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AN IMPROVED MECHANICAL OWL FOR EFFICIENT CAPTURE OF NESTING RAPTORS

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ABSTRACT.—Scientific study of raptors often requires the use of a lure to capture individuals for marking or collecting various data and samples. Live lure owls in the genus *Bubo* are commonly used with mist nets or dho-gazas to trap nesting raptors, but the use of these live lures presents ethical, logistical, and financial challenges. Although owls mounted by taxidermists and mechanical owls have been used in place of a live bird, the success of these types of lures varies widely. We created a more realistic mechanical owl with a greater range of motion than previous models, and then tested the owl on six raptor species in a variety of habitats. For all but one species, capture rates using our mechanical owl were similar to or slightly higher than those reported in studies using live lure owls or previously designed mechanical owls. Time to capture of Northern Goshawks (*Accipiter gentilis*) was, on average, 8 min faster when using our mechanical owl compared to a live owl. Cost analysis revealed that both the initial expense and long-term maintenance of a mechanical owl were less than that of a live lure owl. Mechanical owls can be a useful tool for capturing raptors. Although there are some drawbacks to using a mechanical owl, our results suggest that mechanical birds are comparable to live lure owls and we believe the benefits of using a mechanical owl often outweigh the costs.

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Key Words: *capture technique*; *dho-gaza*; *lure*; *mechanical owl*; *mist net*; *raptor capture.*

UN BÚHO MECÁNICO MEJORADO PARA LA CAPTURA EFICIENTE DE AVES RAPACES NIDIFICANTES

Resumen.—El estudio científico de las aves rapaces frecuentemente requiere del uso de un señuelo que permita capturar individuos para marcarlos como así también recolectar datos y muestras de índole diversa. Para la captura de rapaces que están anidando se utilizan comúnmente búhos del género *Bubo,* como señuelos vivos, asociados a redes de niebla o trampas dho-gaza. Sin embargo, el uso de estos señuelos vivos presenta problemas éticos, logísticos y financieros. Aunque tanto búhos disecados como mecánicos han sido utilizados en lugar de aves vivas, el éxito de estos tipos de señuelos varía enormemente. Creamos un búho mecánico que parece más real y presenta un mayor rango de movimiento que los modelos previos y lo evaluamos capturando seis especies de aves rapaces en una variedad de hábitats. Excepto en una única especie, las tasas de captura usando nuestro búho mecánico fueron similares o levemente mayores que las registradas en estudios que utilizaron búhos vivos o búhos mecánicos previamente diseñados como señuelos. El tiempo de captura de *Accipiter gentilis* fue, en promedio, 8 min más rápido usando nuestro búho mecánico que búhos vivos. El análisis de costes reveló que tanto el gasto inicial como el mantenimiento a largo plazo de un búho mecánico fueron menores que el coste asociado al uso de un búho vivo. Los búhos mecánicos pueden ser una herramienta útil para capturar aves rapaces y, aunque hay algunas desventajas, nuestros resultados sugieren que el uso de aves mecánicas como señuelos es comparable con los búhos vivos. Creemos que los beneficios de usar un búho mecánico a menudo superan los costes de utilizar un búho vivo.

[Traducción del equipo editorial]

Wild animals, including raptors, frequently must be captured and handled for scientific research (Schemnitz et al. 2009). In the case of raptors, direct capture of individuals allows for banding; marking; collection of sex, age, and morphometric data; outfitting with telemetry; and tissue sampling for genetics, toxicology, and disease testing (Bloom et al. 2007). Capturing birds of prey often requires the use of live animal lures (Bloom et al. 2007). However, use of live lures can be challenging because of ethical, financial, and logistical considerations (Bloom et al. 2007, Millsap et al. 2007).

The use of live lure owls in the genus *Bubo,* in conjunction with mist nests or dho-gazas, is one of the most widespread and effective methods for capturing nesting birds of prey (Hamerstrom 1963, Bloom et al. 1992, Steenhof et al. 1994, Jacobs 1996, McCloskey and Dewey 1999, Jacobs and Proudfoot 2002). However, the use of live lure owls is accompanied by a host of challenges including the costs of feeding, veterinary care, equipment, and housing for the owl, difficulty of transport to nest sites, stress on the owl during handling, ethical considerations, the need for additional Institutional Animal Care and Use Committee (IACUC) approvals, and the potential danger during trapping to either the lure owl or wild raptors (Jacobs 1996, McCloskey and Dewey 1999, Bloom et al. 2007). As a result of these challenges, taxidermist-prepared owls have been used for trapping nesting raptors with varying success (Gard et al. 1989, McCloskey and Dewey 1999). The most effective of these have been owls fitted with mechanical components to allow the head to rotate and the body to swivel (Jacobs 1996, Jacobs and Proudfoot 2002).

To our knowledge, there have been no published attempts to improve upon the engineering of the mechanical owl prototypes or to test the effectiveness of mechanical owls more broadly. This is despite the fact that mechanical owls are a relatively inexpensive and easy alternative to the challenges faced when using a live lure owl. Given the benefits of using a mechanical owl, we conducted research to further the development of mechanical owl prototypes. The specific objectives of our research were to (1) construct a more mobile, realistic-appearing, and effective mechanical owl, (2) test the efficacy of the new owl on multiple nesting raptor species in various habitats, (3) compare capture rates to those of studies using live owls and previous mechanical owls, (4) determine if there are differences in the amount of time to capture when using a live owl compared to the mechanical owl, and (5) make our mechanical owl design available to the raptor research community.

METHODS

Owl Construction. We legally obtained Great Horned Owl (*Bubo virginianus*) carcasses from local rehabilitation centers under salvage permits from state agencies and from the US Fish and Wildlife Service (USFWS). We used these carcasses for constructing mechanical lure birds. The starting point for our design was based on the first published plan for a mechanical owl (Jacobs 1996). As in that design, we used a two-channel remote control unit consisting of a transmitter (Futaba®, Mobara, Japan), receiver, battery pack, and two servos.

During construction, the body, head, and wings were separated and prepared following standard taxidermy procedures by licensed taxidermists. The core of the body consisted of a polyurethane foam taxidermy insert specifically designed for Great Horned Owls (Van Dyke's Taxidermy, Granite Quarry, NC, USA) or custom made by the taxidermist preparing the mount. The intact, empty skull was filled manually with either a hard or soft epoxy and we inserted appropriately sized and colored glass eyes into the eye sockets at the same time so that the eyes were held in the skull permanently once the epoxy dried. We removed both wings from the body leaving the top portion of the humerus exposed, and left all other bones intact inside the wings.

We carved out a section from the top of the body insert and used silicon adhesive to mount a servo (Head Actuation Servo shown in Fig. 1) into the top of the body insert. We drilled four holes into the circular plate at the top of the servo and epoxied a small magnet into each of the holes. We created a matching plywood disc, containing four magnets spaced to match those on the body servo, and attached the disk to the bottom of the owl head. This magnetic attachment allows the head to fall off the body if it is struck by an attacking raptor.

We sawed off the end of each humerus in the owl's wing and inserted a 5.1-cm-long threaded rod covered in epoxy into the hollow center. We left the end of the rod exposed and then placed a small washer and a Nyloc nut on the end of the rod. We then inserted a small piece of 1.59 mm (1/16 inch) aluminum into the foam body of the owl. We cut an L-shaped slot in the side of the aluminum and fed the threaded rod through that slot and loosely tightened a Nyloc nut onto the bolt. The nut held the bolt firmly in place in the L-shaped slot but still allowed it to spin freely.

Once the wings were attached, we used three different approaches to attach them to the servo. In one case, we attached a control horn to the wrist of the wing and used a push-rod to connect the horn to a servo between the bird's legs (Wing Actuation Servo in Fig. 1). In another case, we moved the servo to the interior of the foam core and then threaded a push rod through the foam core to connect the servo to the threaded rod in the humerus. In general, we found the push-rod between the legs moved the wings more but was more prone to damage than the push-rod within the foam core. A third option we tried was using a pair of servos mounted in the body and connected to the radio frequency (RF) controller with a reversing Y-cable to operate the wings. The advantage of this method was a reduction of mechanical problems because each wing was driven by its own separate servo.

Finally, we permanently attached the completed owl to either a wooden log or a plastic "rock" perch. We ran the wire from the servos to the receiver and power supply under the owl's feathers or through the core itself. The receiver and power supply were concealed either behind the legs of the owl or under the perch. A basic list of necessary equipment and parts for the construction of a mechanical owl based on this design and some photographic examples of head and wing attachments are available as supplemental materials (online).

Field Testing. During the summers of 2015–2017, we tested the efficacy of our mechanical owl as a lure for trapping six raptor species (Cooper's Hawk [*Accipiter cooperii*], Northern Goshawk [*A. gentilis*], Sharp-shinned Hawk [*A. striatus*], Red-shouldered Hawk [*Buteo lineatus*], Ferruginous Hawk [*Buteo regalis*], and Merlin [*Falco columbarius*] in five states across the United States. In these tests, we used three different mechanical owls that were prepared by two different taxidermists. Each owl was prepared according to the above protocols, although the design of each was slightly different as we identified and implemented improvements.

When trapping, the mechanical owl was set next to a mist net or dho-gaza near occupied raptor nests, following the protocol previously described for using live lure owls (Bloom et al. 2007). We placed the mechanical owl on a slightly elevated perch (approximately 0.5–1 m; hereafter considered a "ground" trap set) when trapping in forest, marsh, and urban habitats, and placed the owl directly on the ground in grassland habitats. We broadcasted conspecific alarm calls and Great Horned Owl

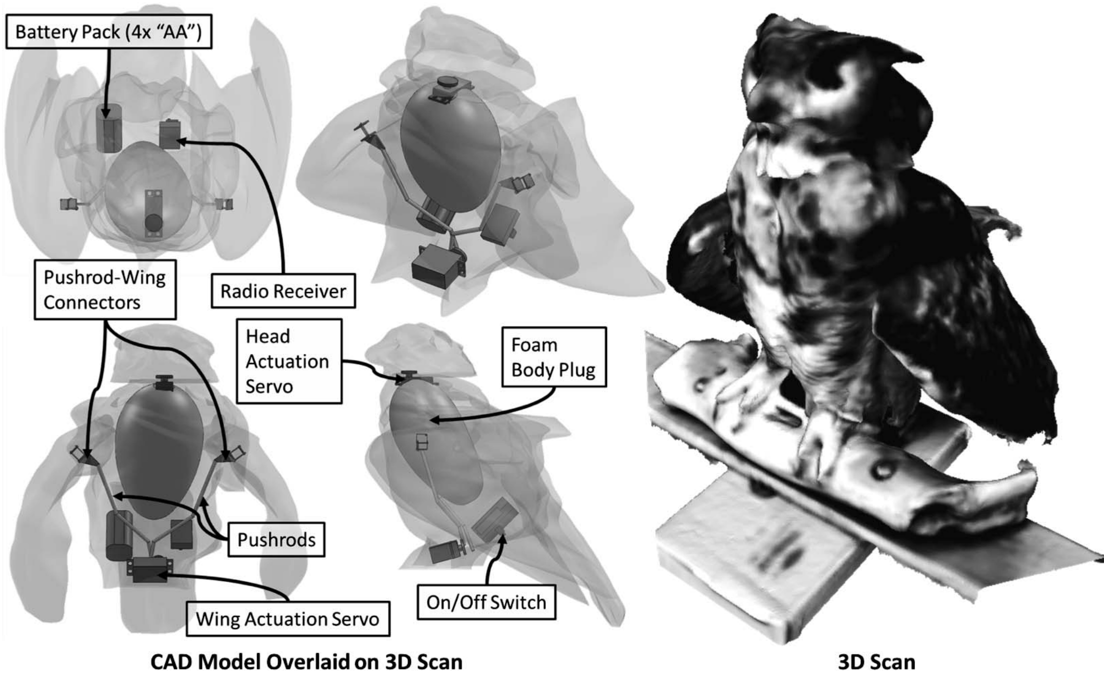

Figure 1. Three-dimensional scan of our first prototype of the new mechanical owl design (right) with CAD model overlay on 3D scan illustrating foam body insert, hardware, and mechanical components and their location (left).

vocalizations using a FoxPro game caller (Lewiston, PA, USA) to attract the attention of target birds. Because different species responded differently to these calls, we played these vocalizations in a context-specific manner. For example, *Accipiter* spp. responded to both owl and conspecific calls and we used both vocalizations when trapping these species. However, Ferruginous Hawks did not seem to respond well to owl calls, so we largely used conspecific calls for this species. While vocalizations were being played, researchers moved the owl using the controls on the transmitter, while remaining hidden from view in a habitat-appropriate blind, until target birds were captured.

Data Organization. We recorded the total number of territories where we attempted to capture raptors using one of the new mechanical owls. If a territory was visited more than once in a given year, it was counted as a single territory. However, if a single territory was visited in subsequent years, it was counted as multiple territories. We recorded the number of individuals that were successfully captured for each species and the order in which the male and female adult birds were caught at each territory (first or second). A few individuals were caught in the net but escaped due to net malfunction or handler error. Although from the perspective of the owl test, this was a success, we did not include these as successful captures so that our data could be directly compared with previously reported capture rates using live lure owls.

When possible, we determined both the "territory capture rate" and the "individual capture rate" for each species trapped. We defined the territory capture rate as the number of individuals caught divided by the total available to be captured, assuming two adults per territory. We defined the individual capture rate as the number caught divided by the number of territorial birds that likely saw the owl. We estimated the number of birds that likely saw the owl from observation in the field. We recorded both types of capture rate because neither of these estimators is a perfect indication of capture success. For example, territory capture rates likely underestimate capture success, since some territorial birds do not see the owl and thus are not available to be caught. In contrast, individual capture rates may overestimate success, since there are likely to be birds that see the owl and are not detected by the researchers. We only report an individual capture rate for Ferruginous Hawks because we only targeted one adult per territory. We stopped all trapping efforts if and when the first adult was captured, to minimize the exposure of nestlings to the sun.

For all Northern Goshawks captured in New York in 2016 and 2017 and in Pennsylvania in 2017, we used the mechanical owl and we recorded time, rounded to the nearest min, of net set and capture. We defined "net set" as the time when researchers were concealed in the blind and additional researchers had vacated the nest area. We defined "capture" as the time the target bird was successfully caught in the net. We used these data to estimate, for each individual caught, a metric that we called "time to capture" that we defined as the difference between the time the bird was captured and the time the net was set. We then compared these data to those from a similar dataset collected by DFB when trapping Northern Goshawks using a live lure owl in Pennsylvania from 2005–2016.

We also determined the capture history for each Northern Goshawk that we successfully trapped. For capture history, individuals were either classified as "first-time" captures or "recaptures." We assumed that all unbanded adults were first-time captures. If a recaptured individual had a USGS leg band, we verified from our records that it was previously captured using the owl and mist net trap set. All previously banded adults had been captured with a live or mechanical owl lure in the same territory during a past trapping season.

Data Analysis. *Capture rates.* We qualitatively compared species-specific capture rates from trapping efforts from this study with published and unpublished data on capture rates using a live lure owl. We also compared the capture rates using our new mechanical owl with those from the first published mechanical owl description (Jacobs 1996). The first published mechanical owl was used in both a ground and a 2.8–8 m elevated trap set (Jacobs 1996, Jacobs and Proudfoot 2002). We compared each of these capture rates to the rates with our new mechanical owl using only a ground trap set because we never used our owl in an elevated set for those species (Cooper's Hawk, Sharp-shinned Hawk, and Red-shouldered Hawk).

Time to capture. We evaluated the difference in mean time to capture of Northern Goshawks when using the mechanical versus a live lure owl (raw data included in Supplementary Table 3). Because we always used the broadcast caller with our mechanical owl, but only approximately 50% of the live owl trapping sessions used such a caller, we used an exponential model to test whether there was a difference in time to capture using the live lure owl with and without accompanying vocalizations. Because we did not detect a difference between the two (slope coefficient = –0.06; Wald test statistic = –0.18, $P = 0.86$; Wald 1945), we combined all live owl data together in subsequent statistical tests.

We modelled time to capture (the response variable) as an exponential random variable within a generalized linear model framework (McCullagh and Nelder 1989). We modelled the expected capture time as a function of owl type (mechanical or live), capture history (first time caught or recapture), and order caught (first or second of the day at a single territory). We included capture history as a covariate because we expected that having been captured in a prior year may have influenced the probability of being captured in the current year. Likewise, we included order caught as a covariate in the model. This covariate was included because the second bird caught in a given day will always take longer than the first bird, as the consequence of the way we calculated time to capture (using net set as the start time). This is because after we caught the first adult, we removed it from the net and secured it before returning to the blind to continue the capture attempt for the remaining adult. In addition, order captured is dependent on which adult(s) is/are present at initial net set. We used the net set time as the start time for both the first and second bird caught so that we could directly compare these data to those using the live lure owl (which were calculated in this manner). We used a Wald test to determine significance ($P < 0.05$) of each covariate in the model (Wald 1945).

We fit a total of eight models, describing all possible combinations of our three covariates and a null model, with custom code in program R version 3.3.1. We compared our models using Akaike Information Criterion (AIC; Akaike 1974) model selection procedures. We ranked the models based on AIC score and models with a ΔAIC of ≤ 2.0 were considered equally well supported by the data (Burnham and Anderson 2002).

Cost Comparison. We estimated the total costs associated with a mechanical owl (based on our design) and with a live lure owl. These estimates included the initial cost of acquiring the lure as well as annual maintenance costs. For the mechanical owl, we included amounts we paid, rounded to the nearest $5 USD, for construction, taxidermy, a

Table 1. Territory and individual capture rates for six species of raptors using mechanical or live owl lures. All mechanical owl capture rates come from our new design with head and wing movement. Location includes states in the USA where trapping attempts occurred with the mechanical lure owl. Live lure owl data are from previous studies with locations of trapping efforts shown in parentheses. Species include Cooper's Hawk (COHA), Ferruginous Hawk (FEHA), Merlin (MERL), Northern Goshawk (NOGO), Red-shouldered Hawk (RSHA), and Sharp-shinned Hawk (SSHA). Individual capture rates were not reported in most published studies.

		Territory Capture Rates		Individual Capture Rates	
Species	Location	Mechanical Owl	Live Owl	Mechanical Owl	Live Owl
COHA	NY, PA	72% (13/18)	52% (32/62) (CA, USA)[a]	76% (13/17)	N/A
FEHA	ID	N/A	19% (66/354) (AB, CA)[a]	55% (6/11)	N/A
MERL	NY	100% (2/2)	90% (77/86) (AK, USA)[a]	100% (2/2)	N/A
NOGO	NY, PA	77% (34/44)	74% (46/62) (PA, USA)[b] 76% (41/54) (CA, USA)[a] 54% (27/50) (CA, USA)[a] 67% (68/102) (CA, USA)[a] 40% (4/10) (Spain)[c]	92% (34/37)	94% (46/62) (PA, USA)[b]
RSHA	NY, WV, VA	42% (21/50)	75% (199/264) (CA, USA)[a]	53% (21/40)	N/A
SSHA	NY, PA	75% (6/8)	53% (18/34) (Spain)[c, d]	86% (6/7)	N/A

[a] Source: Bloom et al. 1992.
[b] Source: D. F. Brinker (unpubl. data).
[c] Source: Zuberogoitia et al. 2008.
[d] No data are available for Sharp-shinned hawk; reported capture rate is for Eurasian Sparrowhawk (*Accipiter nisus*).

transport box, batteries, and annual upkeep (e.g., replacement batteries or parts, super glue and epoxy, etc.). We consulted a local avian rehabilitation center and veterinary hospital to estimate approximate costs, rounded to the nearest $5 USD, for housing, food, falconry equipment (leather jesses, anklets, glove, leash), and veterinary care for a live Great Horned Owl. Estimates for the housing and carriers (mechanical or live) included only the material costs; labor and tool costs were not included. Materials needed for the housing and carrier were estimated based on the minimum federally mandated size requirements for a flighted Great Horned Owl kept in captivity (Arent 2007). We excluded permit costs since these may vary based on the location of trapping efforts. Because our original mechanical owl has been used successfully for three consecutive trapping seasons, we calculated the 3-yr cost for each owl type for comparison of long-term use.

Results

Capture Rates. We used our mechanical lure owl to capture 114 of 144 available adult raptors at 72 occupied territories. As expected, individual capture rates were slightly higher than territory capture rates for five of six species (Table 1). The only exception was Merlins, where individual and territory capture rates were equal (Table 1) but sample size was very low. For five of six species, the territory capture rates were similar or higher when using the mechanical owl compared to a live lure owl (Table 1). The exception was Red-shouldered Hawks; we captured 42% with a mechanical owl, but 75% were captured with the live lure owl. We were only able to compare individual capture rates between the two capture techniques for one species, the Northern Goshawk. Capture rates for this species were nearly identical with the mechanical owl (92%) as compared to the live lure owl (94%, Table 1). We could not locate individual capture rates from published literature for any other species in the study for comparison.

Our mechanical owl performed similarly or better than did the first described mechanical owl in capture of both Cooper's Hawks and Sharp-shinned Hawks (Jacobs 1996; Table 2). This was true regardless of whether we considered their elevated or non-elevated trap set (Table 2). In contrast, the original owl captured more Red-shouldered Hawks (65%) when using the elevated trap set than did our owl (53%) on the ground (Table 2).

Time to Capture. We collected time to capture data on a total of 66 adult Northern Goshawks (live lure owl $n = 34$, mechanical lure owl $n = 32$). The best model to explain the time to capture data included owl type and order caught (Table 3). When

Table 2. Individual capture rates of our mechanical owl compared to those from previous mechanical owl datasets. Species include Red-shouldered Hawk (RSHA), Cooper's Hawk (COHA), and Sharp-shinned Hawk (SSHA). Previous mechanical owl design included head and full body swiveling movement and this design was used both on the ground and in an elevated trap set. Our owl included both head and wing movement and was only used with a trap set on the ground.

SPECIES	ORIGINAL MECHANICAL OWL ON GROUND[a]	ORIGINAL MECHANICAL OWL ELEVATED TRAP SET[b]	OUR OWL ON GROUND
RSHA	54% (15/28)	65% (30/46)	53% (21/40)
COHA	60% (3/5)	67% (2/3)	76% (13/17)
SSHA	77% (48/62)	81% (34/42)	86% (6/7)

[a] Source: Jacobs 1996; Wisconsin, USA.
[b] Source: Jacobs and Proudfoot 2002; Wisconsin, USA.

using the mechanical owl to capture Northern Goshawks, the mean expected capture time was approximately 8 min shorter than when using the live lure owl (slope coefficient = –0.68, Wald test statistic = –2.75, $P = 0.006$, Fig. 2). As expected, the first bird captured on a given day was caught an average of 13 min earlier than the second bird (slope coefficient = –0.93, Wald test statistic = –3.43, $P = 0.0006$, Fig. 2). We had one other competing model with a ΔAIC of 2.0, and this model included all three covariates. However, this model only has one more parameter than the best model. Given that this additional parameter (capture history) was not significant based on the Wald test (slope coefficient = –0.004, Wald test statistic = –0.01, $P = 0.99$), it is likely a "pretending variable" and should not be interpreted as having an effect (Anderson 2008, Arnold 2010). Therefore, we found no evidence to suggest that capture history had a strong effect on time to capture.

Cost Comparison. The initial annual cost of constructing a mechanical owl was approximately $775 USD, including parts, taxidermy, a box for transport, and eight rechargeable batteries with a charger (Table 4). For the first year, housing, a box for transport, food, and proper equipment for handling a live owl costs approximately $2230 USD (Table 4). Subsequent annual maintenance costs are greater for a live owl; approximately $1325 USD compared to only $75 USD for a mechanical owl (Table 4).

DISCUSSION

Mechanical Owls for Raptor Trapping. Our work showed that not only are mechanical owls suitable for capturing wild raptors, but with appropriate design considerations, mechanical owls may, in some of the situations we tested, perform even better than a live owl. The mechanical owls we deployed were effective when trapping six different raptor species in habitat types ranging from forest, to marsh, to grassland. For most target species, capture rates were comparable or better than the published and unpublished results of capture rates with a live lure owl.

This study was the first to directly compare capture times using a mechanical vs. a live lure owl. Although we were only able to make this comparison for Northern Goshawks in the eastern United States, we captured goshawks significantly faster with the

Table 3. Akaike's Information Criterion (AIC), the change in AIC (Δ AIC), and model weight results for time to capture of Northern Goshawks based on owl type (mechanical vs. live), capture history (first capture vs. recapture), and order caught (first of the day vs. second of the day at a single territory).

MODEL PARAMETERS	AIC	Δ AIC	MODEL WEIGHT
Owl type + Order caught	502.9	0.0	0.681
Owl type + Capture history + Order caught	504.9	2.0	0.251
Order caught	508.3	5.4	0.046
Capture history + Order caught	510.2	7.2	0.019
Owl type	513.8	10.9	0.003
Owl type + Capture history	515.6	12.7	0.001
Intercept only	522.2	19.3	0.000
Capture history	524.2	21.2	0.000

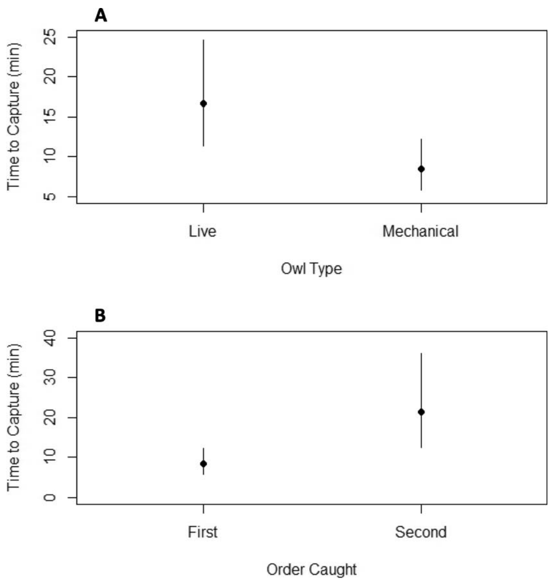

Figure 2. (A) Expected time to capture (min) Northern Goshawks using live and mechanical lure owls. (B) Expected time to capture (min) first and second Northern Goshawk captured at a single nest territory on the same day using either a live or mechanical owl lure. Error bars represent 95% confidence intervals

mechanical owl than with the live owl. This is important from a number of ethical and logistical perspectives. From an animal welfare perspective, quicker capture times presumably reduce the amount of stress on the target bird (this is certainly the case with faster handling times; Romero and Romero 2002, Matson et al. 2006) and reduces the total time the adults are kept away from nestlings. In addition, reduced capture time decreases the probability that potential predators will be attracted to the nest by trapping activity. Likewise, from a logistical perspective, the faster we capture birds in the field, the more opportunity we have to capture other birds during the short nesting season. As researchers, our ultimate goal is to collect sound data as efficiently as possible with minimal impact on wildlife. The use of a mechanical lure owl may be an important step to get us closer to this goal.

One potential reason for the high success of the mechanical owl is that trappers have complete control over the timing, type, and amount of movement exhibited by the mechanical owl. A live owl, especially one that has previously been used for raptor trapping, is aware of the threat from territorial raptors and sometimes remains relatively still or attempts to hide. As a result, it may take longer for the target birds to notice the live owl and the response an intimidated live owl elicits may be weaker than that of a mechanical owl that appears unperturbed by attacking territorial birds. Also, the ability to move the mechanical lure owl immediately when an adult raptor is near the lure may make it more visible and result in a faster attack by the target bird. Finally, if a live owl is placed too close to the net there is a high risk of the owl getting tangled in the net. This is less of a concern when using a mechanical owl. As a consequence, the mechanical owl can be placed very close to the net, helping to increase the likelihood that the target birds hit the

Table 4. Initial and subsequent annual cost estimates in USD for a mechanical vs. a live lure owl.

TIME	ITEM	MECHANICAL OWL	LIVE OWL
First year	Parts	$150	–
	Taxidermy	$500	–
	Batteries/Charger	$25	–
	Transport Box	$100	$150
	Housing	–	$700
	Falconry equipment	–	$80
	Veterinary fees	–	$100
	Food	–	$1200
	Total	**$775**	**$2230**
Subsequent years	Misc. supplies for upkeep	$75	–
	Replacement falconry equipment	–	$25
	Veterinary fees	–	$100
	Food	–	$1200
	Total	**$75**	**$1325**

net when attacking the owl. Finally, the routine use of audio playback in combination with the mechanical owl adds to the stimuli that can be presented to the target raptor to increase the successful use of a mechanical owl beyond that of a live owl used without an audio playback stimulus.

As expected, the first adult bird captured at each nest was captured more quickly than the second. However, this was mainly due to the manner in which the time to capture variable was defined. It may be beneficial in future studies to have a second "start time" for when the second bird arrives near the trap set, rather than using the net set time for both individuals. We were unable to use this approach in our study because the dataset using a live lure owl was collected prior to our study and did not include a second start time, and we designed our data collection and analysis based on the constraints of the live-lure-owl dataset. Also, we expected that capture history would influence time to capture, since previously captured birds may be more hesitant to attack the owl. However, at least in the case of Northern Goshawks, we found that there was no evidence to support this hypothesis. It may be that the strong stimulus of a significant predator near an occupied nest overwhelms any apprehension that developed as a result of trapping history.

Obtaining any owl, live or mechanical, requires some level of investment. A live owl requires permits, housing, food, and veterinary care. A mechanical owl requires permits, mechanical parts, taxidermy, replacement batteries, occasional repairs, and a dry box for storage and protection. These requirements incur costs of time and money, but the cost of a mechanical owl is far cheaper than maintaining a live owl, especially for multiple trapping seasons.

There are also substantial ethical benefits to using a mechanical owl over a live owl. Although IACUC regulations generally allow use of a live owl, live lure owls sometimes exhibit signs of stress when used at a trap site. Likewise, live owls can be injured when trapping and use of a live bird may be unacceptable to some ethics committees and members of the general public. Therefore, the benefits of using a mechanical owl—higher capture rates, lower costs, fewer ethical concerns—likely outweigh their costs. We expect that future design improvements to the mechanical owl and to its application may result in even higher success rates and a greater value to their use as compared to the use of a live lure bird.

Design Considerations. We made several design improvements over previously described versions of the mechanical owl (Jacobs 1996). The most notable of these was the addition of a wing flapping movement. Previously designed mechanical owls included two servos to allow the head and entire body of the owl to spin independently (Jacobs 1996). While the head movement may have mimicked a live owl, the entire body turning on a swivel is not particularly natural-looking.

We believe (but did not test empirically) that the addition of the realistic wing movements improved the chances of target birds seeing the mechanical lure. We designed these movements specifically to mimic those of a young Great Horned Owl flapping its wings in quick short bursts. This may have contributed to our success rates by making the owl look less intimidating than would an adult owl.

Another design improvement was the magnetic attachment for the head. This allowed the head to come off easily, thus reducing the possibility of permanent damage to the mount from impact by especially aggressive raptors. On numerous occasions, raptors of all species knocked the head off the mechanical owl, but the owl remained otherwise intact. We were even able to capture some target birds (especially Northern Goshawks) with the headless owl. We do, however, recommend that when using this method, a lightweight filler is used in the skull of the owl to reduce the chance of damage from impact with the ground.

Finally, our owl design allows the body, head, and wings to be separated for ease of transport and storage. Because of the time required for setup, we rarely used this feature, although it was useful in several space-limited situations. Future designs could improve upon this concept and include parts that allow quick break-down and reconstruction of the owl. This way the owl could be placed in a backpack or other compact unit for easy and safe transport to nest sites. Another useful addition would be waterproofing of all mechanical parts.

Approaches to Comparing Capture Rates. It was not trivial to compare capture rates among different published studies and among different species. We made most comparisons only on territory capture rates because those were the only capture data previous researchers reported. However, because some territorial individuals may not be present at the nest area during capture attempts, territory capture rates do not always accurately reflect success of trapping. Therefore, individual capture rates may be more informative. For example, home ranges of Northern Goshawks during the breeding season can be as large as 25 km^2 and males may range far from the nest area to find food (Reynolds et al. 1992). In our study, it was not uncommon for us to only see one territorial individual during a trapping effort. Thus, reporting a territory capture rate would indicate that the trap set using the lure owl failed to catch a second individual that never saw our trap. In contrast, an individual capture rate would accurately reflect that we never had the opportunity to capture that individual.

Another complication with territory capture rates is that they assume that there are only two territorial adults in a territory. However, it is not unusual for some raptors to form nesting trios (Santana et al. 1986, Kimball et al. 2003). When trapping Red-shouldered Hawks during our study, we often observed two adults and one second-year bird, all of which showed aggression and defensive behavior towards the owl. Therefore, a territory capture rate does not accurately reflect the trapping success in these scenarios because there were actually three individuals that could be captured at some territories.

As a consequence of our inadequacy at assessing both number of territorial birds present and availability of those birds to be trapped, we believe that both these metrics are imperfect indicators of true capture rate. In fact, it is likely that the true capture rate may lie somewhere between the individual capture rate and the territory capture rate. As such, we believe that it is useful to report both rates when trapping nesting raptors with a live or mechanical lure owl in future research.

Future Directions. We take several lessons from our trials with mechanical owls as lures for trapping wild raptors. The most important of our findings is that for the majority of species we tested, mechanical owls are at least as effective, and sometimes more effective, than live lure owls. It will be important to test our mechanical owl design on other raptor species as there may be some species for which a live lure owl is more effective (e.g., potentially Red-shouldered Hawks). However, it is our belief that capture success was far more likely to be influenced by external factors than by the type of lure we used. For example, vegetative cover may have influenced capture success. In particular, the thick marshy habitat where we trapped Red-shouldered Hawks often lacked openings near the nest to place the owl and as a consequence, we suspect that only some of the adult birds saw our lure owl in these areas. This could explain why using a mechanical owl in an elevated net set may result in greater capture success for Red-shouldered Hawks nesting in complex habitat (Jacobs and Proudfoot 2002) and why recent capture attempts on this species with our mechanical owl in suburban settings resulted in higher capture rates than those we report here (V. Slabe unpubl. data). In a similar vein, trapping in open grassland at Ferruginous Hawk nests also presented a challenge. Because of the flat ground and low vegetation, the mist net we used (set as a dho-gaza) was typically highly visible. As a consequence, we often observed numerous attacks at the owl but low overall capture rates.

It would also be useful to compare success rates when trapping urban or suburban nesting hawks compared to those nesting in more "natural" settings. Anecdotally, urban and suburban hawks seemed less timid and easier to capture, possibly a result of habituation to humans that made these individuals less sensitive to researcher presence. In addition, the presence of nontarget species may have also influenced our ability to trap resident raptors. In some territories, broadcast vocalizations attracted American Crows (*Corvus brachyrhynchos*) or nontarget raptor species (e.g., Prairie Falcons [*Falco mexicanus*], Northern Harriers [*Circus cyaneus*]). This only occurred on a few occasions, but we were unable to catch target birds in the presence of nontarget species. Therefore, future studies could evaluate how vegetative cover, net visibility, human habituation, and the presence of nontarget species affect capture success.

We did not find a significant difference in capture time between first-time captures and recaptured goshawks. However, this does not reflect whether previously captured individuals are less likely to be caught in the first place. In recent trapping seasons since performing this study, we have observed a reduction in the capture rate of Ferruginous Hawks. It is possible that when researchers revisit territories, certain raptor species become familiar with the trap and consequently more wary of it. It would be useful to compare capture rates between first-time captures and recaptures on a marked population of individuals.

Finally, although we did not detect a difference in capture time based on the use of vocalizations in our live owl dataset, broadcast vocalizations may be important when using a mechanical owl. Previous research has shown that broadcast vocalizations used in conjunction with an owl mounted by a taxidermist increased success rates (McCloskey and Dewey, 1999). Thus, we always used vocalizations when trapping with our mechanical lure owl, although each trapping team used different strategies for the specific species we were targeting. Future research could test the difference in success rates and time to capture when using the mechanical owl with and without vocalizations.

Conclusions. In the cases we evaluated, the use of mechanical owls as a lure to trap wild raptors presented a suite of advantages over use of live lure owls. Beyond their equal or superior performance in the field, they cost less, are easier to transport, require fewer permits, are ethically superior (for the lure and the target bird), and are likely to be perceived more positively by the public. Use of mechanical owls though, is not without its own set of challenges that are distinct from those associated with use of a live owl. In particular, live owls do not require batteries to operate (batteries that can sometimes fail at extremely inconvenient times), live owls are far more waterproof than a taxidermy mount, and live owls are much better at ducking (and therefore, do not require repairs with superglue). Although mechanical owls may not perform as well as a live owl in every setting, our study suggests that the use of a mechanical lure owl is valuable in a wide variety of situations.

SUPPLEMENTAL MATERIALS

Detailed information on the hardware and materials used for assembly of the mechanical owl (Supplementary Table 1), minimum tool list (Supplementary Table 2), and photographic examples of mechanical owl head attachment (Supplementary Figure 1), wing preparation, and wing attachment (Supplementary Figure 2) can be found online. The raw time to capture data for Northern Goshawks in NY and PA (2005–2017) are also included in the supplementary materials (Supplementary Table 3).

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