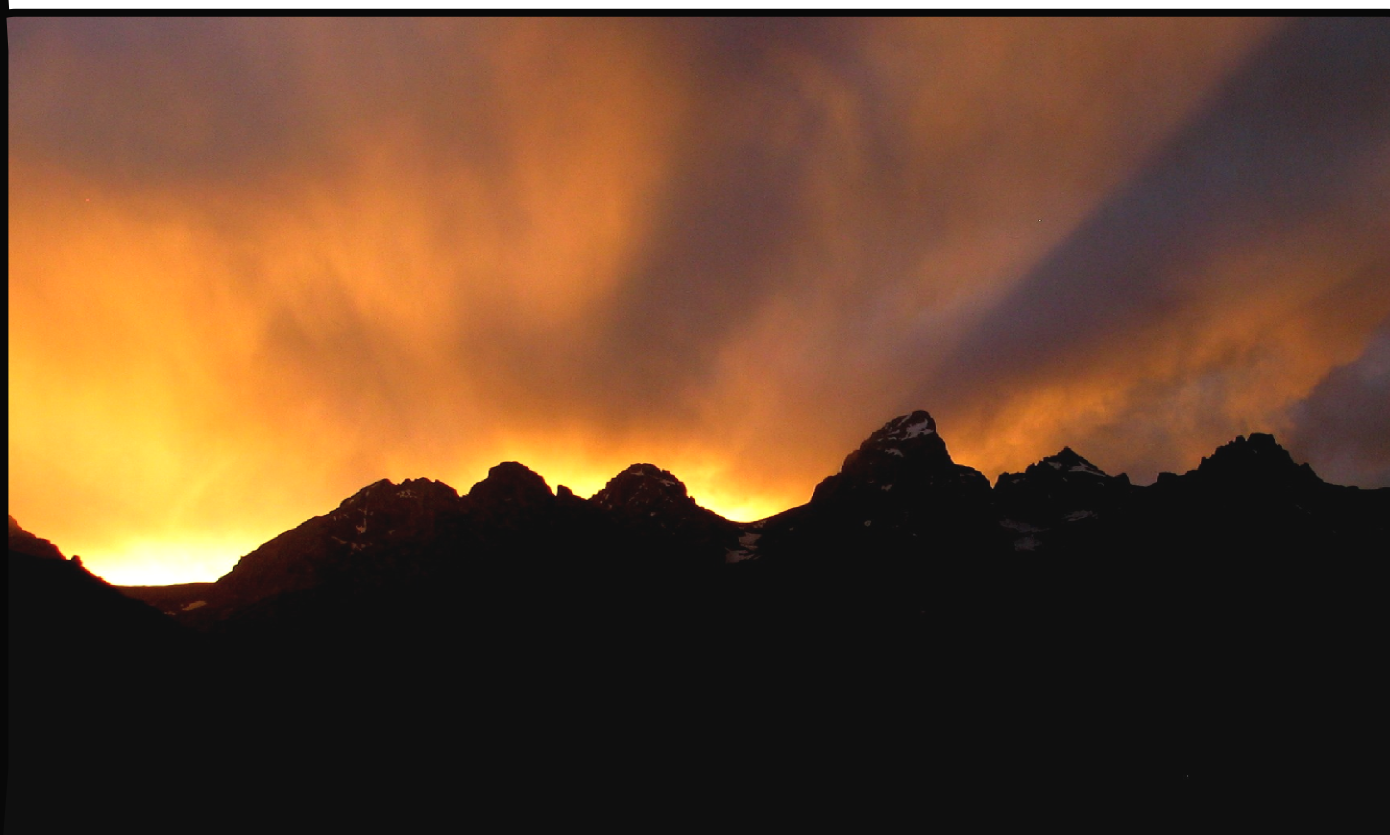
BAT INVENTORY of the GREATER YELLOWSTONE NETWORK

FINAL REPORT

by

DOUGLAS A. KEINATH

Senior Zoologist
Wyoming Natural Diversity Database
University of Wyoming, Laramie, Wyoming



prepared for
National Park Service
Greater Yellowstone Network
Inventory and Monitoring Program

October 2005

CONTENTS

BACKGROUND AND INTRODUCTION

The National Park Service (NPS) is undertaking a nationwide effort to inventory and monitor the biological resources within its management areas. Recognizing the need for a cross-boundary, ecosystem approach to natural resource management, the system of national parks has been grouped into Cooperative Ecosystem Units to facilitate inventory, monitoring, and subsequent management decisions in ecologically meaningful areas. The Greater Yellowstone Network (GRYN) includes Yellowstone and Grand Teton National Parks (YNP and GTNP) and Bighorn Canyon National Recreation Area (BICA). A combined effort of biologists from these parks and regional wildlife experts resulted in the recent release of a study plan for the GRYN inventory and monitoring efforts (NPS, 2000). This document identified significant gaps in information on the species richness, abundance, and distribution of bat species within all GRYN parks and terrestrial mammals in BICA. They have therefore proposed that the NPS conduct a comprehensive inventory of bats throughout GRYN and terrestrial mammals in BICA to establish a benchmark for future monitoring efforts and management actions. The specific goals of these inventory efforts, as stated in the GRYN Study Plan (NPS, 2000), are as follows:

1. To document, through existing, verifiable data and targeted field investigations, the occurrence of at least 90 percent of the species of vertebrates and vascular plants currently expected to occur in Bighorn Canyon National Recreation Area, Grand Teton National Park, and Yellowstone National Park.
2. To describe the distribution and relative abundance of species of special concern, such as threatened and endangered species, non-native species, and other species of special management interest occurring within park boundaries.
3. To provide the baseline information needed to develop a general monitoring strategy and design that can be implemented by parks once inventories have been completed, tailored to specific park threats and resource issues.
4. To make information easily available to park managers, resource managers, scientists, and the public.

With these goals in mind, it is valuable to briefly discuss the effort represented by this inventory in terms of what is reasonable to expect from such an effort. This inventory was designed to generate comprehensive documentation of the bat fauna of the GRYN, with a target, as noted above, of documenting 90 percent of the species that actually occur in these parks. Attainment of this somewhat arbitrary objective is largely dependent upon survey effort expended and is therefore directly related to the amount of time and money spent. With a fixed budget there are many species that are easy to document (e.g., little brown bats) and several, generally rare species, that are difficult to document (e.g., spotted bats). Therefore, (as a hypothetical example) documenting the first 80 percent of species may be fairly straight-forward, while the remaining 20 percent could be fare more difficult. Further, we do not have *a priori* knowledge of which species are present, so we must estimate at which point we have achieved the 90 percent goal. Estimation of completeness is compounded by the fact that there is a fine line defining when a species is rare versus so unlikely to occur that it is not worth the effort to document. As an extreme example, one could spend a lifetime trying to document fruit bats in Bighorn Canyon, which (exceedingly unlikely though it may be) could result in the capture of an errant migrant from southern Texas. Such a finding would not, under reasonable scrutiny, represent a meaningful addition to the fauna of BICA. We believe that this report strikes the appropriate balance between effort expended and inventory completeness.

METHODS

We first identified and compiled all geographically referenced electronic data on features that might be useful in identifying important areas of bat use within and near the parks. We used this data to construct habitat suitability models identifying critical bat habitat for GTNP and YNP (priority areas were already identified for BICA and therefore no model was developed for the recreation area; Keinath 2001). These models incorporated wetland distribution, vegetative landcover, bedrock geology, elevation, and topographic relieve (slope and aspect), as outlined in Figure 1. Models were generated as raster coverages in a Geographic Information System (GIS) with 100 meter resolution. Six coverages were generated, one for each of the main components noted above. Each 100 meter cell in the park units was scored for each of these coverages and then a final habitat score was calculated for each cell by additively combining the six components (Figure 1).

For instance, one of the 6 coverages was based on wetlands as classified by the National Wetlands Inventory (NWI). Each wetland type was given a "type score" of 0 – 3 based on its suitability for use by bats as foraging and drinking habitat, where a score of 0 meant it was never used and a score of 3 meant it was preferred. A given cell was assigned a type score based on the wetland that it contained. Since proximity of a cell to other wetland areas also increases suitability, the same cell was also given a distance score, where low, unsuitable values (e.g. 0) represented long distances to other wetlands, and high, suitable scores (e.g., 3) represented proximity to other wetlands. The type and distance score for each cell was then weighted and combined into a single NWI coverage whose total range of scores was still 0 – 3 (e.g., NWI score = 0.7*type score + 0.3*distance score). A similar process was followed for each of the other main components, resulting in five additional values for the given cell (i.e., HAB, GEO, ELV, CLF, and ASP), each having a score of 0 – 3. The six values of each cell were added, weighting the most important components (wetlands and landcover) slightly more than the rest. This resulted in a final coverage in which each cell had a cumulative value of 0 – 22.5, where higher valued cells were relatively more suitable for finding bats via mist netting and acoustic monitoring activities than lower valued cells.

This information was be used in concert with input from park biologists and to identify specific inventory sites. Sites were be prioritized based on several factors including: 1. their likelihood of being used by bats, 2. the relative diversity of species likely to be present, 3. accessibility issues, and 4. their contribution to achieving a geographically inclusive sample from each park. Our goal was to make the most of our limited time in the parks, so we wanted to insure that sufficiently diverse habitat was sampled to capture all suspected species of bats. The ultimate goal of this phase was to generate an inventory site list to be surveyed repeatedly over the following two summers using the field methods noted below.

Habitat models (for GTNP and YNP) are displayed in Figures 2 and 3, in which the most suitable cells are shaded maroon and red and progressively less suitable cells are green, gray, and white. Focal areas for survey, in order of decreasing priority, are as follows:

1. areas of high maroon and red concentrations,
2. areas of high green concentrations with some red,
3. areas of high green concentration,
4. under-represented habitat features or geographic areas that don't appear in the model.

The initial list of focal areas for which we conducted field visits was as follows:

BICA: Layout Creek (especially ponds by Ewing-Snell Ranch); BICA land near Yellowtail Wildlife Habitat Management Area (YWHMA); Hillsboro Ranch and beaver ponds; Lockhart Ranch and beaver ponds; Caves that on or near BICA (usually on BLM land, but whose bat population likely forages on the recreation area); Cliffs along the walls of Bighorn Canyon and Devils Canyon.

GTNP: Snake River South (including Blacktail Ponds and Moose-Wilson Ponds); Snake River North (including Glade Creek in JDRMP); Snake River Central (including Oxbow bend and Willow Flats); Foothills Lakes (including Moose Ponds and Lupine Meadows, String Lake, and some parts of western Jackson Lake and Leigh Lake); Pilgrim and Pacific Creeks; Northwestern GTNP (including Moose, Berry, and Owl Creeks).

YNP: Bechler area (including Bechcler Canyon, Bechler Meadows and Falls River Basin); Lamar Valley area (including Lamar River, Slough Creek and Soda Butte Creek); Madison Junction area (including Madison River and Gibbon Basin); Grand Canyon area (including Yellowstone River and wetlands south of the canyon); Gardner's Hole area (including Gardner River, Africa Lakes and nearby wetlands); South Central Yellowstone (including Snake River and Lewis River south of Lewis Lake); Old Faithful area (including portions of the Firehole River).

Field technicians searched each of these broad focal areas to identify specific sites that were suitable for conducting mist net and acoustic monitoring activities. Depending on the nature of each site and the bat species expected, we used a variety of survey methods including, actively and passively operated acoustic bat detectors, mist nets, and harp traps. Bat detectors were be used to determine the relative level of bat activity at each site and to preliminarily identify species based on characteristic vocalizations. We then employed mist nets and harp traps at potential roosting, foraging, and transit areas to capture, identify, and photograph the various bat species.

All survey sites were located via GPS, bats were identified to species, their age and sex were determined, photographs were taken to document species occurrence, and the number of individuals captured was documented. No additional data was required by park service staff.

RESULTS AND DISCUSSION

This section provides a brief summary what the inventory process revealed. Most useful data is presented and interpreted in the tables, figures and appendices at the end of this report. A thorough investigation of these items will provide the reader with many insights on the chiroptofauna of the Greater Yellowstone Network. In many ways, this relatively brief section should be read as the preamble to the wealth of information presented therein. Specifically, park biologists may regularly refer to the following items:

- Table 1: The "final" list of bat species in each park unit
- Figure 7: Map-based summary of bat occurrences in the GRYN
- Appendix 1: Species Accounts
- Appendix 2: Geographic Information System data
- Appendix 4: Identification keys to the bats of the GRYN

Species Composition and Abundance

The list of species for each park unit is presented in Table 1, summary capture statistics are presented in Table 2, and geographic representations are presented in Figure 7. Further, occurrence information on a species-specific basis is provided in Appendix 1.

In total, we identified 13 species of bats that occur in the Greater Yellowstone Network, although a few designations are tentative (see Table 1). Each park within the GRYN contains a subset of these 13 species; 8-10 occurring in GTNP, 9-10 occurring in YNP, and all 13 potentially occurring in BICA. Despite representing less than two percent of the area of the GRYN, BICA clearly has the richest and most concentrated bat fauna of the three park units. In general, GTNP and YNP were similar in the apparent composition of their bat fauna and collectively they had a less diversity and relative abundance than BICA. Further, although localized areas in the other parks showed high bat activity and/or abundance, the whole of BICA experiences substantial and diverse bat use. This is due to the fact that, when compared with nearby areas in Wyoming, Montana and Idaho, BICA and the adjacent federal lands (primarily owned by the Bureau of Land Management and the State of Wyoming) are relatively arid, warm, low in elevation, contain an abundance of cliff and cave roosting habitat, contain tree roosting habitat in the form of extensive cottonwood riparian areas, and have all roosting habitat relatively proximate to large expanses of still-water that provides abundant insect life and access to consumable water. BICA is indeed one of the hot-spots for bats in all of Wyoming and perhaps all of the northern Rocky Mountain states.

BICA has high bat abundance and diversity, but managers should note that high bat abundance does not necessarily suggest high species richness, particularly at the scale of individual sites (e.g., Figure 8). More specifically, there seemed to be good correlation between ANABAT® call rates and species richness when richness was low, but high richness sites in our study had quite variable levels of activity. There are many possible explanations for this that could be investigated with more effort, but the take-home message for managers in the GRYN is that just because you get a lot of bat activity does not mean you have a diversity of bats. Sites with high activity could be dominated by one or two common species and actually have lower richness than other, less-active sites. We found this to be the case at numerous sites in YNP and some in GTNP where little brown bats were highly abundant, but few other species were identified. On the other hand, one of the most productive sites in our inventory was also the site with the highest bat species richness; you simply cannot tell based on activity alone.

It is hard to evaluate or rank individual sites using this broad-based inventory. However, a few areas are worth noting:

- Layout Creek (BICA): Layout Creek, and in particular the small pond next to the Ewing-Snell Ranch, was by far the richest location in the study, with all 13 of the GRYN species being documented there. Due to its unique mix of habitat features, it stands out as a pre-eminent batting location in the GRYN.
- Yellowtail Wildlife Habitat Management Area (YWHMA, in BICA): YWHMA is a relatively large area of ideal foraging habitat for many bats of different species. In shear abundance of bats seen foraging, it is probably the most productive area in the GRYN. Along with an apparent abundance of insect life, it has an extensive mosaic of chiropteran foraging habitat from open-water habitat, open grassland and shrubland, cottonwood gallery forest, and extensive edges where these components mingle. This abundance of bats, however, is dependent on the surrounding wealth of roosting habitat (e.g., cliffs, caves, abandoned buildings and mines). Not only the insect diversity and composition of the foraging habitat should be conserved, but the relationship of roost features to YWHMA should be maintained in order to insure bat access to these areas.
- Mammoth (YNP): The active and inactive terraces around Mammoth Hot Springs in YNP seems to support an isolated collection of bat species approaching that of BICA, although on a much smaller scale. In this area thermally heated caves provide maternity colonies for common and rare species (e.g., Townsend's big-eared bat); inactive caves and sink-holes provide non-maternity day roosts and possibly hibernacula for a variety of species; and mature, open forests near varied shrubland provide foraging and roosting opportunities for tree-roosting species.
- Thermal Features (YNP): Bat use of thermal features in the park is unique and poorly documented. There are scattered reports of bats roosting at ground level in thermally heated stumps. We found a sizable maternity colony in a ground-level bolder in Gibbon Geyser basin and documented use of several sink-holes and fishers in the Mammoth area. The extent to which bats use these features and, moreover, to which such use allows a more abundant or diverse community of bats to exist within the park, is intriguing and worth future study.
- Northern GTNP: Portions of north GTNP, including the Two Oceans Lake area and John D. Rockefeller Parkway along Glade Creek, seem to have an unexpectedly large diversity of bats, including some that don't seem typical of the area (notably fringe-tailed myotis). Further investigation of the area to verify this diversity and determine why/how these bats are found there is an interesting question; although one that may not have immediate ramifications to species conservation.
- Southern GTNP: The lowland area of southern GTNP, particularly Blacktail ponds, the Moose-Wilson Road beaver ponds, Blacktail Butte, and White Grass Ranch, supports a variety of habitats that collectively have a high diversity of species. Also, they contain the only records of Townsend's big-eared bat in the park, which further investigation will hopefully confirm as being part of a local breeding population.

Inventory Completeness

Evaluation of capture statistics and ANABAT® recordings was combined to generate a final species list for each park unit in the Greater Yellowstone Network (Table 1). This table represents the condensed result of over 40 days of site evaluation (150+ sites), 63 nights of mist netting (9,500 net-area-hours of effort), nearly 80 nights of passive acoustic monitoring (450 recorded hours), and a dozen days of diurnal roost site investigation (e.g., Figure 5). As much as possible, we let the modeling data (Figures 2 - 4) drive site selection, which resulted in numerous backcountry locations. Over this time we captured 527 bats of 13 species (Table 2) and evaluated over 10,000 individual ANABAT® call files that suggested occurrences of the same 13 species.

Qualitatively, the above-noted level of effort seems sufficient to document all species occurring in the parks. However, a quantitative estimate of progress can be roughly approximated using rarefaction or species accumulation curves (e.g., Soberon and Llorente 1993, Krebs 1999, Moreno and Halffter 2000, Cam et al. 2003, Gotelli and Graves 1996, Chao 1984, Colwell and Coddington 1994). I developed species accumulation curves for GRYN and each park unit therein (Figure 6) and used the EstimateS software package (V 7.5.0, © R. K. Colwell, http://viceroy.eeb.uconn.edu/estimates) to produce species richness estimates using the Chaoe-1 and ACE estimators. All models used the Michaelis-Menten equation for fitting predicted values of the appropriate indicator output to sample effort (i.e., Captures/Hour, Capture/Net-Hour, or Calls/Hour):

$$SpNum = (SpMax * Effort) / (k + Effort)$$

where *SpNum* = number of species predicted for a given level of sampling effort, *Effort* = sampling effort in hours or net-hours, *SpMax* = estimate of the maximum number of species likely to be present, and *k* = approximate level of sampling effort corresponding to half of *SpMax*. *SpMax* and *k* are estimates used to guide the nonlinear regression algorithms, which were implemented in S-Plus (V 6.2, © 2003 Insightful Corp., http://www.insightful.com/).

As shown in Figure 6, the sample-site accumulation curve for the network as a whole has a clear and sharply defined asymptote at 13 species for both captures and Anabat® recordings. This suggests we have accounted for all species present in the GRYN based on our given level of effort. The estimator of species richness generates a smooth curve very similar in form to the true plot of species accumulation and predicts an asymptote of less than 14 species based on capture data (*Smax* = 13.6 ± 0.02 species) and based on call recordings (*Smax* = 13.2 ± 0.01 species). This further indicates a complete inventory, with over 96% of the estimated bat species accounted for (Table 3).

As in most inventories, as you subdivide your study area (e.g., from the whole GRYN to the individual park units), your sampling effort decreases and the results become more variable. This can be seen in Figure 7, where the park-specific capture and Anabat® curves do not all seem to reach clear asymptotes with the available sampling effort. This suggests that although the inventory as a whole has identified virtually all species present, there are likely more species to be discovered in each park unit. Table 3 summarizes these estimates, wherein we can see that we have accounted for between 68% and 88% of the estimated bat species richness in the individual units. Not surprisingly, YNP is fairly low, despite having the largest sampling effort, which is probably due to its large geographic area and commensurately diverse (and difficult to survey) habitat. GTNP exhibits a wide range, since the estimator based on Anabat® varied substantially from that based on mist net captures. We believe this, in part, reflects the difficulty of catching bats in GTNP due to the abundance of water sources. It should be noted, however, that we believe the remaining "undiscovered" species in each of these park units is likely to be encompassed in those identified elsewhere in the inventory. The possible exception to this could be BICA, which may have new species, due to its concentration of unusually good bat habitat.

In conclusion, I am confident that well over 90% of the species occurring in the GRYN have been identified and that something less than, but approaching, 90% of the species in each park unit has been identified. However, I fully expect that the list for each park is not complete. In order to solidify the park-specific lists (Table 1), further effort targeted toward the questionable species must be spent in each park. Such follow-up surveys would use techniques tailored to specific species in specific areas, rather than using the broad-based inventory approach used in this study. Such efforts would aim to conclusively document the questionable species in each park by tailoring mist net activities or *active* ANABAT® surveys to their particular foraging styles and to areas in the parks where they are most likely to occur. See *Next Steps* for how to proceed with these supplemental surveys.

Additional Survey and Biological Results

Considering the number of bats captured, the most productive period to survey for bats is the first 2 hours after sunset (Figure 9). However, as suggested in the species accounts (Appendix 2) and in our capture records, bat species fly during different times of night, so surveying only in the early evening might result in a restricted species list. This inventory thus conducted all mist netting until at least 1:00 AM in the morning, often longer. This means that netting occurred until at least 4 - 5 hours after sunset depending on the date, by which time captures for most species diminished (Figure 9). Passive ANABAT units, however, were regularly left active throughout the night to document later bat activity. With this combination of effort, it seems that we collected an adequate temporal sample to capture all species present in the parks.

Most bats in the GRYN hibernate after migrating short distances to suitable hibernacula within, or near, the parks. A few bats (e.g., hoary bats and silver-haired bats) migrate longer distances and likely winter outside the GRYN. In either case, when trying to document resident, and hopefully breeding, bats, it is important to time surveys appropriately. Although there are undoubtedly species differences, it seems that juvenile bats in the GRYN become volant in mid July, as evidenced by their increasing representation in mist net captures at that point (Figure 10). Given a time from parturition to flight on the order of 3 - 4 weeks (depending on species and climate), this means young in the GRYN are being born in mid-June. Further, for most vespertilionid bats gestation begins as they arouse from hibernation and lasts on the order of 70 days (e.g., Barclay and Harder 2003), suggesting that the bulk of GRYN bats emerge from hibernation in mid-April and arrive on their "summering grounds" shortly thereafter, perhaps in early May. Surveys can thus be conducted as early as mid May, but are best later in the season when temperatures are warmer and bats are more active.

Timing of roost surveys should be more restricted, particularly if maternity colonies are being observed. A few things to consider: 1) even though bats may be present in the GRYN in May, it is not clear when they actually begin roosting at maternity sites; 2) bats are most sensitive to roost disturbance at the time of parturition (mid-June), so roost should not be entered at this time; 3) when young of most bats begin flying (3-4 weeks after birth), they are virtually indistinguishable from adults without examining joint development. Thus, roost surveys aimed at evaluating reproduction should occur after young are born, but before they are difficult to tell from adults (i.e., roughly late June - mid July). Young are not fully weaned until several weeks after they are able to fly, so maternity roost surveys can be conducted into mid-August if estimating the number of young is not critical. It is possible that the whole cycle occurs earlier in BICA than the higher, cooler regions of GTNP and YNP (Figure 10). Although bats can likely be found active in the GRYN until October, I suspect that bats in the GRYN, or at least in GTNP and YNP, begin aggregating for departure to hibernacula in late August, so surveys should be conducted before then to insure that "resident" bats are being surveyed, not migratory individuals.

These findings also have implications for the timing of bat exclusion activities in buildings within the parks; such activities should be completed between late-October and mid-April (e.g., November 1 - April 1) in order to have the least impact on roosting bats.

Next Steps

As noted above (see also Table 1 and Appendix 1), a couple species in each park have only been tentatively identified and further verification of their presence is needed before concluding that they regularly occur in the parks. To "complete" the species list for each park, the following targeted surveys are recommended.

1. BICA: Silver-haired bats (tree-roosting; target mature forested canyons and marshes in central BICA and YWHMA using mist nets and active ANABAT® recording with visual observation)
2. BICA: California myotis (forage around vegetation; target brushy canyon country in central BICA using primarily active ANABAT® recording and targeted canopy netting)
3. GTNP: Western small-footed myotis (forage around vegetation; target vegetated flyways and water bodies in northeast GTNP using canopy netting)
4. GTNP: Yuma myotis (forage over open water; target large ponds and roost structures in JDRNP using active ANABAT® recording with visual observation and netting where possible)
5. YNP: Yuma myotis (forage over open water; target large ponds and roost structures in Bechler area using active ANABAT® recording with visual observation and netting where possible)
6. YNP: Pallid bat (forage around vegetation by arid cliffs; target open forest and vegetated edges in the vicinity of the Mammoth terraces and possibly the Grand Canyon using primarily active ANABAT® recording with visual observation and mist netting over calm bodies of water)

There are three particular cases where further knowledge regarding the occurrence and ecology of known species within the parks would be important to conservation of those species. These are summarized briefly as follows:

1. Townsend's big-eared bat in GTNP: In this study, we documented male Townsend's big-eared bats (*Corynorhinus [= Plecotus] townsendii*) roosting in abandoned buildings in two former ranches within GTNP (White Grass Ranch and Bar B C Ranch). Use of these buildings by *C. townsendii* appears to be a regular and long-term occurrence, since anecdotal investigations 20 years ago also found them (Susan Wolff pers. comm.). The bat diversity around these ranches seems substantial, but Townsend's big-eared bat in particular is a sensitive species throughout the western United States (Western Bat Working Group 1998, Gruver and Keinath 2004). They require particular cave characteristics for maternity colonies that are sparse on the western landscape, which drastically limits the habitat capable of supporting them and makes every maternity colony an important focus of conservation effort (Pierson et al. 1999). Male *C. townsendii* do not generally roost in the maternity colonies, but they only migrate locally and congregate with females in the spring and fall, which suggests that a maternity colony may exist within GTNP. Documenting such a colony, which would be the only one found in the park, and insuring its continued protection is therefore an important conservation goal.
2. Townsend's big-eared bat in YNP: In this study, we documented a maternity roost of Townsend's big-eared bats (*Corynorhinus [= Plecotus] townsendii*) in Devil's Kitchen on the Mammoth Terrace and witnessed additional use of caves on the upper terrace. The possibility exists for *C. townsendii* to be using similar caves as maternity and bachelor roosts. It is important for the park to know which structures are being used so that future activity (either by park staff or visitors) can be viewed in light of potential impacts.
3. Roosting habitat investigations for the fringe-tailed bat: The fringe-tailed bat (*Myotis thysanodes*) is recognized by several federal and state agencies as a sensitive species that is apparently rare and at risk, based on scant knowledge of local, regional, and national populations (Keinath 2004). Suitable roosting sites are a critical habitat component, the availability of which can determine population sizes and distributions (e.g., Humphrey 1975, Kunz 1982). Despite variable range-wide roost use, *M. thysanodes* seems to be locally restricted to only a few roost types, cliff crevasse and snags being those likely in the GRYN (e.g., Weller and Zabel 2001, Cryan 1997). Which roosts are being used in YNP and GTNP, and moreover the character of those roosts, could suggest the nature of the GRYN population and help the parks identify actions that are likely to cause adverse impacts. A roosting study of *M .thysanodes* in these areas is therefore recommended.

REFERENCES

Adams, R. A. 2003. Bats of the Rocky Mountain West: natural history, ecology, and conservation. University Press of Colorado, Boulder, Colorado.

Altringham, J.D. 1996. Bats: biology and behavior. Oxford University Press, Oxford, United Kingdom.

Anderson, S. H., W. A. Hubert, and D. Duvall. 1984. Vertebrate inventory for Bighorn Canyon National Recreation Area. Eighth Annual Report of the National Park Service Research Center, University of Wyoming, Laramie, Wyoming.

Barclay, M. R. and L. D. Harder. 2003. Life histories of bats: life in the slow lane. Chapter 5 *in* Kunz T. H. and M. B. Fenton, Bat ecology, University of Chicago Press, Chicago, Illinois, USA.

Bogan, M.A. and K. Geluso. 1999. Bat roosts and historic structures on National Park Service lands in the rocky mountain region. Unpublished final report. USGS-Midcontinent Ecosystem Science Center, Univ. New Mexico, Albuguerque, NM. 25 pp.

Clark, T. W. and M. R. Stromberg. 1987. Mammals in Wyoming, University of Kansas Museum and Natural History Public Education Series No. 10. University Press of Kansas, Lawrence, Kansas.

Cam, E., J. D. Nichols, J. R. Sauer, and J. E. Hines. 2003. On the estimation of species richness based on the accumulation of previously unrecorded species. Echography 25:102-108.

Cryan, P.M. 1997. Distribution and Roosting Habits of Bats in the Southern Black Hills, South Dakota. Master's thesis submitted to the University of New Mexico, Albuquerque, New Mexico.

Chao, A. 1984. Nonparametric estimation of the number of classes in a population. Scandinavian Journal of Statistics 11:265-270.

Colwell, R.K. and J.A. Coddington. 1994. Estimating terrestrial biodiversity through extrapolation. Phil. Trans. R. Soc. Lond. B. 345:101-118.

Gotelli, N.J. and G.R. Graves. 1996. Null models in ecology. Smithsonian Institution Press, Washington, D. C.

Gruver, J. and D. A. Keinath. In Prep. Townsend's big-eared bat (*Corynorhinus townsendii*): a technical conservation assessment. USDA Forest Service, Rocky Mountain Region. Available at http://www.fs.fed.us/r2/projects/scp/assessments/index.shtml in fall 2005.

Hendricks, P. 2000. Bat survey along the Norris-Madison Juction Road Corridor, Yellowstone National Park, Wyoming 1999. Unpublished report. Yellowstone National Park. 15pp.

Humphrey, S.R. 1975. Nursery roosts and community diversity of nearctic bats. Journal of Mammalogy 56:321-346.

Keinath, D. A. 2001. Bat Habitat Delineation and Survey Suggestions for Bighorn Canyon National Recreation Area. Report prepared for the North American Bat Conservation Partnership and Bighorn Canyon National Recreation Area by the Wyoming Natural Diversity Database, Laramie, Wyoming.

Keinath,D.A. 2004. Fringed Myotis (*Myotis thysanodes*): a technical conservation assessment.[Online]. USDA Forest Service, Rocky Mountain Region. Available at: http://www.fs.fed.us/r2/projects/scp/assessments/fringedmyotis.pdf.

Krebs, C. J. 1999. Ecological methodology, 2nd Ed. Addison-Welsey Educational Publishers, Inc., Menlo Park, California.

Kunz, T.H. 1982. Roosting ecology of bats. Pages 1-55 in T.H. Kunz, editor. Ecology of bats. Plenum Press, New York, New York.

Moreno, C.E. and G. Halffter. 2000. Assessing the completeness of bat biodiversity inventories using species accumulation curves. Journal of Applied Ecology, 37:149-158.

O'Farrell, M.J. and W.L. Gannon. 1999. A comparison of acoustic versus capture techniques for the inventory of bats. *Journal of Mammalogy*. 80:24-30.

O'Farrell, M.J., B.W. Miller and W.L. Gannon. 1999. Qualitative identification of free-flying bats using the Anabat detector. *Journal of Mammalogy*. 80:11-23.

Sorberon J.M. and J. Llorente B. 1993. The use of species accumulation functions for the prediction of species richness. Conservation Biology, 7:480-487.

Priday, J. and B. Luce. 1998. Inventory of Bats and Bat Habitat Associated with Caves and Mines in Wyoming: Completion Report. In Wyoming Game and Fish Threated, Endangered, and Nongame Bird and Mammal Investigations: Anual Completion Report. 12 August 1998.

Thomas, D.W. and S.D. West. 1989. Sampling methods for bats. General Technical Report PNW-GTR-243. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, Oregon. 20 pp.

Worthington, D. and H. N. Ross. 1990. Abundance and distribution of bats in the Pryor Mountains of South Central Montana. Report submitted to the Montana Natural Heritage Program, the Bureau of Land Management, and Custer National Forest by the Division of Biological Sciences, University of Montana, Missoula, Montana.

Weller, T.J. and C.J. Zabel. 2001. Characteristics of fringed myotis day roosts in northern California. Journal of Wildlife Management 65:489-497.

Western Bat Working Group. 1998. Western Bat Species: Regional Priority Matrix. Western Bat Working Group (http://www.batworkinggroups.org/WBWG/wmatrix1.html).

TABLES AND FIGURES

Table 1: Bat species list by Park Unit in the Greater Yellowstone Network.

Table 1a. Bighorn Canyon National Recreation Area.

Species Code	Species Name	Abundance [a]	Status Notes [b]
ANPA	Pallid bat (*Antrozous pallidus*)	Low	localized
COTO	Townsend's big-eared bat (*Corynorhinus townsendii*)	Low-Medium	localized
EPFU	Big brown bat (*Eptesicus fuscus*)	High	widespread
EUMA	Spotted bat (*Euderma maculatum*)	Medium	localized
LACI	Hoary bat (*Lasiurus cinereus*)	Low	sparse but widespread
LANO [b]	Silver-haired bat (*Lasionycteris noctivagans*)	Uncertain	questionable occurrence
MYCA [b]	California myotis (*Myotis californicus*)	Uncertain	questionable occurrence
MYCI	Small-footed myotis (*Myotis ciliolabrum*)	Medium	
MYEV	Long-eared myotis (*Myotis evotis*)	Medium	
MYLU	Little brown bat (*Myotis lucifugus*)	Very High	common and widespread
MYTH	Fringe-tailed bat (*Myotis thysanodes*)	Low	localized
MYVO	Long-legged myotis (*Myotis volans*)	Medium	
MYYU	Yuma myotis (*Myotis yumanensis*)	Medium	
Total Species Richness for BICA		11-13	

Table 1b. Grand Teton National Park (including John D. Rockefeller Memorial Parkway).

Species Code	Species Name	Abundance [a]	Status Notes [b]
COTO	Townsend's big-eared bat (*Corynorhinus townsendii*)	Low	bachelors only
EPFU	Big brown bat (*Eptesicus fuscus*)	Medium	widespread
LACI	Hoary bat (*Lasiurus cinereus*)	Medium	sparse but widespread
LANO	Silver-haired bat (*Lasionycteris noctivagans*)	Medium-High	widespread
MYCI [b]	Small-footed myotis (*Myotis ciliolabrum*)	Uncertain	questionable occurrence
MYEV	Long-eared myotis (*Myotis evotis*)	Medium	
MYLU	Little brown bat (*Myotis lucifugus*)	Very High	common and widespread
MYTH	Fringe-tailed bat (*Myotis thysanodes*)	Low	localized
MYVO	Long-legged myotis (*Myotis volans*)	Medium	
MYYU [b]	Yuma myotis (*Myotis yumanensis*)	Uncertain	questionable occurrence
Total Species Richness for GTNP and JDRNP		8-10	

Table 1c. Yellowstone National Park.

Species Code	Species Name	Abundance [a]	Status Notes [b]
ANPA [b]	Pallid bat (*Antrozous pallidus*)	Uncertain	questionable occurrence
COTO	Townsend's big-eared bat (*Corynorhinus townsendii*)	Low	localized, sensitive
EPFU	Big brown bat (*Eptesicus fuscus*)	Medium	
LACI	Hoary bat (*Lasiurus cinereus*)	Low	sparse but widespread
LANO	Silver-haired bat (*Lasionycteris noctivagans*)	Medium-High	widespread
MYEV	Long-eared myotis (*Myotis evotis*)	Low	
MYLU	Little brown bat (*Myotis lucifugus*)	Very High	common and widespread
MYTH	Fringe-tailed bat (*Myotis thysanodes*)	Low	localized
MYVO	Long-legged myotis (*Myotis volans*)	Medium	
MYYU	Yuma myotis (*Myotis yumanensis*)	Low	localized; accidental?
Total Species Richness for YNP		9-10	

a Abundance is noted using a categorical scale representing the author's subjective assessment from the data collected during this inventory. Low, Medium, High, Very High, and Uncertain designations indicate unit-wide likelihood of occurrence and do not speak to population viability or relevance to broader distributions.

b Generally speaking, questionable, or uncertain, species have been identified only by passively collected ANABAT® recordings, but have not been captured or otherwise identified in the park. These records should be considered tentative and in need of corroboration. The *Myotis californicus* in BICA was captured, but not conclusively identified (final determination will be made by museum experts).

Table 2: Summary of bat captures in the Greater Yellowstone Network.

Table 2a. Bighorn Canyon National Recreation Area. Capture effort in BICA was approximately 2,843 NAH [a].

Species Code	Species Name	Number Captured	Captures Per 100 Net Area Hours [a]
ANPA	Pallid bat (*Antrozous pallidus*)	2	0.070
COTO	Townsend's big-eared bat (*Corynorhinus townsendii*)	5	0.176
EPFU	Big brown bat (*Eptesicus fuscus*)	59	2.075
EUMA	Spotted bat (*Euderma maculatum*)	20[b]	0.704
LACI	Hoary bat (*Lasiurus cinereus*)	1	0.035
MYCA	California myotis (*Myotis californicus*)	1	0.035
MYCI	Small-footed myotis (*Myotis ciliolabrum*)	22	0.774
MYEV	Long-eared myotis (*Myotis evotis*)	9	0.317
MYLU	Little brown bat (*Myotis lucifugus*)	101	3.553
MYTH	Fringe-tailed bat (*Myotis thysanodes*)	2	0.070
MYVO	Long-legged myotis (*Myotis volans*)	29	1.020
MYYU	Yuma myotis (*Myotis yumanensis*)	3	0.106
Total		253	8.900
Richness		12	0.387

Table 2b. Grand Teton National Park (including John D. Rockefeller Memorial Parkway). Capture effort in GTNP and JDRMP was approximately 6,629 NAH [a].

Species Code	Species Name	Number Captured	Captures Per 100 Net Area Hours [a]
EPFU	Big brown bat (*Eptesicus fuscus*)	4	0.060
LACI	Hoary bat (*Lasiurus cinereus*)	15	0.226
LANO	Silver-haired bat (*Lasionycteris noctivagans*)	23	0.347
MYEV	Long-eared myotis (*Myotis evotis*)	6	0.091
MYLU	Little brown bat (*Myotis lucifugus*)	188	2.836
MYTH	Fringe-tailed bat (*Myotis thysanodes*)	1	0.015
MYVO	Long-legged myotis (*Myotis volans*)	7	0.106
Total		244	3.681
Richness		7	0.106

Table 2c. Yellowstone National Park. Capture effort in YNP was approximately 7,931 NAH [a].

Species Code	Species Name	Number Captured	Captures Per 100 Net Area Hours [a]
COTO	Townsend's big-eared bat (*Corynorhinus townsendii*)	1	0.013
EPFU	Big brown bat (*Eptesicus fuscus*)	4	0.050
LACI	Hoary bat (*Lasiurus cinereus*)	2	0.025
LANO	Silver-haired bat (*Lasionycteris noctivagans*)	18	0.227
MYEV	Long-eared myotis (*Myotis evotis*)	1	0.013
MYLU	Little brown bat (*Myotis lucifugus*)	312	3.934
MYTH	Fringe-tailed bat (*Myotis thysanodes*)	1	0.013
MYVO	Long-legged myotis (*Myotis volans*)	1	0.013
Total		340	4.287
Richness		8	0.101

a Net Area Hours (NAH) is a measure of sampling effort for mist netting activities; calculated as the time in hours during which nets are deployed multiplied by the surface area of those nets. For example one 9 m X 2.6 m net deployed for 5 hours results in 117 NAH reported as "square meter hours".

b EUMA were not actually captured, but audibly or visually encountered at net sites during netting activities.

Table 3: Bat inventory completeness summary for the Greater Yellowstone Network; richness curves and summaries of individual estimators are presented in Figures 6 and 7.

Park Unit	Inventory Richness	Estimated Richness (Captures)	Estimated Richness (Anabat®)	Estimated Inventory Completeness
All GRYN	**13**	**13.6**	**13.2**	**96% - 98%**
BICA	12	14.9	13.7	81% - 88%
GTNP	7	8.4	10.3	68% - 83%
YNP	8	10.4	10.3	77% - 78%

Figure 1: Diagram of habitat suitability algorithm

1. Score individual habitat features (Type and Distance Components)

2. Apply weighting factors and structure modifiers

3. Combine each habitat value via modeling formula

General Type Score (tsi)

0 Avoided or Never Used
1 Possible Use
2 Used as Available
3 Preferred Habitat

Distance from Roost Score (dsi)

	Clutter Adapted	Open Adapted
0	>10km	>40km
1	5-10km	20-40km
2	2.5-5km	10-20km
3	<2.5km	<10km

Distance from water score (dsi for NWI)

0 >3km
1 2-3km
2 1-2km
3 <1km

Elevation Score (tsi)

0 >10000ft or 3050m (Ice in Caves, No insects)
1 Mid Elevation
2 <7000ft or 2100m (Vally level, Lowands)

Aspect Score (tsi)

0 North (0-45,315-360)
1 Slight North (45-90,270-315)
2 Slight South (90-135,225-270)
3 South (135-225)

Cliff Modifier Score (smi)

0 not a cliff (<50% slope)
1 cliff (>50% slope)

Geology Modifier Score (smi)

0 bedrock below surface
1 bedrock at surface

Feature Weight (wi)

0 not applicable
0.5
1
1.5
2 very important

Theme	Code	Feature weight (wi)	Type score (tsi)	Distance score (dsi)	structure modifier (smi)
National Wetlands Inventory	NWI	2	0.7*(0-3)	0.3*(0-3)	-
Landcover (habitat)	HAB	1.5	0-3	-	inc in type
Geology (caves)	GEO	1	0.4*(0-3)	0.6*(0-3)	0 or 1
Elevation (temp)	ELV	1	1.5*(0-2)		
Slope (cliffs)	CLF	1	-	0-3	0 or 1
Aspect (thermal heating)	ASP	1	0-3	-	-

Wetlands Score
NWI = wi * (dsi + tsi)

Landcover Score
For GTNP: HAB = wi * (tsi)
For YNP: HAB = wi * (Habitat tsi + Cover tsi)

Geology Score
GEO = wi * (smi * tsi + dsi)

Topography Score
ELV = wi * tsi
CLF = wi * dsi
ASP = wi * tsi

FINAL SCORE = NWI + HAB + GEO + ELV + CLF + ASP

Figure 2: Final bat capture suitability model for Yellowstone National Park

Areas deemed suitable for netting the greatest diversity of bat species within Yellowstone National Park are highlighted in maroon (top 2% of modeled area) and red (top 8% of modeled area). Focal areas for survey, in order of decreasing priority, were 1. areas of high maroon and red concentrations, 2. areas of high green concentrations with some red, 3. areas of high green concentration, 4. under-represented habitat features or geographic areas.

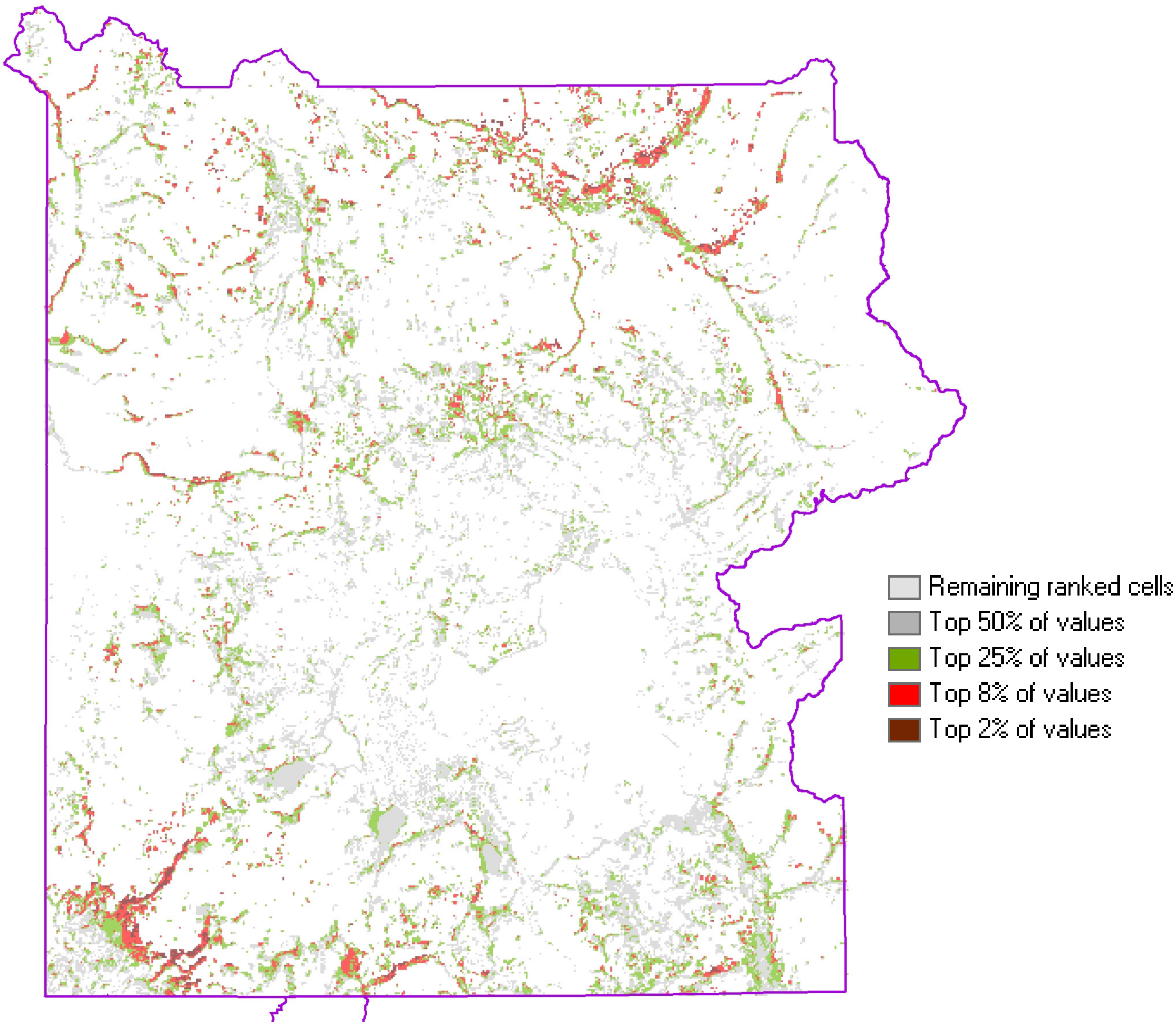


Figure 3: Final bat capture suitability model for Grand Teton National Park

Areas deemed suitable for netting the greatest diversity of bat species within Yellowstone National Park are highlighted in maroon (top 2% of modeled area) and red (top 8% of modeled area). Focal areas for survey, in order of decreasing priority, were 1. areas of high maroon and red concentrations, 2. areas of high green concentrations with some red, 3. areas of high green concentration, 4. under-represented habitat features or geographic areas.

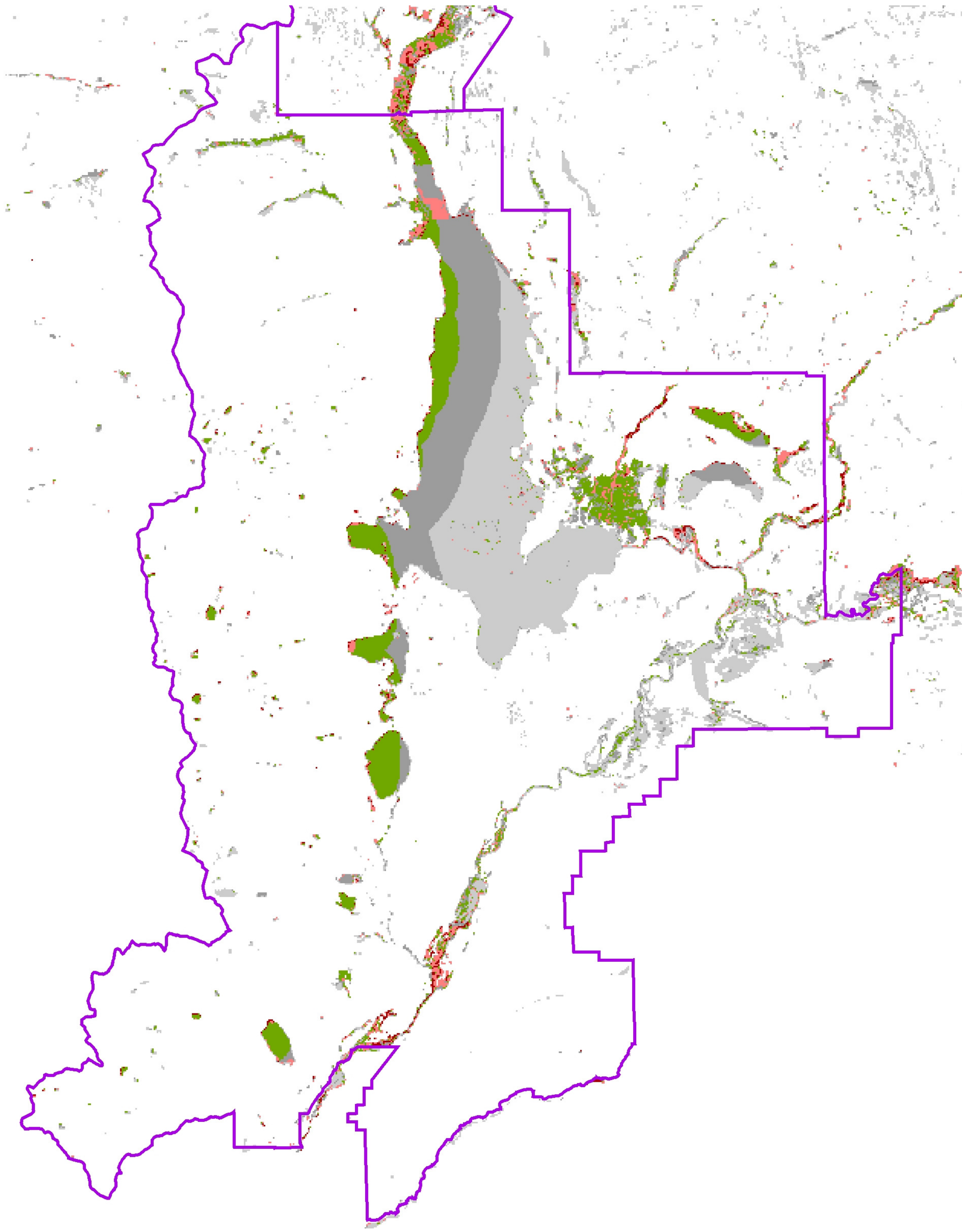
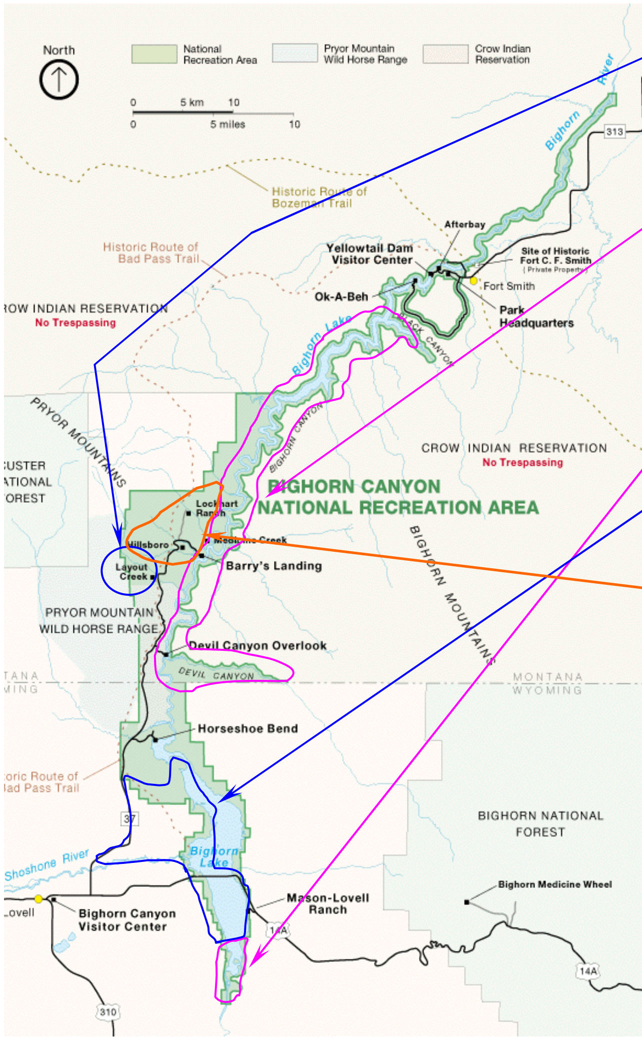


Figure 4: Priority bat survey sites in Bighorn Canyon National Recreation Area



Detailed map reproduced from National Park Service Homepage (http://www.aqd.nps.gov/grd/parks/bica/maps.htm).

Site	Rationale
Layout Creek and nearby tributaries	Layout creek has at least one still pond and lies within the high probability area delineated by the Townsend's big-eared bat model. It is also just below much cliff roosting habitat and contains the only documented occurrence of spotted bat activity in the recreation area.
Cliffs along the walls of Bighorn Canyon and Devils Canyon.	The canyon walls represent the most extensive complex of spotted bat rooting habitat in the area and there are anecdotal reports of spotted bat calls along the rim of Devil's Canyon.
Yellowtail Wildlife Habitat Management Area (YWHMA), specifically:	YWHMA contains a wealth of bat foraging and roosting habitat. Areas for survey are highlighted because:
a. Ponds at the southernmost extent of YWHMA.	a. The Kane Caves, just south of YWHMA are known bat roosts, including Townsend's big-eared bats.
b. Known and potential roost buildings anywhere in the management area and small ponds anywhere in YWHMA.	b. At least one building in YWHMA has very high bat activity, and others in the vicinity are also likely to receive some use. Bats forage over the extensive wetlands in YWHMA. The most likely place to capture them is over small bodies of flat water over which they would feed and drink.
Hillsboro Ranch and beaver ponds and Lockhart Ranch and beaver ponds.	These ranches consist of several uninhabited structures along drainages containing numerous beaver ponds in otherwise dry country. They are therefore likely to concentrate bats foraging in the drainages and there is evidence that at least some of the buildings serve as night roosts.
Caves that are just off BCNRA, usually on BLM land, but whose bat population likely forages on the recreation area.	These caves include Horse Thief Cave, Bighorn Caverns, Natural Trap Cave, Mystery Cave, and numerous others to the east of the recreation area.
Other habitats, such as cottonwood riparian corridors and edges in conifer forest.	As time and budget permit, other habitats might be sampled to increase the diversity of sites.

Figure 5: Bat inventory site distribution throughout the Greater Yellowstone Network (parks are not to scale)

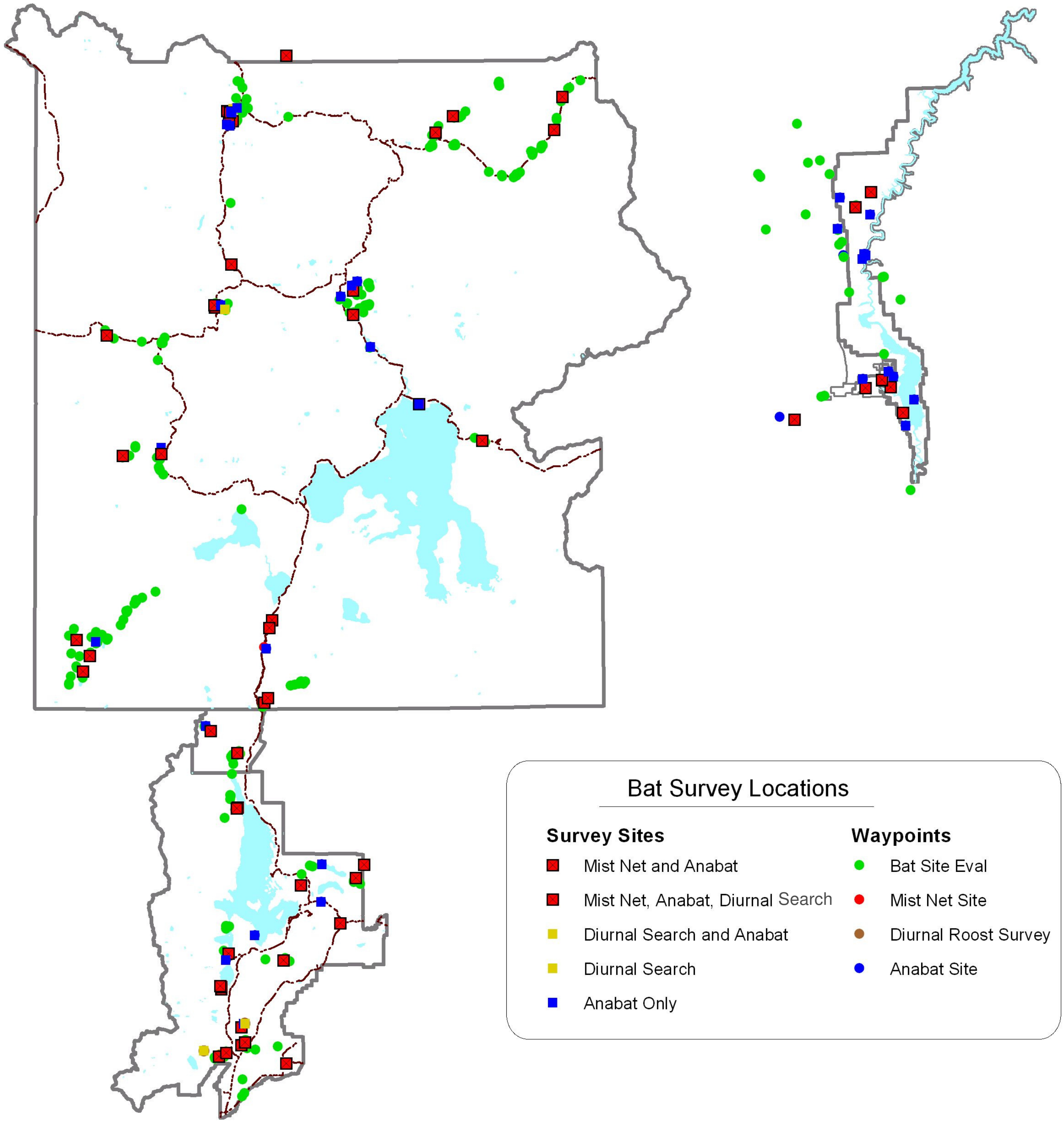
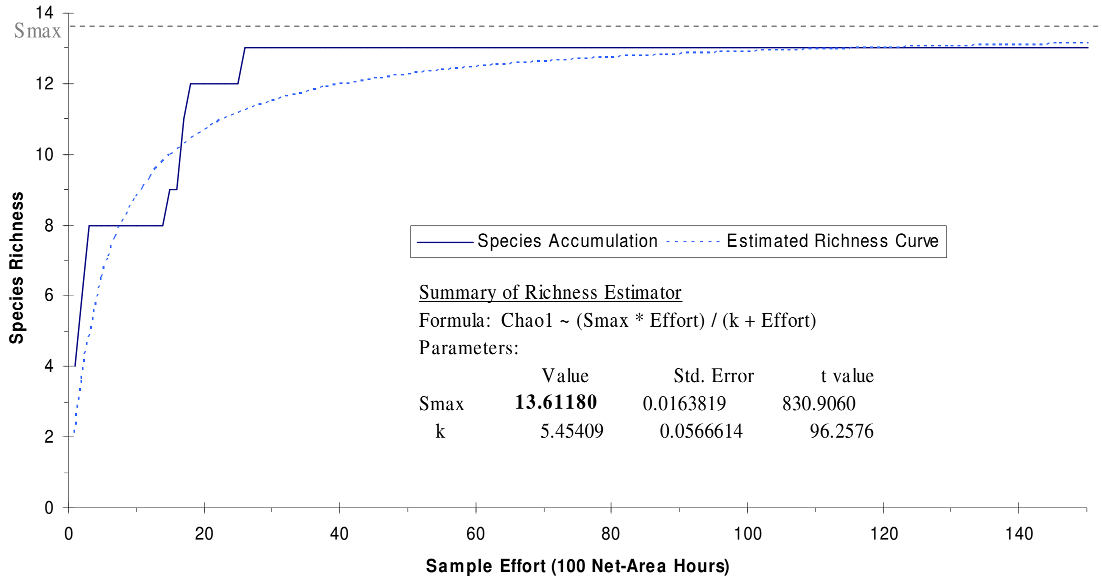


Figure 6: Species accumulation curves and richness estimators for the Greater Yellowstone Network using: a) capture data from mist netting activities and b) recorded echolocation calls from Anabat® surveys.

(a)



(b)

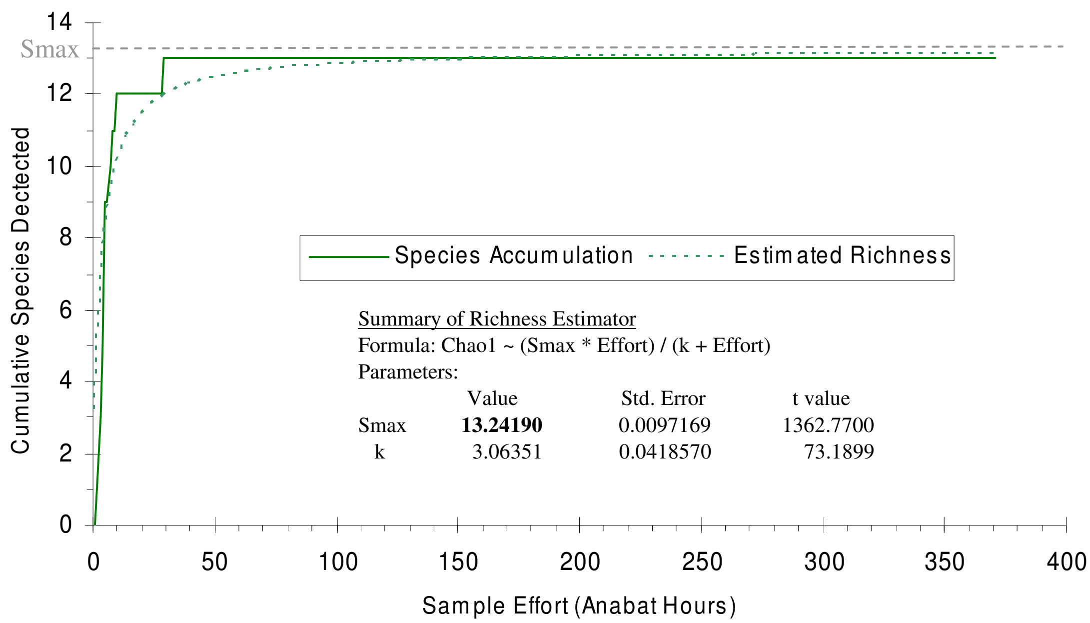
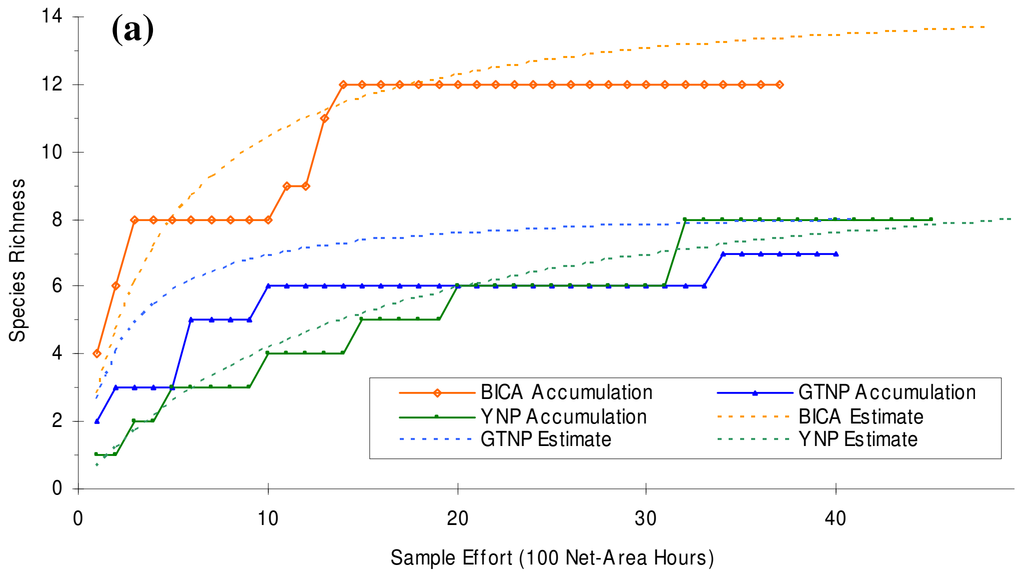


Figure 7: Species accumulation curves and richness estimators for each park unit in the Greater Yellowstone Network using: a) capture data from mist netting activities and b) recorded echolocation calls from Anabat® surveys.



Estimator for BICA
Formula: Chao1 ~ (Smax * Effort)/(k + Effort)
Parameters:

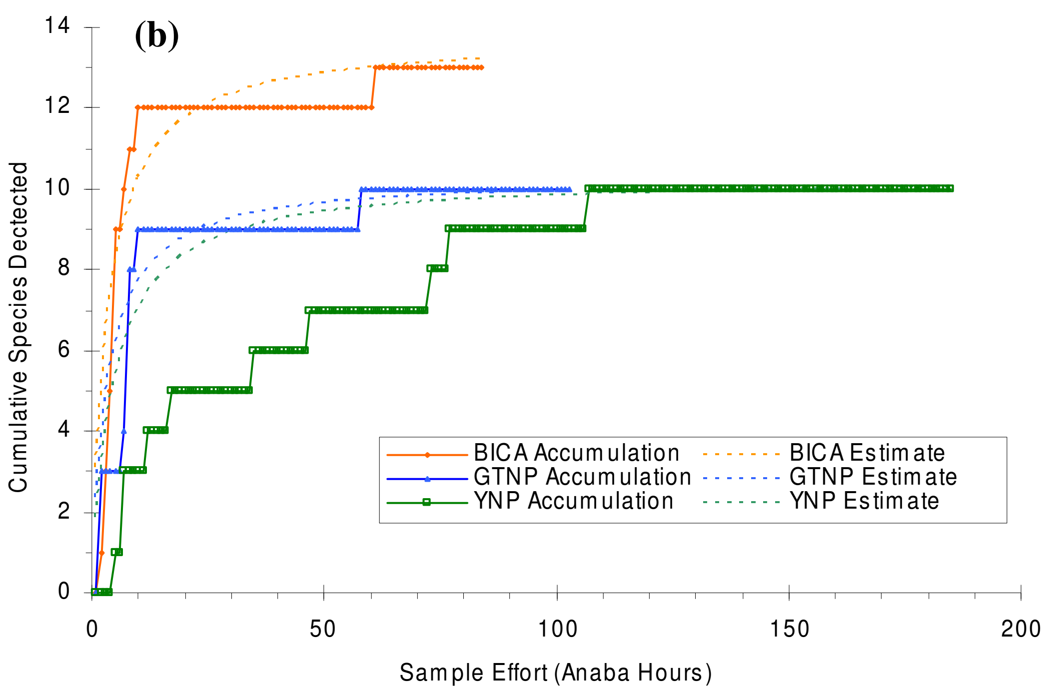
	Value	Std. Error	t value
Smax	**14.88520**	0.153025	97.2731
k	4.25426	0.231969	18.3398

Estimator for GTNP
Formula: Chao1 ~ (Smax * Effort)/(k + Effort)
Parameters:

	Value	Std. Error	t value
Smax	**8.36783**	0.0386934	216.2600
k	2.10481	0.0695252	30.2741

Estimator for YNP
Formula: Sobs ~ (Smax * Effort)/(k + Effort)
Parameters:

	Value	Std. Error	t value
Smax	**10.3921**	0.256363	40.5365
k	14.9147	1.156200	12.8997



Estimator for BICA
Formula: Chao1 ~ (Smax * Effort)/(k + Effort)
Parameters:

	Value	Std. Error	t value
Smax	**13.74190**	0.0420474	326.8190
k	3.38373	0.0838500	40.3546

Estimator for GTNP
Formula: Chao1 ~ (Smax * Effort)/(k + Effort)
Parameters:

	Value	Std. Error	t value
Smax	**10.29540**	0.0237806	432.9310
k	3.32927	0.0700298	47.5407

Estimator for YNP
Formula: Chao1 ~ (Smax * Effort)/(k + Effort)
Parameters:

	Value	Std. Error	t value
Smax	**10.29110**	0.0113985	902.8470
k	4.54544	0.0529804	85.7949

Figure 8: Summary of bat occurrences; (a) estimated bat species richness, (b) ANABAT® records per hour, and (c) bat captures per net-area-hour by site in the Greater Yellowstone Park Network.

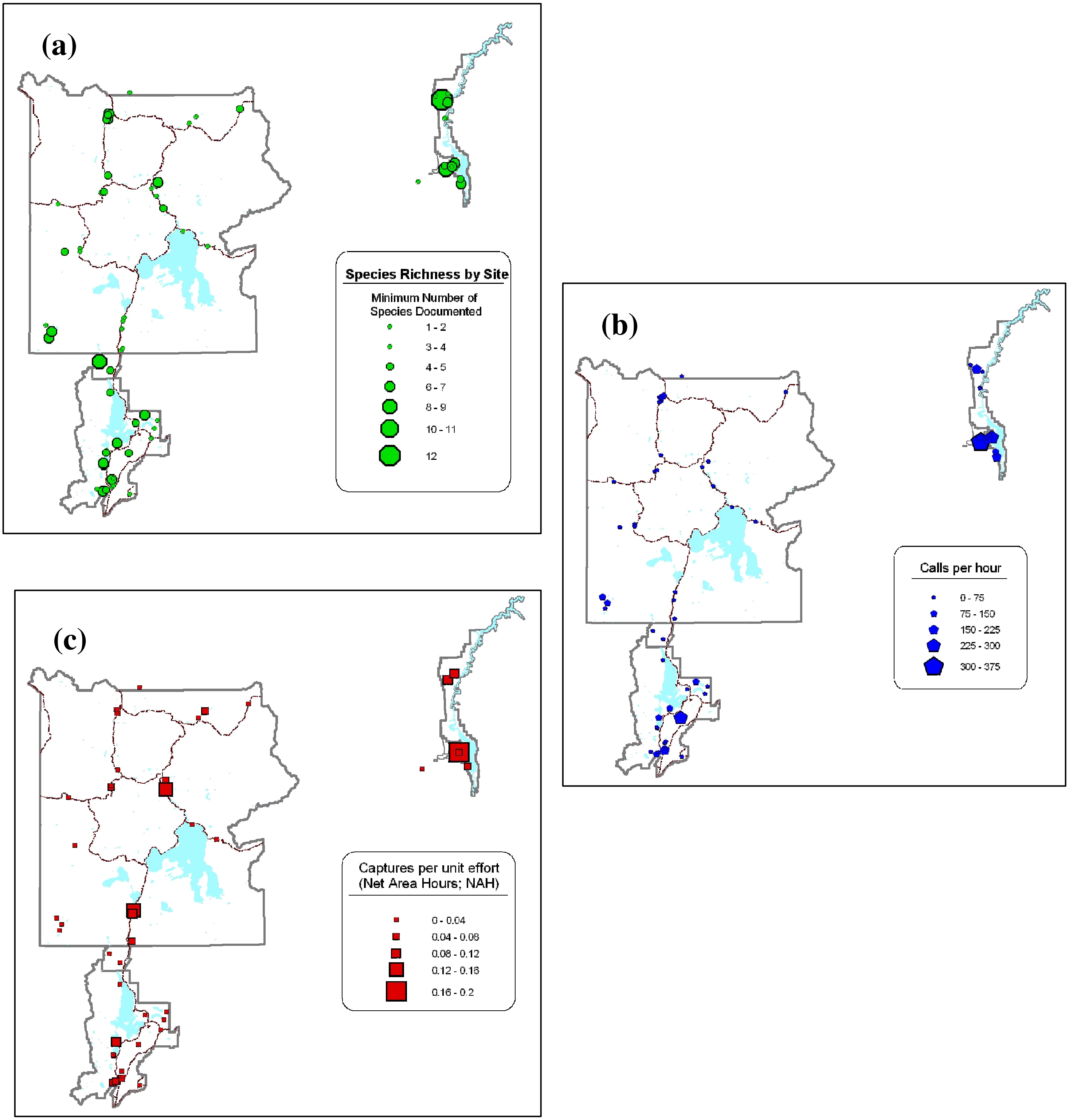
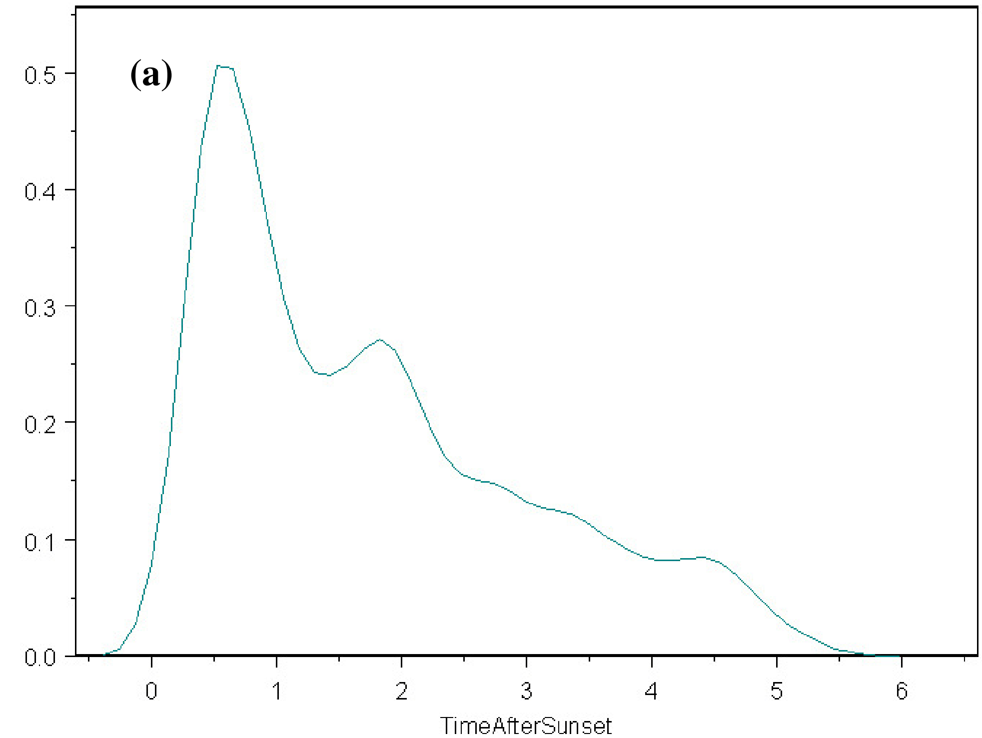


Figure 9: Bat captures as a function of time of day as (a) frequency of all captures combined and (b) ranges for individual species.



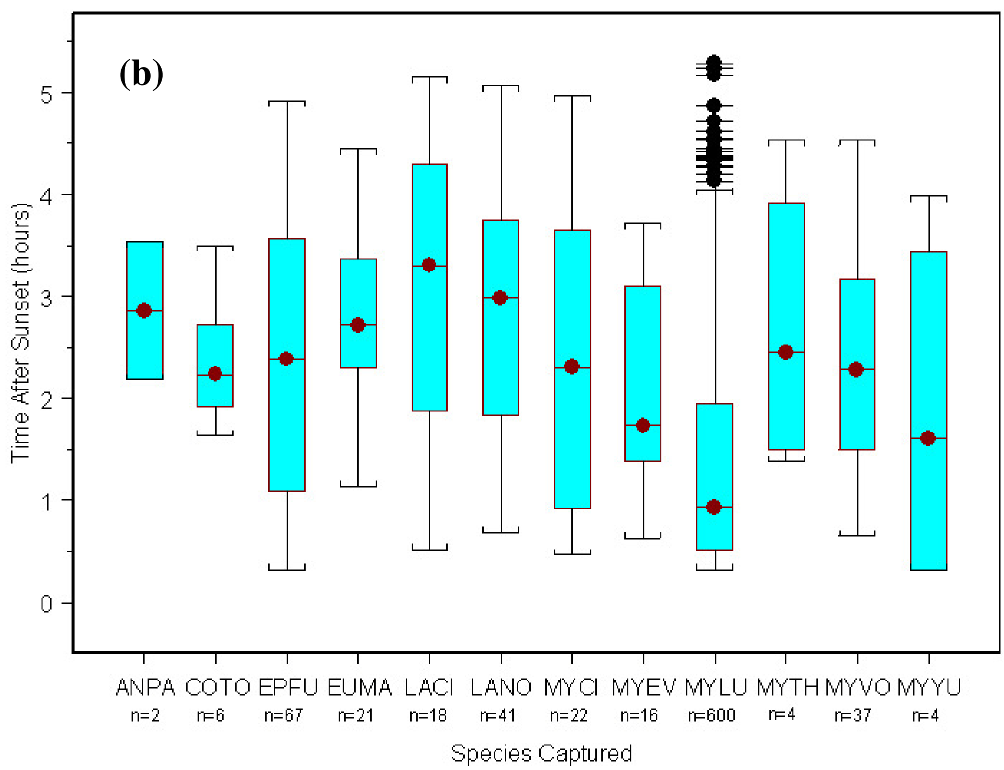
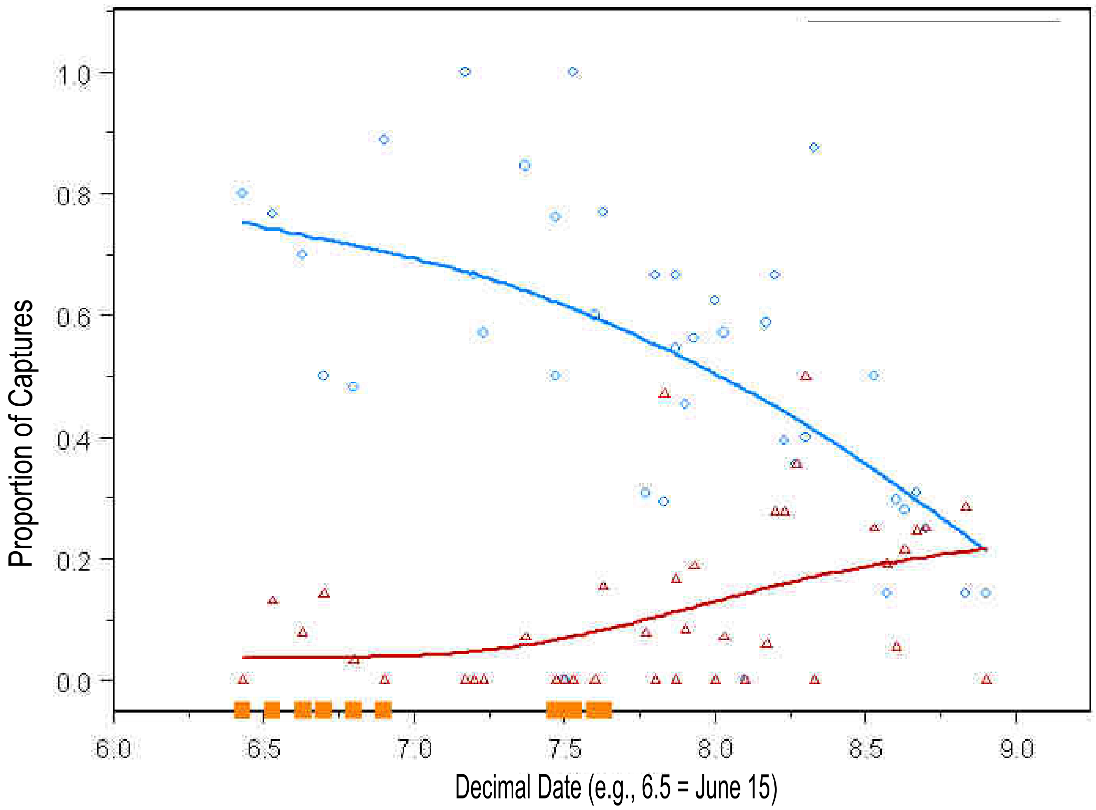


Figure 10: Captures of reproductively active adult bats and juveniles by time of year (summer months only) for the Greater Yellowstone Ecosystem.



Proportion of captures that were reproductively active adults (Females: pregnant, lactating, post-lactating; Males: tentacles descended). Line represents the cubic smoothing spline of the data.

Proportion of captures that were juveniles. Line represents the cubic smoothing spline of the data.

Dates during which capture activities occurred at Bighorn Canyon, where temperatures are warmer and parturition likely occurs earlier.