# CONSERVATION AND RESTORATION OF A GREAT BLUE HERON BREEDING COLONY IN EAST CENTRAL MINNESOTA

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# DEDICATION

This thesis is dedicated to my wife Betsy S. Von Duyke, to my daughters Anna and Ellie Von Duyke, and to my parents Marilu Laubenthal and David A. Von Duyke.

# ABSTRACT

Thesis Presented to the Graduate School of the University of Minnesota in Partial Fulfillment of the Requirements for the Degree of Master of Science

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A Great Blue Heron (*Ardea herodias*) colony located at Peltier Lake, in east central Minnesota, was formerly one of the state's largest. Beginning in 2000, the nesting birds abandoned this site for the first of five consecutive seasons. Because of its regional ecological importance and high community value, the conservation of the Peltier Lake colony was prioritized by the Minnesota Department of Natural Resources. Early management efforts focusing on anthropogenic disturbance mitigation were unsuccessful in halting colony abandonment. At its lowest point, the nesting population at Peltier Lake dropped >90% from an estimated maximum of >1,100 nesting pairs. To determine the cause(s) of colony abandonment, I used intra-nest video surveillance to monitor nesting behavior and document events occurring within the colony. Video data demonstrated that, while human disturbance rates at Peltier Lake were similar to those at another regional colony, predation by raccoons (*Procyon lotor*) was an important cause of chick mortality. Great Horned Owl (*Bubo virginianus*) depredation was also confirmed using physical evidence, but the impact of owls on the colony was not determined. Based on these results, a strategy of predator management was recommended for Peltier Lake. Methods included installing predator guards and relaxing furbearer trapping restrictions within the county park where this colony is located. Scratches on the predator guards demonstrated that raccoons attempted to climb trees containing active nests significantly more often than inactive trees. Following predator management, the productivity of the Peltier Lake colony increased significantly. Continued lack of productivity in unprotected nest-trees demonstrated the efficacy of the predator guards; and also suggested that, despite removal efforts, enough predators remained present to opportunistically exploit unguarded active nest-trees. The events at the Peltier Lake colony and model results demonstrating the disproportionately large impact that a small population of arboreal mesopredators can have support the predation hypothesis as a cause for colony abandonment. The implications of this study underscore the value of strong empirical evidence as well as the importance of predation to the success of colonial waterbird conservation efforts.

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## *Introduction*

Starting in the year 2000, a very large mixed-species waterbird colony located at Peltier Lake in east-central Minnesota (45°11'N / 93°3'W) abandoned for the first of five consecutive seasons. The net result of abandonment was the complete or nearly complete failure of the colony due to the loss of each season's chick cohort. Anecdotal evidence suggested human disturbance as a likely cause. Highly valued by the local community, much effort was invested in its conservation, including passage of a contentious "no-wake" ordinance for boaters on Peltier Lake by the cities of Lino Lakes, MN and Centerville, MN. Subsequent colony abandonments and reductions in the number of nesting pairs at the colony suggested that disturbance mitigation may not have addressed the most important cause(s). The objective of this case study is to highlight the population status, threats, and management activities at the Peltier Lake colony in order to identify insights that may be useful in addressing other similar wildlife management scenarios and challenges.

### *Colonial Waterbirds*

Long-legged wading birds (Ciconiiformes) belong to a polyphyletic group known as "colonial-nesting waterbirds" (hereafter referred to as 'waterbirds'). All waterbirds share two behavioral characteristics: (1) they aggregate into large groups called colonies for nesting; and (2) they obtain all or most of their food from aquatic environments. While numerous hypotheses have been proposed to explain colonial behavior (Ward and Zahavi 1973, Burger 1981, Rodgers Jr. 1985, Simpson et al. 1987, Gibbs and Kinkel 1997), evolutionary theory predicts that for a behavior to persist, the fitness benefits of such a behavior must, on average, outweigh the fitness costs. Over shorter temporal scales, this benefit-cost ratio can fluctuate in response to ecological processes and likely explains much of the variance observed in waterbird colony location, composition, population, and lifespan.

*The Peltier Lake colony*

One of Minnesota's largest Ardeid breeding colonies (MN-DNR Natural Heritage Waterbird Database 2006), the Peltier Lake colony (45°11'N / 93°3'W) was once occupied by three co-occurring species: Great Blue Heron (*Ardea herodias*), Great Egret (*Ardea alba*), and Black-crowned Night-Heron (*Nycticorax nycticorax*). At its peak, > 1,000 nesting pairs occupied Anoka County's only mixed-species waterbird colony (MN-DNR Natural Heritage and Nongame Research Program - Colonial Waterbirds Database 2006). In 1997, nesting Black-crowned Night-Herons abandoned and failed to re-nest the following season (MN-DNR Nongame Wildlife Program, *unpubl. data*). The 1997 season also marked the beginning of a nine year annual decline in nesting pairs at Peltier Lake (Figure 1). In 2000, the entire colony (> 700 active nests) abandoned, resulting in complete colony failure due to loss of that year's chick cohort. This pattern of colony-wide abandonment and reproductive failure continued annually at Peltier Lake up to and including the 2004 nesting season (MN-DNR Nongame Wildlife Program, *unpubl. data*, Amie 2002). By the 2005 season, the Peltier Lake colony declined by more than 90% from its maximum of > 1,100 nesting pairs. Additionally, Great Egrets and Black-crowned Night-Herons no longer nested at the site.

Concerned local citizens raised the problem of this declining colony to the Minnesota Department of Natural Resources (MN-DNR) and local news media outlets. After the 2001 season, the MN-DNR identified the conservation and restoration of the Peltier Lake colony as high priorities because of its regional ecological importance and community appeal (Figure 2). To facilitate meeting these goals, a grassroots coalition of concerned citizens, stakeholders, and professional resource managers established the "Peltier Lake Heron Task Force".

*Potential Causes of Abandonment*

Numerous hypotheses for the abandonments at the Peltier Lake colony were considered (Appendix I). However, given the apparent correlation between the initial decline of the Peltier Lake colony and the establishment of a slalom water-ski course, the fact that its first abandonment coincided with nearby highway construction, and that it was subjected to regular aircraft and possible pedestrian disturbances, a good case was made for anthropogenic noise disturbance as "the most likely" cause of abandonment (Peltier Lake Heron Task Force minutes 2002). This conclusion was based upon the following details:

*Watercraft Disturbance*

A controversial source of noise disturbance began when a slalom water-ski course was illegally installed in the shallow northern end of Peltier Lake. Spanning the width of the lake (800m), the water-ski course passed within 50 m of the colony's northern extent (Figure 3). The magnitude of noise associated with waterskiing activities, its persistence, the timing of colony abandonment, and the failure of Black-crowned Night-Herons to re-nest at Peltier Lake after water-skiing began, all suggested that the water-ski course may have played an important role in colony abandonment.

Personal watercraft (PWC) have been found to elicit larger flush distances than other motorized watercraft due to wake size and the amount of associated noise (Rodgers Jr. and Schwikert 2002). It is conceivable that a ski-boat pulling a slalom water-skier may meet or even exceed disturbance levels caused by a PWC. Despite their propensity to habituate to anthropogenic disturbance (Nisbet 2000, Newbrey et al. 2005), Great Blue Heron productivity was found to be negatively correlated to recreational activity upon lakes (Drapeau et al. 1984). And given their sensitivity to disturbance, larger buffer distances (100-180m) have been recommended for Ardeids than for other waterbirds (Vos et al. 1985, Rodgers Jr. and Smith 1995, Rodgers Jr. and Schwikert 2002).

Water-ski activity was also correlated with an abrupt decrease of the lake's water quality. The water depth in the vicinity of the water-ski course averages < 2 m deep (MN-DNR 1993). One result of the repeated back and forth track followed by the ski-boats was the eventual shredding of all submergent macrophytes within the corridor of the slalom course (Figure 3). Consequently, the lake became hyper-eutrophic likely as a result of the combined suspension of shredded autochthonous material and phosphorus rich silt, greatly increasing the lake's nutrient load. Overall, water quality was diminished from increased turbidity, increased water temperature, decreased levels of dissolved oxygen, and algal blooms (including anaerobic cyanobacteria). As visual hunters, heron foraging success may be reduced by wave action and turbidity in response to use by recreational watercraft (D Mock, *pers. comm.*).

*Aircraft Disturbance*

Low flying aircraft were considered to be another potentially important source of noise disturbance. A private seaplane base and a municipal airport operated locally, and it was not uncommon for seaplanes to fly low over Peltier Lake to perform water landings and takeoffs. Furthermore, MN-DNR "water-bomber" firefighting aircraft scooped water from Peltier Lake on practice runs. Finally, Peltier Lake is located within the operational area of the Metropolitan Mosquito Control District (MMCD). MMCD helicopters routinely flew over the extensive marshes surrounding the Peltier Lake colony to dispense a mosquito larval growth inhibitor. While there were no direct observations of airplanes causing colony disturbances, helicopter activity was reported to flush breeding adult herons from their nests (Peltier Lake Heron Task Force 2003). These observations led to the speculation that aircraft noise, if occurring near the colony during critical nesting periods, could cause enough disruption to lead to nest and possibly colony-wide abandonment.

*Construction Noise*

Interstate 35W borders the northern shoreline of Peltier Lake and, at the shortest distance, is situated within 700m of the colony (Figure 4). Major road construction (MN-DOT State Project No. 0280-49) adjacent to Peltier Lake took place from 8 April to 1 July, 2000 (throughout the active nesting period). Construction tasks included milling and repaving the road-bed and occurred over long work days (MN-DOT 2007). Because the colony had yet to fail, construction noise was not considered problematic and therefore no sound mitigation was attempted. By mid June of the 2000 nesting season, the first documented abandonment of the Peltier Lake colony was documented.

In the year 2003, construction plans for a large church campus (Eagle Brook Church, 7775 20$^{th}$ Ave N, Lino Lakes, MN 55038) were announced. Located on land adjacent to the NE quadrant of Peltier Lake, this project represented a second potentially large scale disturbance in close proximity to the heronry.

*Pedestrian Traffic*

As part of the Anoka County Parks system, the island on Peltier Lake was available for public use during daylight hours throughout the year. However, beginning in 1997, Anoka County Parks has managed the island as a bird-sanctuary and “off limits” to pedestrian traffic while the herons were actively nesting (J Perry, *pers. comm.*).

## *Methods - Management Efforts (2002-04)*

The initial management strategy for the Peltier Lake colony (summarized below) was to mitigate anthropogenic disturbances and to employ low-cost, low-risk activities as deemed appropriate by the Heron Task Force.

*1. Mitigate anthropogenic noise*

Recreational boating noise was addressed through passage of City Ordinance #03-02, a joint powers action between the cities of Lino Lakes, MN and Centerville, MN which designated the shallow northern portion of Peltier Lake as a "no-wake" zone (Figure 5). Signage posted at the public boat launch and marker-buoys were used to notify boaters of the no-wake zone. Aircraft noise was addressed by notifying the local airports, the MN-DNR and the MMCD of the fragile status of the Peltier Lake colony. While the birds were nesting, the MN-DNR requested that pilots voluntarily observe a "no-fly zone" near the colony. Construction noise was addressed in cooperation with EBC construction management by proactively minimizing potential colony disturbances. Actions included delaying the groundbreaking until well past critical nesting periods (June 2004) and limiting heavy equipment access to only the eastern portion of the property. Eventually, a permanent conservation easement of 6.8 ha (16.7 acres) along the western portion of EBC property was negotiated. This ensured that the shoreline in the NE quadrant of Peltier Lake remained undeveloped and acted as a buffer for the colony.

*2. Discourage pedestrian traffic within the colony during nesting*

Signage was erected at conspicuous locations along the island's perimeter and at the public boat ramp on Peltier Lake to assure that the public was aware of the island's status as a bird-sanctuary and off limits while the herons were actively nesting. This was part of Anoka County's existing park management activities. Volunteer observers monitored the status and activity of the heronry and human compliance with the bird-sanctuary restrictions. Visits by wildlife managers to the island were also kept to a minimum to minimize disturbance.

*3. Augment nest construction materials*

To address a scenario of nest material limitation (Gibbs et al. 1987), two "stick-fields" were established to supplement the available naturally occurring nest material. Caches of sticks were scattered along the eastern and western shores of Peltier Lake (Eagle Brook Church and Anoka County Parks property respectively). The Anoka County parkland surrounding the western stick-field was closed to the public and the private property on the eastern shore ensured that there was minimal human interference with herons gathering nest materials. Observations at both stick-fields were used as an index of colony nesting activity.

*4. Monitor regional waterbird colonies*

Phenology, activity, and population size was monitored at the Peltier Lake colony and other regional waterbird colonies (Table 1) via bi-weekly aerial surveys. Aerial surveys were part of ongoing wildlife management operations conducted by the

MN-DNR Nongame Wildlife Program. Winter nest counts were also conducted by the MN-DNR and Anoka County Parks and Recreation to monitor the relative growth or decline of the Peltier Lake colony and of other regional waterbird colonies.

## *Results*

### *Mitigate anthropogenic noise*

Because the no-wake ordinance (implemented on 11 June, 2002) took effect approximately 75 days after herons normally initiate nesting at Peltier Lake, most of the 2002 nesting season, including the critical first three weeks of chick rearing, proceeded without the benefit of the no-wake zone. Local residents noted heavy recreational boating activity, much occurring in the northern end of Peltier Lake, throughout May and especially over the Memorial Day weekend of that year (Peltier Lake Heron Task Force 2003). After placement of the no-wake zone marker-buoys and "No Trespassing" signs on the island, local residents reported that there was general compliance by the public. Local airports, the MN-DNR, and the MMCD complied with requests to observe a no-fly zone during the critical early nesting period at Peltier Lake (M Asleson, *pers. comm.*), resulting in an overall reduction of aircraft noise. Equipment noise related to EBC construction did not appear to cause disturbances within the colony (A Von Duyke, *unpubl. data*).

*Discourage pedestrian traffic within the colony during nesting*

During the 2002 and 2003 nesting seasons, vigilance on the part of lake residents was the only effort to monitor human presence on the island. Nevertheless, anecdotal evidence suggested that island use after ice-out was minimal. More intense monitoring in 2004 suggested that, other than investigator presence, few if any people ventured onto the island during critical nesting periods (A Von Duyke, *unpubl. data).*

*Augment nest construction materials*

Observers recorded that herons readily used the stick-fields throughout the course of the 2002-2004 nesting seasons. Nest material collection peaked prior to egg-laying and declined quickly with the onset of brooding. However, this behavior continued well into chick-rearing (Anoka County Department of Parks and Recreation, *unpubl. data*; A Hawkins, *unpubl. data*). Active use of stick-fields corroborated shore and water-based observations of colony activity (Anoka County, *unpubl. data*).

*Monitor regional waterbird colonies*

Bi-weekly aerial survey flights and shore and water-based observations confirmed the presence and activity of Great Blue Herons during the 2000-2004 nesting seasons. Aerial survey data confirmed that Peltier Lake's colony phenology fell within the previously reported normal range of dates (MN-DNR Nongame Wildlife Program, *unpubl. data*) and was not markedly different from other regional waterbird colonies.

Winter nest counts served as an index of colony size. Counts spanning the five nesting seasons (2000-04) during which colony abandonment occurred, suggested that the Peltier Lake colony declined by 74% from a high of > 700 active nests (MN-DNR Nongame Wildlife Program, *unpubl. data*).

### *Colony Productivity*

Despite noise mitigation efforts, Peltier Lake continued to experience colony-wide abandonment, productivity loss, and a further decline in number of nesting pairs (Figure 1). The colony abandoned in June of 2002, shortly after the start of the no-wake enforcement. In 2003, during the first full nesting season after enactment of the no-wake ordinance, observers reported that "some" of the >300 pairs of Great Blue Herons and a "few" of the 12 Great Egret pairs had successfully nested (MN-DNR, *unpubl. data*). However, Great Egrets failed to nest at the Peltier Lake colony during and after the 2004 nesting season. Finally, a ground survey on 15 June, 2004 confirmed that the Peltier Lake colony had once again been abandoned by all nesting birds.

## *Discussion*

The history of events at the Peltier Lake colony offers insights into waterbird biology, the likelihood that anthropogenic disturbances caused colony abandonment, and the validity of the assumptions supporting initial management actions. Budget limitations and concern for the potential negative impacts of more direct colony observations restricted the quantity and quality of supporting data collected during this early period. Consequently, anecdotal evidence and the literature were used to support what appeared to be a strong case for the human disturbance hypothesis. The no-wake ordinance was the primary management tool employed to address the problems at Peltier Lake. In addition to protecting the heron colony, lake management was recommended to improve water quality, protect shorelines and waterfowl habitat, and increase quality of life (City of Lino Lakes Council Minutes 2004). The enactment of the no-wake ordinance was a contentious undertaking that strained relationships among some of the stakeholders.

That anthropogenic disturbance mitigation did not appear to halt the population decline or abandonment of the Peltier Lake waterbird colony suggests that other types of disturbance were not identified or that a different process(es) were involved. Fluctuating waterbird populations and shifts in colony sites are not unprecedented in central Minnesota (MN-DNR Natural Heritage Waterbird Database 2006). However, the mechanisms by which these events occur are poorly understood. Ecological factors such as: foraging distance (Gibbs 1991, Custer and Galli, 2002; Custer et al. 2004), disturbance rate (Bjorklund 1975, Skagen et al. 2001, Stolen 2003), and predation pressure (Kelsall and Simpson 1979, Vennesland and Butler 2004) can vary over time, space, and in relation to human activity. It is reasonable to speculate that when these factors surpass a theoretical optimal threshold, a colony will (a) experience a drop in productivity, (b) fail to produce altogether, and/or (c) move to a new location. While this strategy of leap-frogging colony locations as ecological conditions mandate is effective in a landscape with available habitat options, urbanization is leading to more human/wildlife conflicts (Butler et al. 2000). As the landscape regime shifts to a more urbanized pattern, potential locations for waterbird colonies decrease; thus increasing the value of all existing sites.

Early attempts to stem colony-wide abandonment at Peltier Lake were impeded by uncertainties over the cause(s), and reliance upon anecdotal evidence of human disturbance to guide management. The net result of early management activities yielded little benefit to the colony. The continued colony-wide abandonment, despite anthropogenic disturbance mitigation, underscored the need for a better understanding of events occurring within the colony. Yet, few data were available to direct future management activities.

Despite these early setbacks, resource managers remained committed to conserving the Peltier Lake colony. Acknowledging the need for better data, and in light of the Peltier Lake colony's further decline, the MN-DNR initiated a study in 2004 to determine the cause(s) of colony decline/failure at Peltier Lake and to recommend and implement appropriate management measures (Chapter 2). A strategy employing season-long intra-nest observations was recommended. It was anticipated that a comparison between Peltier Lake and a successful local colony would provide insights into the cause(s) and process(es) of colony abandonment and suggest appropriate management measures. These are described in Chapter 3 of this thesis.

## Conclusion

Several lines of anecdotal evidence strongly suggested anthropogenic disturbance as a cause of abandonment at the Peltier Lake colony. However, events occurring at the colony from 2000-2004 demonstrated that other important factors had not been considered. The worsening conditions at Peltier Lake prompted a change in management strategy from a low-impact to a data-rich paradigm.  Ultimately, this new approach yielded information useful in guiding the conservation of the Peltier Lake colony.

# CHAPTER 2 - Use of intra-nest video-surveillance to study colony failure of Great Blue Herons in east central Minnesota

## *Introduction*

A large mixed-species Ardeid breeding colony, located at Peltier Lake (45°11'N/93°3'W) in east central Minnesota, failed to fledge any young during each of five consecutive nesting seasons (2000 – 2004). This colony, once one of the largest in the state, experienced a > 74% population reduction over this same time period. Identified as important to the maintenance of regional waterbird populations, and with encouragement and support from a grassroots coalition of concerned citizens and professional resource managers, the conservation and restoration of the Peltier Lake colony was given a high priority by the Minnesota Department of Natural Resources (MN-DNR).

Previous conservation efforts at Peltier Lake, which emphasized anthropogenic disturbance mitigation (Chapter 1), were unsuccessful and did not yield sufficient data to establish the cause(s) of this colony's annual failures. To address this deficiency, the MN-DNR proposed that a detailed season-long record of events and activity occurring within active heron nests be collected. It was anticipated that this information would help narrow down or even identify the cause(s) of abandonment from among a long list of possibilities (Appendix I). Additionally, this study was established to develop future management actions. Yet, because access to the nests in a Great Blue Heron colony is difficult and potentially harmful to the nestlings, long term observation of adult breeding behavior, chick development, and events occurring in or near the nests presents logistical challenges and introduces potential biases to the data.

Great Blue Herons require up to 20 weeks after nest initiation to fledge chicks. Although clutches are occasionally replaced if they are lost early in the season, nest success declines with nest initiation date (Butler 1997). This fact restricts Great Blue Herons to a single clutch per season at northern latitudes. It was assumed that Great Blue Heron natural history predisposes the adults to high parental investment in a single clutch and that adult herons would be reluctant to abandon their nests unless their chicks were dead. Thus, colony abandonment should occur only after widespread nest failure (i.e., chick mortality).

The following three hypotheses, summarized in Table 2, were proposed to explain how nest failure could occur on a large enough scale to cause a large heron colony to abandon.

1. Disturbance within the colony reduced breeding success leading to colony failure: Adult herons flush from their nests when disturbed. Chicks $< 3$ weeks of age are unable to thermo-regulate independently (Bennett et al. 1995) and can die from exposure after adults have flushed. Eggs and young chicks are also vulnerable to avian predators in the absence of brooding adults. Feeding rates may be reduced if disturbed adults are kept from returning to their nests. And finally, chick alarm behavior includes food regurgitation which, in sufficient quantities, can lead to starvation and/or dehydration.

2. Environmental stochasticity (e.g., weather events) reduced breeding success leading to colony failure: A potential cost of colonialism is a shared vulnerability to catastrophic weather events. As exemplified recently (Figure 6), catastrophic weather events can decimate waterbird colonies. It is conceivable that, in sufficient frequency, duration, and/or magnitude, a pattern of bad weather could result in colony destruction. Given that urbanized landscapes can influence localized weather patterns (Huff and Changnon 1973), it is also conceivable that a colony could systematically experience enhanced precipitation and storm magnitude because of its geographic location relative to large urban areas. This would explain the annual failure of a single colony while others nearby continue to be productive.

3. Predation of eggs and young herons reduced breeding success leading to colony failure: The Peltier Lake region is inhabited by a variety of known Great Blue Heron predators (Table 3). Heron nestlings are semi-altricial and remain confined to their treetop nests for up to 12 weeks post hatching (Butler 1992), during which time they are vulnerable to predation. Other factors such as disturbance or weather can amplify the relative impact of predation.

Previously, heron nesting behavior has been studied by direct observation from blinds (Mock 1976). Yet, this method of data collection poses several logistical and behavioral challenges. For example, access to heronries in central Minnesota is often difficult given their typically remote settings (e.g., islands, riparian zones, and swamps). Moreover, Great Blue Herons prefer to nest in the tops of the forest canopy (Butler

1992). Heron sensitivity to disturbance also means that investigator presence can bias the data, negatively impact a colony, and potentially increase the risk of abandonment. Thus, a tradeoff exists between minimizing risks to an already struggling colony, while still collecting sufficient unbiased data to provide an understanding of the event(s) leading to abandonment. Finally, the logistical and financial resources necessary to conduct a large scale season-long observational study in the forest canopy can be substantial.

Video surveillance technology has shown its value in a variety of wildlife research applications (Reed et al. 1975; Stewart et al. 1997; Shivik and Gruver 2002). Although once prohibitively expensive, declining cost and increasing function have allowed this technology to become increasingly available as a tool for wildlife research. Remote video-surveillance offered a solution to the conflicting needs of this study because (1) it was capable of collecting long-term behavioral data simultaneously from multiple nests, (2) its use minimized the potentially disturbing presence of investigators within study colonies, (3) it could provide unbiased data, and (4) it required less logistical support to employ. However, most studies using video surveillance for avian research have centered upon ground and shrub nesting species (McCallum and Hannon 2001, Keedwell and Sanders 2002, Renfrew and Ribic 2003, Nack and Ribic 2005, Sabine et al. 2005). Fewer studies monitored canopy nesters (Bradley and Marzluff 2003). And at the time of this study (2004), no methods appropriate for monitoring colonies of tree nesting waders were available in the literature. To meet the objectives set forth by the MN-DNR, a new and inexpensive method for remote video-surveillance of tree-nesting waders was developed. Video data from Peltier Lake and a control colony (Pig's Eye Lake - 44°54'N / 93°1'W) was comparatively analyzed. And finally, colony management recommendations were generated based on the results of this video study.

The objectives of this paper are to:

1. Describe the video monitoring system developed for this study and how it was implemented for use in recording intra-nest behavioral data and events occurring within multiple nests and colonies.
2. Summarize video data collected during the 2004 season and comparatively analyze the data to identify differences in disturbance rates, number of stochastic events, and/or the number of predators/predation rates.
3. Use the video analysis to elucidate the cause(s) of reproductive failure, colony abandonment, and population decline.
4. Use the video surveillance data to provide management recommendations to reduce risk of future colony failure.

## *Methods*

### *Video surveillance*

Great Blue Herons often re-use preexisting nesting platforms annually (Butler 1992). However, because there was no way to know which nests in a particular tree would be occupied, it was necessary to select a number of potential trees in which cameras could be installed (hereafter referred to as ‘camera-trees’). For optimal video performance, suitable camera-trees had required high enough nest density (Figure 7) to efficiently monitor a subset of the colony and detect larger scale disturbances. This also helped to minimize overall colony disturbance during equipment installation by increasing the ratio of cameras installed to trees climbed. Clear sight lines ensured that branches would not obscure the camera’s field of view. This was partially accomplished by selective pruning of branches as needed. Tree health and/or sturdiness ensured that it was climbable and would remain standing over the course of the nesting season.

A variety of potential camera-trees were identified prior to the onset of nesting in mid March. The final selection of camera-trees depended upon nest occupancy and tree configuration. The setup employed for this project (Figure 8) consisted of an amalgamation of readily available video-surveillance equipment manufactured for the security services industry. The selected camera (SuperCircuits© #PC164C-BW) had a “super-low-light” rating (0.0003 lux ~ ‘star-light’) and accommodated standard C-mount and CS-mount lenses. During the 2004 season, 12mm fixed-focal-length lenses were used exclusively. Standard weatherproof enclosures and mounting brackets shielded the camera/lens assemblies from the elements. When possible, the camera was directly mounted to the tree trunk using three inch square-drive deck screws and a cordless drill. If the branches in the canopy were not strong or stable enough, a wooden plank wired to several branches provided a secure platform to which cameras were mounted (Figure 8A). Whenever possible, the orientation of the camera was directed such that the field-of-view peered down into the nest. Tree configuration and nest orientation also dictated that cameras be mounted 2 to 4 m from the nest. The use of longer focal-length lenses (5-15 mm and 6-60 mm) in 2005 made longer distance shots (>20m) possible.

A digital multiplexer (Polaris Industries® QDP-300) simultaneously recorded multiple camera signals onto a single video tape. A minimum of three and a maximum of seven camera channels were recorded simultaneously. A Sanyo® TLS-9960 time-lapse video cassette recorder (VCR) archived the video data onto six-hour Sony® T-160 video-tapes. Depending upon the selected recording speed, varying amounts of calendar time could be archived onto a single video tape. During this study, the inter-frame recording interval did not exceed 5.7 seconds. This enabled about one week of video data from four nests to be stored upon a single video-tape.

Each recording "station" consisted of up to seven cameras, a digital multiplexer, and a time-lapse VCR; and was powered by two Trojan® SCS225 12-volt DC deep-cycle marine batteries (130 amp/hr/battery). Because the time-lapse VCR operated on 110-volt AC power, a Tripp-Lite® 375 Watt power inverter was used to convert the 12-volt DC battery power to 110-volt AC power. A wiring-harness, used to transmit power up to the cameras and the video signal back down to the VCR, was fabricated from 75 ohm RG59 coaxial cable (video) and outdoor rated heavy duty 14 gauge extension-cord (power). Wiring-harnesses were securely attached as needed to the tree using fence-staples. Weather protection was provided by enclosing the recording equipment within a Rubbermaid® Roughneck® 14-gallon tote and security from theft or vandalism was provided by enclosing the recording equipment and batteries within a welded steel security box chained to the base of the study-tree (Figure 9). Weather stripping and duct tape was used to tightly seal the security box and provided further protection from the elements.

To maximize data collection, ensure nests were active, and minimize the risk of abandonment by adults, cameras were installed as soon after the hatch date as weather permitted. The first cameras were installed at Pig's Eye on 4 May, 2004 and at Peltier Lake on 10 May, 2004. A second set of cameras was installed at Peltier Lake on 26 May, 2004. The camera height was about 100 feet (30.5 m) at Pig's Eye Lake and about 75 feet (22.9 m) at Peltier Lake. Camera duty-cycle was 24 hours per day, seven days per week from mid May until nest-abandonment or fledging (early June and late July respectively). Batteries were changed every two days and video-tapes were replaced every four days on average. Battery and video-tape replacements typically took no longer than 15 min. Data collection began on 14 May at Pig's Eye Lake and 15 May at Peltier Lake. The total equipment cost (2004) per study tree, including: cameras (4), batteries (4), recording equipment, and other supplies totaled $2,500 (i.e., 625/nest).

*Assessment of factors related to colony abandonment*

Table 2 summarizes the predictions supporting the disturbance, environmental stochasticity, and predation hypotheses. A detailed timeline documenting behavioral states, weather events, predator presence, and predation events for each nest was constructed from the video recordings and was archived using Microsoft Access and was comprised of the following: (i) Mean % time spent brooding (% hrs brooding/day/nest), (ii) mean % time of adult nest attendance (% hrs adults attended nest/day/nest), (iii) mean feeding rate (feedings/day/nest), (iv) mean number of disturbances as indicated by heron behavior (disturbances/day/nest), (v) mean disturbance duration in response to investigator presence (minutes/disturbance-event/nest), (vi) duration of wind and rain events (hrs/day), (vii) predator presence and predation (total counts), and (viii) nest fate (mean productivity per nest).

Camera limitations resulted in < 24 hours visibility per day. Consequently, behavioral states were calculated as a percentage of daily visible hours. For example, if there were 18 hours of visibility on a particular day, and an adult was observed brooding for a total of nine hours; brooding-time was recorded as 50% of visible hours. Also, because the Pig's Eye Lake colony hatched 10 days prior to the Peltier Lake colony, chick ages were synchronized before performing comparative analyses. Because camera installation occurred after the hatch of chicks, observed brood size and fledge rate were used as indexes of productivity.

## Results

### *Video-surveillance*

During the 2004 nesting season, 13 individual heron nests in three trees at two breeding colonies were monitored with a total of 12 cameras. At the Peltier Lake colony, eight nests were monitored for a total of 1,994 hours of video during 904 camera nights. Although four cameras were deployed at Pig's Eye Lake, two nests were monitored on a single channel, enabling five nests to be monitored. Data collection at the Pig's Eye Lake colony lasted until 23 July. Only data collected from

15 May to 8 June were analyzed and compared to Peltier Lake; a total of 1,678 hours of video during 435 camera nights.

Overall visibility was defined as the ability to ascertain the behavioral state, weather conditions, or presence of predators in the nest from the recorded video. Though rated to 0.0003 lux, the cameras were unable to record quantifiable data during the darkest hours of the night. When pooled over the entire season, visibility was significantly higher at Pig's Eye Lake ($mean_{Peltier}$ = 17:07 ± 0:32/day, $mean_{Pig's\ Eye}$ 19:21 ± 1:00/day; T-test, $t = -1.809$, df = 42, $p = 0.039$). Camera malfunctions biased these data and after the repair on 26 May, there was no significant difference in visibility for the remainder of the season ($mean_{Peltier}$ = 19:11 ± 0:03/day, $mean_{Pig's\ Eye}$ 17:40 ± 1:18/day; T-test, $t = 0.965$, df = 13, $p = 0.176$). Furthermore, pair-wise comparisons of total daily hours of visibility showed no significant difference between the two study colonies (Matched-pairs T-test, $t = -1.314$, df = 22, $p = 0.101$).

*Brooding and adult nest attendance*

The mean percentage of daily visible hours spent brooding (Figure 10) at the two colonies did not differ significantly (Matched-pairs T-test, $t = 0.0398$, df = 15, $p = 0.484$). Adult nest attendance was calculated as the average percent of daily visible hours during which an adult was either brooding eggs/chicks or present (i.e., visible) at the nest (Figure 11). During the early nesting period (chick age < 23 days) when chicks are unable to thermo-regulate independently, there was no statistically significant difference in adult nest attendance behavior between the Peltier Lake and Pig's Eye Lake colonies (Matched-pairs T-test, $t = 0.398$, df = 9, $p = 0.350$). Predictably, after this critical period, when chicks are able to thermo-regulate and require more food than a single adult can provide, parental nest attendance declined. After chick age 23 days, parental attendance was significantly greater at Peltier Lake than at Pig's Eye Lake (Matched-pairs T-test, $t = 3.932$, df = 6, $p = 0.004$).

*Feeding rate*

The feeding rate at Peltier Lake dropped significantly (T-test, $t = 2.5$, df = 9.918, $p = 0.032$) after chick age 14 days (Figure 12). During a comparison period of chick ages 14 to 30 days, the feeding rate was significantly higher at Peltier Lake than at Pig's Eye Lake (Matched-pairs T-test, $t = 3.178$, df = 16, $p = 0.003$).

*Alert / alarm behavior*

Video evidence based on behavior (Table 4) suggested that Peltier Lake experienced a significantly higher rate of disturbances than the Pig's Eye Lake colony (Matched-pairs T-test, $t = 4.11$, df = 24, $p = 0.0002$). While the disturbance rate at the Pig's Eye Lake colony remained uniform over the season (regression line slope = -0.005), the daily disturbance rate at Peltier Lake showed a significant increase (T-test, $t = 4.59$, df = 20, $p <<< 0.05$) at chick age 22 days (i.e., 1 June) (Figure 13A & 13B). This increase in disturbance also coincided with the first video observation of a raccoon in a heron nest (Figure 13C).

Investigator disturbances were clustered at both colonies and centered around 13:00 and 16:00 at Peltier Lake and Pig's Eye Lake respectively (Figure 14). Post equipment maintenance disruption (Figure 15) lasted significantly longer at Peltier Lake than at Pig's Eye Lake (Matched-pairs T-test, $t = 4.50$, df = 12, $p = 0.0004$). No significant difference in nest disruption was observed (Matched-pairs T-test, $t = 1.78$, df = 4, $p = 0.075$) until after the fifth equipment maintenance visit (Matched-pairs T-test, $t = 6.15$, df = 7, $p = 0.0002$).

The frequency of disturbance behavior falling under the category of "other" (i.e., not associated with equipment maintenance or investigator presence) was more widely distributed than investigator disturbances (Figure 16). Peltier Lake experienced disproportionately higher amounts of "other" disturbances than Pig's Eye Lake (Chi-square test, $X^2 = 14.2$, df = 2, $p = 0.0002$) (Figure 17). Finally, while "other" disturbances experienced at Pig's Eye Lake were evenly distributed over the daylight hours, those at Peltier Lake were more widely distributed and showed peaks beginning in the evening hours and continuing into the early morning hours (18:00 - 03:00) as well as a small peak at midday.

*Environmental stochasticity: historical weather data (1988 - 2006)*

A comparison of weather station data (1988 - 2006) throughout the Great Blue Heron nesting season (Figure 18) showed that average temperatures fluctuated significantly more at the Peltier Lake colony than at either the Pig's Eye Lake or Coney Island colonies (One-way ANOVA, $F(2,12) = 15.538$, $p = 0.0005$). Among these same three colonies, there was no significant difference (One-way ANOVA $F(2, 12) = 0.075$, $p = 0.929$) in historical rainfall amounts throughout the nesting season (Minnesota Climatology Working Group, accessed 2007). Thunderstorm frequency (NOAA Satellite and Information Service, National Climactic Data Center, accessed 2007) did not differ significantly among the three counties in which these three colonies reside (One-way ANOVA, $F(2,39) = 0.147$, $p = 0.864$). Nesting season thunderstorm frequencies, while similar among the three colonies, appear to have been much higher in Carver County in the late 1990's and in Anoka County (Peltier Lake) in 2005.

*Environmental stochasticity: weather data (video)*

Video data (Figure 19) reveal that weather events were relatively synchronous at Peltier and Pig's Eye lakes, but the duration was longer at Peltier Lake. Peltier Lake experienced significantly more rain (Matched-pairs T-test, $t = 2.484$, df = 24, $p = 0.010$) and wind (Matched-pairs T-test, $t = 3.309$, df = 24, $p = 0.001$) than did Pig's Eye Lake. Because chicks hatched at Pig's Eye Lake 10 days earlier than at Peltier Lake, only seven days (chick ages 15-21 days) overlapped during the critical period in which nestlings cannot thermo-regulate on their own. Within this block of time, Peltier Lake experienced 6.5x longer rain duration than Pig's Eye Lake (31:08 vs. 4:45). However, two discreet long lasting storm events at Peltier Lake (Figure 19B) accounted for significantly higher variance at the Peltier site than at Pig's Eye Lake (F-test, $f = 25.965$, df = 6, $p = 0.0005$). Thus, despite the large difference in total rain duration, the difference in daily rain duration was not statistically significant (Matched-pairs T-test, $t = 1.559$, df = 6, $p = 0.085$). Finally, no significant difference in wind duration (94:57 at Peltier Lake vs. 90:36 at Pig's Eye Lake) was found (Matched-pairs T-test, $t = 0.221$, df = 6, $p = 0.416$).

*Predation*

Two known heron predators (Figure 20) were recorded on video in active or recently abandoned heron nests: raccoon (*Procyon lotor*, n = 15), and Turkey Vulture (*Cathartes aura*, n = 1). Great Horned Owls (*Bubo virginianus*, n = 3) were captured on video during a second season of surveillance in 2005. All cases of heron predators in a heron nest were detected only at Peltier Lake. However, one raccoon was sighted within 10 m of a study tree while performing scheduled maintenance at Pig's Eye Lake. Upon seeing the investigator, the raccoon climbed a tree nearby where it remained until the investigator departed.

Based upon video evidence, the sole cause of chick mortality directly observed at Peltier Lake was raccoon predation (n = 9), accounting for the confirmed loss of 10 out of the 15 chicks detected. Video showing a raccoon feeding upon chicks in the nest (though no predation event was observed) suggested predation of two other nestlings. Finally, footage showing a single chick that appeared to be chased from its nest onto a limb from which it fell, also suggested raccoon activity. This interpretation is supported further by the observation that two other chicks from the same nest had been killed earlier by raccoons. Based on these observations, raccoon predation was responsible for a minimum of 66.7% and possibly as much as 86.7% of heron chick mortality in the study trees at Peltier Lake.

Physical evidence found during surveys suggested that avian predators were present and active on Peltier Island. Great Horned Owl predation (n = 3) was confirmed when the remains of at least two Great Blue Heron chicks were found in an active Great Horned Owl nest; also, a Great Horned Owl fledgling was observed perched among the remains of another heron chick which it presumably had just consumed (Figure 21). Heron eggs with holes pecked in the sides (n = 2) were found on the ground, suggesting that American Crows (*Corvus brachyrhynchos*) had preyed upon these eggs (Figure 22).

No chick mortality was directly observed in the video monitored nests t the Pig's Eye Lake colony. Three chick carcasses were found at the base of the study tree at Pig's Eye Lake, but video evidence showed that they did not come from the nests being monitored. Without video evidence, and because the carcasses were found decomposed and scavenged, little physical evidence remained (Figure 23) to aid in determining the cause of mortality (Larivière 1999). It is noteworthy that despite finding a single dead chick at Pig's Eye Lake bearing wounds consistent with siblicide, only one case of sibling aggression was documented on video in 2004.

*Nest productivity*

Based on aerial survey data (MN-DNR, *unpubl. data*) the Peltier Lake colony had a maximum estimated total of 180 active nests in 2004. An aerial survey conducted on 25 May, 2004, documented a large number of abandoned nests. This observation took place only six days prior to the increased disturbance rate detected on video. A ground survey confirmed that all nests at the Peltier Lake colony were abandoned by 15 June, 2004.

There was no significant difference between the two study sites in mean brood size as detected on camera (T-test, $t = -0.4973$, df = 6.083, $p = 0.3182$). At Peltier Lake, one monitored nest failed to hatch chicks. Based on video evidence, the remaining seven nests hatched a total of 15 chicks (2.14 ± 0.14 chicks/nest). Of the five nests monitored at Pig's Eye Lake, one failed to hatch chicks despite the adults' ongoing brooding activity. The remaining four nests hatched a total of 11 chicks (2.75 ± 0.25 chicks/nest). While none of the chicks at Peltier Lake survived to fledge, eight chicks (73%) at Pig's Eye Lake survived to at least 85 days of age (23 July, 2004); after which they no longer remained visible in the camera's field of view. Ground survey results suggested that these chicks fledged. Observed nest productivity at Pig's Eye Lake was 1.6 ± 0.4 fledglings per nest.

## Discussion

*Video-surveillance*

The desired specifications for the cameras to be used in this study included: zero light capability (0 lux), variable focal-length lenses, low power consumption, and adequate resolution; but in 2004, a single camera with all of these attributes and which fit within the budget did not exist. As a compromise, "super-low-light" rated cameras (0.0003 lux) were used in place of the zero-light (0 lux) cameras. Consequently, an overall average of only 18.46 hours (± 25 minutes) of useable data per day was recorded. Since 2004, the capabilities of video surveillance technology have dramatically increased while costs continue to drop. As such, a variety of cameras are currently available that meet these specifications.

Pilot study results suggested that, for tree nesting waders in central Minnesota, a lens focal-length of at least 12 mm was required to see nest activity clearly enough to ascertain the cause(s) of abandonment (Figure 24). One drawback to variable-focus lenses was the need for a large video-monitor in the field to ensure proper focus. In a second season of video surveillance at the Peltier Lake colony, longer variable-focal-length lenses were also used (5-15mm and 6-60mm). Drawbacks to zoom lenses included their need for more light to capture the images clearly and their tendency to amplify any tree movement.

Solar power, either as a primary power source or to extend battery life, was not a viable power option for several reasons. The power demands of the equipment would have required excessively large and expensive solar panels. The heavily wooded, shady setting also yielded conditions that were suboptimal for solar power. Ideal placement of the solar panels, above the forest canopy and out of the shade, would have created perches for the birds; the resulting buildup of excrement on the panels eventually would render them non-functional. Battery power would still have been necessary. And most importantly, the added complexity and longer equipment installation time would have increased disturbance duration and magnified the risk of temperature stress and/or nest predation to the exposed eggs/chicks; potentially jeopardizing the health of the colony and/or causing abandonment.

Because they can record multiple video channels onto a single video tape, digital multiplexers greatly reduced equipment cost, complexity, and power demands. Note that when using a digital multiplexer/time-lapse VCR setup, the interval between recorded frames is dependent upon both the VCR recording speed and the total number of camera channels being multiplexed (Figure 25). For nesting Great Blue Herons, an inter-frame recording interval of 5.7 seconds provided a good balance between minimizing data loss and maximizing storage efficiency.

Power inversion, to run the AC equipment using a DC power-source, came at a substantial efficiency cost (~ 35% according to manufacturer's specifications). One possible solution is to use a VCR that runs off of 12 volt DC. Though not common, they are available, but are 3 to 4 times more costly. Another alternative is to use digital video recorders (DVRs) which offer many advantages over VCRs. One is their enormous data storage capability, thus eliminating the need to change tapes. Another advantage is that many DVRs offer multiplexer capabilities, thus eliminating the need for a separate piece of hardware. Consequently, DVRs have quickly taken over the video-surveillance industry. Despite the fact that DVRs operate on DC, they require dual voltages (12 volt and 5 volt DC) and are not easily connected to a battery without the use of a power inverter with its associated power efficiency loss. Recently, a 12/5 volt DC power splitter has been developed that eliminates the need for a power inverter, operates at 95% efficiency, and greatly increases battery life (Von Duyke et al., *unpubl. data*). This technology has been successfully used in the field for a video study of Piping Plovers (*Charadrius melodus*) in the Great Lakes (Brudney, *unpubl. data*).

During installation, all adults in each study tree, and in the surrounding trees, flushed from their nests and remained away for the duration of the procedure. To minimize the impact of the colony disturbance caused by equipment installation, a goal for the maximum duration of disturbance was set at 90 min (Mock, *pers. comm.*). Despite efforts made to streamline the installation process, setting ropes and climbing 20 to 30 m into a tree required more time than anticipated. The actual disturbance time lasted about 120 min per study tree. A working solution to this problem was to divide the equipment installation process into separate stages on different days. On the first day, cameras were installed, aimed, and focused; while the recording equipment was staged at the base of each study tree. Second day tasks included hooking up the cameras to the recorders and programming the recording equipment. In hindsight, if inexpensive nylon lines had been set in all potential camera trees during preseason scouting, climbing ropes could have been quickly set prior to equipment installation. This would have substantially shortened the disturbance time caused by equipment installation.

*Brooding and adult nest attendance*

Adult herons flush from their nests if subjected to a disturbance of sufficient intensity. If a colony regularly experienced such disturbances, it was predicted that brooding time and adult nest attendance would be lower at Peltier Lake than at Pig's Eye Lake. The results did not fit this prediction. Rather, adults from both colonies brooded young a similar percentage of time. Only after chick age 22 days was a difference detectable and in this case, adult nest attendance was greater at Peltier Lake. Given their preference for large bodies of water as foraging habitat and their solitary foraging behavior (Custer and Galli 2002), it is reasonable to assume that foraging flights for Great Blue Herons are longer at large colonies than at small colonies, and explains the difference in nest attendance behavior observed.

Periodic disturbance alone is not necessarily problematic for nesting herons. However, if disturbance occurs during critical periods it can have negative impacts. Very early disturbances may disrupt courtship, causing a colony to relocate. Chronic disturbance may lead to dehydration and malnutrition in chicks that regurgitate the contents of their stomachs as a defensive response (Kury and Gochfeld 1975, Parsons and Burger 1982). However, Parsons and Burger (1982) also showed no difference in chick weight between frequently disturbed and control Black-crowned Night Heron chicks. They also suggested that maximum vulnerability to disturbance occurred during the egg stage. Because of their inability to thermo-regulate independently, chicks < 21 days old are vulnerable to temperature stress if adults flush in response to a disturbance. By the time chicks are able to thermo-regulate independently, both adults must forage in order to keep up with the metabolic requirements of their rapidly growing nestlings. So, despite the decrease in nest attendance, disturbances at this time do not represent a substantial increase in vulnerability to temperature stress, and may only slightly increase the risk of predation from diurnal avian predators. Bald Eagles are known to prey on heron chicks, juveniles, and adults. Yet, despite their abundance in central Minnesota, particularly in the area surrounding Peltier Lake, no eagle predation of Great Blue Herons was observed during this study. Chick dehydration/starvation is possible from food regurgitation in response to nearby disturbances. Food regurgitation occurred occasionally when investigators worked within the two study colonies and others. However, this behavior was never observed on video in response to stress or disturbances including predation. Overall, non-raccoon disturbances experienced by chicks over three weeks old did not appear on camera to have a long lasting effect on the nestlings at either colony.

If the Peltier Lake colony experienced more disturbance (quantity and/or intensity), and if disturbed adults were reluctant to return to the nest or were kept away by the disturbances, then it was predicted that feeding rates would be lower at Peltier

Lake than at Pig's Eye Lake. However, based on video data, the feeding rate at Peltier Lake was higher than at Pig's Eye Lake. It is possible that if foraging trips for adult herons at a large colony were longer than at small colony, the effect of disturbance upon feeding rate would not be as great at Pig's Eye Lake. The difference in feeding rate may also be explained by forage quality differences at each location. Clutch size is correlated to nutrition (Custer et al. 1996). Though clutch size was not directly measured, brood size visible on camera was lower at Peltier Lake than at Pig's Eye Lake (though not statistically significant). Fledge rates at Peltier Lake beginning in 2005 were lower than published results (Butler et al. 1995, Carlson and McLean 1996) and suggests that food and/or foraging habitat may be of lower quality at Peltier Lake (Butler 1997). Due to limited visibility, no data on bolus size or quality could be collected at either colony. Insights into the relative forage quality may be gained by means of comparative fish survey data from lakes located within the median foraging distance (2.7 km radius) for Great Blue Herons (Butler 1997, Custer and Galli 2002, Custer et al. 2004).

*Alert / alarm behavior*

Video evidence was used to quantify "alert" and "alarm" behaviors of both adults and chicks; higher rates of these behaviors would lend further support to the disturbance hypothesis. The results showed that Peltier Lake experienced higher disturbance rates than Pig's Eye Lake. As the season progressed, the rate of disturbance increased significantly at Peltier Lake while remaining consistent at Pig's Eye Lake. Disturbances at Pig's Eye Lake primarily corresponded to regularly scheduled equipment maintenance visits. These visits are also detectable on video at Peltier Lake; however, non-equipment related disturbances were more abundant and increased as the season progressed.

It is plausible that a colony that routinely experiences deleterious disturbances would require a longer time period to "recover" from a disturbance than a less disturbed colony (i.e., the lag-time necessary to revert from 'disturbed' behavior to 'non-disturbed' behavior). Moreover, if disturbances were not routinely deleterious, then habituation should result in little or no detectable differences in recovery time. During the early critical period (chick age < 21 days), no significant difference in disturbance rate was observed between the two study colonies. At Peltier Lake, high early disturbance rates were followed by what appeared to be a period of habituation, and after chick age 22 days, the disturbance rate increased (possibly in response to heightened raccoon foraging activity). In contrast, the disturbance rate at Pig's Eye Lake stayed consistent throughout the season. The disruption time results from Peltier Lake fit the prediction for a colony subjected to deleterious disturbances. As the season progressed, the response to investigator presence increased at Peltier Lake but gradually decreased at Pig's Eye Lake. Nest location may partially explain this difference. The nests at Pig's Eye Lake, being 7.6 m (25 feet) higher than at Peltier Lake, may simply have been more shielded from and therefore less likely to be affected by investigator presence, particularly as the tree foliage filled in.

High disturbance rates at other regional colonies are not unprecedented, yet the behavior of nesting herons, egrets, and cormorants suggests that they have become habituated (Nisbet 2000). For example, the Pig's Eye Lake colony is located within a high density urban/industrial area of St. Paul and falls directly within the final approach corridor of the St. Paul Metropolitan Airport (Figure 26). Grubb (1979) observed that Great Blue Herons at Pig's Eye Lake appeared to have habituated to aircraft noise disturbances as high as 100 dBc. Another large regional mixed-species wader colony named Coney Island (44°52'N / 93°47'W) is located on a heavily used recreational lake. Despite experiencing regular pedestrian and recreational boat traffic, this colony has thrived and grown to four nesting species and over 1000 active nests (MN-DNR, *unpubl. data*). The longer recovery time after a disturbance at Peltier Lake than at Pig's Eye Lake, which increased over the season, indicated that some of the disturbances experienced at Peltier Lake may have been deleterious in nature. It does not suggest that disturbance by itself caused abandonment.

*Environmental stochasticity*

The recent destruction of two regional heron colonies (Figure 6) demonstrates their vulnerability to catastrophic weather events. In combination with disturbances that drive adult herons from the nest, inclement weather can be can be particularly harmful during the egg stage (Parsons and Burger 1982) and to nestlings within the first three weeks after hatching when they are unable to thermo-regulate independently. Examination of historical weather data (1988 – 2006) demonstrated that Peltier Lake was similar to other area colonies, differing only in temperature fluctuation. And, at the onset of colony abandonments at Peltier Lake, thunderstorm frequency in Anoka County (Peltier Lake) was lower than Carver County (Coney Island) or Ramsey County (Pig's Eye Lake). It is difficult to accept that weather alone could have led to repeated annual colony abandonments particularly when other colonies in close proximity did not fail during the same time period.

Weather conditions during equipment installation were deemed satisfactory (overcast, temperatures ranging in the upper 50°s to low 60°s F, no precipitation, and a light breeze). Video recording started four days after camera installation and documented the apparent early failure of one out of the five nests monitored at Pig's Eye Lake and one out of the eight nests monitored at Peltier Lake. The timing of these failures, early in the season when temperatures are cooler and more volatile, suggested a possible negative impact related to equipment installation. Despite these early nest failures, the mean value of $1.6 \pm 0.4$ fledglings per nest at Pig's Eye Lake was similar to that found by Butler et al. (1995).

Although time-lapse over-estimated wind intensity and under-estimated rain frequency, a relative comparison indicated that Peltier Lake was significantly rainier and windier than Pig's Eye Lake. Peltier Lake's geographic location relative to the urban core of the Minneapolis/St. Paul metropolis may have predisposed this colony to experience harsher weather events than other central region colonies. It has been shown that large metropolitan areas, through a phenomenon known as the urban heat island (UHI) effect, have the capacity to bifurcate weather systems such as thunderstorms and to amplify the duration and magnitude of these weather events in a geographically consistent manner (Huff and Changnon 1973, Bornstein and LeRoy 1990, Changnon 2001). Peltier Lake, unlike Pig's Eye Lake which is located within the St. Paul urban center, resides in an exurb north east of the urban core within a corridor that appears to systematically experience these bifurcated and amplified weather systems. Video data in 2004 indicate that despite large spikes in rain and wind events during the time that chicks were most vulnerable to hypothermia all hatched chicks fared well.

### *Predation*

Predation has been documented as the primary cause of avian nest failure for many species of birds (Ricklefs 1969) and a cause of waterbird colony abandonment (Kadlec 1971, Shealer and Kress 1991, Whittam and Leonard 1999, D Mock *pers. comm.*). Presence of predators near and within the heron nests at Peltier Lake was a clear difference from Pig's Eye Lake. All monitored nests failed at Peltier Lake, 75% of which were visited or attacked by a raccoon at least once. Video evidence showed that raccoon predation was the cause of chick mortality in up to 87% of deceased chicks. Cameras on three separate occasions also recorded the presence of >1 raccoon foraging in a single nest-tree (Figure 27). Video and ground survey results also demonstrated that Great Horned Owls at Peltier Lake preyed upon heron chicks. And, two incidences of egg predation were documented during ground surveys (possibly caused by American Crows). The importance of opossum foraging behavior upon heron nest productivity, specifically egg predation, is not known because cameras were not installed until after eggs hatched. However, the ensuing furbearer management in the park (Chapter 3) suggested that opossum density may be higher on the island than raccoon density and could also be important to nest productivity. Conversely, Pig's Eye Lake successfully fledged chicks from 80% of monitored nests. Video indicated no signs of predator harassment despite much sign of raccoon presence at the Pig's Eye Lake colony. Given the very large size of the Pig's Eye Lake colony, the probability of predation being observed was not high. Furthermore, Pig's Eye Lake could, given its size, suffer substantial predation while still remaining productive.

## *Conclusion*

Through novel use of video-surveillance, it was possible to collect data on a variety of factors hypothesized to be related to colony abandonment. Important similarities and differences between a successful and an unsuccessful heron colony were identified. Video evidence showed no direct deleterious effects of disturbance at Peltier Lake, but did demonstrate that Great Blue Herons, despite their sensitivity to disturbance, are resilient enough to endure a conscientiously applied intra-nest video-surveillance study. Behavioral data also indicated that, provided colony visits are carefully planned and conducted, nesting Great Blue Herons will tolerate the presence of investigators within a colony. The elevated disturbance rates, as shown on video, are likely to have been caused by foraging mesopredators; while increasing disruption times may be indicative of behaviorally conditioned herons reacting to raccoon presence and hunting activity. Ultimately, foraging raccoons were shown to have caused up to 87% of observed chick mortality.

Protection of active nests and nestlings via a strategy of mesopredator management was recommended based upon the results of this study. Two primary approaches include: (i) predator exclusion from nest-trees and bridge-trees (i.e., those trees providing access to nest-trees) by means of "predator guards"; and (ii) predator removal by means of trapping and/or hunting. Assuming that Great Blue Heron fledglings exhibit natal philopatry and that the presence of adults within a colony is attractive to other herons (Fasola et al. 2002), then reducing chick depredation should not only increase nest-success, but also the size of the colony. Provided that Great Blue Herons continue to tolerate appropriate levels of investigator caused disturbance based upon their nesting phenology, it should be possible to continue to closely monitor the nesting activity and overall status of the Peltier Lake colony. If managers are able to assess colony status in a timely manner, then management practices can be readily adjusted in response to changing conditions.

Video surveillance was an important method to increase understanding of this confusing and sometimes contentious wildlife management challenge. As this technology continues to advance, it is becoming more and more accessible through declining costs. As such, new approaches to observational studies and experimentally based investigations are becoming available and will facilitate new discoveries about the ecology of species that have been traditionally difficult to study.

CHAPTER 3 - Use of predator exclusion and removal to restore an urban Great Blue Heron colony: Peltier Lake management activities (2005-2008)

## *Introduction*

Beginning in 2000, a formerly large mixed-species waterbird colony, located at Peltier Lake (Lino Lakes, Minnesota), failed to fledge chicks over five consecutive nesting seasons. During this same time period the number of nesting pairs declined by 74% and two of the original three resident species stopped nesting at Peltier Lake. Previous management efforts, from 2001 to 2003, focused upon anthropogenic noise mitigation but did not prevent subsequent colony abandonment or population decline at Peltier Lake. These initial attempts to protect the colony yielded little information useful for determining the cause(s) of abandonment and provided no constructive insights to guide further colony management.

To determine what was occurring in the colony that caused desertion and nest failure, a remote video-surveillance study was initiated in 2004 at the Peltier Lake and at a control colony called Pig's Eye Lake (Chapter 2). The goals of this study were to: (i) develop a video surveillance system and methodology for use in tree nesting waders (ii) use video cameras to document intra-nest activities and behaviors, stochastic events, and predator activity at the Peltier Lake colony; (iii) determine the cause(s) of chick mortality; and (iv) provide management recommendations based on video evidence.

By 8 June, 2004, all breeding herons had abandoned their nests and deserted the Peltier Lake colony (Chapter 2). Intra-nest video footage demonstrated that all monitored heron nestlings appeared to be healthy and were developing normally up until nest failure. Fifteen chicks were detected in the two study trees at Peltier Lake. Up to 13 of these chicks (87%) died as a result of raccoon (*Procyon lotor*) predation. The remaining two chicks died from unknown causes. At Pig's Eye Lake, 73% (n = 8) of the observed chicks fledged and no predation was detected. All cases of chick mortality in the nests monitored at Pig's Eye Lake (n = 3) were from unknown causes. In contrast, video data suggested that chick mortality from predation was an important and possibly limiting factor to nest success at the Peltier Lake colony. Although the population of raccoons living on the island appeared to be low (Anoka County Department of Parks and Recreation, *unpubl. data*), results from a simple foraging model (Appendix II) demonstrate that predation, even by a small number of experienced raccoons in a large colony, can have a large impact on nest productivity. Thus, additive mortality via raccoon predation, particularly in combination with other types of mortality, may be able to cause a heron colony to fail.

Considering its precarious status, a rapid and fairly aggressive intervention was deemed necessary to stem the further decline and possible loss of the Peltier Lake colony. Although it has been well established that predation is important to wader colony site selection (Rodgers Jr. 1985, Simpson et al. 1987, Butler 1992) and productivity (Baker 1940, Kelsall and Simpson 1979, Frederick and Collopy 1989, Vennesland and Butler 2004), prior management of wader colonies has almost exclusively focused on habitat management (Parnell et al. 1988, Pollowy 2001, Mauchamp et al. 2002) and disturbance mitigation (Rogers Jr. and Smith 1995, Rogers Jr. and Schwikert 2002). However, because these two strategies had previously proven ineffective at Peltier Lake, an alternative plan for predator management was proposed. Two primary approaches for predator management were available: (1) predator exclusion and (2) predator removal.

Predator exclusion as a means of wader nest colony management has been rarely used and remains largely untested. Hjertass (1982) successfully defended a Great Blue Heron colony in Ontario, Canada from apparent raccoon predation by wrapping the trunks of nest trees with sheet metal "raccoon guards". A similar method was used to protect a Wood Stork (*Mycteria americana*) colony (Coulter and Bryan Jr. 1995) but ultimately proved ineffective, primarily because raccoons were able to use the understory as a "bridge" past the predator guards. In contrast, predator guards (sheetmetal flashing and cones) have been successfully used to protect cavity nesters (Strange et al. 1971, Neal et al. 1993, VanDruff et al. 1996). And, similar methods have been used by utility companies to reduce "animal induced power outages" (Frazier and Bonham 1996).

Predator removal via trapping and removal of furbearers is problematic for several reasons. Trapping is not an effective means of population control in raccoons (Ratnaswamy et al. 1997, Rosatte 2000, Frey et al. 2003) and Prange et al. (2003) found that whatever small gains were achieved via trapping were quickly lost in the absence of control efforts. This suggests that trapping and removal needs to be an ongoing effort, yet, trapping is not an economically viable management tool (Chesness et al. 1968). From a public relations standpoint, trapping is controversial (Gentile 1987, Andelt et al. 1999); and the possibility of non-target captures, particularly of pets also adds to the challenges associated with predator removal. The Peltier Lake colony resides on public land and pet owners, though not permitted (Anoka County Parks Ordinance #2000-1), regularly exercised their dogs off-leash on the island (A Von Duyke, *pers. observ.*). If a pet was injured or killed in a trap, the potential for a strong negative reaction from the community would be high. However, if raccoon densities on the island were low, and if only a few were responsible for most of the predation, and if non-target captures (pets) could be prevented, then trapping could make a difference. Theoretically, through reducing the overall local population of furbearers, some if not all of the raccoons that had presumably become conditioned to exploit heron nests could also be removed.

Given the challenges associated with trapping and removal of mesopredators, this predator management option was not utilized for the 2005 season. Predator guards appeared to be the best option. Predator exclusion had no negative connotations and was safe for pets. And if correctly installed, predator guards should operate independently of mesopredator density and with less labor. This study had the following objectives: (i) develop and implement a viable predator exclusion methodology ('predator guards') to reduce mammalian predation in Great Blue Heron nest trees at the Peltier Lake colony; (ii) monitor predator guard performance via ground surveys and scratch analyses, (iii) monitor colony productivity at Peltier Lake; and if the guards failed to increase nest success, (iv) supplement predator exclusion efforts with limited furbearer trap/removal.

## *Methods*

### *Predator guards*

Functional and/or economic constraints made predator exclusion by means of fences, electrified barriers, or cones impractical. During the winter of 2004-05, all trees with intact nests were wrapped at breast height with sheet metal (aluminum roof flashing). Material thickness was at least 24 ga. and each tree was wrapped to a width of at least 36 inches (91.4 cm) at breast height or higher (Figure 28). Adjacent trees offering a route to the canopy or to a nest tree were also wrapped. Most flashing was factory coated brown or tan. Bare metal flashing was painted gray to reduce glare, limit possible visual disturbance to nesting herons, and improve visual aesthetics within that area of the park. Flashing was attached to the trees with three inch (7.62 cm) square drive exterior rated deck screws and one inch (2.54 cm) fender washers. In total, 173 trees (108 with intact nests) were protected with predator guards. Of these, 75 were wrapped with heavy aluminum flashing. Although the wraps of flashing were kept loose, most guards eventually had to be loosened to accommodate annual tree growth. Each wrapped trunk was mapped and data (e.g., tree species, DBH, previous nesting activity) were recorded. As needed, understory shrubs, primarily Red Elderberry (*Sambucus pubens*) and Pin Cherry (*Prunus pensylvanica*) were trimmed back from any metal flashed trunks to eliminate bridges past the predator guards. Supplemental predator guards were installed or replaced as needed prior to the 2006 (n = 32) and 2007 nesting seasons (n = 4).

*Colony status / Predator guard performance*

To assess the status of the Peltier Lake colony and monitor the performance of the predator guards, a ground survey was conducted at least once per week throughout the nesting season. Data collected included: colony status (i.e., qualitative description), nest status (i.e., active? inactive? depredated? successful?), colony productivity (i.e., complete census of brood size in every active nest), predator activity (i.e., scratches on guards, carcasses beneath active nests, sign), and status of predator guards (i.e., general condition, repairs needed?). Successful nests were defined as having fledged at least one chick. Whenever possible, trees were observed from a distance to facilitate easier viewing into the nest and to avoid disturbing the herons. Blaze orange dots were painted on the predator guards above the height of the understory to facilitate identification of active trees from a distance.

Raccoon climbing attempts and successes at breaching the predator guards were estimated by evaluating patterns of claw-marks left in the flashing (Figure 29). To avoid double counting, all scratches were circled with paint markers. Early results indicated that, as initially installed, the predator guards performed below expectations. In response, the following modifications were implemented: (1) wrap additional "bridge trees" with metal flashing; (2) raise the metal flashing on multi-stemmed trees to the height at which the stems were separated by at least 24 inches (60 cm); (3) rotate the seam on the metal flashing to the downward side of the trunk if possible; and (4) fell "suckers", as needed, near the main trunk of the tree (typically on basswoods, *Tilia americana*).

*Furbearer removal*

Further decline of the Peltier Lake colony during the 2005 season and the disappointing performance of the predator guards drove the decision to supplement predator exclusion with a short-term limited furbearer removal campaign. The Anoka County Department of Parks and Recreation hired professional licensed trappers to operate, in accordance with Minnesota trapping regulations, within the Park. Trapping also took place on private property along the nearby eastern shoreline of Peltier Lake (Figure 30). Trapping and removal of furbearers including raccoon (*Procyon lotor*) and Virginia opossum (*Didelphis virginiana*) occurred from 21 November to 29 November, 2005. The following season, trapping ran from 30 October to 20 November, 2006. No trapping occurred during the fall of 2007.

## *Results*

*Colony status*

With only 36 active nests in 24 trees, the 2005 season marked the lowest population of the Peltier Lake colony since 1990. In 2005 only four Great Blue Herons fledged from three nests located in two trees. However, these juveniles represented the first confirmed productivity from Peltier Lake since at least 2003 and possibly since 2000. From 2006 to 2008, ground survey data (Table 5) indicated a general increase in the size and productivity of the Peltier Lake colony. In 2008, a minimum of 29 active trees, 54 active nests, and 70 chicks were documented. This represented an increase above 2007 levels by 7.4%, 28.6%, and 29.6% respectively (Figure 31). As of 8 July, 2008, a minimum of 58 surviving chicks (presumed to have fledged) were documented; this estimate was a 34.9% increase above that recorded for the 2007 season. Since 2005, the Peltier Lake colony experienced significant growth in the number of successful trees (Chi-squared test, $X^2 = 10.70$, df = 3, $p = 0.013$) and productive nests (Chi-squared test, $X^2 = 14.86$, df = 3, $p = 0.002$). The average number of active nests per tree did not change significantly (One-way ANOVA, F(3, 109) = 1.83, $p = 0.145$). Additionally, while the maximum number of chicks visually detected during ground surveys (Table 4) suggested that brood size remained consistent since 2005 (One-way ANOVA, $F(3, 109) = 0.33$, $p = 0.80$), the number of fledglings per nest (Table 4, Figure 31D) increased significantly (One-way ANOVA, $F(3, 109) = 6.56$, $p = 0.0004$).

*Predator guard performance*

An examination of the metal flashing on the two successful trees in 2005 showed no sign of mesopredator climbing activity on one tree, but the second tree appeared to have been climbed successfully (i.e., 'breached') despite having a predator guard. Given that this tree produced fledglings, I assumed that the raccoon climbed past the predator guard after the chicks fledged. Scratch patterns in the painted sheet-metal suggested that raccoons attempted to climb 47% (n = 81) of all protected trees during the 2005 season, 60% (n = 49) of which appeared to be successful (Figure 32). Overall, 28% of the protected trees were successfully climbed. Thirty-nine trees showing evidence of climbing attempts contained intact nests. Of the 19 active nest trees within the colony, 79% (n = 15) showed evidence of attempted climbs and 58% (n = 11) appeared to have been successfully climbed. Trees containing active nests were scratched disproportionately more than those containing inactive nests (Chi-squared test, $X^2 = 11.15$, df = 1, $p = 0.0008$). Based on nest status (active vs. inactive), no significant difference in predator guard failure rate was detected.

Since 2005, there was an overall reduction in mesopredator climbing activity. The proportion of successful climbs also demonstrated a downward (Figure 33) trend by a nearly significant margin (Chi-squared test, $X^2 = 4.94$, df = 2, $p = 0.084$). The percentage of all protected trees showing evidence of attempted climbs was 25.3% (n = 50) and 9.8% (n = 20) in 2006 and 2007 respectively. The percentage of active nest trees showing evidence of attempted climbs was 39.3% (n = 11) and 18.5% (n = 5) in 2006 and 2007 respectively. The percentage of active trees that were climbed successfully by raccoons (i.e., past the predator guards) was 3.6% (n = 1) in 2006 and 0.0% (n = 0) in 2007.

*Furbearer removal*

In the fall of 2005, a total of 10 raccoons (3 ♀) and 7 opossum (4 ♀) were harvested over a total of 181 trap nights. During the fall of 2006, a total of four raccoons (4 ♀) and 14 opossum (only 2 ♀ were recorded) were harvested over a total of 324 trap nights (Figure 34). During both seasons, trapping activity was temporarily halted when island access became impossible during the lake’s winter “freeze-up” and as raccoon activity decreased with the temperature. Public use of the island increased after “freeze-up” because the frozen lake provided easy access to the island. Consequently, all trapping activity was halted to avoid injuring or killing free roaming pets via non-target captures in leg-hold or body-gripping traps. No trapping/removal took place prior to the 2008 nesting season. Nest fate data (Table 6) demonstrated that active nest trees with no predator guards were extremely vulnerable to predation and had a very low probability of success.

## *Discussion*

### *Colony status*

Survey data demonstrated that, while brood size has remained consistent at Peltier Lake since 2005 (Figure 31D), the ratio of fledglings to chicks detected has increased and overall chick survival (i.e., number of fledglings per nest) has increased significantly.

### *Predator guard performance*

Initially, the results of this methodology were unsatisfactory. In 2005, widespread nest failures and scratch data, collected during end of season surveys, suggested that the climbing ability of raccoons was underestimated. Given the decreasing proportion of successful climbs per attempt, refinements to the tree guarding techniques appear to have made some difference. This reduction in climbing success was not significant however, which underscores the challenge of colony-wide tree protection. Additionally, scratches on the flashing likely underestimated raccoon climbing success given the forest density, the abundance of climbing routes available, and raccoon climbing abilities.

An interesting example of the benefits of tree guards is illustrated by the history of a specific large basswood which was composed of three large trunks in close proximity (tag numbers #708, #709, #999). This tree complex contained five and four active heron nests in 2005 and 2006 respectively. Raccoon predation caused all of these nests to fail during both seasons. Raccoons were able to thwart the predator guards by pushing off of one trunk to gain climbing traction on its neighbor (Figure 29B). Prior to 2007, a concerted effort was made to secure this tree complex by raising the metal flashing to a height at which the trunks were angled too far apart to offer a climbing advantage. This tree complex had high nest occupancy during the 2007 and 2008 seasons (six and five nests respectively). However, no successful climbs or nest predation by mesopredators was documented. This tree complex produced a total of 17 fledglings during the 2007 and 2008 seasons. Another tree (#714), which produced fledglings annually since 2005, provides a different perspective. Its configuration and distance from other trees made it easy to protect. In 2005, an audio recorder attached to the base of this tree clearly recorded the sound of an animal attempting to climb past the metal flashing. In the background, the alarm calls of Great Blue Heron chicks were also clearly audible. Upon inspection the following morning, muddy tracks and scratches indicated that a raccoon had attempted but failed to circumvent the flashing. This securely guarded tree was one of only two that produced fledglings in 2005. This appears to be the first time since Hjertaas (1982) that a tree nesting wader colony has been successfully protected using predator exclusion.

*Furbearer removal*

It is likely that some of the resident raccoons removed from the island were experienced heron predators. However, any gains achieved via trap/removal are certainly temporary (Prange et al. 2003). Of note is that 50% more opossum were removed than raccoons over the two trapping seasons, suggesting that opossum density was higher than raccoon density. Opossum are similar to raccoons in that the 160m span of open water between the mainland and the island poses no barrier to their movements (Figure 35). Additionally, human habitation correlates positively to opossum survival and population density (Kanda 2005, Markovchick-Nicholls 2008). Foraging model results (Appendix II) demonstrated the disproportionately large effect that a small number of tree climbing predators can have upon a heronry, particularly if the predators learn to specifically exploit active nest trees. When egg depredation is factored in, the probability of colony failure increases (Appendix II). Because no data were collected until after chicks hatched, evidence (video or otherwise) of egg depredation by opossum or any other predator is lacking. Therefore, the importance of egg predation on nest success at Peltier Lake is unknown.

Because no trapping has occurred since the 2007 nesting season, I anticipated that evidence of raccoon foraging activity might increase. Alternately, residual effects from trapping may have resulted in a continued decline in tree climbing activity through elimination of the learned foraging behavior in resident mesopredators. If predator guards made tree climbing sufficiently difficult within the colony, then the learned association between climbing and the reward of an available food source should weaken in the absence or reduction of positive reinforcement (Thorndike 1911). Moreover, if individuals who have learned this foraging behavior are eliminated, then the length of time needed for young or immigrant raccoons to become conditioned to hunt herons would take longer than without the predator guards. However, the pronounced difference in nest success depending upon the presence of predator guards strongly suggests that (1) experienced heron predators are still present within the resident raccoon population and/or (2) the plastic and opportunistic foraging behavior of the island's resident raccoons enables them to exploit vulnerable trees (i.e., no behavior modification has occurred), and finally (3) the predator guards are working.

Raccoon density is correlated to landscape modifications associated with urbanization (Zeveloff 2002, Prange and Gehrt 2004). These modifications (e.g., removal of trees) reduce the number of den sites which raccoons require for over-wintering and raising young. Peltier Island, however, is heavily forested and we located many den sites used by raccoons (Figure 36). Given the overlapping breeding phenologies of the herons and raccoons, the abundant, but ephemeral, food resource (e.g., heron eggs and chicks) became available to the raccoons just when the lactating females were at their highest metabolic stress.

Geographic attributes and how local predators interact with them may predispose a colony to higher than average risk of predation. For example, of 14 metropolitan region heron colonies, 64% (n = 9) are situated on islands in rivers, 21% (n = 3) are located on islands in lakes, and the remainder (14%) are located in a swamp (n = 1) or upland (n =1). Pig's Eye Lake (Figure 26), a large and very old colony, may not be limited by predation. It is located on an island in a wide spot on the Mississippi River and is subjected to fluctuating water levels. Although water has been shown to be of little deterrent to raccoons, seasonal flooding of riparian colonies may be important. Flooding scours the forest floor of olfactory and visual stimuli that could attract and condition mesopredators to hunt herons (e.g., excrement, regurgitated fish, and dead chicks). Additionally, seasonal flooding may reduce the negative effects of herons on soil chemistry due to high levels of nitrogenous waste in the herons' excrement (Weseloh and Brown 1971) and ultimately protect the health of the trees herons use for nesting.

Conversely, the colony at Islands of Peace Park, located on Dunham Island (45°4'N / 93°39'W), near Minneapolis, Minnesota abandoned permanently in 2003. Although situated on an island in the Mississippi River (Figure 37), landscape attributes may have predisposed it to limiting levels of predation. For example, its proximity to a dam mediates fluctuating water levels. Conceivably, olfactory attractants may not be sufficiently washed away beyond the notice of mesopredators. Furthermore, its high density urban setting facilitates high raccoon densities. The narrow channel and slow current are not a deterrent to dispersing raccoons that den on the island, eventually concentrating raccoons in or near the colony and setting the stage for a burgeoning population of locally conditioned heron predators.

## *Conclusion*

Video data recorded a high level of raccoon foraging activity in the Peltier Lake colony, suggesting that predation was an important cause of colony abandonment (Chapter 2). Based upon this video evidence, it was recommended that a management strategy of predator exclusion and/or removal be utilized, along with close monitoring of the colony's status. The results of these recommendations have been encouraging. Since 2005, there has been a reduction in predator sign and climbing success, increased colony productivity, and a four-year trend of colony growth at Peltier Lake.

Although neither approach was perfect, survey data suggest that predator management has halted the colony failures and population reduction at the Peltier Lake colony. Trapping is controversial, labor intensive, and costly, but may be necessary under certain conditions. Continued productivity at Peltier Lake in the absence of trapping prior to the 2008 season suggests that, as a supplement to predator guards, trapping does not need to be ongoing, but can be used selectively and as conditions dictate. Three seasons were necessary to refine the use of the predator guards. Now installed, their upkeep is relatively simple and is easily maintained by a crew of six over a single workday each fall. Predator exclusion by means of predator guards met the goals of working semi-autonomously regardless of mesopredator density while also serving as a valuable tool to collect data on mesopredator climbing success and activity. Overall, the predator guards were an important management tool for restoration of the Peltier Lake colony.

Considerably more effort has been devoted to discovering the cause(s) of colony abandonment at Peltier Lake than to understanding what caused Peltier Lake to become a colony in the first place. The Peltier Lake colony is surmised to have originated and grown as two nearby colonies (Rice Lake and Lamprey Pass) decreased in size. Although, no data exist to explain the spatial movements of these colonies, it is reasonable to speculate that this process may have been driven by predator-prey interactions similar to those observed at Peltier Lake since 2004. The events documented at Peltier Lake suggest a snapshot of a larger dynamic in which predators, after a certain lag-time (i.e., operant conditioning) can rapidly shift the cost to benefit ratios associated with waterbird colony site location to suboptimal levels. It is likely that this cycle of immigration, predator conditioning, and emigration is important to the dynamics of waterbird colony site selection and longevity. Key to this process is the availability of alternative colony locations. However, given the finite amount of appropriate waterbird habitat, and as urbanization in Minnesota's central region continues to increase, so too will the management challenges associated with waterbird conservation. The successful conservation efforts at Peltier Lake demonstrate that it is possible to rescue a failing colony and have also helped to refine a combination of methods that may prove useful for protecting other waterbird colonies of special interest.

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APPENDIX I:  A summary of alternate hypotheses for colony abandonment at the Peltier Lake colony

*Environmental Stochasticity*

One cost of colonialism is a shared risk of catastrophic events such as inclement weather.  Great Blue Herons in central Minnesota initiate nesting during the early spring (mid March) and are subject to potentially volatile weather extremes.  This was dramatically demonstrated at the Peltier Lake colony in 2002 when it experienced a snowstorm, a high of 86° F, and another snowstorm on 3 April, 18 April, and 21 April respectively (Peltier Lake Heron Task Force 2003).  Because chicks are unable to thermo-regulate during the first three weeks after hatching (Bennett et al. 1995), they are especially vulnerable to temperature extremes, windy, and/or wet weather, particularly if the attending adult flushes from the nest in response to a disturbance.

Thunderstorms can also devastate a heronry (Figure 6).  Urban effects on weather systems (Huff and Changnon Jr. 1973; Bornstein and LeRoy 1990; Changnon 2001) explain how weather may develop in geographically consistent patterns due to the juxtaposition of landscape and cityscape.  Colonies unfortunate enough to be situated in such corridors may systematically experience, on average, amplification of weather events.  Over the long term, this phenomenon might explain how a single urban colony could be storm-damaged at higher rates than other more favorably situated colonies.

*Disturbance*

Sensitivity to disturbance in nesting Great Blue Herons has been well documented. Mueller and Glass (1988) found that Ardeids are more sensitive than other waterbirds to noise disturbances. Active heron colonies have also been observed to shift areas of highest nest density away from the point of disturbance (Werschkul et al. 1976, Watts and Bradshaw 1994). With disturbance type and timing influencing the magnitude of adult bird response and ground based or early season disturbances eliciting the greatest responses (Tremblay and Ellison 1979, Vos et al. 1985, Carlson and McLean 1996, Stolen 2003). When disturbed adults flush from the nest, this behavior can exacerbate other factors; temporarily abandoned nests render chicks/eggs vulnerable to exposure and/or predation (Kelsall and Simpson 1979). Thus, disturbance can not only negatively impact productivity, but also, in sufficient magnitude and at critical times, cause widespread mortality; potentially leading to colony abandonment (Bjorklund 1975; Carney and Sydeman 1999).

Another suggested source of disturbance was the presence of predators. Similar to human disturbance, avian predators such as Great Horned Owls (*Bubo virginianus*) have been implicated in causing colony wide disturbances (i.e., panic). The resulting chaos makes the impact of a single pair of owls disproportionately large when compared to the amount of prey they are able to take (D Mock, *pers. comm.*). The presence of Bald Eagles (*Haliaeetus leucocephalus*) presumably can cause similar disturbances within a heronry (Figure 38).

*Predation*

Avian nest predators such as American Crows (*Corvus brachyrhynchos*) and Great Horned Owls (*Bubo virginianus*) will exploit unattended eggs and/or chicks given the opportunity (Baker 1940, Taylor and Michael 1971, Gretch 1987, Houston et al. 1998). Though not yet documented in Minnesota, Bald Eagles are also known to prey upon Great Blue Heron eggs, chicks, (Table 3, Figure 38), juveniles, and even adults (Norman et al. 1989; Vennesland and Butler 2004; Heiman 2007). Bald Eagles have also been observed harassing and pirating food from adult Great Blue Herons and have been implicated in causing colony abandonments (Bayer 1979, Kelsall and Simpson 1979, Butler and Baudin 1999). Furthermore, mammalian predators such as raccoons (*Procyon lotor*) and Virginia opossum (*Didelphus virginianus*) have been documented either preying directly upon herons or upon their eggs (Lopinot 1951, Hjertaas 1982, Frederick and Collopy 1989, Coulter and Bryan Jr. 1995).

All previously mentioned predators are present within the Peltier Lake region. Several active Bald Eagle nests are located nearby, and Bald Eagles are commonly observed flying above the colony or perched nearby (MN-DNR *unpubl. data*, A Von Duyke *pers. observ.*). Raccoon density should be locally high given their tolerance for fragmented and urbanized landscapes (Prange and Gehrt 2004) such as those surrounding Peltier Lake. Also, the heavily wooded island at Peltier Lake provides good raccoon denning habitat (Zeveloff 2002) which, given their overlapping phenologies, provided an abundant food source (the heron colony) just when the lactating females were under their highest metabolic demands.

*Locally reduced carrying capacity*

The Peltier Lake colony is currently situated within a region of rapid urbanization among the outlying exurbs of the Minneapolis/St. Paul metropolitan region (Figure 39). Landscape regime change as a result of land development represents a potential for alteration to regional carrying capacity and/or habitat. Ardeid nest colony distribution is influenced by foraging efficiency (Gibbs 1991, Custer et al. 2004). Furthermore, since herons are only able to carry at most two to three sticks at a time during flight, nest construction is energetically costly and colony location may be optimally located for access to nest construction materials (Gibbs et al. 1987). In a pristine landscape, alternative locations would be colonized when habitat became suboptimal. Yet, as urban encroachment reduces the availability of alternative colony locations, herons may continue to occupy suboptimal colony sites. This could lead to greatly reduced productivity in comparison to more favorably situated regional colonies and possibly greater intra-specific competition for other limited resources such as nest construction materials.

*Infectious disease*

A cost associated with colonialism is disease transmission. The decimating effects of the mosquito borne West Nile Virus (WNV) are well documented in Corvids (Marfin et al. 2001, McLean et al. 2001, Yaremych et al. 2004). Given that mosquito abundance increases with Cliff Swallow (*Petrochelidon pyrrhonota*) colony size

(Brown and Sethi 2002), it is plausible that waterbird colonies could attract large numbers of mosquitoes. Could WNV be exacting a toll on Ardeids?

Great Blue Herons were not shown to be overrepresented as blood meal hosts by mosquitoes (Cupp et al. 2004). Furthermore, when purposely infected with WNV-99, Black-crowned Night-Herons (*Nycticorax nycticorax*) and Cattle Egrets (*Bubulcus ibis*) were found to be moderately competent and incompetent hosts for the virus respectively (Reisen et al. 2005); suggesting that Ardeids, unlike Corvids, do not easily contract WNV. This evidence casts further doubt on WNV as a cause, as does the conspicuous absence of Ardeids with WNV in wildlife necropsy records (USGS-NWHC Quarterly Mortality Reports, http://www.nwhc.usgs.gov/publications/quarterly_reports/; last accessed, April 2008). Finally, the question of why a single colony would be more susceptible to WNV while other regional colonies seemingly prosper suggests that infectious disease may not be the most probable cause of breeding colony abandonment.

*Localized pollution*

Biomagnification of pollutants within aquatic food chains is problematic for piscivorous birds (DeLuca-Abbott et al. 2001, Gray 2002). Furthermore, local watersheds in which herons forage, can accumulate waterborne environmental contaminants from vast regions. If the residents of a single Ardeid breeding colony were to forage within an area exclusive of other regional colonies, and if the watershed did not fall within the foraging radius of multiple breeding colonies, then it could be argued that localized pollution might potentially be manifested within a single heronry as colony-wide mortality, particularly of chicks.

Little study has been done on natal philopatry in Ardeids. If it could be shown that colonies contain discreet sub-populations within a larger region, a point source pollution hypothesis would be more valid. Yet, Great Blue Herons have been shown to have low sensitivity to organochlorine and PCB contamination (Hart et al. 1999, Thomas and Anthony 1999), suggesting that other fish eating birds would be affected before Great Blue Herons. Additionally, other regional colonies have not experienced the same recent large fluctuations in productivity as the Peltier Lake colony. And observations that large foraging distances of Great Blue Herons and Great Egrets overlap with those of birds from other seemingly “normal” metro area breeding colonies (Custer and Galli 2002) and that these “normal” colonies reside in the same watershed as Peltier Lake also do not support a pollution hypothesis.

APPENDIX II: A simple model to better understand the potential impact of predation upon waterbird colony productivity

*Description*

A stochastic model was built using Microsoft Excel software to investigate the effect of predation upon large Ardeid breeding colonies. The primary goal was to determine if a small number of mesopredators (i.e., raccoons) could potentially cause a colony to abandon through the destruction of all nests. A second goal was to estimate how many predators (raccoons) it would take to cause colonies of varying sizes to fail.

*Model Assumptions*

1. All heron mortality occurred in the chick stage (i.e., no egg-destruction or adult mortality). Egg-destruction (e.g., by opossum or crows) can be modeled as a smaller brood size.
2. Clutch size was 3 eggs/nest and 100% of eggs hatched simultaneously.
3. All trees are uniformly distributed across the island on which the colony is located.
4. All active nest trees had equal nest density (3 nests/tree).
5. The maximum number of predation events occurring within the colony on any single night did not exceed the total number of predators present (i.e., predators attacked a single nest per night).
6. All predation events resulted in the loss of a single chick per event.
7. Chick vulnerability ends (i.e., P(predation) = 0) at a finite age. Based on video and ground survey observations, this age was set at 56 days.
8. Three hunting techniques and two predation probability scenarios were tested:

a. RANDOM-CONSTANT (RNDC): All trees have an equal probability of predation: $P(predation_{RND}) = 1/\#trees_{foraging\ area} * \#predators$. For example, if the entire island was the foraging area, and it has an estimated 2000 trees, then $P(predation_{RND}) = 1/2000 = 0.0005 * \#predators$. Predators do not "remember" active trees. The term CONSTANT states that a predator's ability to detect active trees remains consistent throughout the nesting season. At chick age 56 days, the predation probability immediately drops to zero as chicks are assumed to be too agile to be hunted in the tree canopy.

b. RANDOM-CONSTANT-LEARN (RNDCL): Initially the same as RNDC. However, if a predator climbs an active tree, it remembers this tree and systematically returns every night thereafter until the active tree no longer holds any chicks. In other words, the $P(predation_{RND\text{-}C\text{-}L})$ after detection of an active tree = 1.

c. NON-RANDOM-CONSTANT-LEARN (NRNDCL): Same as RNDCL. However, assuming that predators use olfactory, auditory, and/or visual cues to locate active trees, this scenario decreases the size of the foraging area to the extent of the colony itself. For example, the colony at Peltier Lake in 2004 occupied roughly 25% of the island's area ($P(predation_{RND}) = 1/500 = 0.002 * \#predators$). Thus, any active tree, by virtue of being active, has a higher probability of predation than mere random chance.

d. NON-RANDOM-VARIABLE-LEARN (NRNDVL): Same as NRNDCL. However, the new term 'VARIABLE' states that a predator's ability to detect active trees increases over the course of a nesting season; making active trees more vulnerable as the season progresses (Figure 40). The predation probability decreases to zero over the course of the last seven days; simulating the increasing ability of chicks to evade predators. Eventually, P(predation) = 0 at chick age 56 days as chicks are assumed to be too agile to be hunted in the tree canopy.

*Results*

As presented, the different foraging techniques (RNDC, RNDCL, NRNDCL, NRNDVL) resulted in increasing hunting efficiency. Figure 41 demonstrates that a purely random or opportunistic approach causes very little mortality in nestlings over the course of an eight-week period of vulnerability. However, once learned behavior is factored into the model, the rate of depredation increases. Non-random foraging (i.e., deliberate hunting for nestlings in active trees) can cause substantial chick mortality; particularly if the predator not only exploits known active trees, but is able to either do so more efficiently with practice or to more easily detect active trees as the season progresses (presumably drawing upon olfactory, visual, and auditory stimuli). Thus, while a purely random or an opportunistic + memory strategy typically caused mortality in no more than 25% of nestlings, active searching and learned exploitation of a heron colony resulted in approximately 80% chick mortality.

*Discussion*

As built, this model took a very conservative approach. It did not consider other causes of chick mortality such as diurnal and nocturnal avian predators, egg predators (i.e., American Crow and Virginia opossum), food limitation, sibling aggression, stochastic events, or synergies among multiple variables. Furthermore, the assumption that only a single nestling is killed at any predation event has been shown through video evidence to be invalid. This model also assumed that a single predator would only attack a single nest per night. Though this last assumption cannot be directly discounted through video evidence, it does not seem very realistic. Therefore, this model likely underestimates the maximum potential impact of predators upon chick mortality.

Figure 42 shows the minimum number of predators required to cause 20% of model replications to lead to colony failure (complete loss of all nestlings due to depredation) in a large colony containing 300 active trees with 900 nests. Directly mirroring the hunting efficiency results above, this model suggests that a relatively small number of predators (n = 25) that are able to learn from experience, employ a suite of sensory organs and behaviors to locate their prey, and, over time, either improve at taking their prey or are better able to locate prey, are able to have a very large impact on Ardeid nest colony productivity.

Though not sophisticated, this model helped to validate the predation hypothesis as a possible explanation for repeated colony failure at Peltier Lake. Future models showing the accumulation of learned experience and cultural transmission of foraging (hunting) behavior will prove useful in helping to explain the dynamics of Ardeid colony site selection.

| Colony Name | County | Lat/Lon |
|---|---|---|
| Blue Lake | Scott | 44°49'N/93°27'W |
| Boot Lake | Anoka | 45°20'N/93°8'W |
| Cedar Bend | Washington | 45°17'N/92°44'W |
| Coney Island | Carver | 44°52'N/93°47'W |
| Coon Rapids Dam | Hennepin | 45°8'N/93°18'W |
| Dayton | Hennepin | 45°15'N/93°32'W |
| Mississipi River - 44th Ave N | Hennepin | 45°2'N/93°17'W |
| Peltier Lake | Anoka | 45°11'N/93°3'W |
| Pig's Eye Lake | Ramsey | 44°54'N/93°2'W |
| Rush Lake | Chisago | 45°41'N/93°5'W |
| Stillwater | Washington | 45°4'N/93°47'W |

**Table 1 - Active heronries in the MN-DNR "Metro" region (2004)**

| Factor | Observation | Prediction | Justification |
|---|---|---|---|
| A. Disturbance | Total mean brooding time | Peltier Lake lower | Adult(s) flush from nest as a result of disturbance. This can exacerbate other factors such as exposute to weather, risk of predation, and heightened risk of food limitation. Feeding rates can be lower if adults are reluctant to return to nest as a reaction to disturbance stimuli. |
| | Total mean adult nest attendance time | Peltier Lake lower | |
| | Total mean disturbance rate | Peltier Lake higher | |
| | Total mean feeding rate | Peltier Lake lower | |
| B. Stochastic events | Seasonal wind duration | Peltier Lake higher | Until 21 days of age, nestlings are unable to thermoregulate independently. Chronically bad weather, particularly if adults have flushed, can cause death via exposure. |
| | Seasonal rain duration | Peltier Lake higher | |
| | Seasonal combined wind/rain duration | Peltier Lake higher | |
| C. Predation | Total count - predator presence | Peltier Lake higher | Direct loss of eggs or nestlings through predation and indirect negative impact through disturbance, regurgitation, and exposure. |
| | Total count - predation events | Peltier Lake higher | |

**Table 2 - Predictions supporting three hypotheses:** (A) disturbance, (B) stochastic events, and (C) predation as hypotheses explaining colony abandonment.

| | Species | Source |
|---|---|---|
| **Avian Predators** | Bald Eagle *Haliaeetus leucocephalus* | Bayer, 1979<br>Kelsall and Simpson, 1979<br>Norman et al., 1989<br>Butler and Baudin, 1999<br>Vennesland and Butler, 2004 |
| | Great Horned Owl *Bubo virginianus* | Gretch, 1987<br>Mock, 2004 (pers. comm.) |
| | Turkey Vulture *Cathartes aura* | Mehner, 1951<br>Temple, 1969 |
| | American Crow *Corvus brachyrhynchos* | Baker, 1940<br>Kelsall and Simpson, 1979 |
| **Mammalian Predators** | Raccoon *Procyon lotor* | Lopinot, 1951<br>Frederick and Collopy, 1989<br>Coulter and Bryan, 1995<br>Hjertaas, 1982<br>Ivanovs, 1968<br>Kelsall and Simpson, 1979 |
| | Virginia Opossum *Didelphis virginiana* | Frederick and Collopy, 1989<br>Kelsall and Simpson, 1979 |
| | Mink *Mustela vison* | Kelsall and Simpson, 1979 |

**Table 3 - Potential predators of Great Blue Herons in central Minnesota**

|  | Behavior category |  |
|---|---|---|
|  | **Alert** | **Alarm** |
| **Adult** | Stops current behavior<br>Attention focused outside of nest<br>Head up posture | Puffs up feathers<br>Visible vocalizing<br>Head thrust<br>Crest raised<br>Flushes from nest |
| **Chick** | same as adult | Vocalizatin<br>Head thrust<br>Escape to tree limb<br>Hide - cower |

**Table 4 - Ethogram of "disturbance" behavior in nesting Great Blue Herons**

| | | Year | | | | % change | | |
|---|---|---|---|---|---|---|---|---|
| | | **2005** | **2006** | **2007** | **2008** | **2006** | **2007** | **2008** |
| **Trees** | Active | 24 | 33 | 27 | 29 | 37.5 | -18.2 | 7.4 |
| | Failed | 22 | 20 | 10 | 9 | -9.1 | -50.0 | -10.0 |
| | Successful | 2 | 13 | 17 | 20 | 550.0 | 30.8 | 17.6 |
| **Nests** | Active | 36 | 41 | 42 | 54 | 13.9 | 2.4 | 28.6 |
| | Failed | 33 | 24 | 11 | 12 | -27.3 | -54.2 | 9.1 |
| | Successful | 3 | 17 | 31 | 42 | 466.7 | 82.4 | 35.5 |
| **Chicks** | Nestlings | 53 | 68 | 63 | 73 | 28.3 | -7.4 | 15.9 |
| | Deceased | 49 | 36 | 20 | 15 | -26.5 | -44.4 | -25.0 |
| | Fledglings | 4 | 32 | 43 | 58 | 700.0 | 34.4 | 34.9 |
| **Chicks/nest*** | mean | 1.52 | 1.59 | 1.42 | 1.56 | 4.6 | -10.6 | 9.5 |
| | var | 0.592 | 0.460 | 0.355 | 0.446 | -22.3 | -22.8 | 25.7 |
| | n | 36 | 41 | 42 | 54 | 13.9 | 2.4 | 28.6 |
| | SE | 0.128 | 0.106 | 0.092 | 0.091 | -17.4 | -13.2 | -1.1 |
| **Fledglings/nest** | mean | 0.10 | 0.72 | 0.94 | 1.14 | 620.0 | 30.6 | 21.3 |
| | var | 0.173 | 1.108 | 0.755 | 0.961 | 539.0 | -31.9 | 27.4 |
| | n | 36 | 41 | 42 | 54 | 13.9 | 2.4 | 28.6 |
| | SE | 0.069 | 0.164 | 0.134 | 0.133 | 136.9 | -18.5 | -0.5 |
| **Nests/tree** | mean | 1.50 | 1.24 | 1.56 | 1.86 | -17.3 | 25.8 | 19.2 |
| | var | 0.96 | 0.38 | 1.03 | 2.05 | -60.4 | 171.1 | 99.0 |
| | n | 24 | 33 | 27 | 29 | 37.5 | -18.2 | 7.4 |
| | SE | 0.20 | 0.11 | 0.19 | 0.27 | -45.0 | 72.7 | 42.1 |

**Table 5 - Census data from the Peltier Lake colony (2005-08):** Ground based survey data was collected at least once per week from hatch to fledging. *This value was based solely upon visual detection, typically after chick age 21 days, and is not indicative of actual clutch size.

**A.**

| | **2005** | | | **2006** | | | **2007** | | | **2008** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Tree #** | nests | chicks | fledglings | nests | chicks | fledglings | nests | chicks | fledglings | nests | chicks | fledglings |
| 05-999 | 1 | 1 | 0 | | | | | | | | | |
| 08-001 | | | | | | | | | | 1 | 1 | 0 |
| old 152 | | | | | | | | | | 1 | 1 | 0 |
| old 400 | | | | 1 | 1 | 0 | | | | | | |
| old 440 | | | | | | | | | | 1 | 2 | 0 |
| old 476 | | | | 1 | 1 | 0 | | | | | | |
| old 479 | | | | | | | | | | 2 | 2 | 0 |
| old 495 | | | | | | | | | | 2 | 2 | 0 |
| old 749 | | | | 1 | 2 | 0 | | | | | | |
| **Total** | 1 | 1 | 0 | 3 | 4 | 0 | 0 | 0 | 0 | 7 | 8 | 0 |

**B.**

| | **Predator Guards** | | | | | **No Predator Guards** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Year** | trees | nests | chicks | trees failed | fledglings | trees | nests | chicks | trees failed | fledglings |
| 2005 | 23 | 35 | 52 | 21 | 4 | 1 | 1 | 1 | 1 | 0 |
| 2006 | 30 | 38 | 55 | 17 | 31 | 3 | 3 | 4 | 3 | 0 |
| 2007 | 27 | 42 | 54 | 10 | 43 | 0 | 0 | 0 | 0 | 0 |
| 2008 | 29 | 54 | 70 | 3 | 58 | 5 | 7 | 8 | 5 | 0 |
| **Total** | 109 | 169 | 231 | 51 | 136 | 9 | 11 | 13 | 9 | 0 |

**Table 6 - Fate of nests in unguarded trees.** (A) Over four seasons, all nine unprotected trees (i.e., no predator guards) that were occupied by herons failed to produce fledglings. (B) In contrast, over the same time period, 53.2% (n = 58) of active protected trees produced 136 fledglings.

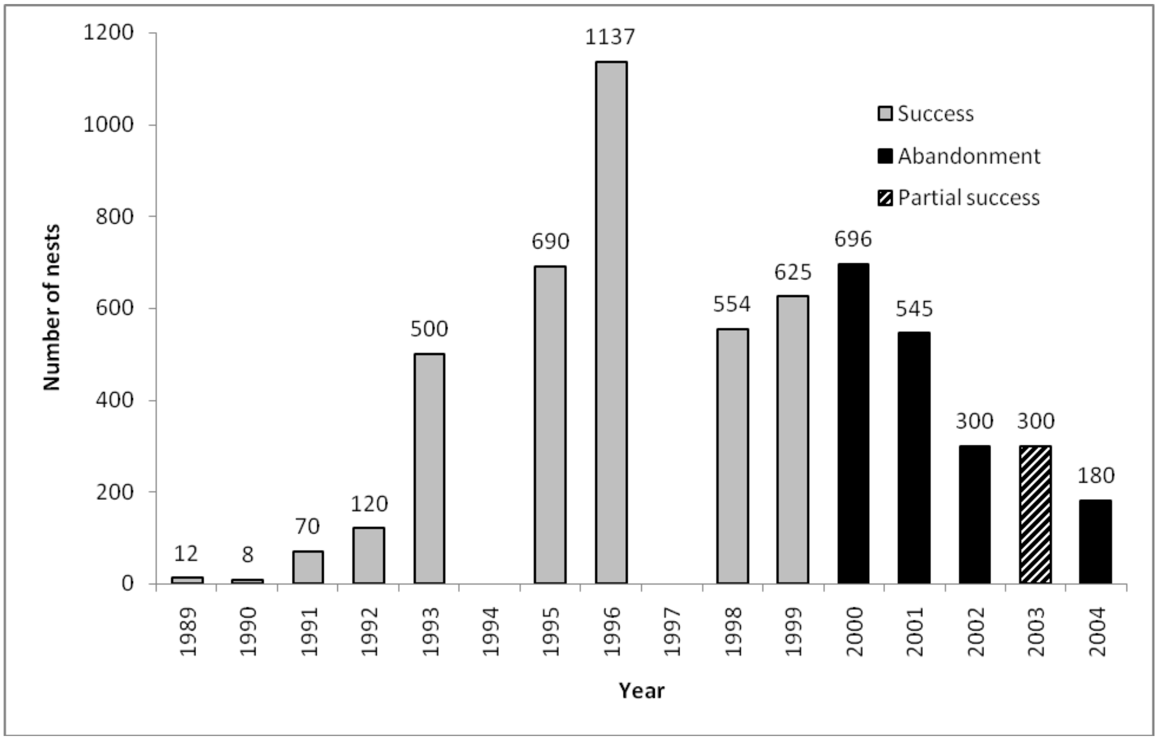



**Figure 1 - Peltier Lake census data.** Annual colony size estimates at the Peltier Lake colony were based upon winter nest counts (Anoka County Department of Parks and Recreation, *unpublished data*) and aerial surveys (MN-DNR, *unpublished data*). Cost and time constraints did not allow for correction factors to be calculated and thus all data should be considered an index to colony size only. Note that the "no-wake zone" was instituted in 2002. Partial colony success was determined by observing active chicks "branching" late in the nesting season and "a few" foraging juvenile herons on Peltier Lake. Anecdotal evidence suggests that this heronry may have been in existence at least 10 years earlier than documented in MN-DNR records.

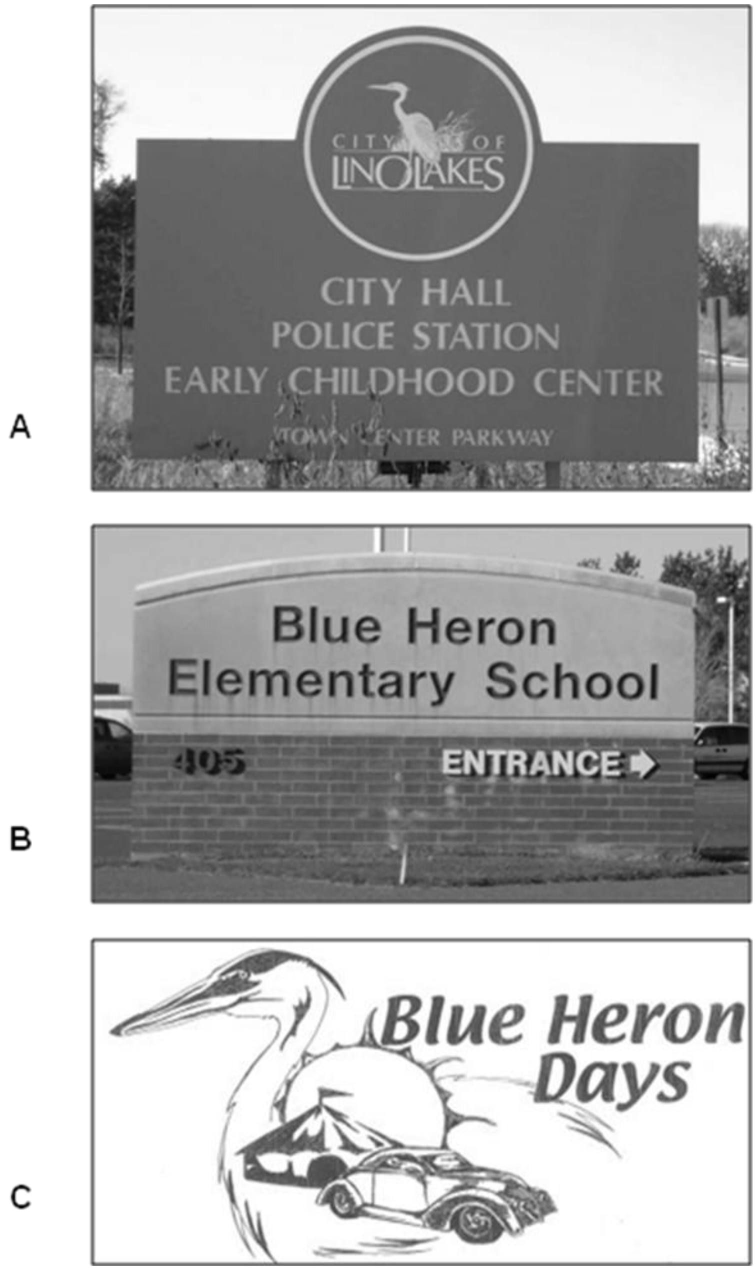



**Figure 2 - Community value of the Peltier Lake heronry.** A) Incorporation of the image of a Great Blue Heron into the city logo of Lino Lakes, Minnesota; B) Naming of a local elementary school after the Great Blue Heron; and C) Annual summer festival called “Blue Heron Days” that features the “Rookery Run 5K” as one of its events. (Photos: Andy Von Duyke; Logo: Lino Lakes Jaycees)

A 

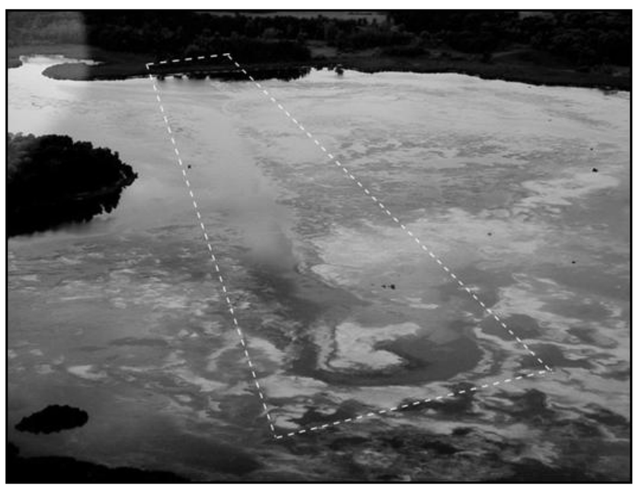
B 

**Figure 3 - Extent of slalom water-ski course at Peltier Lake.** (A) The slalom water-ski course can be seen on this enhanced aerial photo of Peltier Lake inside the dashed rectangular box (800m x 125m). The dark strip is the path which was cut through the submergant aquatic vegetation by the boat props. Ski boats, at their closest, passed within 50m of the northern end of the island. (B) Aerial Photo of Aquatic Plant destruction, 14 July, 2001. The northern end of Peltier Lake is ~ 1.5m deep. Lake eutrophication and increased turbidity resulted from the added nutrient load due to the shredded macrophytes and churned/suspended lake bottom sediments. (Top photo: Globexplorer; Bottom photo: Wayne Leblanc)

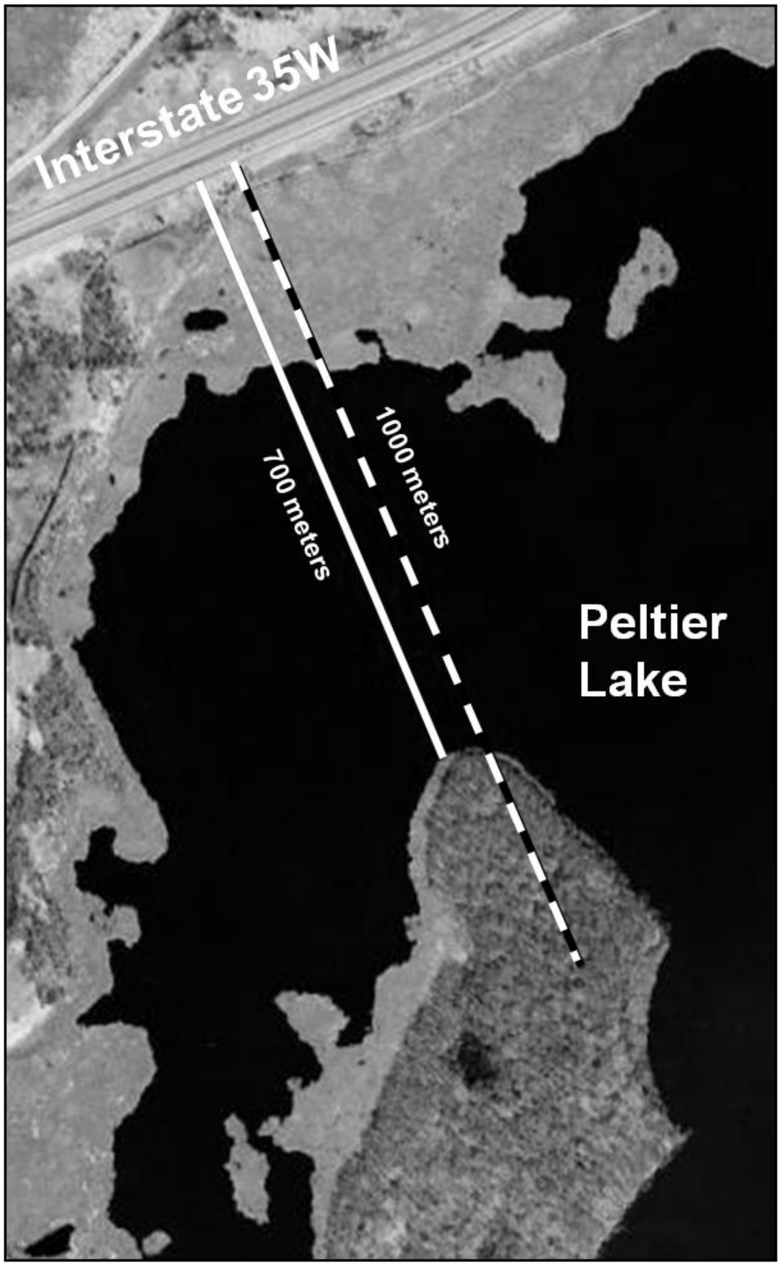



**Figure 4 - Highway construction adjacent to Peltier Lake.** In the year 2000, highway construction (State Project No. 0280-49) along Interstate 35W coincided with the nesting season at the Peltier Lake colony. It was hypothesized that noise disturbance may have had a negative impact on the heron colony. The solid line shows the shortest distance (~700m) from the highway to the island on which the Peltier colony resided. The dashed line shows the shortest distance (~ 1,000m) from the highway to the densest area of the colony (Image: Google Earth).

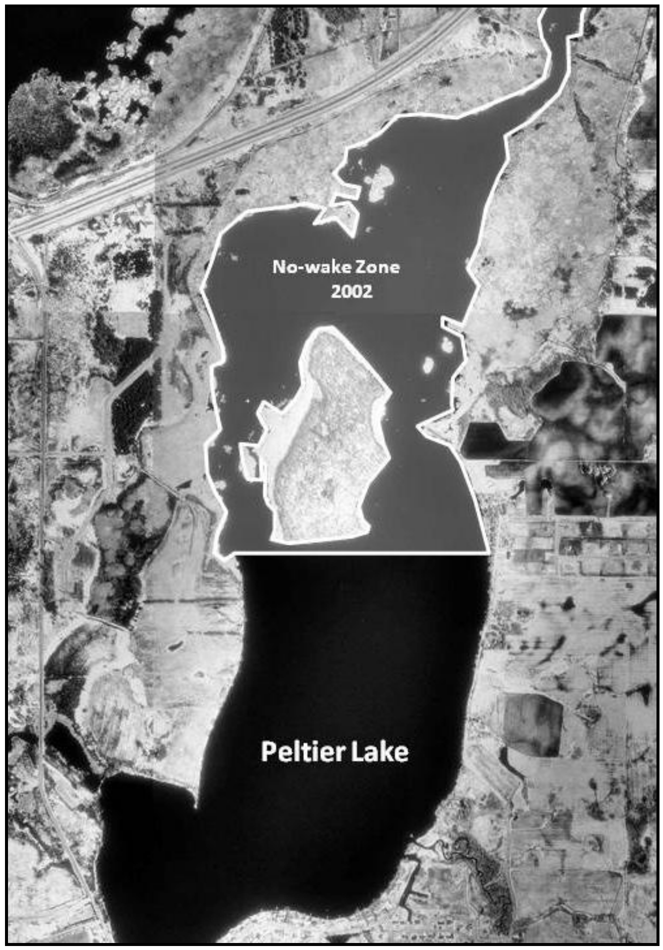



**Figure 5 - No-wake zone at Peltier Lake.** In 2002, through a joint powers action by the cities of Lino Lakes and Centerville, Minnesota, the northern end of Peltier Lake was designated as a no-wake zone (City ordinance #03-02). This action was seen as a means to not only protect the waterbird colony on the island, but also to improve water quality, minimize disturbance to other wildlife, and improve the quality of life on the lake. Additionally, while the herons were actively nesting, the island was designated as bird sanctuary and all foot traffic was restricted (Source: City of Lino Lakes).


A.


B.

**Figure 6 - Storm damage to local heronries.** Catastrophic storm events are known to have destroyed two large local heron colonies recently. (A) An early season thunderstorm with high winds in Chippewa Flowage, Wisconsin (45°55'N/91°12'W) killed over 100 adult Great Blue Herons (Wisconsin Department of Natural Resources, 2003). (B) This carcass of a six week old Great Blue Heron chick was one of hundreds which were blown out of their nests by a late season thunderstorm at Rush Lake, MN (45°40'N/93°05W). The entire colony was destroyed in this storm (MN-DNR 2004).

**Figure 7 - An ideal camera tree.** In central Minnesota, Great Blue Herons prefer the highest extremities of mature hardwood forests for nest placement. Here a climber installs cameras in the crown of a Black Ash (*Fraxinus nigra*) at the Peltier Lake colony. Camera height was estimated to be 75 feet (22.9m). Cameras at Pig's Eye Lake were installed in Eastern Cottonwoods (*Populus deltoides*) over 100 feet (30.5m) high. (Photo: Steve Kittelson, MN-DNR)

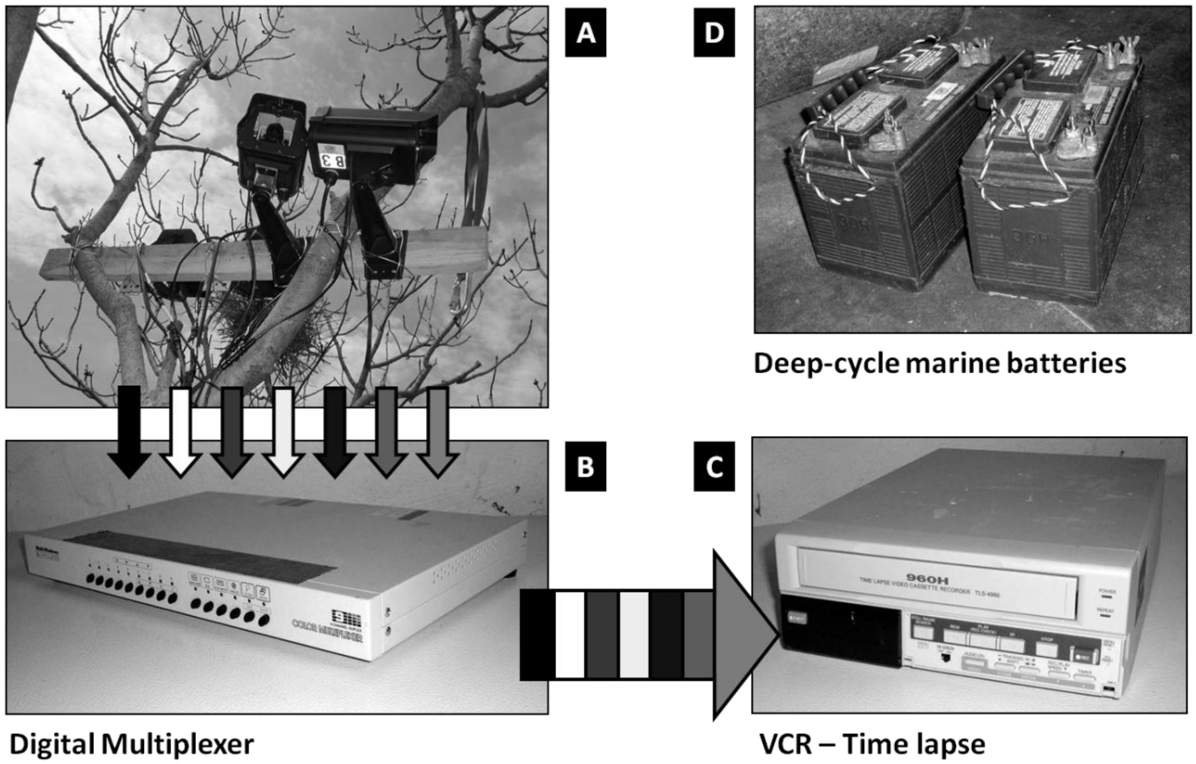



**Figure 8 - Video equipment.** In order to monitor nesting activity, super low-light cameras (A) were aimed into active nests. Multiple channels of video signal (up to nine) were carried by coaxial cables to a digital multiplexer (B) which digitally rearranged the signals so that they could be recorded onto a single VHS tape using a time-lapse VCR (C). The entire setup, including the cameras, was powered by two 12v deep-cycle marine batteries (D). This equipment could operate continuously for approximately 48 hours between battery charges.

**Figure 9 - Weather and theft protection.** A welded steel security box, chained to the base of each study tree, protected recording equipment from theft, vandalism, and the elements. The open lid is visible on the left side of the box and was sealed using weather stripping and duct-tape. The purple plastic tote provided additional weather protection. (Photo: Steve Kittelson, MN-DNR)

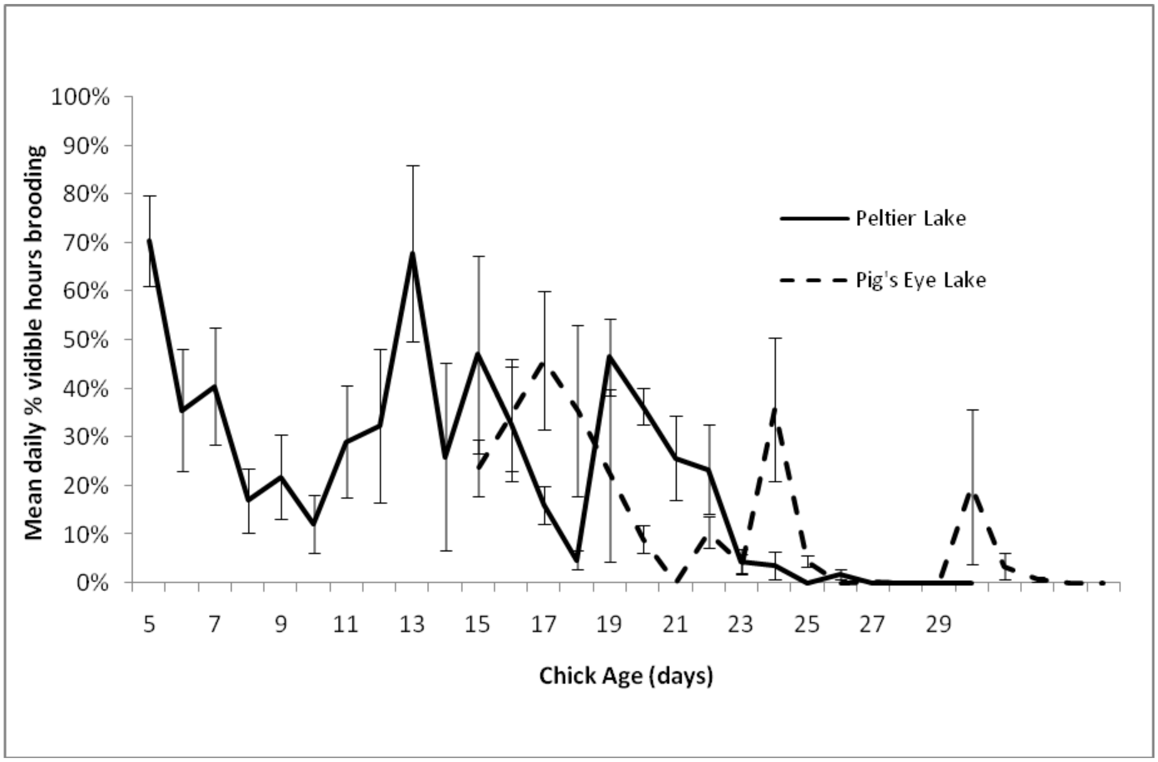



**Figure 10 - Comparison of brooding behavior.** No significant difference in the percentage of time adults spent brooding, was detected on video (Matched-pairs T-test, $t = 0.0398$, df = 15, $p = 0.484$). Bars show 95% CI.

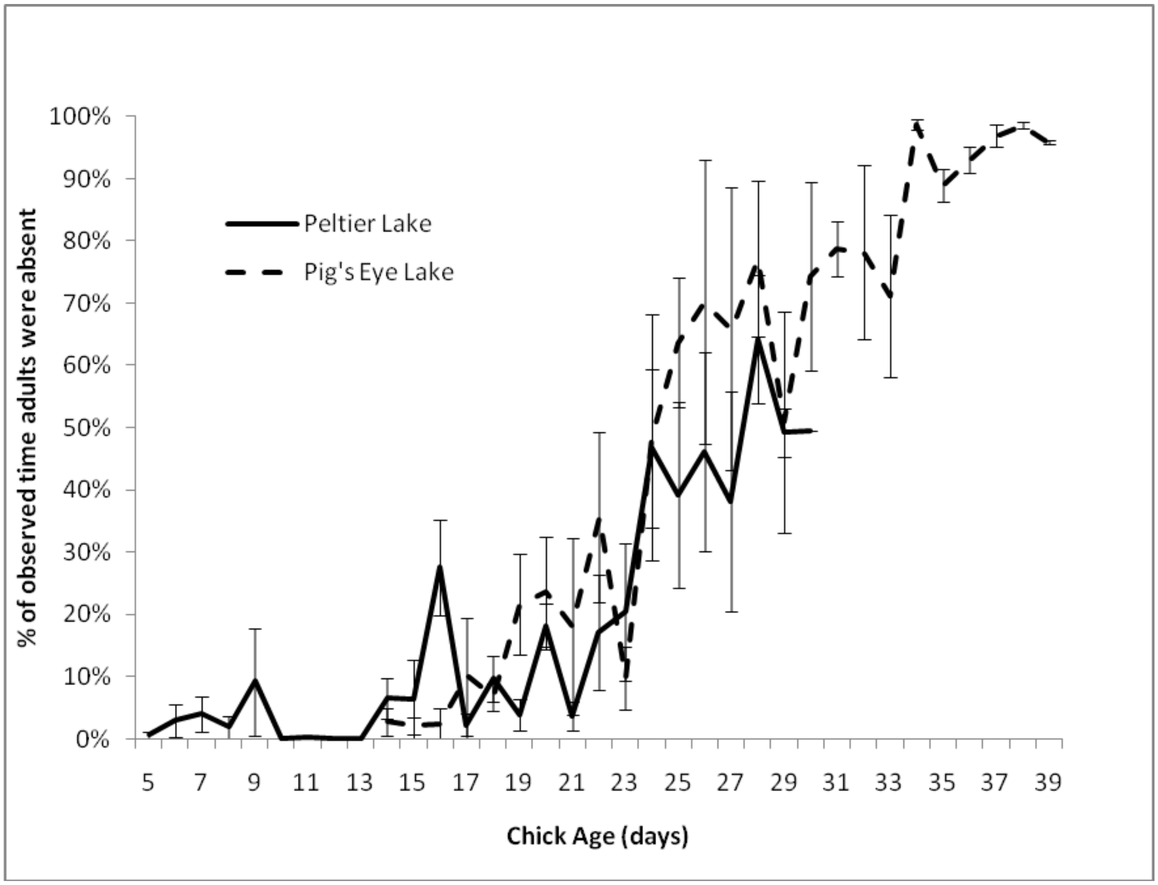



**Figure 11 - Comparison of adult nest attendance.** During early nesting (chick age < 23 days), there was no significant difference in adult attendance (Matched-pairs T-test, $t$ = 0.398, df = 9, $p$ = 0.350). After chick age 23 days, adult absence from the nest was significantly greater at Pig's Eye Lake than at Peltier Lake (Matched-pairs T-test, $t$ = 3.932, df = 6, $p$ = 0.004). The need to travel farther to forage from a large colony than from a small colony predicts that nest attendance should be greater at Peltier Lake than at Pig's Eye Lake. This predicted difference is observed at Peltier Lake and Pig's Eye Lake colonies. Bars show SE.

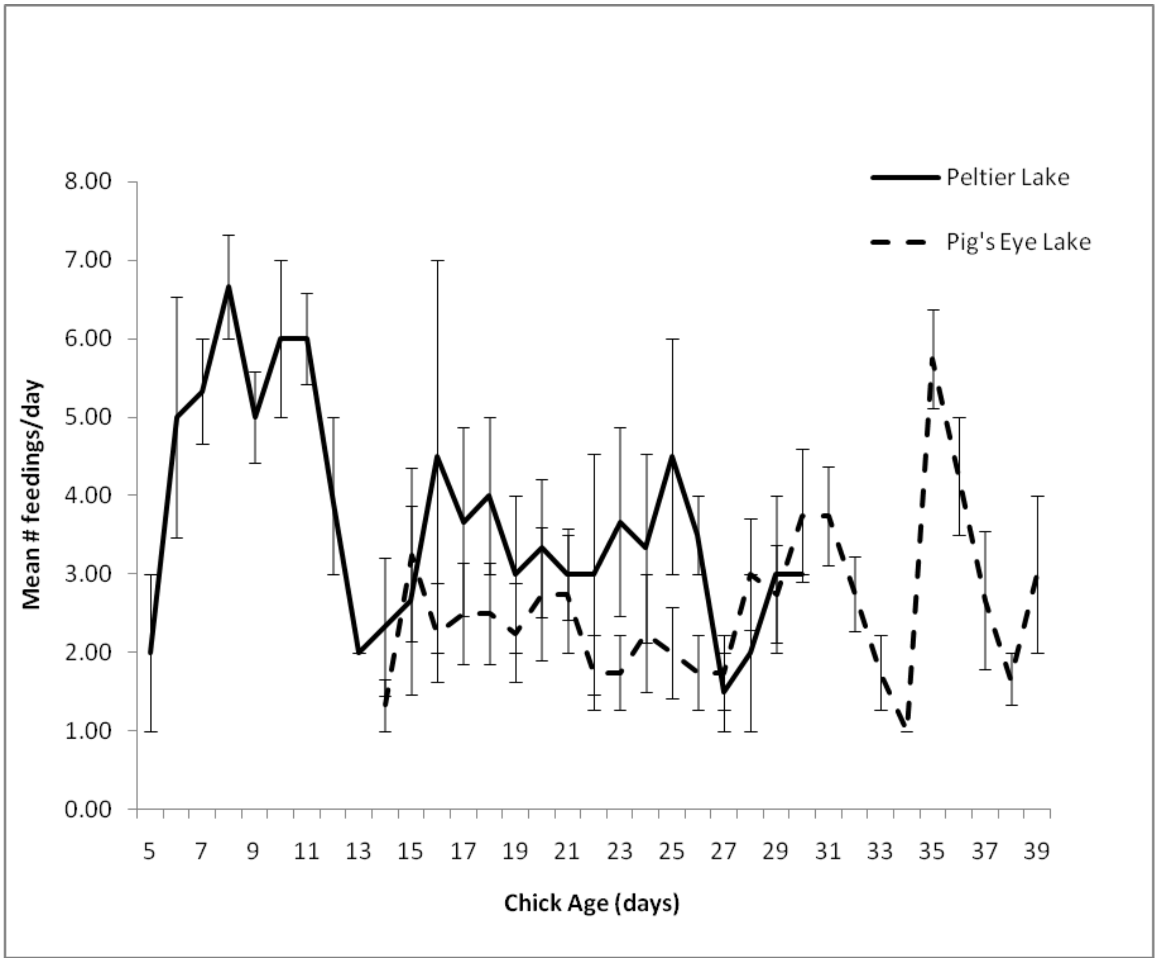
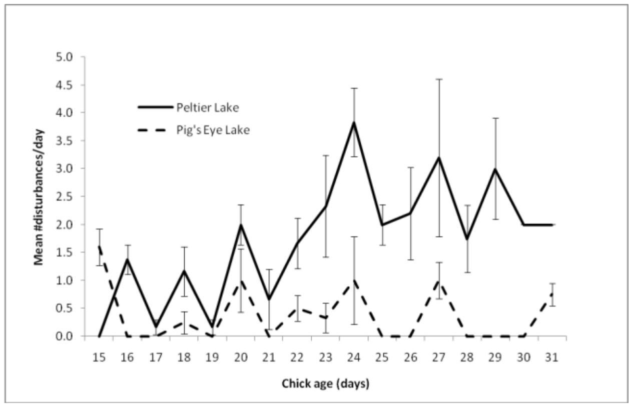
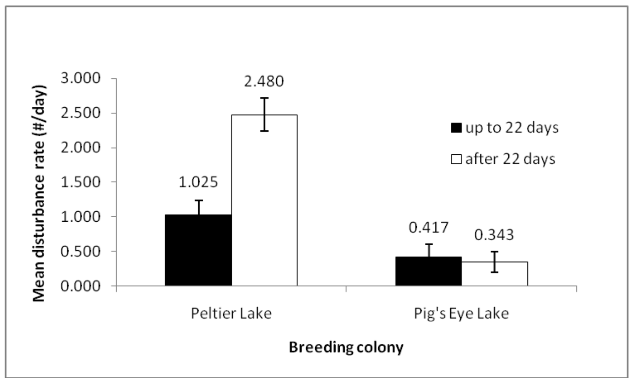


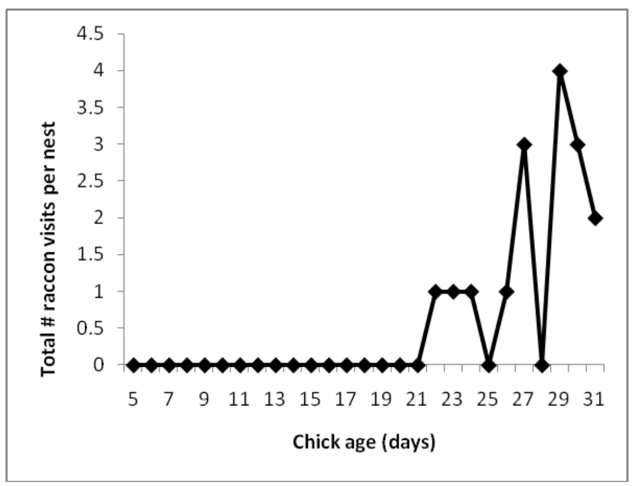

**Figure 12 - Comparison of feeding rates.** The feeding rate at Peltier Lake dropped significantly after chick age 14 days. Because the two study colonies hatched about 10 days apart, chick ages were synchronized and only the overlapping data were compared. Bars show SE. During the period of comparison (chick ages 14 to 30 days), the feeding rate at Peltier Lake was significantly higher (Matched-pairs T-test, $t = 3.178$, df = 16, $p = 0.003$).




**A.**

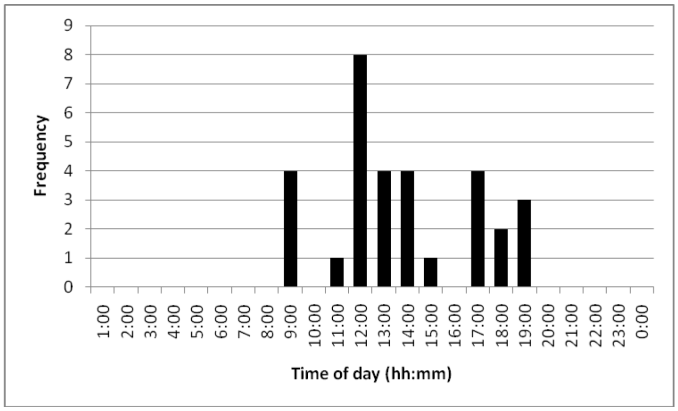



**B.**

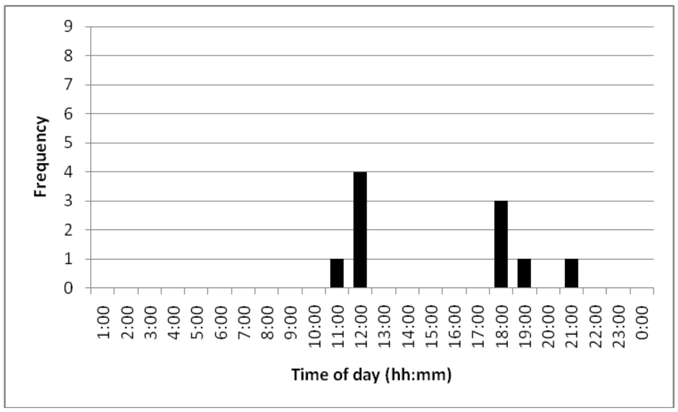



**C.**

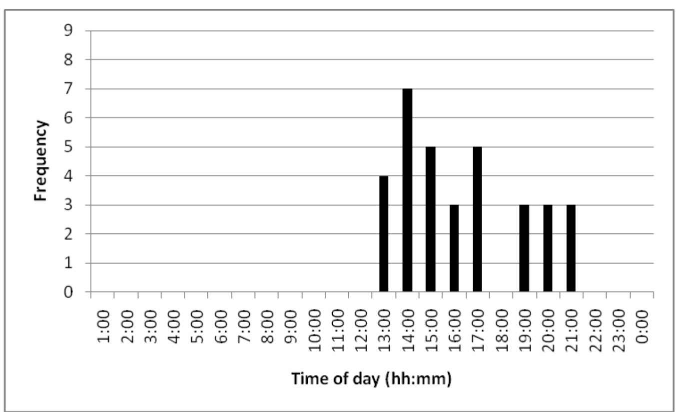
**Figure 13 - Comparison of nest disturbance rates.** (A) 2004 Mean daily disturbance rate - Video data show that spikes in the daily disturbance rate occurred every two days corresponding with the regular equipment maintenance schedule. (B) 2004 Mean daily disturbance rate for nestlings younger and older than 22 days - Mean disturbance rate was significantly higher at Peltier Lake before and after age 22 days (age < 22 days: T-test, $t = 2.16$, df = 24, $p = 0.02$; age > 22 days: Matched-pairs T-test, $t = 12.14$, df = 8, $p <<< 0.05$). After age 22 days, the disturbance rate at Peltier Lake increased significantly (T-test, $t = 4.59$, df = 20, $p <<< 0.05$). It is plausible that heightened raccoon activity within the colony was detected on camera as increasing disturbance rates. (C) 2004 Raccoon presence at Peltier Lake - The first raccoon was detected on video in the nest at chick age 22 days, roughly corresponding to the elevated disturbance rate detected on video beginning at about chick age 22 days. Bars show SE.




**A.**




**B.**




**C.**

**Figure 14 - Equipment related (investigator) disturbances.** In general, equipment maintenance at both colonies from late morning to the late evening. A. Histogram for Pelt-1 Equipment Disturbance shows a peak at 12:00 and range from late morning to early evening (n = 33). B. Histogram for Pelt-2 Equipment shows fewer disturbances due to the shorter time recording (n = 10). C. Histogram for Pig's Eye Equipment Disturbance (n = 33) peaks at 14:00. The two hour lag between peaks in equipment disturbances is indicative of the systematic manner in which colonies were visited on the same day.

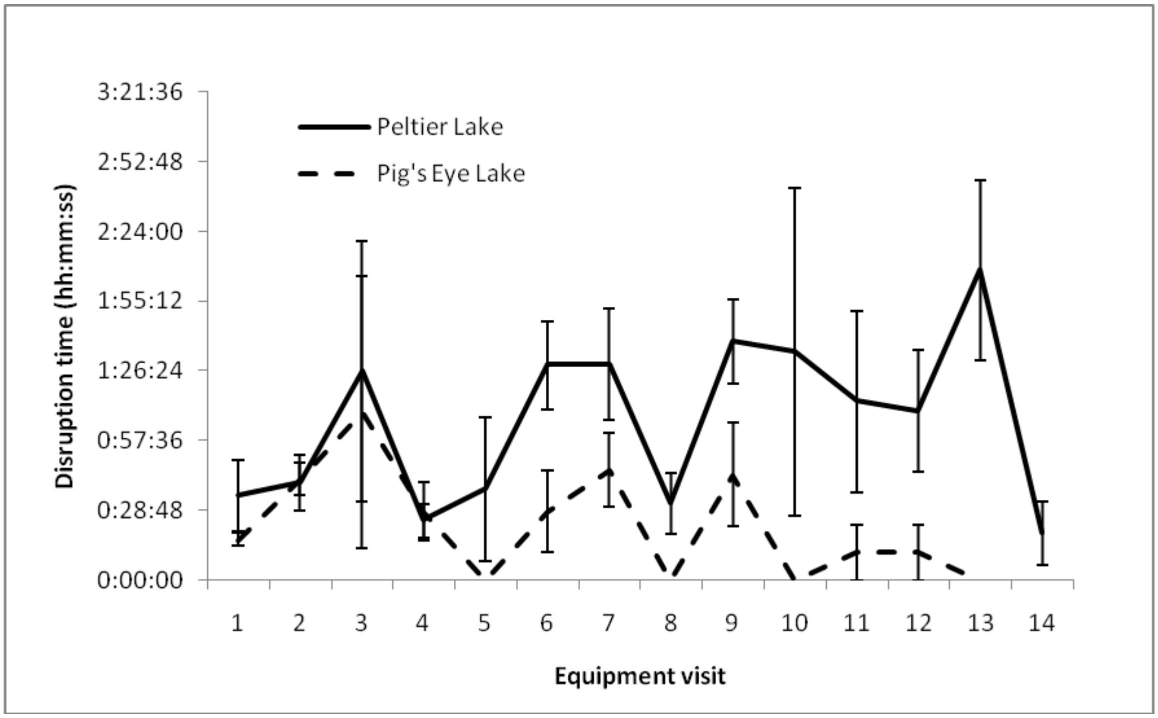
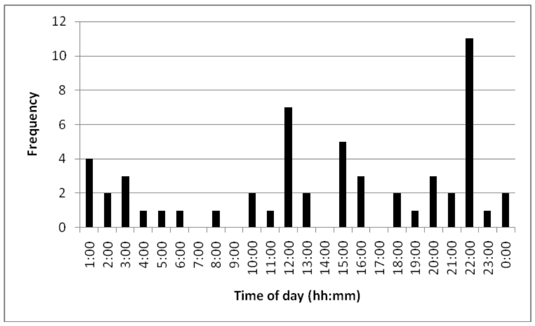
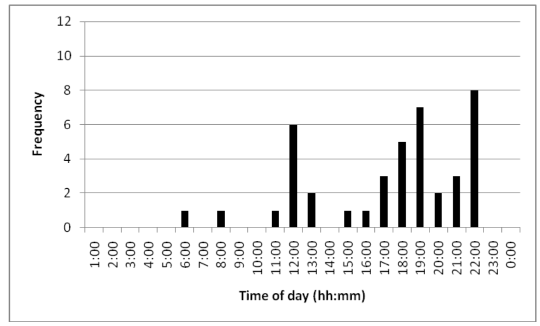


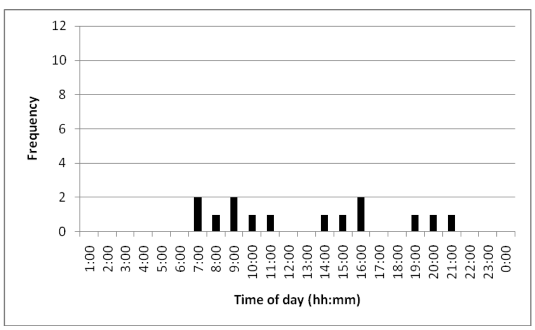

**Figure 15 - Comparison of nest disruption times caused by equipment maintenance.** Early equipment maintenance visits, up to visit #5, appeared to have similar effects upon nesting herons at each study site (Matched-pairs T-test, $t$ = 1.78, df = 4, $p$ = 0.08). After visit #5, differences in disruption times increased significantly (Matched-pairs T-test, $t$ = 6.15, df = 7, $p$ = 0.0002). Seasonally, the Peltier Lake colony showed greater reaction to investigator presence than the Pig's Eye Lake colony (Matched-pairs T-test, $t$ = 4.50, df = 12, $p$ = 0.0004). Bars show SE. At Pig's Eye Lake the slightly decreasing mean disruption time suggests that the herons were becoming habituated. In contrast, the increasing mean disruption time at Peltier Lake suggests that no habituation was occurring; rather these herons became more sensitive to disturbances as the nesting season progressed. Differences in canopy height and/or raccoon activity may account for the differing responses to disturbance at each colony.



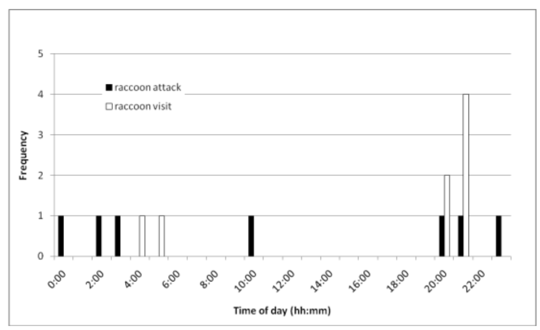

**A.**




**B.**




**C.**




**D.**

**Figure 16 - "Other" disturbances.** Peltier Lake (A and B) experienced more non-equipment related disturbances (n = 68) than did (C) Pig's Eye Lake (n = 14). The times at which these disturbances occurred were also more widely spread at Peltier Lake than at Pig's Eye Lake ($SD_{\text{Peltier Lake}} = 0.123$; $SD_{\text{Pig's Eye}} = 0.110$), though the variance was not significantly different (F-test, $f(13, 67) = 0.512$, $p = 0.09$). (D) Raccoon visits/attacks at the Peltier Lake colony were clustered in the early morning and the late evening hours.

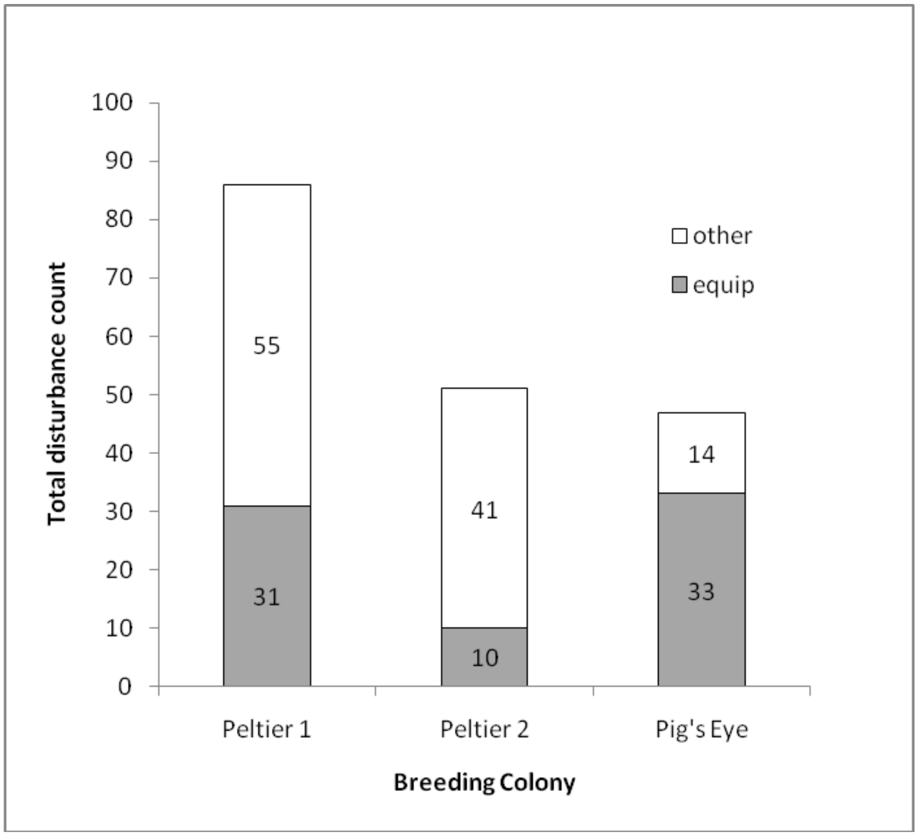
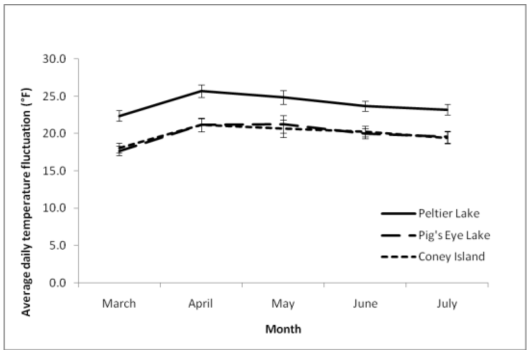
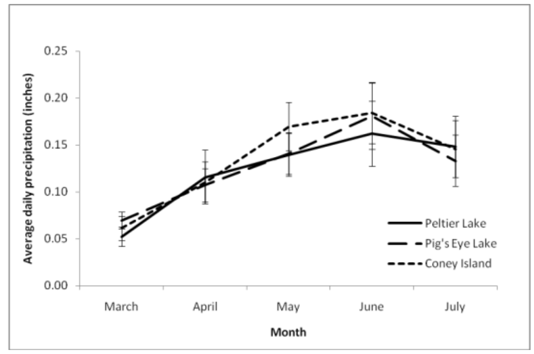


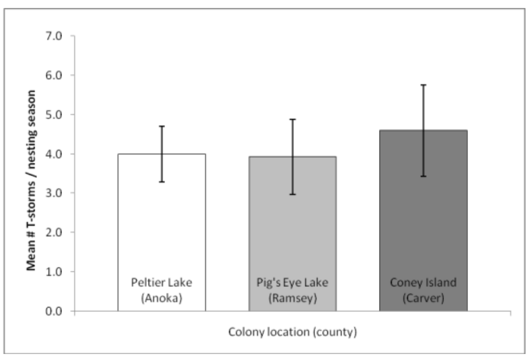

**Figure 17 - Comparison of nest disturbance category and timing.** Disturbance was categorized into two categories: "equipment" and "other". Both colonies experienced similar counts of equipment related disturbance. Note however that Peltier 2 had fewer due to its shorter time under surveillance. However, Peltier 1 and Peltier 2 had similar amounts of "other" disturbance in spite of their unequal lengths of time under surveillance. "Other" disturbances at Peltier 1 occurred disproportionately more than at Pig's Eye (Chi-squared test, $X^2 = 14.2$, df = 2, $p = 0.0002$).



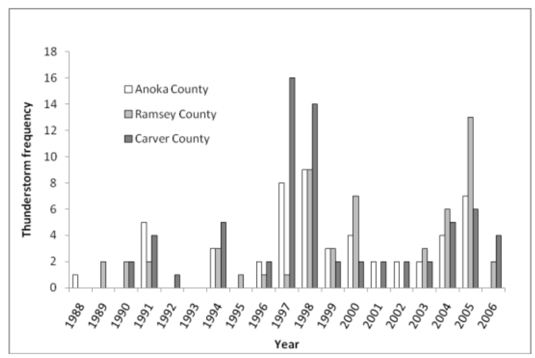

**A.**




**B.**

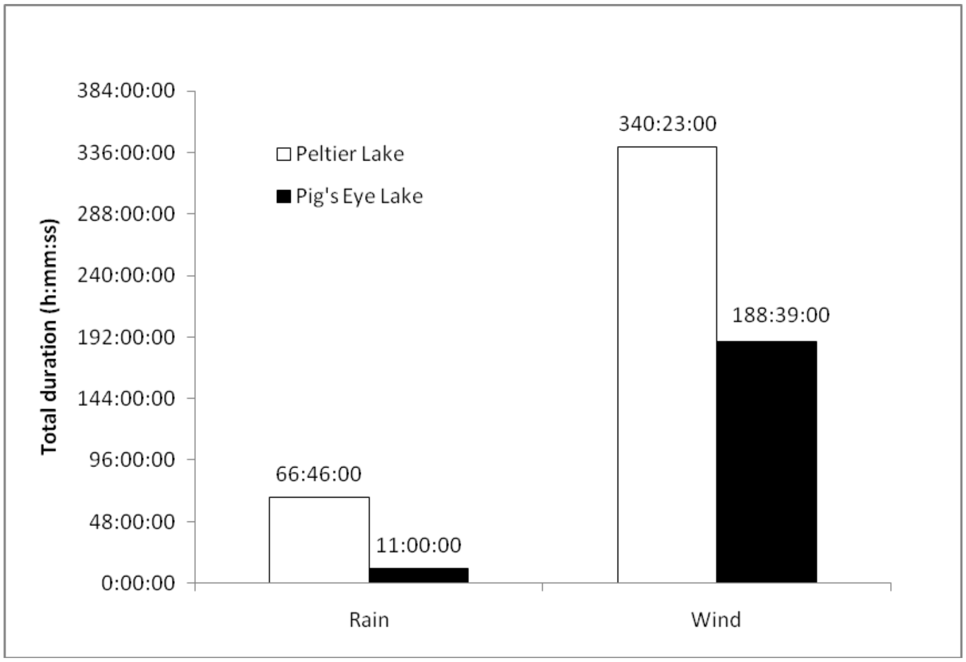



**C.**

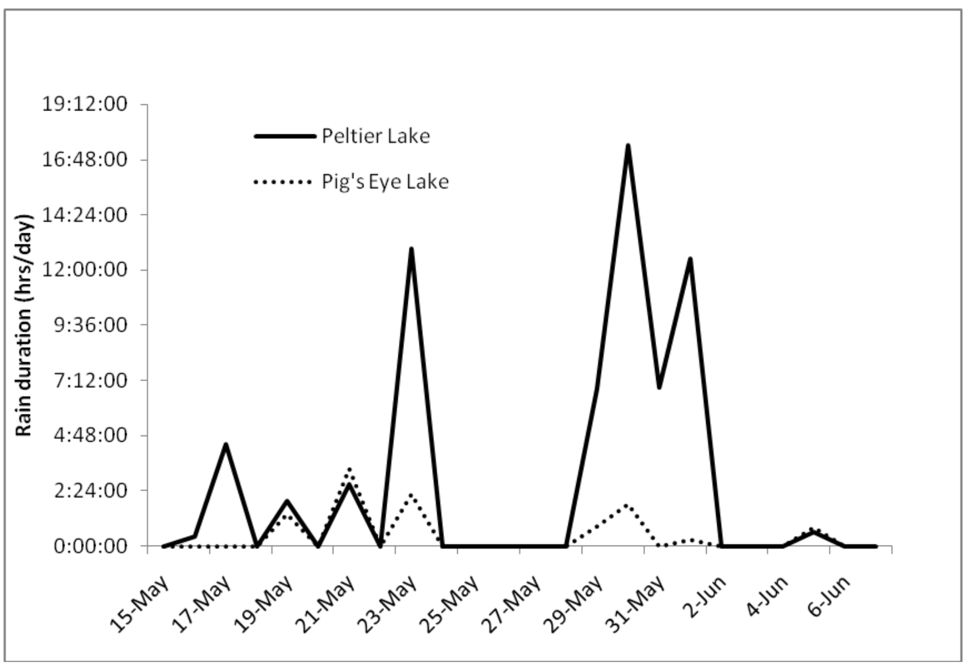



**D.**

**Figure 18 - Comparison of weather station data (1988-2006).** (A) Mean daily temperature fluctuations at Peltier Lake colony were significantly higher than at Pig's Eye Lake or Coney Island (One-way ANOVA F(2,12) = 15.538, p = 0.0005). Bars show 95% CI. (B) Mean daily precipitation did not differ significantly (One-way ANOVA, $F(2,12) = 0.075$, $p = 0.929$). Bars show 95% CI. (Minnesota Climatology Working Group 2007). (C) Thunderstorm frequency during the nesting season did not show significant differences (One-way ANOVA, F(2,39) = 0.147, P = 0.864). (D) Histogram of thunderstorms shows that Anoka county had lower T-storm frequencies in general. Regional peaks occurred 1997-2000 and from 2004-05. (NOAA Satellite and Information Service, National Climactic Data Center 2007).




**A.**




**B.**

**Figure 19 - Comparison of wind and rain event count and duration.** (A) Total duration of rain and wind (15 May to 6 June, 2004): Peltier Lake experienced significantly more rain (Matched-pairs T-test, $t = 2.484$, df = 24, $p = 0.010$) and wind (Matched-pairs T-test, $t = 3.309$, df = 24, $p = 0.001$). (B) Daily rain duration (15 May to 6 June, 2004): Despite the synchrony and similar number of precipitation events, Peltier Lake showed significantly more variance (F-test, $f = 25.965$, df = 6, $p = 0.0005$). Furthermore, two large spikes (5-23 and 5-31 through 6-2) fell within the chicks' vulnerable period during which they are not able to thermo-regulate on their own.


**A.**


**B.**


**C.**

**Figure 20 - Presence of predators in Great Blue Heron nests.** (A) Video evidence suggests that Raccoons (*Procyon lotor*) accounted for up to 86.7% of chick mortality at Peltier Lake. (B) Though Great Horned Owls (*Bubo virginianas*) were not recorded on video in 2004, physical evidence suggested that owls had depredated at least 3 heron chicks. Their overall impact is not known. (C) Turkey Vultures (*Cathartes aura*) were observed scavenging depredated nests in 2004 and 2005. Occasionally, vultures kleptoparasitize heron chicks and, on rare occasions, have preyed upon herons (Mehner 1951).


**A.**


**B.**

**Figure 21 - Evidence of Great Horned Owl predation.** (A) This owl fledgling was observed perched among remnants of and presumably feeding upon a Great Blue Heron chick. (B) During camera installation on 26 May, 2004, the remains of at least two Great Blue Heron chicks were found in an abandoned heron nest that had been used as nest by Great Horned Owls. In this case, a young owl fledgling was flushed off out of its nest.


A.

B.

**Figure 22 - Evidence of avian egg predation.** Holes pecked in Great Blue Heron eggs (A) and (B) are consistent with being pecked open by an avian predator such as an American Crow (*Corvus brachyrhynchos*). It is unknown however whether this was predation of fertile eggs, or scavenging of infertile eggs.


**Figure 23 - Predation or scavenging?** Once a chick has landed upon the ground, very little physical evidence remains that can help to ascertain what happened. In this particular case, the chewed ends of the tibia (visible just above the tape measure at the far left) suggest that a mesopredator consumed this Great Blue Heron nestling. Whether this was predation or scavenging is impossible to tell.

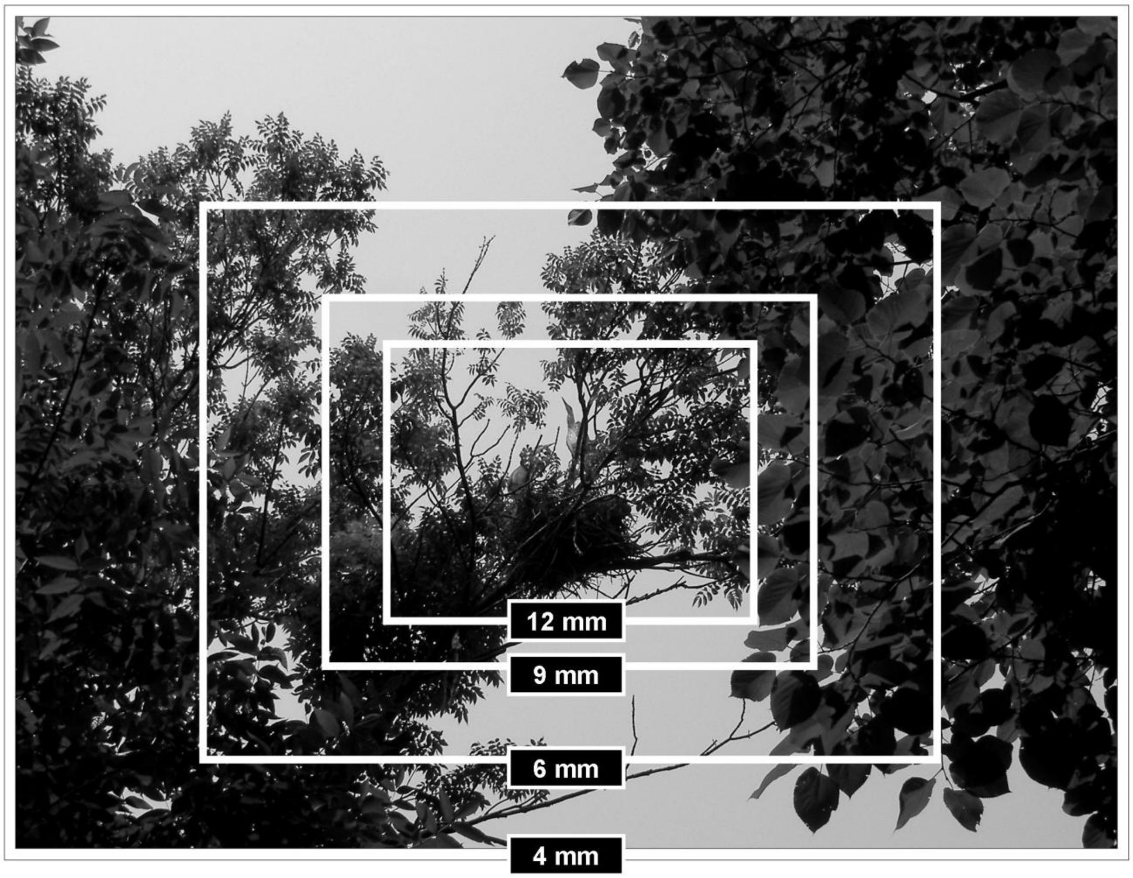



**Figure 24 - The effects of lens focal length upon field of view.** This example illustrates the differences in the field of view depending upon lens focal length. Camera capability and lens quality were factors that had to be reconciled in a manner that best met the study objectives. This image of eight week old Great Blue Heron chicks was taken from a distance of ~ 6.5m. The nest is approximately 1m wide.
(Photo: Andy Von Duyke)

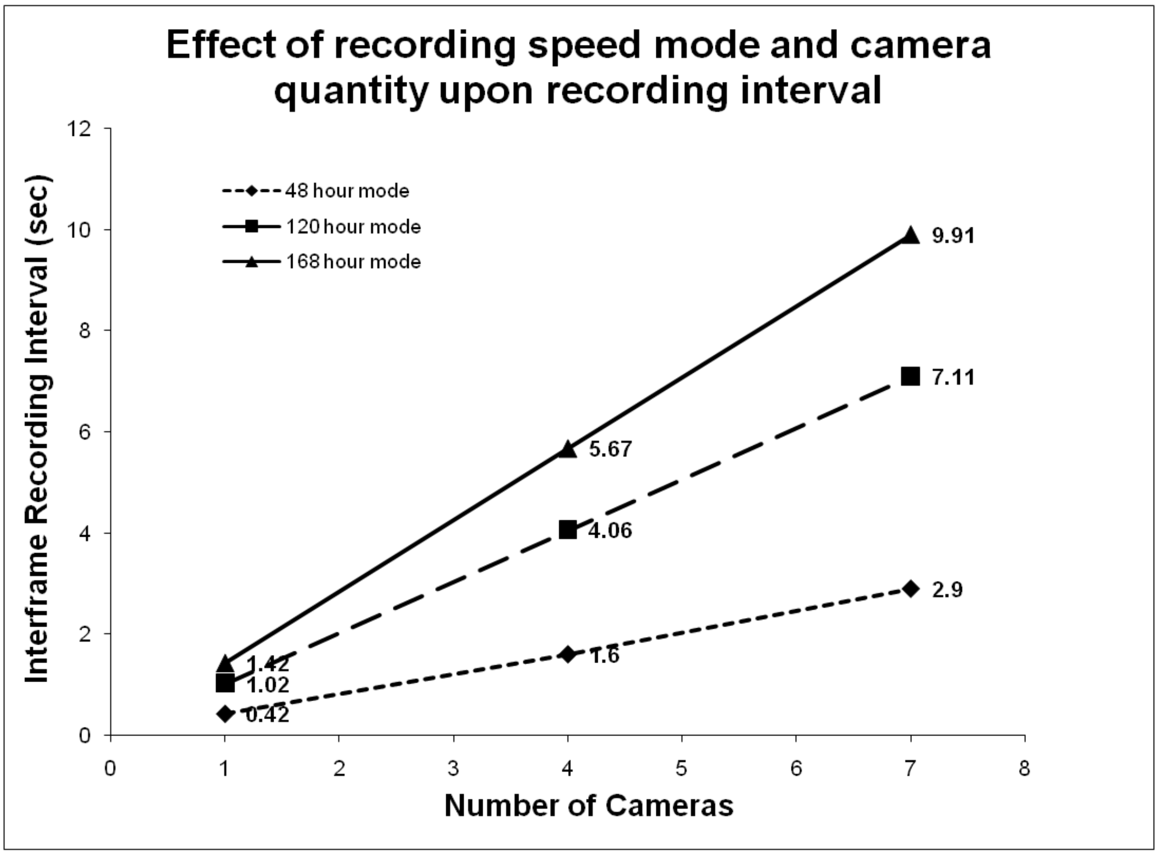



**Figure 25 - Effect of camera quantity upon multiplexed inter-frame intervals.** Recording intervals between frames for the three time-lapse modes used during this study varied depending on the number of cameras being multiplexed. Understanding this principle is important, since the multiplexer cannot record > 1 camera simultaneously. Digital multiplexers work by sequentially recording frames from each camera (i.e., camera #1 → #2 → #3 → #4 → #1 → #2 …). This means that the number of cameras <u>and</u> recording speed work together to determine the inter-frame recording interval. Note that as the number of cameras increase, the recording interval also increases due to the linear manner in which multiple cameras are recorded. Therefore, care should be taken during planning and setup to ensure that the inter-frame recording interval is appropriate for the species being studied and the research questions being investigated. For this study, an inter-frame interval ≤ 5.7 seconds was considered optimal.

A.

B.

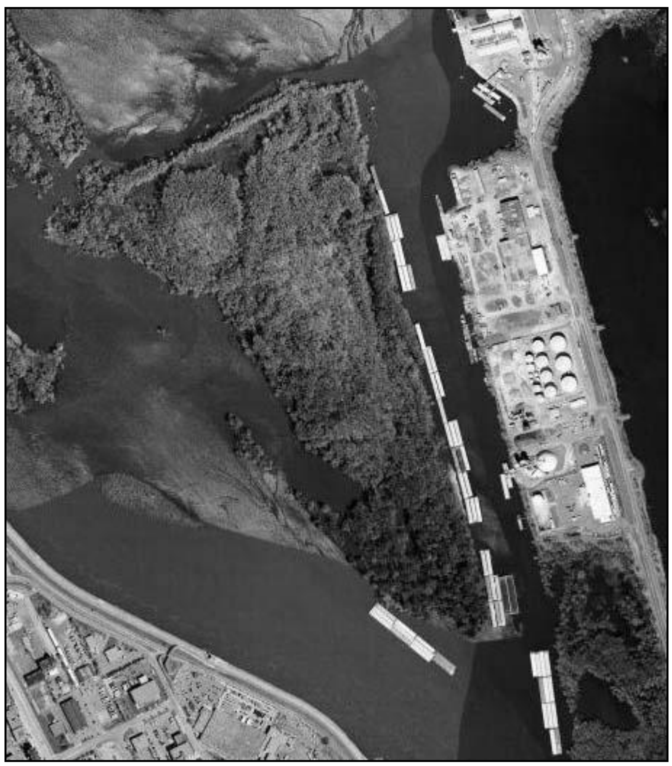


**Figure 26 - Geographic context of the Pig's Eye Lake colony.** A) The dashed circle in this aerial photograph surrounds the Pig's Eye Lake colony. The surrounding landscape is highly urbanized. Note the St. Paul Municipal airport to the northwest (large circle). Though difficult to see at this scale, there are 56 barges tied up to the eastern shore of the island. B) Another photo at higher resolution illustrates the large potential for disturbance experienced at the Pig's Eye Lake colony. In this photo, 48 barges are tied up directly to the shore of the island. (Photos: Google Imagery 2007)


**Figure 27 - Multiple raccoons simultaneously foraging in Great Blue Heron nests.** On three separate occasions, the video record documented two separate raccoons foraging in heron nests simultaneously.

**Figure 28 - Installing a predator guard on a nest tree.** Material is 36” (91.4 cm) wide aluminum sheetmetal roof flashing, painted gray and attached with square drive screws and fender washers. (Photo: Andy Von Duyke)

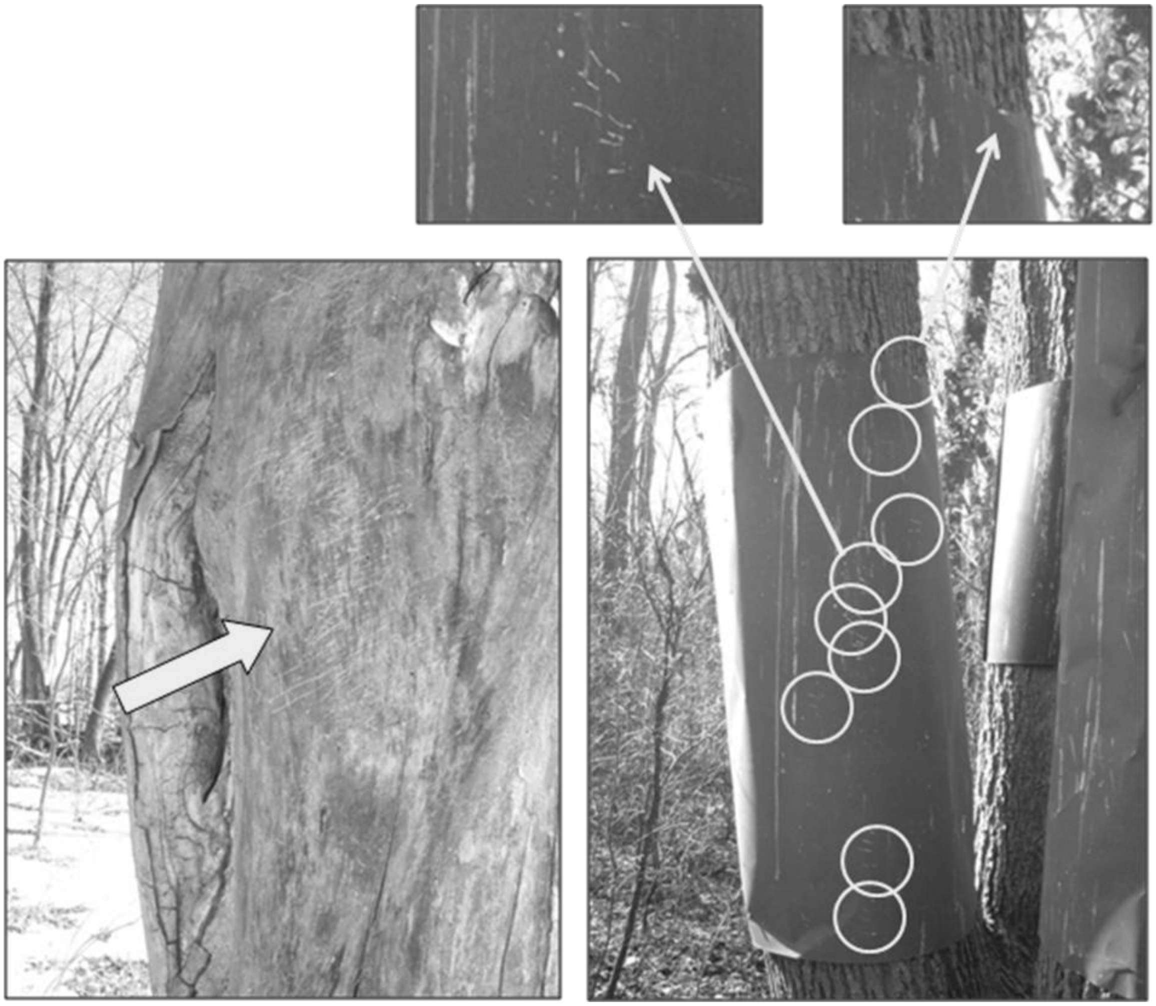


**Figure 29 - Scratches indicative of raccoon climbing activity. (**A) Scratches were easily detected on dead standing trees, and with practice, were detectable on the bark of live trees. It became apparent that most of the trees within the active region of the colony had been climbed multiple times by raccoons. (B) The circles and left inset highlight scratches left in the paint on the flashing and suggest that this multi-stem basswood (*Tilia americana*) was successfully raided by raccoons. Note how the uppermost edge of the flashing is bent over (right inset). Despite the presence of the predator guards, this tree was successfully raided by raccoons during the 2005-06 nesting seasons. Prior to the 2007 nesting season, the predator guards, with the aid of an extension ladder, were raised to a height of 8m. At this height the trunks angled outward enough to open a distance ≥ 60cm between each trunk; enough distance to prevent raccoons from using two trunks to aid in bypassing the predator guards. (Photos: Andy Von Duyke)

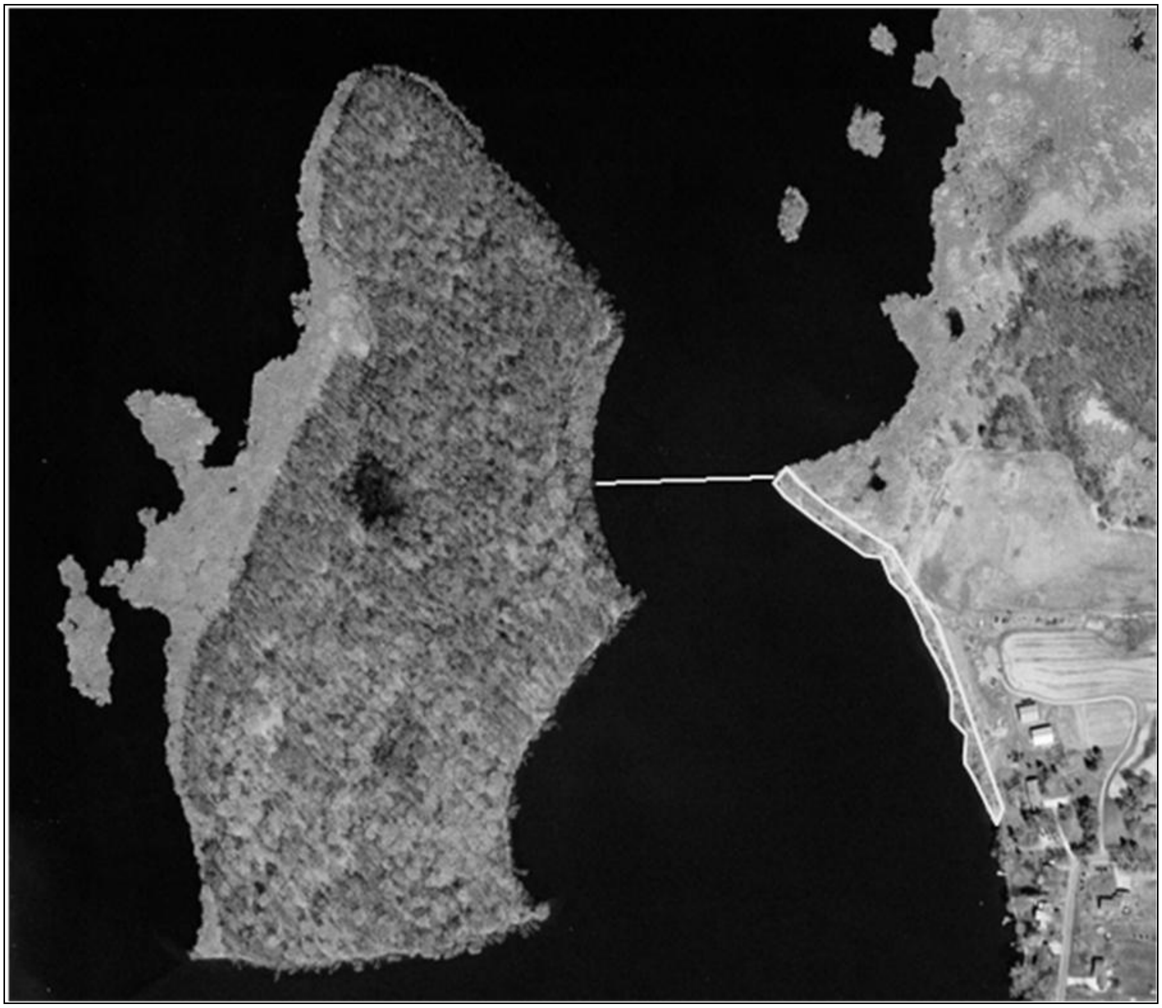
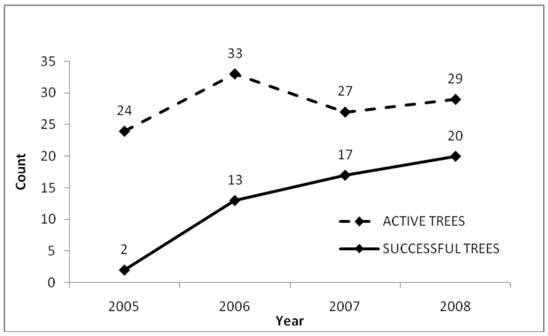
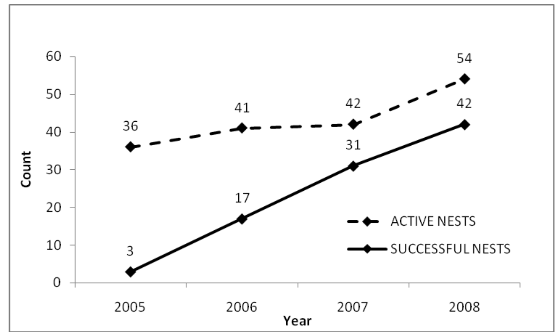


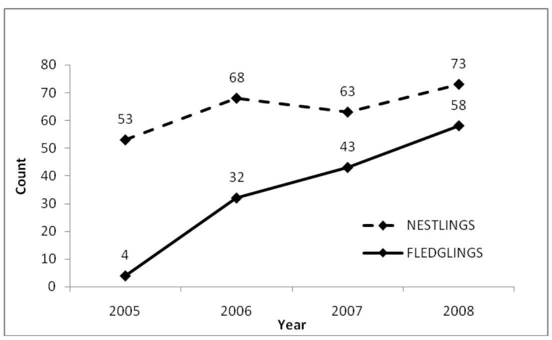
**Figure 30 - Areas of furbearer trap/removal (2005-06).** Trapping and removal of mesopredators (raccoons and opossum) took place on the island and outlined region of shoreline prior to the 2006 nesting season. Prior to the 2007 nesting season, trapping only occurred on the island. Open water proved to be no barrier whatsoever to raccoons, which regularly crossed the 160m span shown by the white line (Photo: Google Imagery 2007).



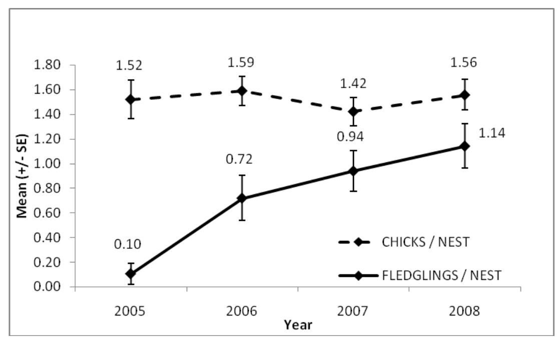

**A.**




**B.**




**C.**




**D.**

**Figure 31 - Peltier Lake nesting data (2005-08).** Steady growth has occurred since 2004, when the Peltier Lake colony declined to its smallest size since 1990. The number of (A) successful trees increased but not significantly (Chi-squared test, $X^2$ = 6.156, df = 3, $p$ = 0.1043). The number of (B) successful nests have increased significantly since 2004 (Chi-squared test, $X^2$ = 6.8207, df = 3, $p$ = 0.002). (C) The number of fledglings has increased significantly (Chi-squared test, $X^2$ = 15.32, df = 3, $p$ = 0.002). (D) The mean #nestlings/active nest has increased steadily since 2004. Bars show SE.

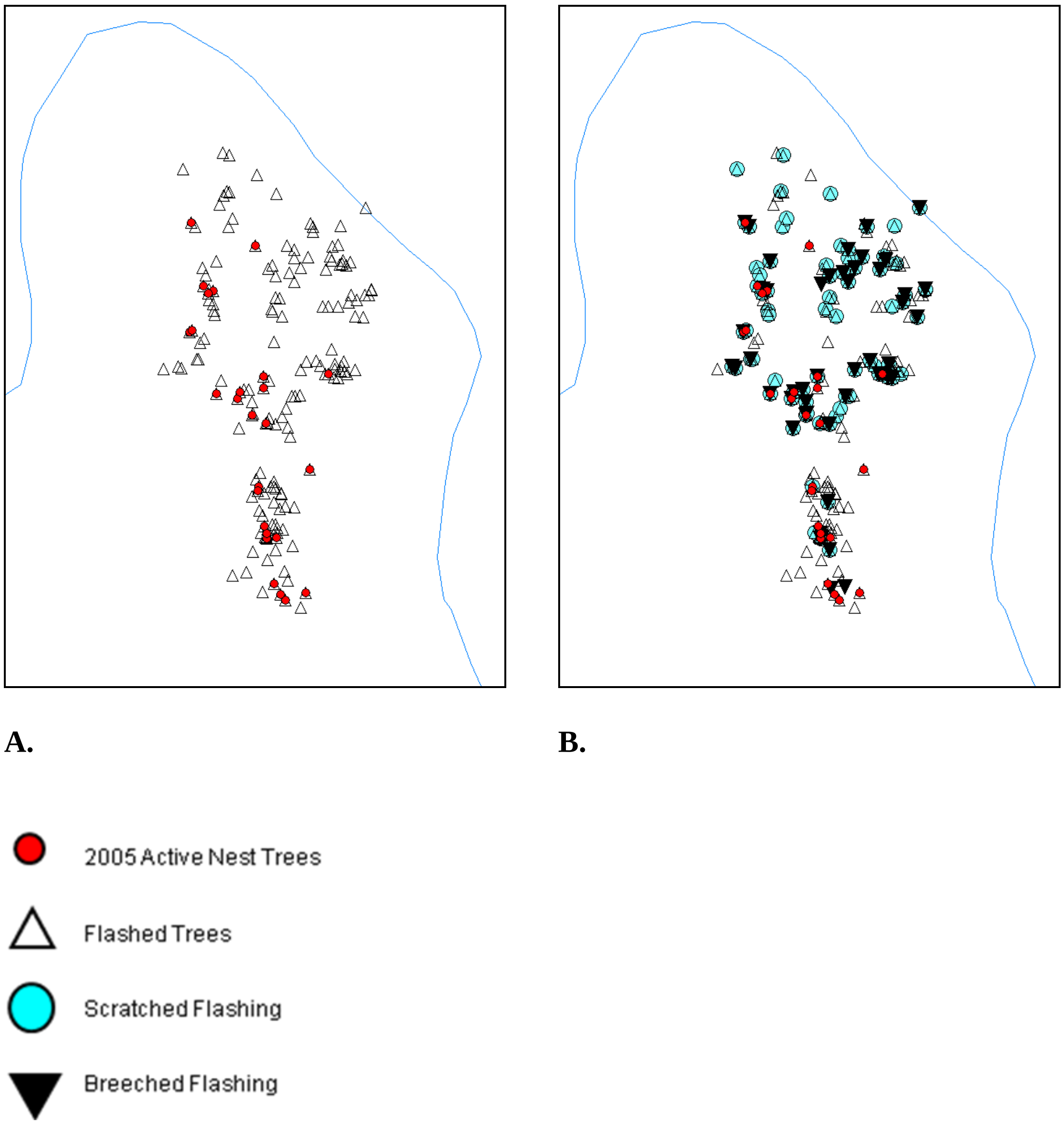



**Figure 32 - Extent of raccoon climbing activity (2005).** (A) The hollow triangles show all trees guarded prior to the 2005 nesting season (n = 173). The red circles indicate active nest trees in 2005 (n = 25). (B) Based upon scratch patterns in the metal flashing, climbing attempts (blue circles) are apparent on most of the guarded trees (n = 81). Over half (n = 49) of these climbing attempts were successful (black triangles).

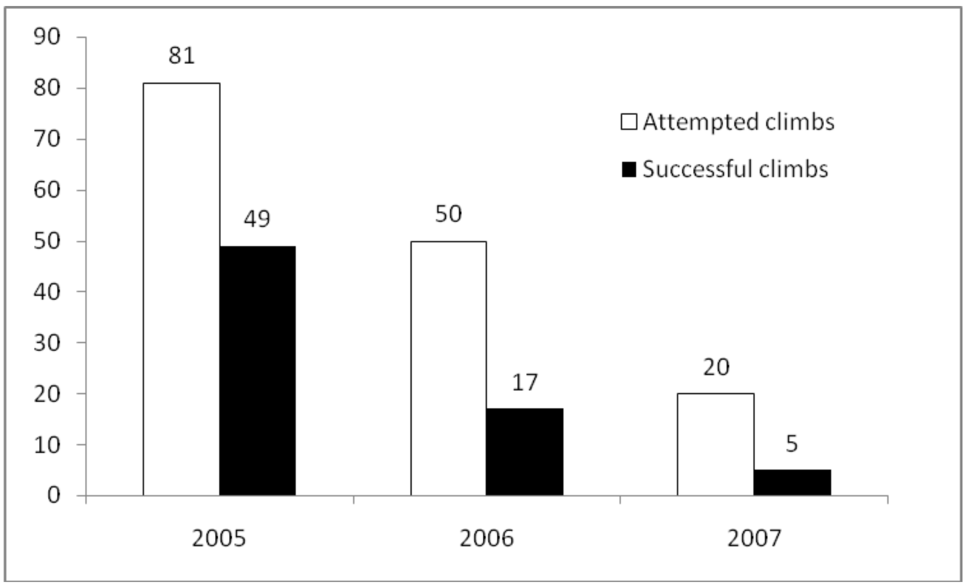
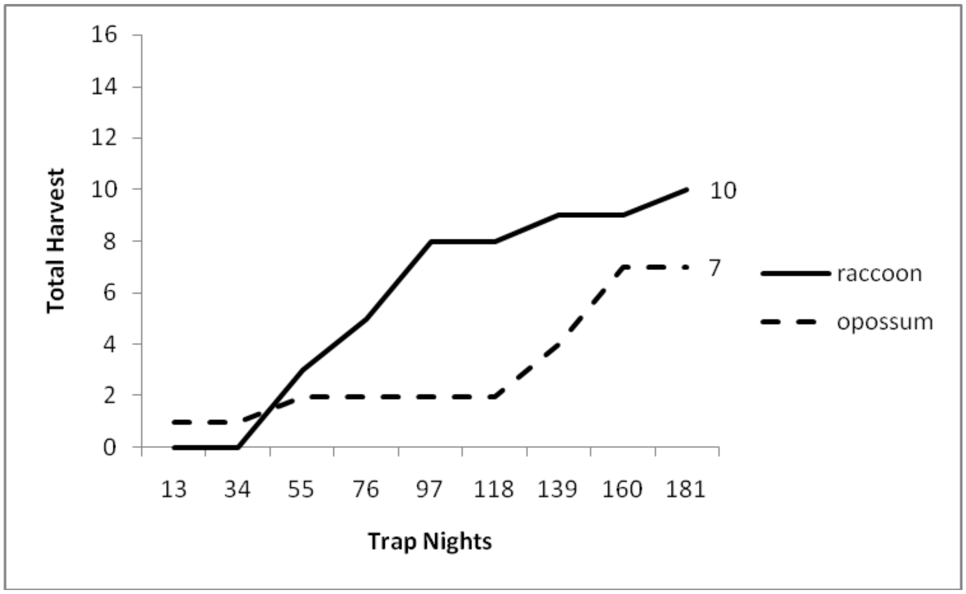
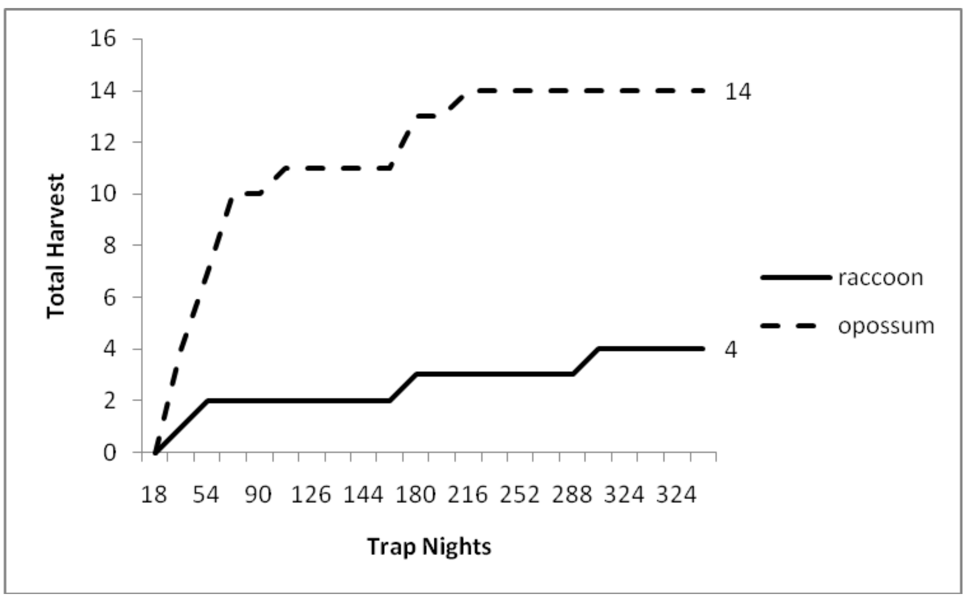



**Figure 33 - Predator guard performance at the Peltier Lake colony.** Efficacy appeared to improve over three seasons' of use, though not significantly (Chi-squared test, $X^2$ = 4.94, df = 2, $p$ = 0.084).




**A.**




**B.**

**Figure 34 - Peltier Lake furbearer harvest data.** (A) 2005: Trapping began on 21 November and ended on 29 November on Peltier Island and on adjacent private property. (B) 2006: Trapping began on 30 October and ended on 20 November. Trapping occurred only on Peltier Island in 2006. Though neither trapping season proved to be very productive, the very low raccoon harvest in 2006 suggested that the 2005 harvest may have reduced the raccoon population on the island. No trapping was done prior to the 2007-08 nesting seasons.

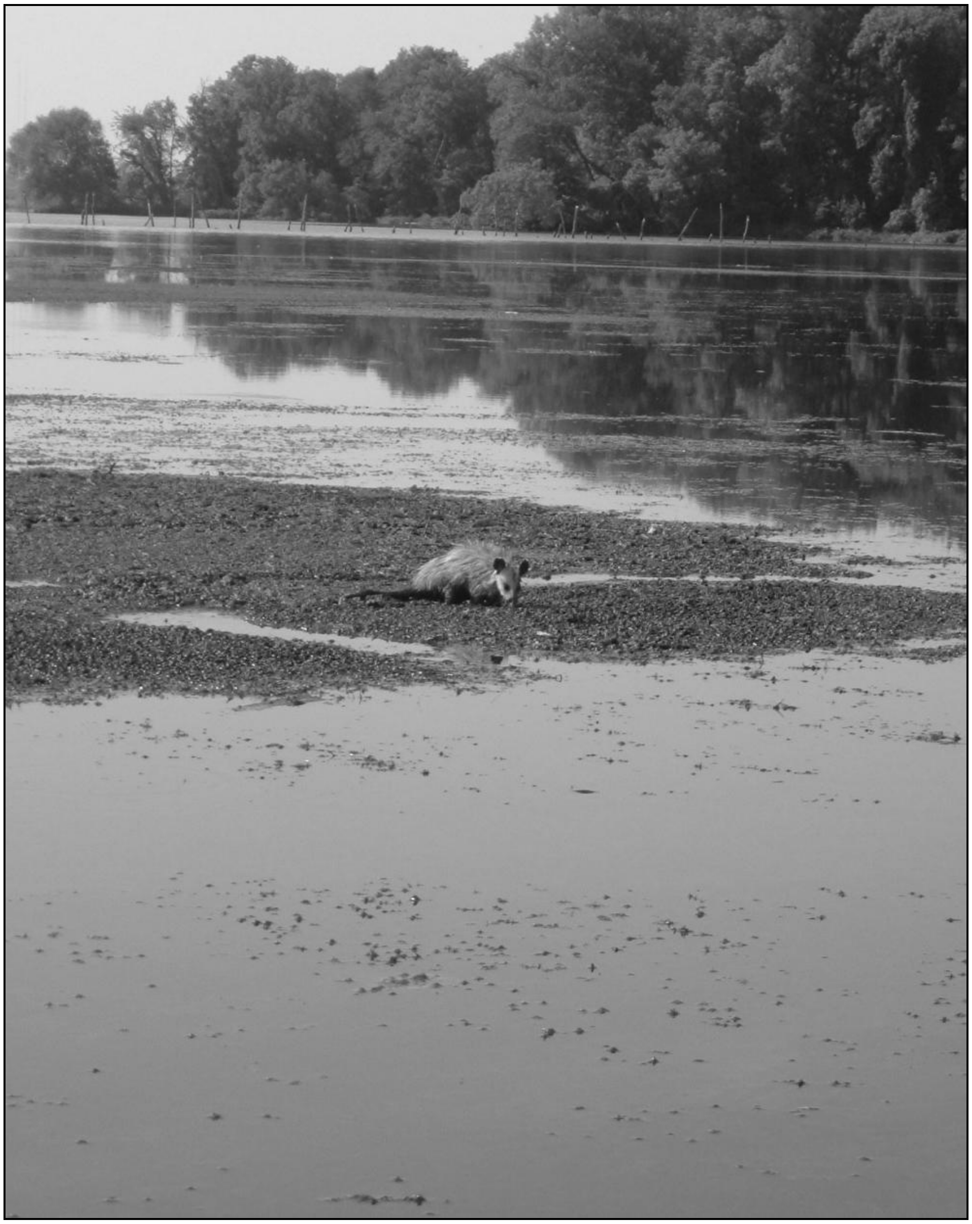


**Figure 35 - Opossum not deterred by water.** This Virginia opossum (*Didelphus virginianus*) was observed foraging on a mud flat island in the middle of the northeast quadrant of Peltier Lake (~ 200m from shore). This behavior suggests that water poses no barrier to these opportunistic mesopredators. (Photo: Andy Von Duyke)

**A.**

**B.**

**Figure 36 - Raccoon den requirements.** (A) An abundance of dead and hollow trees at the Peltier Lake colony provide ample winter den sites for torpid raccoons. (B) In addition to over-wintering, raccoons rely upon secure dens as shelters for protecting young. (Photos: Andy Von Duyke)

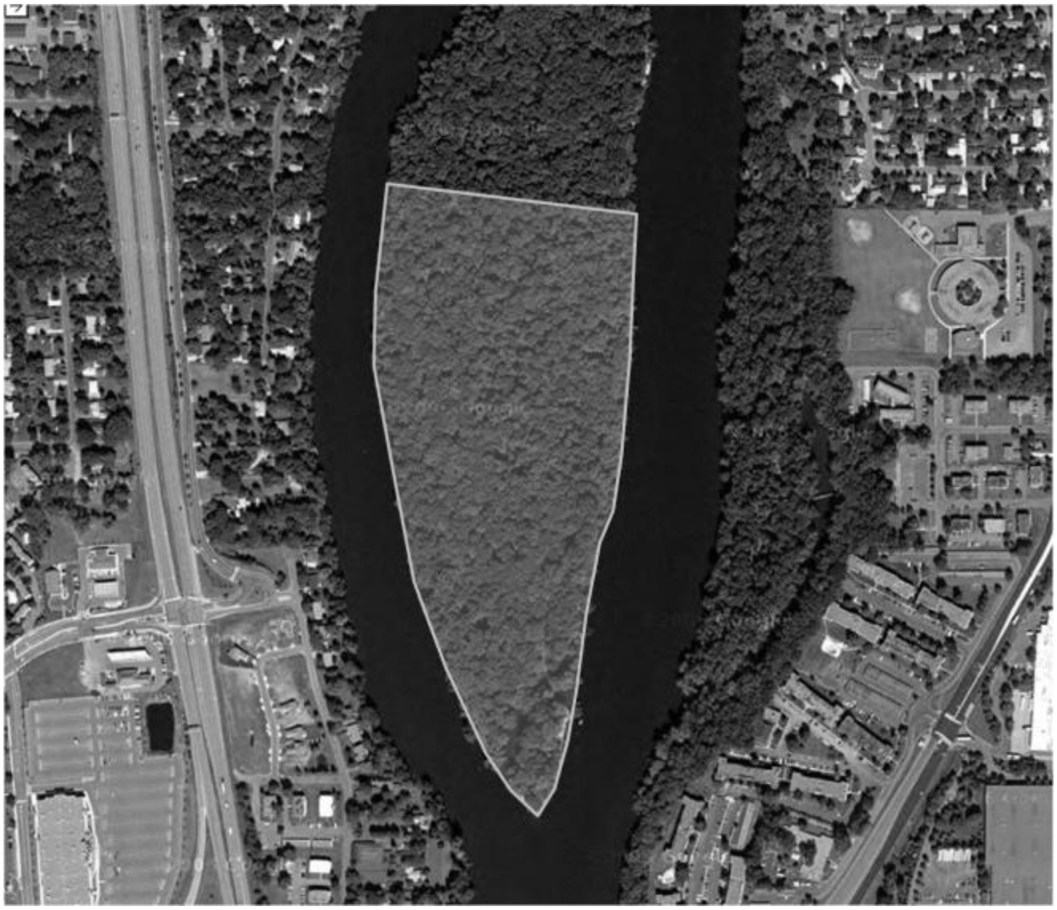


**Figure 37 - Geographic context of the Islands of Peace (Dunham Island) colony.** The extent of the former heronry is shaded. The river channel separating the island from the highly urbanized community is narrow (< 100m) with a slow current. Evidence of human presence including fireworks, illegal fires and parties suggest that this colony may have relocated as a result of human disturbance. However, wooded riparian corridor running through a highly urbanized setting provides ideal habitat for raccoons (*Procyon lotor*); a known predator of herons (Zevelloff 2002).

**Figure 38 - Bald Eagle predation within a Great Blue Heron colony.** Adult Great Blue Herons attempt to drive off a Bald Eagle from within their breeding colony in Breeds Hill Park, Victoria, British Columbia, Canada. It was reported (Heiman 2007) that 71 heron nests in the park were abandoned over the weekend after a persistent female Bald Eagle raided heron nests and ate at least 39 chicks and 187 eggs. (Photo: Rhiannon Hamdi)

| | | Metro | Central | other |
|---|---|---|---|---|
| Total # counties | | 16 | 23 | 71 (64) |
| % MN population | | 63% | 70% | 37% (30%) |
| Average pop growth % | | 12.5% | 9.2% | -0.7% |
| Total # In top 10 | Total population | 8 | 9 | 1 |
| | Net pop. change | 9 | 10 | 0 |
| | Fastest growing | 9 | 9 | 1 |

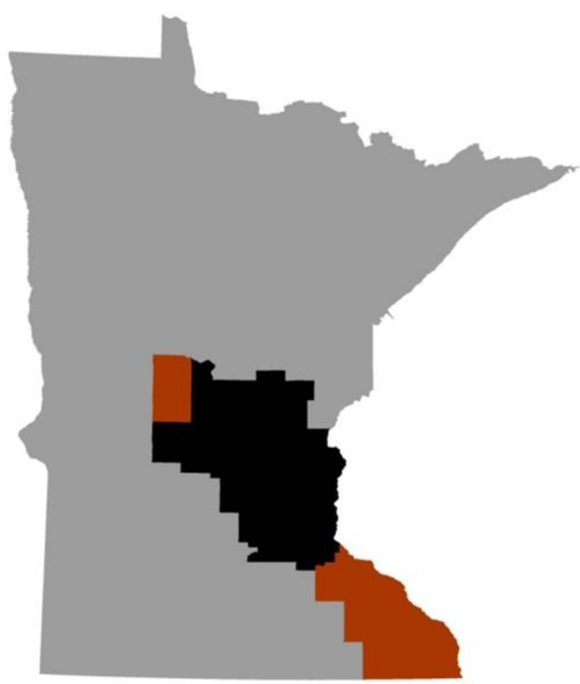


**Figure 39 - Human population trends in Minnesota.** The metro region (black) of Minnesota has 63% of the state's human population, which has grown 12.5% during the period of 2000-2005. The central region (orange + black) has 70% of the state's population and has grown 9.2% during the same time period. This contrasts with the negative population growth outstate (gray). The top 9 out of 10 most populous and fastest growing counties in Minnesota are located in the central region; a trend that underscore the potential impact that urbanization can have on a landscape level.
Source: http://quickfacts.census.gov/qfd/states/27000.html - last accessed 4-3-08

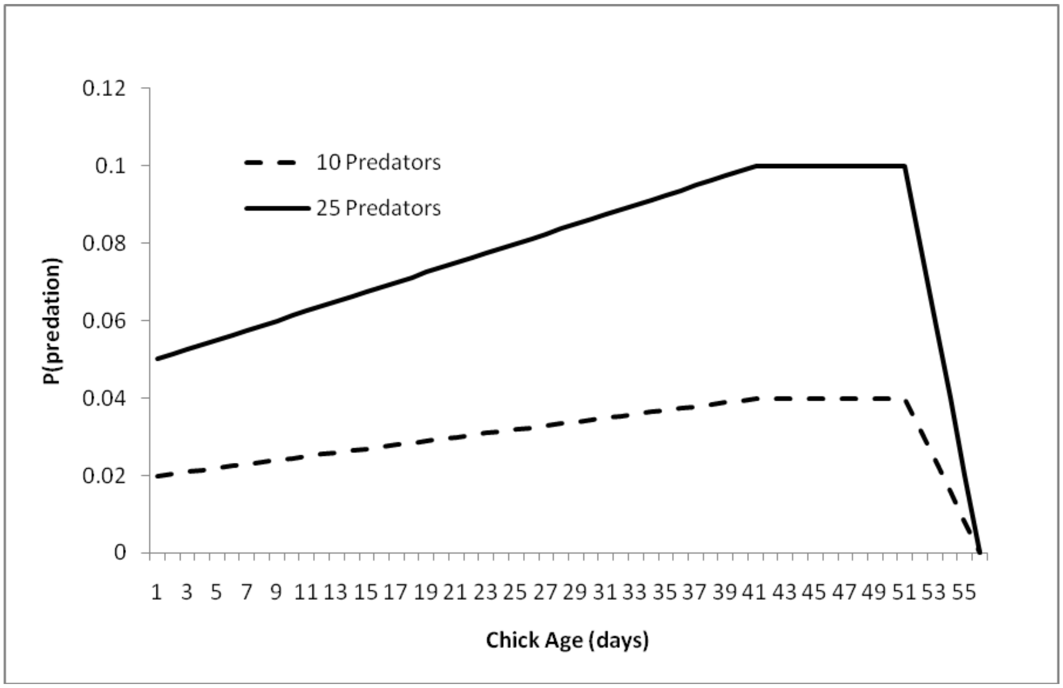



**Figure 40 - Pattern of variable P(predation) for 10 and 25 predators.** Both are related to the number of predators present. The underlying assumption is that actively nesting trees become easier to identify as a nesting season progresses. Additionally, with experience, predators' hunting skills should improve over the course of a season. The rapid decline in P(predation) at the last week is due to the increasing agility of chicks and their higher likelihood of evading predators in the tree canopy.

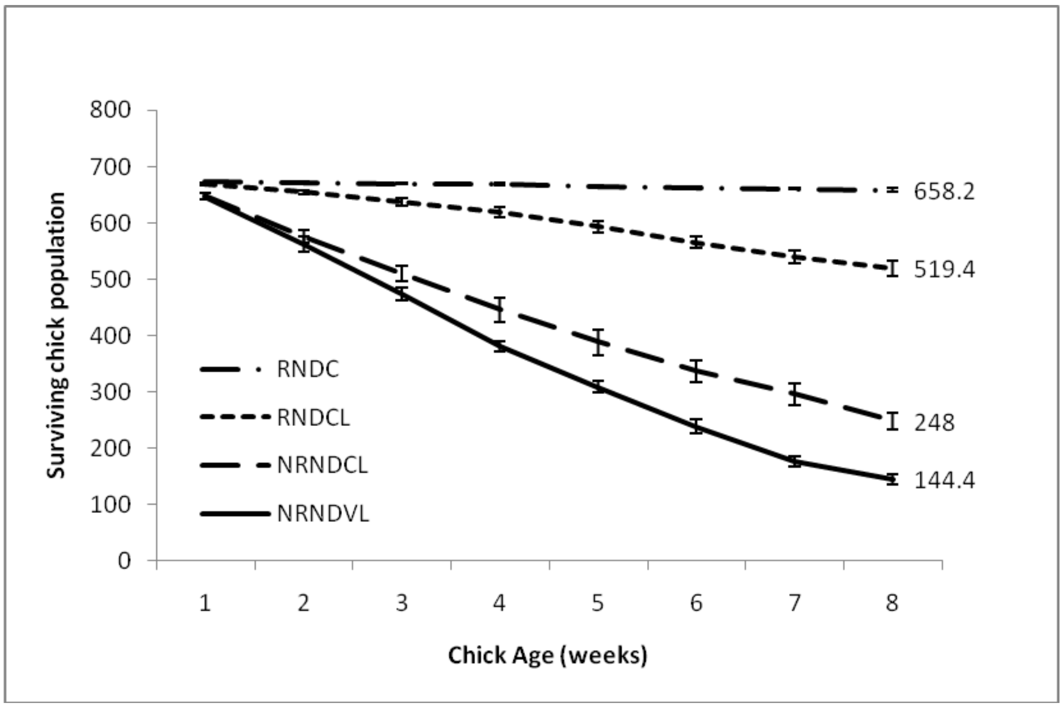



**Figure 41 - Impact of foraging strategies on a colony of intermediate size.** The total number of predators = 10. RNDC = random/constant P(predation); RNDCL= RNDC with the ability to remember and exploit active nest trees; NRNDCL = non-random/constant P(predation)/learning; NRNDVL = same as NRNDCL but with a variable P(predation). Bars show SE.

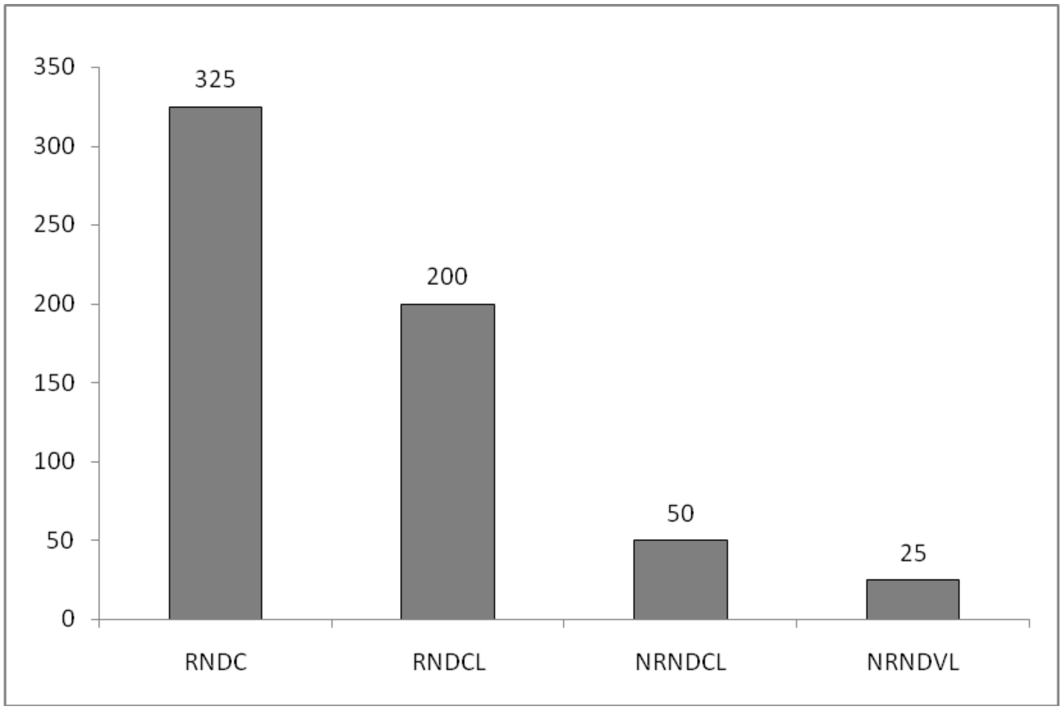



**Figure 42 - Number of predators needed to cause colony failure in 20% of trials.** The bars indicate the number of predators required to cause complete colony failure (100% chick mortality) in 20% of the model replications for a large colony containing 900 nests in 300 trees. Neither "random" technique appears to be capable of causing sufficient mortality to be a primary cause for colony abandonment. Conversely, both "non-random" approaches (i.e., active hunting for heron nests to raid) appear to be capable of being a primary cause of mortality and thus colony abandonment.