Recommendations for use of artificial bat roosts and acoustic lure technology

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Introduction

Artificial bat roosts are commonly deployed to aid bats. However, these increasingly popular conservation tools can pose a risk to bat safety and health in certain environments[1]. Some bat box designs overheat (internal temperatures >40°C [104°F]), leading to bats experiencing heat stress or dying[2–5]. When artificial roosts are poorly designed or placed, they may offer less suitable microclimates than the natural tree hollows and crevices to which bats are adapted[6–8]. Climate change adds another layer of risk to this problem and may compound the risk of heat stress to bats in artificial roosts[1,9–10]. Unfortunately, there is still much uncertainty about optimal artificial roost design and placement, which will vary by species and landscape[1]. Therefore, while artificial roosts provide valuable alternative habitat, they should not be considered a panacea for inadequate natural roosting habitat. Even when bats readily use artificial roosts, individual animals may switch to suitable natural roosts on occasion, so it is important that both are present. Here, we provide 1) suggestions and strategies to reduce overheating risk, backed by empirical research, with the goal of improving the safety of artificial bat roosts for bats, 2) a cost assessment for different components related to artificial roost use, and 3) materials lists and protocols for the artificial roosts, acoustic lures, and monitoring techniques used in NDCEE Project 20-10124[11].

Artificial roost placement

High solar exposure can increase artificial roost temperature and overheating risk[5,12-13]. Because maternal bats typically select solar-exposed artificial roosts over shaded alternatives[14-15], we recommend roosts receive some shade during the hottest part of the day. For example, roosts positioned near tree lines to provide shade for part of the day have been successful[5].

Various aspects of bat ecology should be considered when placing artificial roosts. For example, small bat species frequently fly directly to the trees upon emergence. When bats emerge at dusk, they are still at risk of attack by diurnal predators that can hunt by the waning light. However, insect abundance also peaks at dusk, so bats must balance increased predation risk with the advantages of easier access to insect prey[16]. To address this risk, bats tend to forage in or near trees early in the evening, where they may be safer from predators. Placing artificial roosts near tree lines may help further mitigate predation risk.

Consider the known travel distances of the target species. Roost uptake will likely be faster if roosts are within the typical nightly commuting range for bats emerging from known, occupied roosts. For example, home ranges of little brown bats (*Myotis lucifugus*) can exceed 30 ha, with minimum flight distances exceeding 2.5 km, and greater activity closer to roosts post-parturition than during pregnancy[17]. Foraging areas northern long-eared bats (*Myotis septentrionalis*) can exceed 6 ha[18], with home ranges documented larger than 65 ha[19]. When attempting to relocate bats from one part of a property to another, the distance between the two sites should be less than or equal to the typical nightly travel distance of that species.

Placing roosts in or near ideal foraging habitat should increase the likelihood of uptake and ensures bats are not unduly stressed by needing to commute long distances to foraging sites. Passive acoustic surveys will yield information on areas of high foraging activity across an installation. We recommend conducting spatially distributed acoustic surveys for at least 4 nights with warm and dry conditions during the maternity season (e.g., May–August in much of the temperate zone), ideally simultaneously, at various sites under consideration for placement of artificial roosts. The areas with the highest acoustic activity for the target species should be prioritized for artificial roost placement. Though artificial roosts do not need to be directly adjacent to water, close proximity to water is still important, especially for maternal females who need to visit water more frequently to support milk production. Many bat species also prefer to forage on aquatic insects emerging from streams, ponds, and lakes, which should be considered in site assessments.

When evaluating sites for installing artificial roosts, it is important to consider bats' sensitivity to disturbance. Ideally, roosts will be located away from high-activity training areas so noise and lights do not disturb bats. While bats may sometimes roost in areas with human disturbance (e.g., in buildings in urban areas), these could be stressful roosting situations and negatively impact bat health. We further recommend avoiding areas where pesticides or other toxins are used, as these chemicals could be harmful to bats. Because individual bats eat many insects per night, bats may accumulate pesticides that are sprayed on their insect prey. Pesticides tend to bioaccumulate in the fat tissues of animals and could even be passed from mothers to nursing pups.

Number of artificial roosts to deploy

Artificial roost uptake and use will be higher when roosts are placed in clusters (i.e., a few feet apart) and when multiple roost clusters are placed on the landscape. Bats perceive a cluster of bat boxes as one roost site, switching among structures daily in a fission-fusion fashion observed for many bat species[20]. Frequent roost switching allows bats to select ideal microclimates and to avoid overcrowding and an accumulation of parasites that may occur in heavily used roosts. When a colony of bats identifies certain designs as high quality, such that they are preferred over other designs or natural roosts, we have observed that the colony will form a search image for this structure type and more readily use the same design wherever it is installed on the same landscape.

Seasonal considerations and energy costs for bats

Bats' energetic demands vary across the maternity season, as does the weather. In spring, females of cavity- and crevice-dwelling species (e.g., *Myotis 2sodalis*, *Myotis lucifugus, Myotis septentrionalis*) that reside in temperate regions are in the early stages of pregnancy and tend to select warm roosts that offer conditions conducive to speeding up fetal development. However, wild temperature swings and severe storms are also a threat. Accordingly, we have observed that females tend to roost in sheltered trees or bat boxes during the spring[5]. Even though this may be before trees leaf out, clusters installed inside the forest, with some buffering of weather from surrounding trees and incidental sunlight, may be preferable for females during this time. Moving into early summer, females enter the late stages of pregnancy, followed by the birth of their pup(s) and a 4–5-week lactation period. Energetic demands are highest at this time, so females generally seek out their warmest roosts, such as large structures with high thermal mass, roosts with high solar exposure, or a combination of both features. Colony sizes swell during this period, too. Designing artificial roosts that retain heat later into the night (e.g., water jacket rocket box, Appendix A) should promote pup development and enhance survival rates. Such artificial roosts should have microclimate conditions more similar to those found in natural roosts, which are larger and more insulated. Thus, we suggest installing roost clusters in more open conditions, facing south or east to ensure the roost receives morning sun. For the latter portion of the summer and early fall, bats will often roost in smaller groups and may regularly switch roosts to meet their changing energy demands and avoid crowded roost sites. During this time, bats will alternate between more sheltered sites and open roost clusters. This is also an exploratory period, making it a good time to monitor newly installed roosts for uptake and use. We also recommend focusing roost attraction efforts (e.g., acoustic lures) during this period. Given the technological limitations (i.e., battery life) of lure technology, if season-long lure use is logistically infeasible, this time of year may be the most efficient time to broadcast the lure because it coincides with natural colony dispersal periods and higher bat activity.

Artificial roost color, material, and size

We recommend avoiding dark-colored artificial roosts because dark colors substantially increase overheating[9,12] and bats may preferentially select dark artificial roosts[13,21-23], which further increases the risk. We recommend lighter colors like gray or tan, as these absorb less solar radiation and will be cooler, thus decreasing overheating risk[12,24]. For example, we found that temperatures inside unpainted boxes in southern Florida rarely reached dangerous temperatures. In an experimental evaluation of unoccupied roosts colored on a gradient from white to black, we found that overheating (>40°C [104°F]) occurred most often in 60–100% black boxes on sunny days, but that all boxes cooled quickly at night, regardless of color. We suggest that the warming benefits of colors >40% black (i.e., light-medium gray or darker) may not be worth the risk of overheating. In temperate climates, such as Minnesota, painting a box light-medium gray will allow the box to heat up on sunny days with a lower risk of overheating. In subtropical climates like southern Florida, we suggest not painting boxes and allowing them to weather or painting them a light color (e.g., light gray). We did not find a strong effect of roost material on internal temperature, with pine, oak, and thermally modified timber all performing similarly. Small artificial roosts (both in volume and height) with low mass may overheat more readily and not offer bats safety from high temperatures[1,6]. Alternatively, tall artificial roosts with four sides (or multiple accessible roost chambers) provide large temperature gradients[5,24–28] and allow bats to move to avoid high temperatures. Therefore, we recommend increasing insulation (e.g., polystyrene) and heat storage (e.g., water packets), not dark paint colors or different materials, to provide warm, stable roosting environments in artificial roosts.

Artificial roost monitoring

After installation, boxes should be monitored long-term for bat use and weathering of the box. Newly installed boxes should be checked at least once a month to look for evidence of bat uptake. Guano traps placed below box entrances can be useful for monitoring bat use without intensive field visits. Once boxes have established bat use or colony formation, monitoring should be conducted at least 2 times during the summer months to document the size and persistence of maternity colonies. Emergence surveys are preferred for obtaining a more accurate estimate of the total number of bats in a colony versus spotlight surveys (Appendix B). A qualitative assessment of artificial roosts should be conducted annually to ensure the structure is still viable as a roost through severe weather events and time. Artificial roosts require monitoring efforts long-term for both structural integrity and bat use to ensure roosts are functioning as intended.

Cost assessment

Raw materials and number of boxes to deploy

Because the external water jacket roost was the most thermally stable and least likely to overheat, we recommend this style for future deployments (see Appendix A for materials for each design). The estimated cost of raw materials for a two-chamber external water jacket rocket box is $250.00 (compared to $130.00 for a standard two-chamber rocket box). However, the cost per box decreases as more boxes are made (e.g., using extra screws, caulk, and paint for additional boxes). Evidence suggests that deploying boxes in clusters, as in this project, can facilitate roost discovery and colonization[23]. Therefore, we recommend deploying at least 3 boxes in each cluster, which was successful for this project and prior work[2,25]. The cost of raw materials for a single cluster of 3 external water jacket boxes is $750. Recent research suggests that bats will move to different roost solar exposures (e.g., full shade, easterly sun, westerly sun) as their energetic needs change over the course of the summer maternity season[5]. This necessitates deploying at least 3 roost clusters in 3 distinct solar exposures. The cost of raw materials for 3 clusters would be approximately $2,070. This number of roosts should be sufficient space to house a large maternity colony of approximately 250-400 bats. Multiple replicates will be needed if more than one colony is targeted. Constructing an individual artificial roost requires 8–10 hours of labor (non-consecutive due to time for glue and paint to dry). Assuming a wage of $20 per hour, the cost of labor for a single roost would be $160-200.

We do not recommend building boxes out of oak or thermally-modified timber (TMT) boards as these materials do not increase roost temperatures on cool, cloudy or cool, sunny days compared to pine boards. Further, the cost of an oak two-chamber rocket box (the cheapest rocket box option) would cost $280 and the cost of a TMT two-chamber rocket box would be $220, compared to $150 for a pine two-chamber rocket box. However, we recognize that oak or other wood may be more weather resistant and thus may provide a long-term cost benefit in terms of box longevity.

Site selection

To select locations for deploying artificial roost clusters, we recommend conducting a site-wide acoustic survey to locate bat activity hotspots over a period of approximately 2 months. Suitable locations near these hotspots may be good sites for artificial roost deployment as bats will likely discover them more quickly. We recommend surveying 1 site per week, moving the detector each week to minimize the cost of needing multiple detectors. The cost of one Wildlife Acoustics SM4BAT FS bat detector is $1,200. The cost of a one-year subscription to Kaleidoscope Pro auto bat identification software is $400 per year. The time commitment for analyzing 2 months of acoustic data is approximately 1 week. Assuming a wage of $20 per hour and a standard 40-hour work week, the cost of analyzing acoustic data would be $800.

Bat box deployment

Similar to the cost of building roosts, the cost per roost for deploying artificial roosts decreases as more roosts are installed. The cost of renting a two-person auger for one day to dig holes for roosts is approximately $120 (Appendix A). Installation of 18 roosts requires approximately 2 working days of labor (16 hours). Assuming a minimum team of 4 individuals to deploy roosts, with wages set at $20 per hour, the total cost of deployment would be $1,400.

Acoustic lure cost

We used two lure technologies during this study (Appendices C and D). The preferred technology based on our experience is the Apodemus bat lure due to ease of use and lower cost to run compared to the Binary Acoustic Technology AT100 lure. The cost of the Apodemus bat lure system is $2,900. This device has programmable start/end time and can run for the duration of the night. The AT100 is similarly priced ($3,000) but will only run for about 4 hours due to power constraints. It also requires a laptop to operate in the field. The drawback of the Apodemus bat lure is that this system can only accommodate frequencies up to 100 kHz, limiting its utility for high frequency bat species (e.g., *Myotis* genus). If full spectrum call files are used, high frequency harmonics may be cut off, whereas the AT100 can handle frequencies up to 120 kHz.

Monitoring

We recommend that roosts are checked for occupancy at least once per month (see Appendix B for methods). Assuming a wage of $20 per hour, a typical box and acoustic lure check for 6 clusters of artificial roosts would last approximately 6 hours (including 2 hours of commute time between clusters). For a cost of $120 per month. Assuming a standard monitoring window of approximately 6 months (in the temperate zone), the total cost of labor to monitor boxes and maintain equipment would be $720 annually. However, more frequent site visits will better detect fine-scale temporal movements of bats between roost clusters and could aid in detecting seasonal use of boxes (e.g., shaded boxes in spring vs. solar-exposed boxes during the summer[5]). Monthly visits are sufficient to detect general presence or absence and abundance of bats but will not provide detailed information on seasonal phenology.

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APPENDIX A: HOW TO DEPLOY BAT BOXES AND HOW TO CONSTRUCT ROCKET BOX/WATER JACKET/ATTIC BOX

Box deployment

To deploy a post or pole-mounted rocket box, you must use an auger and dig a 3-4' deep hole (Figure 1). Once the hole is dug, place the base of the post/pole near the hole. Using 4-6 people slowly raise the post or pole upward until the base drops to the bottom of the hole (Figure 2). Use a bubble level to ensure the post/pole is straight (plumb) and pour in 100 lbs of fast-setting concrete (Figure 3). Be sure to add water to the concrete. Backfill the hole with any remaining dirt. Using pulleys and ropes attached to the top of the post/pole can aid in getting the box airborne. For post-mounted boxes, we recommend bracing the base of the post with 2” x 4” x 4’ boards attached with 3” screws.

Auger rental for a day is approximately $120. Six to ten boxes can typically be erected in a day, depending on distance between deployment sites.

Figure 1. Drill hole with an auger.

Figure 2. Raise the pole and roost into vertical position.

Figure 3. Pour concrete and water into the hole and set with a level.

Florida single-chamber rocket box

This is a single-chamber rocket box modified from Bat Conservation International's two-chamber rocket box design. This box is made of standard 1" thick untreated pine boards. This box is 10" wide, and 36" tall, and offers 2-1/4" chamber spacing. This box is mounted on a 21' long 2" schedule 40 galvanized steel pole. The box is attached to the pole with 4-1/2" carriage bolts. This box takes approximately 8 hours to construct.

Figure 4. Single-chamber rocket box with vents on two sides used in Florida.

<u>Materials list reference rocket box (Florida Design)</u>

Construction

Item	Quantity	Unit price (December 2022)	Cost
1" x 12" x 3' untreated pine board	1	8.83	8.83
1" x 10" x 6' untreated pine board	2	10.48	20.96
1" x 4" x 8' untreated pine board	2	5.48	10.96
2" x 4" x 4' untreated pine stud	1	2.98	2.98
2" exterior screws #8 or 9 (1lbs box)	1	8.97	8.97
1-5/8" exterior screws #8 or 9 (1lbs box)	1	8.37	8.37
1-1/4" exterior screws #8 or 9 (1lbs box)	1	8.97	8.97
2.5" corner braces (2 pack with screws)	2	7.90	15.80
Latex caulk (clear)	1	3.58	3.58
Non-toxic wood sealer (1 Qt.)	1	18.98	18.98
TOTAL			**$108.40**

Deployment

Item	Quantity	Unit price (December 2022)	Cost
2” x 21’ galvanized steel schedule 40 pipe	1	130.19	130.19
3/8” x 4-1/2” Carriage bolts	2	1.09	2.18
3/8” washers	2	0.24	0.48
3/8” hex nuts	2	0.16	0.32
Red locktite	1	7.98	7.98
Fast setting concrete (50lbs bags)	2	6.71	13.42
Two-man auger (8” or 10” diameter bit)	1	120.00	120.00
TOTAL			**$274.57**

Florida single-chamber external water jacket box

This design is a single-chamber external water jacket rocket box. It adds an additional sealed outer shell to the standard rocket box filled with water packets. This box is made from standard 1” thick untreated pine boards. This box is 13” wide, and 36” tall, and offers 2-1/4” chamber spacing. The external jacket contains 12 water packets each containing 750ml of water in vacuum-sealed food freezer bags. This box is mounted on a 21’ long 2” schedule 40 galvanized steel pole. The box is attached to the pole with 4-1/2" carriage bolts. This box takes approximately 10 hours to construct.

Figure 5. Single-chamber external water jacket box with no external vents used in Florida.

Materials list external water jacket box (Florida Design)

Construction

Item	Quantity	Unit price (December 2022)	Cost
1” x 12” x 3’ untreated pine board	1	8.83	8.83
1” x 10” x 6’ untreated pine board	2	10.48	20.96
1” x 4” x 8’ untreated pine board	2	5.48	10.96
1” x 8” x 6’ untreated pine board	4	8.38	33.52
2” x 4” x 4’ untreated pine stud	1	2.98	2.98
2” exterior screws #8 or 9 (1lbs box)	1	8.97	8.97
1-5/8” exterior screws #8 or 9 (1lbs box)	1	8.37	8.37
1-1/4” exterior screws #8 or 9 (1lbs box)	1	8.97	8.97
2.5” corner braces (2 pack with screws)	2	7.90	15.80
Latex caulk (clear)	1	3.58	3.58
Non-toxic wood sealer (1 Qt.)	1	18.98	18.98
Food Vacuum sealer	1	47.14	47.14
11" x 16' Vacuum Sealer Roll	1	18.04	18.04
3/8" x 2" oak dowel pins (18 pack)	1	2.68	2.68
Wood glue	1	9.98	9.98
TOTAL			**$219.76**

Deployment

Item	Quantity	Unit price	Cost
2” x 21’ galvanized steel schedule 40 pipe	1	130.19	130.19
3/8” x 4-1/2" Carriage bolts	2	1.09	2.18
3/8” washers	2	0.24	0.48
3/8” hex nuts	2	0.16	0.32
Red locktite	1	7.98	7.98
Fast-setting concrete (50lbs bags)	2	6.71	13.42
Two-man auger (8” or 10” diameter bit)	1	120.00	120.00
TOTAL			**$274.57**

Florida chamber box

This design is the standard chamber box deployed by Florida Wildlife Conservation Commission. This box is made from standard 1” thick untreated pine boards and the inside is grooved to facilitate hanging by bats. This box is 14.5” wide, and 29” tall, and offers 1-7/8” chamber spacing. This box is mounted on a 21’ long 2” schedule 40 galvanized steel pole. The box is attached to the pole with 2–4" galvanized steel hose clamps. This box takes approximately 8 hours to construct.

Figure 6. Single-chamber flat-faced box typically used for Florida bonneted bats.

Materials list chamber box (Florida Design)

Construction

Item	Quantity	Unit price (December 2022)	Cost
2” x 6” x 8’ untreated pine board	1	6.98	6.98
1” x 8” x 8’ untreated pine board	1	10.98	10.98
1/4" x 20 hanger bolts (12 pack)	1	15.63	15.63
1/4" washers (6 pack)	2	1.38	2.76
1/4“ x 20 wingnuts (5 pack)	2	5.57	11.14
1-5/8” exterior screws #8 or 9 (1lbs box)	1	8.37	8.37
1-1/4” exterior screws #8 or 9 (1lbs box)	1	8.97	8.97
1/4" x 1-1/2" hex bolt	2	0.16	0.32
1/4" hex lock nut	2	0.12	0.24
1-1/4" galvanized steel pipe hangers (4 pack)	1	3.13	3.13
3” galvanized steel hose clamps	2	3.78	7.56
Non-toxic wood sealer (1 Qt.)	1	18.98	18.98
TOTAL			**$95.06**

Deployment

Item	Quantity	Unit price (December 2022)	Cost
2” x 21’ galvanized steel schedule 40 pipe	1	130.19	130.19
Fast-setting concrete (50lbs bags)	2	6.71	13.42
Two-man auger (8” or 10” diameter bit)	1	120.00	120.00
TOTAL			**$263.61**

Minnesota two-chamber rocket box

This design is constructed following the specifications of Tillman et al. (2021). This box is made of standard 1” thick untreated pine boards. This box is 9.5” wide, 36” tall, and offers 3/4” chamber spacing. This box is built around a 4” x 4” x 12’ untreated pine post and is attached to an additional 4” x 4” x 12’ treated pine post with 4 2” x 4” x 4’ treated pine studs with 3” exterior grade screws. This box takes approximately 8 hours to construct.

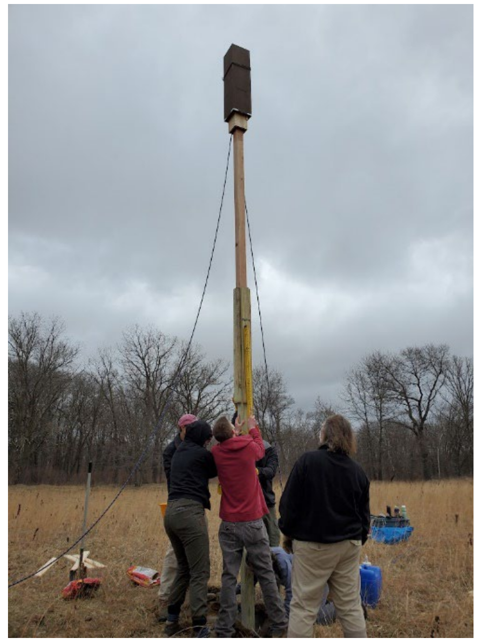

Figure 7. Two-chamber reference rocket box design used in Minnesota.

<u>Materials list reference rocket box (Minnesota Design)</u>

Construction

Item	Quantity	Unit price (December 2022)	Cost
1” x 12” x 3’ untreated pine board	1	8.83	8.83
1” x 10” x 6’ untreated pine board	2	10.48	20.96
1” x 8” x 8’ untreated pine board	2	10.98	21.96
4” x 4” x 12’ untreated pine post	1	16.98	16.98
2” exterior screws #8 or 9 (1lbs box)	1	8.97	8.97
1-5/8” exterior screws #8 or 9 (1lbs box)	1	8.37	8.37
1-1/4” exterior screws #8 or 9 (1lbs box)	1	8.97	8.97
2.5” corner braces (2 pack with screws)	2	7.90	15.80
Latex caulk (clear)	1	3.58	3.58
Paint exterior grade (1 Qt.)	1	14.98	14.98
TOTAL			**$129.40**

Deployment

Item	Quantity	Unit price (December 2022)	Cost
4” x 4” x 12’ treated pine post	1	9.88	9.88
2” x 4” x 4’ treated pine studs	4	3.78	15.12
3” exterior screws #9 (1lbs box)	1	8.97	8.97
Fast-setting concrete (50lbs bags)	2	6.71	13.42
Two-man auger (8” or 10” diameter bit)	1	120.00	120.00
TOTAL			**$167.39**

Minnesota two-chamber external water jacket box

This design is a two-chamber external water jacket rocket box. It adds an additional sealed outer shell to the standard rocket box filled with water packets. This box is made from standard 1” thick untreated pine boards. This box is 12-1/2” wide, and 36” tall, and offers 3/4” chamber spacing. The external jacket contains 12 water packets each containing 750ml of water in vacuum-sealed food freezer bags. This box is built around a 4” x 4” x 12’ untreated pine post and is attached to an additional 4” x 4” x 12’ treated pine post with 4 2” x 4” x 4’ treated pine studs with 3” exterior grade screws. This box takes approximately 10 hours to construct.

Figure 8. Two-chamber external water jacket rocket box design used in Minnesota.

<u>Materials list external water jacket box (Minnesota Design)</u>

Construction

Item	Quantity	Unit price (December 2022)	Cost
1” x 12” x 3’ untreated pine board	1	8.83	8.83
1” x 10” x 6’ untreated pine board	2	10.48	20.96
1” x 8” x 8’ untreated pine board	6	10.98	65.88
4” x 4” x 12’ untreated pine post	1	16.98	16.98
2” exterior screws #8 or 9 (1lbs box)	1	8.97	8.97
1-5/8” exterior screws #8 or 9 (1lbs box)	1	8.37	8.37
1-1/4” exterior screws #8 or 9 (1lbs box)	1	8.97	8.97
2.5” corner braces (2 pack with screws)	2	7.90	15.80
Latex caulk (clear)	1	3.58	3.58
Paint exterior grade (1 Qt.)	1	14.98	14.98
Food Vacuum sealer	1	47.14	47.14
11" x 16' Vacuum Sealer Roll	1	18.04	18.04
3/8" x 2" oak dowel pins (18 pack)	1	2.68	2.68
Wood glue	1	9.98	9.98
TOTAL			**$251.16**

Deployment

Item	Quantity	Unit price (December 2022)	Cost
4” x 4” x 12’ treated pine post	1	9.88	9.88
2” x 4” x 4’ treated pine studs	4	3.78	15.12
3” exterior screws #9 (1lbs box)	1	8.97	8.97
Fast-setting concrete (50lbs bags)	2	6.71	13.42
Two-man auger (8” or 10” diameter bit)	1	120.00	120.00
TOTAL			**$167.39**

Minnesota two-chamber attic box

This is a two-chamber attic rocket box design. It is based on the same dimensions as the standard two-chamber rocket box, but the outer shell is 59" long instead of 36" for the standard rocket box. The extra length extending above the 36" mark is the "attic" space blocked off with 1/4" hardware cloth so that bats cannot use the attic space. This box is made from standard 1" thick untreated pine boards. This box is 9.5" wide and offers 3/4" chamber spacing. This box is built around a 4" x 4" x 12' untreated pine post and is attached to an additional 4" x 4" x 12' treated pine post with 4 2" x 4" x 4' treated pine studs with 3" exterior grade screws. This box takes approximately 8 hours to construct.

Figure 9. Two-chamber attic rocket box design used in Minnesota.

<u>Materials list attic rocket box (Minnesota Design)</u>

Construction

Item	Quantity	Unit price (December 2022)	Cost
1" x 12" x 3' untreated pine board	1	8.83	8.83
1" x 10" x 6' untreated pine board	4	10.48	41.92
1" x 8" x 8' untreated pine board	2	10.98	21.96
4" x 4" x 12' untreated pine post	1	16.98	16.98
2" exterior screws #8 or 9 (1lbs box)	1	8.97	8.97
1-5/8" exterior screws #8 or 9 (1lbs box)	1	8.37	8.37
1-1/4" exterior screws #8 or 9 (1lbs box)	1	8.97	8.97
2.5" corner braces (2 pack with screws)	2	7.90	15.80
Latex caulk (clear)	1	3.58	3.58
Paint exterior grade (1 Qt.)	1	14.98	14.98
1/4" galvanized steel mesh (3' x 5' roll)	1	13.99	13.99
TOTAL			**$164.35**

Deployment

Item	Quantity	Unit price (December 2022)	Cost
4” x 4” x 12’ treated pine post	1	9.88	9.88
2” x 4” x 4’ treated pine studs	4	3.78	15.12
3” exterior screws #9 (1lbs box)	1	8.97	8.97
Fast-setting concrete (50lbs bags)	2	6.71	13.42
Two-man auger (8” or 10” diameter bit)	1	120.00	120.00
TOTAL			**$167.39**

APPENDIX B: INSTRUCTIONS/RECOMMENDATIONS FOR SPOTLIGHT CHECKS AND EXIT COUNTS TO MONITOR BATS IN ROOSTS

Spotlight checks

- Supplies:
  - Spotlight (2200 lumens; approximately $65).
  - Binoculars for close-range viewing
  - Camera (optional)
  - Datasheet
    - Record date and temperature (recommended)
    - Record species and the number of bats observed
- Instructions:
  - Use the spotlight to illuminate as many angles of the box or roost as possible.
  - Count all the bats you can see. If there are likely more bats than you can count, then add a plus sign (e.g., 25+) to show that the count is an underestimate.
  - Use binoculars or a camera to identify the species (or the number of species), if possible. Take multiple photos with a long lens if unable to identify bats in the field.
  - To minimize disturbance:
    - Keep noise level generally low, no loud bangs or talking.
    - Keep the time you're shining a light on the bats to a minimum time that reasonably determines number of individuals and species, especially if you suspect there are endangered species in residence.
  - Any sign of restlessness or agitation in the bats is a warning sign, cut it short if necessary.
  - If the temperature is above 90°F, reduce disturbance or avoid checking roosts with spotlight, as bats are more likely to flush/emerge when it is warm.

Exit counts

- Supplies:
  - Chair
  - Tally counter (handheld or phone app, like Click Counter)
  - Insect netting or bug spray (optional)
  - Data sheet
    - Time of arrival and exit
    - Time of sunset
    - Temperature
    - Number of bats that emerge
    - Time of first and last bat emergence
  - Pen/pencil
  - Flashlight, preferably with a red light setting to reduce disturbance
- Instructions:
  - Arrive on site for exit counts, ideally a half hour before sunset, keeping noise levels down while you set up for emergence. At the latest, you should be ready to survey 15 minutes before sunset.

- Make observations from a spot where the roost exit is silhouetted against the sky (no trees in the background) to give the best view.
- Multiple (2–3) observers are ideal to ensure all potential exits are watched. Observers should be trained for consistency in exit count protocols. This is particularly important when you suspect there are a lot of bats in the roost or are unsure where they will exit the roost.
- Count all bats that emerge from the roost.
    - If it is a maternity colony with pups, be aware that females will return to the roost. Be prepared to keep track of bats entering and exiting during the observation period, as doing so will alter your total count.
- Continue with the emergence survey until at least 10 minutes after the last bat is observed, it is too dark to see, or many bats are returning to the roost.

APPENDIX C: ACOUSTIC LURE FOR FLORIDA BONNETED BAT (APPLICABLE TO LOW-FREQUENCY BATS), AS DEMONSTRATED IN NDCEE PROJECT 20-10124

Apodemus Bat Lure (https://batmanagement.com/products/apodemus-batlure)

- Lure is optimized for bats that emit low-frequency sounds (below 30 kHz)
- Lure operates on a timer and external battery source and can play for a full night without the presence of a technician or laptop

Bat lure configuration file is stored on an SD card and gives the lure parameters, which are:

- Time expansion
  - We used the default setting of 1 (played at true/normal time)
- Track pause (time between tracks, if multiple tracks are used)
  - This setting was not applicable because we only had one track
- Startup volume
  - Volume goes 0–40, we used 30
  - At volume of 30, we tested out distances where the lure sound would not be picked up by the acoustic detector. With the lure pointed away from the detector, the minimum distance to avoid the lure being picked up by the detector was 20 m, so this is where we placed it.
- Repeat
  - Number of times to repeat a wav file (only when the file is shorter than repeat time)
  - We used 5 as a placeholder, as our file was not shorter than the repeat time
- Repeat time
  - If the file/playlist is shorter than this value (in seconds), it will repeat
  - We used 302, as we did not want the file to repeat and our file was 5 minutes (300 seconds) long
- List pause
  - Pause time at the end of the playlist
  - Our lure protocol was for 5 minutes on, 5 minutes off. We set this to 300 seconds or 5 minutes.
- Sine modulation
  - Can simulate a moving source of sound; we did not use this setting
- **Be sure to test out the configuration file in the office before deployment in the field!**

Apodemus timerbox

- Has the ability to turn the lure on/off, as well as days playing
- Turning lure on/off:
  - Use H+ and M+ to select the times to turn on and off the lure
  - We set the timerbox to turn on the lure 30 minutes before sunset and to turn off the lure 30 minutes after sunrise. To adjust for sunset and sunrise times moving, we adjusted the timerbox settings every week while replacing the batteries (e.g., moved start time 3 minutes later to account for a 3 minutes later sunset than a week prior)

- Days playing:
    - Use D+ button to select which days of the week (or all of them) you want the lure to be playing
    - We selected all days of the week, so the lure played every night of the week, excepting battery failures

Setup

- Secure the setup in an electrical box or similar. Use a white cover for a solar shield to prevent overheating.
    - Powered by 12V, 18 amp-hour battery, changed weekly
- Lure device inside the box, connected to speaker by 3m external cable
- For an external speaker:
    - Secure a 10' PVC pipe to a 5' garden stake
    - Zip-tie the external speaker to the top of the pipe
- If in a likely flooding zone, we used 2' x 4' boards and a plywood square to construct a flood table to elevate the box. This table sat 3' above ground and prevented flooding. Secured by bungee cords to the garden stake as a precaution

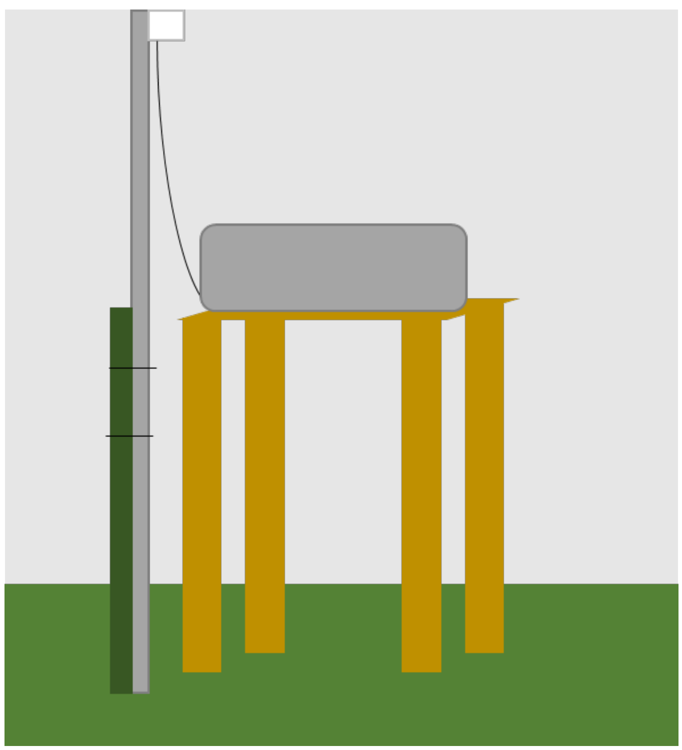

Figure 1. Schematic of lure box on wooden table with cable to external speaker which is elevated on PVC post.

Figure 2. Solar shield over box with lure components.

Figure 3. Inside of box with battery, timer, and lure device.

Troubleshooting if the lure is not working

- Replace internal or external batteries
- Double check connection to the external batteries (if applicable)
- Double-check connections to the timer box (if applicable)
- Replace the SD card

Materials necessary for playing low-frequency lure for bats

Item	Quantity	Unit Price (December 2022)	Vendor
Apodemus bat lure	1	$2195.00	Bat Conservation and Management
Apodemus timerbox	1	$249.00	Bat Conservation and Management
Apodemus external speaker	1	$295.00	Bat Conservation and Management
10ft PVC pipe, 1.5” diameter	1	$23.48	Home Depot
6ft metal garden stake	1	$7.64	Home Depot
Zip ties (20 pack)	5-10	$4.21	Home Depot
Bungee cord	1	$9.98	Home Depot
2”x4”x8’ pressure treated lumber	3	$4.88	Home Depot
Sanded plywood 23/32”x2’x2’	1	$16.34	Home Depot
12V battery	1	$39.99	Home Depot
TOTAL		**$2,851.07**	

APPENDIX D: LURE FOR LITTLE BROWN BAT (OR OTHER HIGH-FREQUENCY BATS), AS DEMONSTRATED IN NDCEE PROJECT 20-10124

Lure: AT100 Bat Lure (Binary Acoustics Technology; http://binaryacoustictech.com/)

- Used for high-frequency species (minimum frequency >35 kHz)
- Requires Windows operating system to function
- Connects to computer via USB 2.0 cable
- Proprietary software program PLAYR controls lure operation

PLAYR settings

- Select final lure file
- Select loop to continuously play the 5 min file repeatedly
- Volume was turned to a maximum level of 36.1, detectable at least 30 feet from the speaker
- Audio Level was 100 db with volume setting

Laptop setup

- Laptop HP 250 G8 Windows operating system
  - Intel® Core™ i5-1135G7
  - 16 GB memory; 256 GB SSD storage
- External battery pack: Omni Ultimate+ 120v
- Task Scheduler: Laptop shutdown
  - Laptop was shut down at midnight
- Laptop was turned on near sunset (before bat emergence)
- Due to the use of a laptop, lure could only be played on evenings when personnel were present

Weatherproofing for laptop

- Plano Sportsman's Tote
- Size 24" x 12" x 13", 56 qt
- Drilled holes in both sides of the tub to allow for airflow
- Covered holes with a mesh screen to act as a barrier for insects and water
- Box was spray-painted white to reduce solar absorption
- A hole was drilled in the side of the tub to allow cable to connect to speaker outside of tub
- Duct tape covered the hole where the cable entered to prevent insects from entering
- Laptop was placed on hanging wire shelf basket to elevate laptop and provide airflow beneath computer to prevent overheating (Home Depot, Everbilt Hanging Wire Basket, $16.98)

Weather Proofing for AT100 Bat Lure

- Charlotte Pipe 4 in. PVC DWV 45-degree hub elbow fitting
- Charlotte Pipe 4 in. PVC coupling
- 4 in. Semi-Rigid dryer duct
- Gorilla duct tape
- PVC pieces housed the speaker and the cable passed through the dryer duct; these materials protected the speaker and cable from rain and sun exposure
- Elbow allowed projection of lure sound forward at 45-degree angle and protected speaker from rain
- Rain guard built from duct tape to prevent entry of water into speaker

Lure stand

- Platform built with 2’ x 2’ plywood board
- (8) 2’ x 4’s were used to build table legs and diagonal brackets for support
- Second 2’ x 2’ plywood board was attached to platform with hinges to act as a sun shield on south side of the box
- Sun shield leaned on plano box and supported speaker with weather proofing
- 2 screws acted as a bracket to hold speaker mount in place
- Stand was secured with guidewires attached to stakes in the ground to prevent tipping

Troubleshooting

- Stands sometimes fell over when knocked over by animals or high winds
- Laptop battery did not always last through the week
- Laptop did not always accept shutdown schedule

Figure 1. View inside of laptop storage tub. Air holes are visible near the top lip of the tub, and wire shelf allow airflow for the laptop to prevent overheating. External battery fits next to the wire shelf.

Figure 2. Complete lure set-up on the wooden stand. Lure speaker faces south, pointed away from the bat boxes and acoustic detector (pictured in the foreground). White tub houses and protects computer, battery, and cables. Lure speaker is housed in PVC pipe and dryer duct (not seen), while the black rain guard keeps water from entering speaker.

Materials necessary for playing high-frequency lure for bats

Item	Quantity	Unit Price (as of 21 Dec 2022)	Vendor
AT100 Bat Lure	1	$1,650.00	Binary Acoustic Technology (http://binaryacoustictech.com/batpages_files/at100.htm)
Laptop HP 250 G8	1	$809.00	HP
Omni Ultimate+ 120v External Battery	1	$399.00	OmniCharge
Plano Sportsman's Tote 56 qt	1	$14.99	Cabela's
Screen repair tape	1	$8.48	Home Depot
Hanging wire basket	1	$16.98	Home Depot
Gorilla Glue duct tape	1	$6.48	Home Depot
White spray paint	1	$6.48	Home Depot
Charlotte Pipe 4 in. PVC DWV 45-degree hub elbow fitting	1	$12.45	Home Depot
Charlotte Pipe 4 in. coupling	1	$6.25	Home Depot
4 in. Semi-Rigid dryer duct	1	$16.98	Home Depot
Plywood board 2' x 2'	2	$7.70	Home Depot
2" x 4" x 4' treated pine studs	8	$3.78	Home Depot
Utility hinges 2 ½ in. (2-pack)	1	$3.47	Home Depot
3" exterior screws #9 (1 lb box)	1	$8.97	Home Depot
Garden stakes (12-pack, only need 2)	1	$14.86	Home Depot
Paracord (50-ft roll, only need 5 ft)	1	$4.75	Home Depot
TOTAL		**$3,024.78**	

APPENDIX E: DEPLOYING TEMPERATURE SENSORS TO MEASURE ARTIFICIAL ROOST INTERNAL TEMPERATURE

Temperature sensing equipment

- iButtons (QTY: 3; Maxim Integrated, model DS1921G, 0.5°C increments, ± 1.0°C accuracy)
- iButton reader (QTY: 1; Model DS1402D-DR8+)
- Computer or laptop with USB port

Mounting equipment

- 3D printed iButton mounts (QTY: 3; Figure 1)
- Lath (36”L x 3/4"W x 1/2"H) (QTY: 1)
- Raising spacers (3”L x 3/4"W x 1-1/2"H) (QTY: 2, for Florida bonneted bat boxes only)
- 3/4" screws #6 (QTY: 8; 6 for Florida bonneted bat boxes)
- 1-5/8” Screws #9 (QTY: 2, for Florida bonneted bat boxes only)

Tools

- Drill
- Drill bits

Instructions (for one iButton stick*) see end of section for items marked with an *

1. Program iButtons using the iButton reader and a laptop or computer.
    a. Set the specified sample frequency (i.e., number of minutes between samples; sampling every 2 hours allows for ~6 months of data collection which is ideal for summer studies where you will not be swapping out iButtons).
    b. Set start delay (in minutes). It is useful to use an online countdown timer to determine the number of minutes until your intended start date/time.
    c. Set mission status to True
2. Attach iButtons to the lath using the 3D printed mounts and 3/4" #6 screws (Figure 2).
    a. Position iButtons at the top, 17” from the top, and 4” from the bottom of the lath.
    b. Drill pilot holes before attaching mounts to prevent the lath from splitting.
    c. Ensure there is space between the iButton and the outer shell of the rocket box (Figure 3).
    d. If making a box with a large chamber, add 2 raising spacers** to the bottom of the lath using one 1-5/8” screw. One spacer flush with the bottom of the lath and one 5” from the top of the lath (Figure 4)
3. Insert lath into the box along the edge of the inner shell until 2” of lath is protruding below the entrance. This will be the anchor point (Figure 5).
    a. Anchor lath using two 3/4" #6 screws (or two 1-5/8” #9 screws for larger, single-chamber boxes).

*We only use one iButton stick placed on the south face of the box. Multiple iButton sticks would restrict movement around the box and result in bats having to leave the roost to be able to select a different box face aspect.

**Adding raising spacers in large chamber boxes reduces the distance between the iButton and the outer wall of the bat box. This reduces the chance of a bat being able to come into direct contact with the temperature-sensitive surface of the iButton and skewing temperature data.

Figure 2. 3D printed iButton mount used to attach iButtons to lath strips.

Figure 3. iButtons mounted to lath strips using 3D printed mounts.

Figure 4. Visually inspect mounted iButtons to ensure that the iButton is not in contact with the outer shell (brown) of the rocket box.

Figure 5. Example of iButton lath sticks mounted on raising spacers.

Figure 6. Example of an iButton stick inserted and anchored to the inner shell of a rocket box using two 3/4" #6 screws.