6 km of the active quarry and plant operations, this project will position Lehigh Hanson as a leader in providing and protecting suitable roosting habitat for the endangered *Myotis* species.

There were three objectives for this research project:

1) Development of a thermally-stable roost prototype
2) Provide healthy roosting areas for the two species of interest
3) Conduct ongoing monitoring of the prototype's roost occupancy

## Methods

### *Classic Design Development*

Classic bat box designs were constructed by the team to contrast the thermal stabilization potential of these boxes against our prototypes (Appendix 3 and 11). Each box was made from construction-grade wood and treated as per regional recommendations. The classic designs built included multi chambers and rocket boxes, and followed Bat Conservation International designs [12].

### *Prototype Design and Development*

Three bat box prototypes were built to contrast thermal cycling with classic bat boxes (Appendix 4). The third prototype, our latest, includes Infinite R$^{TM}$: Phase-Change Material (PCM) as an insulator, supplied by one of our project partners, INSOLCORP©. This material is very efficient in altering interior temperatures based on outside environmental conditions (which preserves internal heat in cold temperatures and reduces thermal gain in hot temperatures). (Appendix 3 and 11).

### *Environmental Chamber Testing*

In-situ testing of the thermal ambient conditions was conducted in a Thermotron walk-in environmental chamber (Appendix 5) with a 24-hour thermal regime that approximated conditions from previous roost research along Alberta's Rocky Mountains (Appendix 6). This allowed us to closely assess conditions that our boxes would experience and provided insight on the fluctuation of internal temperatures of both the prototypes and classic designs prior to field placements. Internal heaters were used to build daily thermal curves as well as a 2kW halogen lighting array that heated and provided solar gain to assess sunlight positioning and shading effects. Internal microclimatic conditions were measured and evaluated statistically between the prototypes and the classic designs. Each testing phase was replicated three times to ensure statisticallydefensible results. Bat boxes were also tested individually to reduce convective air current influence between boxes.

### *Preliminary Field Testing*

Prior to field placement at the quarry site, we placed prototypes version two and three, one multi chamber, and one rocket box on an acreage outside of Edmonton (Appendix 7). Temperature data were recorded for the two latest prototypes, as well as the two classic roosting box designs (multi chamber and rocket box) using HOBO data loggers. However, data were only collected from three of the boxes, due to a datalogger malfunction within the rocket box. It should also be noted that on May 23rd, 2018, outdoor temperatures exceeded our reference point based upon local Environment Canada weather station data. This is notable because on this day, solar gain contributed to the heating of the boxes resulting in temperatures approaching 40℃ in the multi chamber boxes. Additionally, field-testing has only provided us with cooler spring temperatures, as opposed to high-heat temperatures that we have tested in the Thermotron. Future field testing incorporated redundant data logger systems to ensure complete data sets.

### *Site Selection*

The location of the bat stand was selected based on microclimate stability, avoiding active operations, and future site developments (Appendix 7). Mounting the bat boxes in the same location was completed to ensure repeatability and consistency within the data collected, rather than dispersing the boxes throughout the quarry site. We compiled weather data from the Luscar Environment Canada weather station (Appendix 8) from 2014-2018 from May to October, which reflects bat box usage times. Maximum ambient temperatures from August 2018 reached 31℃, and a minimum of -18.6℃ in May of 2015 (Appendix 8). From this, the average ambient air temperature is recorded to be 9.5℃ over the 4.5-year sample period. This information allowed us to understand the range of summer roosting temperature fluctuations that the microbats would need to cope with biologically and behaviorally before the prototype bat box was deployed.

### *Stand Design and Development*

The stand was designed and constructed with the help of the Lehigh Hanson Cadomin Quarry staff and was made entirely of upcycled materials from the quarry site. The stand included a cable spool with eight vertical drilling stems along its perimeter and one taller central drill stem for box placements (Figure 1). Every second post height was varied on the stand to avoid impeding sunlight exposure from box to box and to optimize potential solar gain on site.

*Figure 1.* A conceptual design of the stand prior to its construction (1a) and the bat stand with eleven boxes mounted onto it for field testing at the quarry site (1b).

### *Annual Field Deployment at the Cadomin Limestone Quarry*

In August 2018, the team mounted two prototypes as well as nine other bat boxes from classic designs, each with three different treatment types: painted, burnt, and raw wood (Appendix 9). The painted boxes were covered with black paint, the burnt boxes were charred as per traditional Shou-Sugi-Ban techniques, and lastly, the raw wood boxes were left with no additional treatments. Of the classic designs, three rocket boxes, three multi chambers, and three small multi chambers with guano traps were installed (Figure 1); the three small multi chambers were successful previously in Isaac Creek, Alberta, and were installed based on local knowledge and resource officials' input on the project. The boxes were mounted using flexible metal strapping, screws, and wood wedges for stabilization; it should be noted that the rocket boxes were simply slid over the poles and stabilized with wooden wedges. Two HOBO H8 data loggers recording temperature and relative humidity were secured inside each box prior to the placement on the stand. Additionally, bat counters were installed on each side of the landing pad; this included a 'trip wire' sensor created by infrared beams that will record the number of warm-blooded occupants in each box. The bat counters also included external and internal temperature sensors, and light sensors to measure time of day in relation to temperature and overall sunlight exposure of the boxes.

## Results

To analyze the data recorded, we compared the internal temperatures of the boxes to a reference point of 29.2℃, as this was the phase-changing point of the PCM selected to avoid bat overheating and maintenance of temperatures suitable for decreasing WNS growth. Upon analyzing the mean hourly data collected from the Thermotron, it was observed that the rocket boxes, the single chambers, and the multi chambers all had internal temperatures exceeding 29.2℃ 60% of the roosting time, while the version two prototype only exceeded that temperature 30% of the time. Our latest prototype with the PCM as an insulator, however, exceeded that temperature 0% of the time, making it the most efficient (Figure 2).

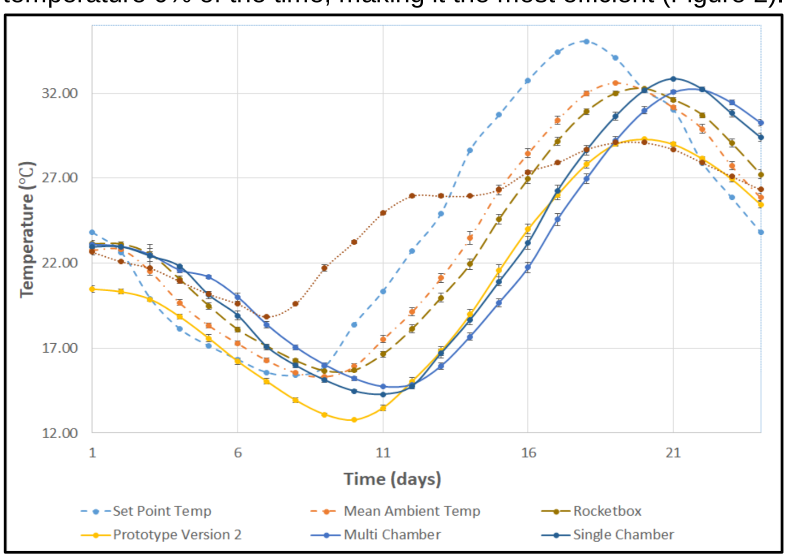


*Figure 2.* Hourly thermal response for bat box designs tested using a Thermotron WS-664 CHM 30-30. (Error bars represent Standard Error)

Upon completion of the Thermotron data analysis, we conducted the same analysis on the data collected from the preliminary field test, which took place over 22 days between May 5th - 27th, 2018. We compared the mean hourly data from the temperatures recorded within the boxes in relation to the 29.2℃ reference point of the PCM (Figure 3). It was observed that the multi chamber had internal temperatures exceeding the reference point 14% of the time, while the version two prototype exceeded 29.2℃ 8.7% of the time; the latest prototype with PCM only exceeded that temperature 0.17% of the time (Figure 3 & 4). Data were only collected from three of the four boxes placed (multi chamber, version two prototype, and PCM prototype) due to data logger malfunction within the rocket box.

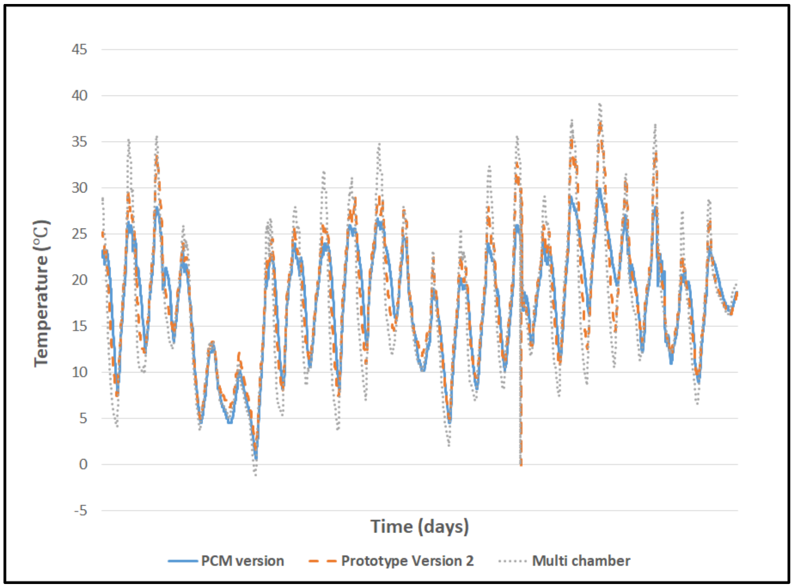


*Figure 3.* Daily thermal response for bat box designs tested during preliminary field testing from 8:00-20:00, on May 5th to May 27th, 2018.

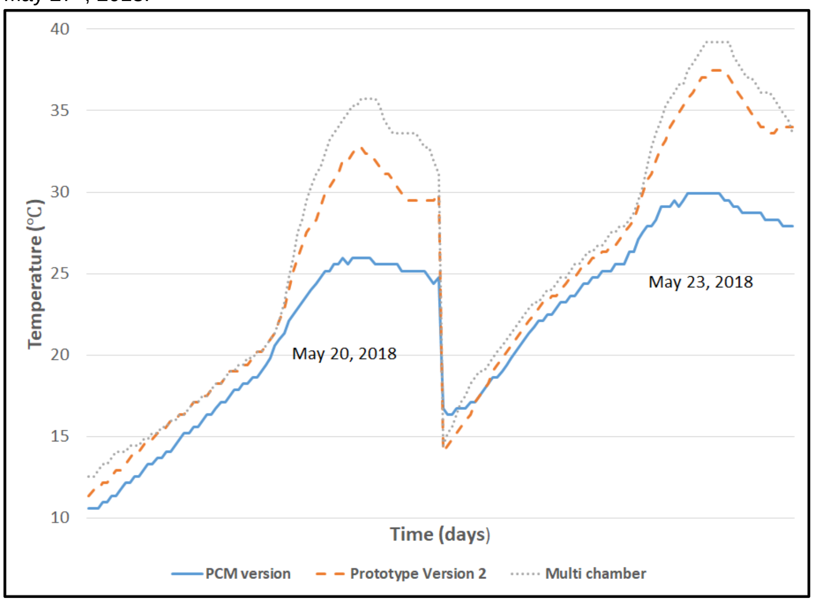


*Figure 4.* Compressed mean daily thermal response during roosting period of preliminary field trial (08:00 - 20:00) May 20th and 23rd, 2018 added for clarity.

## Discussion

### *Analysis of Results*

The results obtained from the Thermotron and preliminary field-testing data trials have provided critical microclimatic information related to the internal temperatures within our most recent prototype (version three). These microsite temperatures are directly correlated to the external ambient conditions as we opted to not connect the solar heating system in the first field trial to evaluate power system failure against classic designs. Because this is an annual project, we will be extracting higher temperature data in the field season of 2019 in order to receive a better understanding of our boxes' performance to high-heat summer temperatures at the quarry site. These data should give us additional support about the thermal regulation performance of our prototype when compared to the other classic boxes, and will provide us with an idea of bat roost preference in relation to occupancy. Roost preference incorporates bio-thermal regulation, which is heat-generated from biological process of the microbats and their behavioral positioning, and is primarily found as characteristics of gregarious (congregating) roosting species. Currently we have not been able to assess the impacts of this bio-thermal regulation and aim to collect further data on this in future field seasons on this project.

The results we have obtained for the classic bat box designs indicated that they were very inefficient in controlling their internal temperatures, based upon varying outside ambient temperatures. Poor thermoregulation properties that were recorded within the classic designs from both the Thermotron and preliminary field-testing results is associated to their lack of insulation and construction materials. These classic designs yielded poor thermoregulation results; this was also observed in a study conducted in May 2018 by Canadian researchers Webber and Willis from the University of Winnipeg [13]. They monitored 34 captive female MYLU to determine if the ambient temperature of roosts affected their roost preferences. Upon the completion of their data analysis, they determined that artificially-heated roosts were preferred by MYLU, as opposed to unheated roosts, and that occupancy was lower when the roost temperature exceeded the ambient outside temperature [13]. These results are similar to our findings, as the classic designs were very inefficient in controlling microclimates as opposed to our prototype.

Our results support that the PCM insulator was the most efficient at controlling and stabilizing internal temperatures of the boxes when compared to the classic designs even without the inclusion of the heating element in the current data set. A study conducted in 2017 in Toronto and Vancouver had similar results when looking at PCM in terms of thermal energy storage in buildings [3]. It was determined that the use of PCM as an insulator in buildings resulted in 29% cooling success in Toronto. In Vancouver, closer to the location of our boxes in western Canada, PCM was reported to have 59% cooling success [3]. Furthermore, this reaffirms our hypothesis of the success that PCM has in its ability to mitigate changes in internal temperature.

Similar to a previous Quarry Life Award research project done in Australia that looked at the ability of roosting boxes as a means of conserving populations of tree-roosting microbats [6], our objective is that this project will instigate similar conservation practices here in Canada. The use of anthropogenic roosting structures, such as the bat box, provides an additional area of refuge for roosting bats to further determine the success of bat boxes as a conservation tool [3]. With the incorporation of annual monitoring, we aim to determine specific benefits that our prototypes will provide to the Cadomin Limestone Quarry site.

### *Benefits to the quarry*

Current benefits to the Cadomin Limestone Quarry:

1) This project will position Lehigh Hanson as a leader in providing and protecting suitable roosting habitat for the endangered *Myotis* species. This is done by implementing our prototypes on the site to increase microbat occurrence and biodiversity in the area, which could be ecologically-beneficial and significant to the quarry.

2) Some bats also exhibit talus roosting, which is roosting in crevices of large rocks and debris; mid-flight roosting diversity is essential to healthy populations. This project augments talus, cave and forest roosting sites and supports a multitude of species. The Cadomin Limestone Quarry site offers ample space for talus roosting due to the production of large rock debris piles and leaving it on site in rock dumps. With subtle positioning preplanning this could be another benefit for bats and the quarry by creating more roosting opportunities. Ultimately, this would reduce cost for the debris management, with less crushing of overburden, and could also be adopted into future reclamation plans of these sites.

### *Recommendations for Future Project Development*

There are several implementations that could be used for further project development on the Cadomin Limestone Quarry.

1) Maintain and manage boxes placed on the quarry site
As a result of the potential annual monitoring on site, continued management of both the boxes and the stand must be conducted to ensure the data being collected remain consistent and accessible for future prototype enhancements.

2) Assess cement-based bat box prototypes on quarry site rock walls
Refocus bat box development to incorporate cement-based components as either thermal ballasts or complete boxes. The use of a limestone product will potentially provide thermal stability and align with cavernicolous species roosting patterns. Further assessment of powered heating systems may need to be pursued to ensure thermal suitability.

3) Restructure existing out-of-production resource extraction shafts into artificial hibernacula
In addition to providing thermally optimal roosting locations, we suggest monitoring environmental conditions in both the local hibernacula and out of production, mine shafts to optimize potential for repurposing these areas into artificial hibernaculum. Provision of roosting microsites and bat-friendly access while preventing public access will be of primary consideration moving forward.

4) Assess bat activity and species composition on quarry site acoustically.
Current acoustic technology allows for annual deployment of bat detection equipment that will assist in understanding microbat movements on the quarry site. Understanding timing and movement patterns will enhance mitigation planning that supports species use and survival. This aligns strongly with local governing agency mandates.

## Conclusion

We have successfully achieved two of our research objectives: designing and constructing a thermally-optimal bat roost prototype and providing a healthy roosting area for two of the endangered bat species in North America. Our third objective, which is to monitor occupancy and roosting success in our prototype, will be pursued annually and assessed during the summer of 2019 forward. Our PCM prototype is the most efficient at controlling and stabilizing its internal temperatures when compared to classic construction methods and traditional bat box designs. Furthermore, there is currently no need for external grid powered heating systems and a dramatic reduction in maintenance requirements for the annual deployment of this prototype.

One potential drawback on the prototype design is the price point at ~$1600.00 CAN. Corporations and governing agencies will likely be aligned to support this quality of bat box rather than most home owners. Along the northern extent of the Myotis distribution, in North America, the land is managed primarily by government and large scale industrial operations which aligns closely with the microbat needs near active hibernacula. Moreover, shifting from the prototype development phase to a market phase will lower manufacturing costs.

Continuing our project and the monitoring of our boxes and prototypes on the Cadomin Limestone Quarry site is not only beneficial to the quarry site, but it is also important in order to enhance population biodiversity of the *Myotis* species within this area. Through using a biologically suitable internal microclimate temperature (29.2℃) within our prototype, we will facilitate the accumulation of the pre-hibernation lipid storage of this species; thus increasing their probability of WNS survival. The integration of our prototype on the quarry site will provide us with the means necessary to further our research towards providing the most thermally-optimal bat roosting box. Subsequent sampling seasons will facilitate minor adjustments that can be made to enhance occupancy and bat box success for the Myotis species across the Heidelberg Cement group's international footprint.

Our final project component involves public education through outreach. The team continues to link the Quarry Life Award page through social media and has delivered several talks to the general public across Alberta with stakeholders interested in the mitigation potential of the boxes. Involvement of government, not-for-profit, and general public stakeholder groups will greatly enhance the potential success of this project into the future. The team plans to continue their effort talking with school groups and other academics to ensure greater understanding of the role we will all play in the survival of the Myotis species by building enhanced habitat that combats the impacts of WNS.

## 1. Contestant profile

| | |
|---|---|
| ▪ Contestant name: | **Dave Critchley (Team Supervisor)** |
| ▪ Contestant occupation: | Program Chair and Restoration Ecologist |
| ▪ University / Organisation | NAIT (Northern Alberta Institute of Technology) |
| ▪ Number of people in your team: | 8 Primary and 5 secondary contributors for 13 total participants |

## 2. Project overview

| | |
|---|---|
| Title: | Ruling the Roost: Developing Thermally Optimal Roosts to Enhance Microbat Population Biodiversity. |
| Contest: (Research/Community) | Research |
| Quarry name: | Lehigh Hanson Cadomin Quarry |

**Project tags (select all appropriate):**

This will be use to classify your project in the project archive (that is also available online)

Project focus:

☐Beyond quarry borders
✓Biodiversity management
✓Cooperation programmes
☐Connecting with local communities
✓Education and Raising awareness
☐Invasive species
☐Landscape management
☐Pollination
✓Rehabilitation & habitat research
☐Scientific research
☐Soil management
✓Species research
☐Student class project
☐Urban ecology
☐Water management

Flora:

☐Trees & shrubs
☐Ferns
☐Flowering plants
☐Fungi
☐Mosses and liverworts

Fauna:

☐Amphibians
☐Birds
☐Insects
☐Fish
✓Mammals
☐Reptiles
☐Other invertebrates
☐Other insects
☐Other species

Habitat:

✓Artificial / cultivated land
✓Cave
☐Coastal
☐Grassland
☐Human settlement
☐Open areas of rocky grounds
☐Recreational areas
☐Sandy and rocky habitat
☐Screes
☐Shrub & groves
☐Soil
☐Wander biotopes
☐Water bodies (flowing, standing)
☐Wetland
☐Woodland

Stakeholders:

✓Authorities
✓Local community
✓NGOs
✓Schools
✓Universities