Management of Biological Invasions (2022) Volume 13, Issue 3: 534–556

Special Issue: Effectiveness of Goodnature A24 self-resetting rat traps for invasive rodent control
Guest editors: Aaron B. Shiels and Christopher A. Lepczyk

Research Article

Testing Goodnature A24 rat trap excluders and trap height placement to prevent non-target bird mortality

Aaron B. Shiels[1,*], Lisa H. Crampton[2], Danika R. Spock[1], Alison L. Greggor[3], Katelynn Earnest[3], Lainie Berry[4] and Bryce Masuda[3]

[1]*USDA, APHIS, Wildlife Services, National Wildlife Research Center, 4101 LaPorte Avenue, Fort Collins, CO 80521, USA*
[2]*Kauai Forest Bird Recovery Project, Pacific Cooperative Studies Unit, 3751 Hanapepe Rd, Hanapepe, HI 96716, USA*
[3]*San Diego Zoo Wildlife Alliance, Conservation Science and Wildlife Health, Volcano, HI 96785, USA*
[4]*Hawaii Department of Land and Natural Resources - Div. of Forestry and Wildlife, 1151 Punchbowl Street, Room 325, Honolulu HI 96813, USA*

**Corresponding author*
E-mail: *aaron.b.shiels@usda.gov*

Co-Editors' Note: This study was contributed in relation to the Island Invasives Symposium at the 29th Vertebrate Pest Conference held in Santa Barbara, California, U.S.A., March 2–5, 2020 (http://www.vpconference.org/). The Island Invasives Symposium included 22 speakers from 7 countries/commonwealths and was the stimulus for organizing this special issue of Management of Biological Invasions. The Vertebrate Pest Conference is held every 2 years, and since its inception in the 1960s it has provided a venue for the exchange of information and solutions for the management of invasive species and vertebrate pests.

Citation: Shiels AB, Crampton LH, Spock DR, Greggor AL, Earnest K, Berry L, Masuda B (2022) Testing Goodnature A24 rat trap excluders and trap height placement to prevent non-target bird mortality. *Management of Biological Invasions* 13(3): 534–556, https://doi.org/10.3391/mbi.2022.13.3.05

Received: 30 September 2022
Accepted: 13 October 2022
Published: 24 October 2022

Handling editor: Christopher Lepczyk
Thematic editor: Catherine Jarnevich

Abstract

Birds can be unintentionally injured or killed by mammal traps. Unfortunately, some birds in Hawai‘i, including puaiohi (*Myadestes palmeri*), and in New Zealand, have been killed by the widely used Goodnature® A24 rat-stoat self-resetting trap (A24s) during rodent control. To help address this problem, we conducted two sets of aviary trials using (1) barriers and (2) existing A24 excluders with red-winged blackbirds (*Agelaius phoeniceus*), European starlings (*Sturnus vulgaris*), and a single puaiohi. We conducted barrier trials to inform future bird excluder designs by establishing the minimum gap-height beneath a barrier that blackbirds and starlings successfully overcome. During barrier trials, starlings defeated barriers significantly lower (≥ 1.9 cm) than blackbirds (≥ 2.9 cm). We then presented disarmed A24s with no excluder or with one of two excluders (plastic Goodnature, 11 cm length; and metal mesh, 10 cm, or 15–17 cm length for puaiohi) to each bird species. We placed the A24s and excluders low (11–25 cm trap height, 0–10 cm excluder height) and high (50–83 cm trap height, 37–72 cm excluder height) above ground to test bird entry abilities at trap heights used by land managers to control rodents. During the A24 excluder trials, all three bird species entered the trap at low or high heights with no excluder, confirming bird risk of injury when excluders aren't used. Excluders greatly decreased entry into A24s by blackbirds and puaiohi, but not by starlings. Plastic and metal excluders prevented puaiohi entry at low height only. Based on our trials and recent field uses, the plastic excluder performed best for excluding all three bird species if placed so the lower edge of the excluder is 0–2 cm above ground. However, plastic and metal excluders can clog with dead rodents when positioned low. Future trials aiming to exclude all small birds from A24s while maintaining trap efficacy against target rodents should consider new excluder designs incorporating the 1.9–2.9 cm gap-height thresholds. When deciding whether to use excluders and appropriate trap heights, managers need to consider both the risk of non-target injuries or deaths and the impact of potentially decreasing trap efficacy.

Key words: endangered species, European starling, height threshold, passerine blocker, puaiohi, red-winged blackbird, vertebrate pest management

Introduction

A key goal in vertebrate pest management is to implement methods that effectively reduce target pests and associated problems while minimizing harm to non-target species. Birds are common non-target species that can be injured or killed by mammal traps. While ground-dwelling birds may be prevented from accessing traps by simply elevating the trap (e.g., Morriss et al. 2000), additional modifications to the traps themselves (e.g., Morriss and Warburton 2014), and placement of traps in boxes (King et al. 2011; Pender et al. 2013), are also commonly used to reduce the probability of non-target injury or mortality of birds (also see New Zealand Department of Conservation [DOC], 2021).

Goodnature® A24 rat-stoat self-resetting traps (hereafter A24 or A24s) are used extensively for invasive rat control in a variety of countries and environments (Carter et al. 2016; Shiels et al. 2019; Gronwald and Russell 2022; Kreuser et al. 2022). A24s are not species-specific traps, meaning that other (non-target) small animals besides the target rodent or stoat may access the trigger and be injured or killed by the trap. Unlike classical snap-traps (e.g., Victor®) where animals access the bait and the trap along an uncovered surface, A24s consist of a vertical cylinder which animals enter to reach the bait and triggering components. The diameter of the A24s vertical cylinder was designed to exclude many types of non-target species. However, some non-target species that can fit a part of their body within the vertical cylinder remain at risk to injury or death by A24s, such as the nationally endangered kea (*Nestor notabilis* Gould, 1856) in New Zealand (DOC 2018).

Although it is not known if bird deaths from A24s result in population-level reductions, there is concern that A24s may be causing more passerine deaths than observed or reported during rodent control operations. Currently, we know of two published reportings where accidental passerine mortalities have occurred from A24s when excluder attachments were not utilized. The first report is from New Zealand where deaths of one non-native and six native birds were documented (Gillies et al. 2014). The second report is from Kauai Island, Hawaiʻi, where up to five puaiohi (*Myadestes palmeri* Rothschild, 1893), an endemic and endangered forest bird, were documented as being killed by A24s (Kreuser et al. 2022; Crampton et al. 2022).

To reduce risk to kea when using A24s, Goodnature designed, and DOC tested, a plastic bird excluder that would exclude these parrots from gaining access to the triggering components of the trap (DOC 2018). This plastic excluder extends and decreases the opening of the vertical cylinder, and is now being sold by Goodnature to attach to the A24. A similar homemade excluder created from metal mesh (hardware cloth) has been used by land managers in Hawaiʻi to exclude the highly endangered ʻalalā, (Hawaiian crow, *Corvus hawaiiensis* Peale, 1848) from A24s during rat control efforts (Vickery et al. 2020). When affixed to A24s, these two types of excluders have been successful at preventing large-bodied birds (parrots and crows) from gaining access to the internal trigger, thereby reducing risk of injury (DOC 2018; Vickery et al. 2020). However, the effectiveness of such excluders for A24s against smaller birds, particularly passerines, remains largely untested and is the focus of our study. Developing and testing trap modifications are necessary to give trap users an option to reduce bird access to traps, and thus prevent bird injury and mortality, while maintaining an effective, efficient, and attractive trap for rodent control (Short and Reynolds 2001). One potential problem with the current A24 excluder designs (i.e., Goodnature plastic, and homemade metal mesh) is that they are cylindrical excluders about the same diameters as the A24 entrance (~ 5 cm) and they can get clogged with a rodent carcass if the excluder is placed too low to the ground (Vickery et al. 2020). In such cases, trap efficacy is reduced for the target species as the carcass does not clear from the excluder or trap entrance to allow a subsequent rodent to freely enter the trap. In forests in Hawaiʻi, Crampton et al. (2022) conducted field trials to help determine if the presence of excluders reduced invasive rat entry into A24s. They reported that attaching 16 cm long metal excluders to A24s resulted in approximately a 3-fold and 4-fold reduction in rats killed per trap night relative to when plastic excluders and no excluders, respectively, were attached to A24s. The knowledge gap of whether excluders are effective at preventing non-target passerine entry into A24s still remains, and this was investigated during our study.

The first objective of our study was to inform future A24 excluder designs by establishing the minimum barrier height that allows birds to pass beneath. Such minimum gap-heights can be used to design future excluders that prevent small bird entry, keeping in mind that the gap-height would also ideally enable rodent carcasses to freely clear from the trap entrance and therefore maintain adequate trap efficacy. Realizing that every bird species is of different size and behavior, there may not be a single excluder type that prevents all bird species from entering A24s. Instead, an excluder that includes an adjustable gap-height may be a viable approach to target groups of birds within the same size classes.

The second objective was to test existing A24 bird excluders, mainly the plastic Goodnature excluder and the homemade metal mesh excluder, at two heights (low and high) above ground to determine which of these configurations is best to eliminate or minimize bird entry and their subsequent triggering of A24s. These trap height and excluder configurations were chosen for testing because they are currently used by land managers to control invasive rodents with A24s. Elevating the A24s affixed with and without bird excluder attachments is also of interest to managers that have feral pigs (*Sus scrofa* L., 1758) in their management areas because pigs have been known to dislodge A24s from the trees for which they are secured when they are fastened close (< 25 cm height) to the ground (Crampton et al. 2022).

Table 1. Morphometrics (mean ± SE) of trialed red-winged blackbirds (n = 25), European starlings (n = 10 for lengths, and n = 23 for mass), and non-trialed puaiohi (n = 69; wild-caught on Kauai Island, Hawai'i). Total leg length is shown in the final column (tarsus+tibia). All birds were adults at the time measured.

Species	Mass (g)	Body length (mm)	Tarsus length (mm)	Tarsus+Tibia length (mm)
Blackbirds	55.5 ± 2.1	119.5 ± 1.6	30.9 ± 0.3	72.8 ± 0.7
Starlings	69.7 ± 1.3	136.0 ± 3.7	29.4 ± 0.4	72.1 ± 0.9
Puaiohi	38.0 ± 0.3	–	35.0 ± 0.2	–

We conducted aviary trials, using disarmed A24s, with red-winged blackbirds (*Agelaius phoeniceus* L., 1766), European starlings (*Sturnus vulgaris* L., 1758), and a single puaiohi. Aviary trials are logistically superior to field trials for scientifically testing (in a replicated fashion) whether it is physically possible for these bird species to defeat barriers and excluders. The three species share the following morphological and behavior characteristics: similar sizes (e.g., adult averages: 38–70 g; Table 1), ground foraging, and generalist diets of invertebrates and fruit/seed. Starlings are known for their enhanced curiosity and accessing small crevices and holes (Ingold 1998), and therefore we expected them to pass under the shortest barrier heights and defeat more excluder configurations than the other species tested. For the A24 trials involving all three bird species, we tested the following two hypotheses and stated corresponding predictions.

Hypothesis 1: The presence of an excluder reduces or prevents bird entry into A24s more than when an excluder is absent. We predicted that excluders of any type would reduce bird entry into A24s relative to A24s lacking excluders.

Hypothesis 2: Metal mesh excluders perform better than Goodnature plastic excluders for reducing or preventing bird entry into A24s. We predicted that at both low and high heights, the Goodnature plastic excluder would not exclude birds as well as the homemade metal mesh excluder because the plastic excluder has a perching lip at the entrance of the excluder that could facilitate bird entry. For the puaiohi, we also predicted that both the coiled wire tube and homemade metal mesh excluders would exclude entry into the A24 because of the long lengths (15–17 cm) of these two excluders.

Materials and methods

Origins of study birds and the aviary settings

In January 2020, 60 male red-winged blackbirds (hereafter blackbirds; 47–65 g; Table 1) and 60 European starlings (starlings; 56–94 g; Table 1) of both sexes were captured from feedlots in Northern Colorado and transported to the U.S. Department of Agriculture's National Wildlife Research Center's headquarters (animal research facilities) in Fort Collins, Colorado (NWRC). Birds were held as single species flocks in outdoor aviary pens (5 m × 7 m × 3.5 m, w × l × h) when they were not on trial. The standard seed diet for blackbirds was a mixture at ratio of 2 millet: 1 milo:

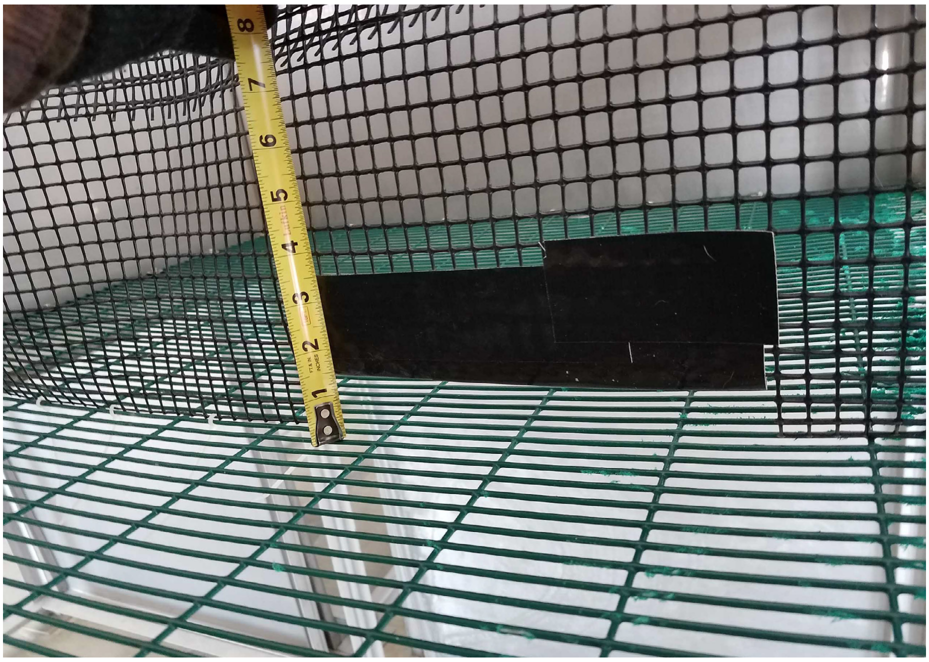

Figure 1. The barrier trials set up showing the temporary barrier (1.27 cm gauge plastic mesh) dividing the cage in half. The adjustable gap at the bottom of the barrier is set and measured to test whether red-winged blackbirds and European starlings can pass under the gap. The pictured gap is set to approximately 1 3/8" (3.5 cm). Photograph by Danika R. Spock.

1 cracked corn: 1 safflower seed, plus 5–10 sunflower seeds placed on top. The starlings diet was Purina Layena Poultry Layer Pellets. All trials with blackbirds and starlings occurred from February 2020 to April 2021.

The puaiohi trials were conducted during 2019 at the Keauhou Bird Conservation Center in Volcano, Hawai'i Island, where conservation breeding of Hawaiian birds is conducted by the San Diego Zoo Wildlife Alliance's Hawai'i Endangered Bird Conservation Program. The female puaiohi (age 5 years, hatched in managed care) was given access to the disarmed A24s in her home aviary, and fed a standard daily diet of egg, mealworms, crickets, papaya, apple, and bird pellets.

Trials determining gap-heights below barriers for which birds cannot pass beneath

To inform future excluder designs, we conducted trials with barriers to challenge blackbirds and starlings at NWRC to access a food source on the other side of a barrier – these trials established minimum heights for which the birds can duck under barriers. If metal mesh excluders are lowered to just below the minimum height threshold we establish, it should prevent birds of the same type or size from entering the A24 while maintaining a gap for target rodents to enter. We used stainless-steel cages measuring approximately 90 cm w × 120 cm l × 120 cm h. Temporary barriers (1.27 cm gauge plastic mesh) were constructed inside 10 cages and were fastened to divide the cage in half. The barriers were set up with an adjustable gap at the bottom so the height of the gap from cage-bottom to the bottom of the barrier could be set and measured (Figure 1). Two trays lined with paper were placed under each cage to collect waste. The cage paper was replaced daily, and the presence of food or droppings on the cage paper enabled us to determine if birds had successfully passed under the barrier – that is, if the bird was not physically present on the opposite side of the cage that it began on when each trial initiated. There was a perch and water bowl on each side of the barrier. Food (standard diet) was always in a dish on the right side of the barrier, as trials always began with the birds on the left. During an acclimation period of at least 30 hours before trials, the barrier was raised to 20–25 cm above the cage bottom so the birds could easily pass beneath the barrier and access the food dish on the other side.

Two types of barrier trials were conducted – one used three birds per cage, and the other used one bird per cage. Our aim was to encourage each trial bird to attempt to pass under the barrier and reach the other side of the cage, and to do this at multiple heights so a single lowest height defeated could be established for each individual. To encourage such behavior, we used enticing food items, and in some cages we increased bird density to three birds. When trials began, the barrier was set to a height below 6 cm and the cage was observed after 16 hours. If there was evidence that the barrier was defeated (i.e., bird present, or seed or droppings in trays below the right side of the cage) then the barrier was lowered further for the next day's trial. This process was repeated with the barrier height being lowered incrementally (0.2–2 cm) until the birds could not defeat the barrier. The range of heights tested was 0.5–6 cm, and each set of trials lasted 5–15 days. Any evidence of a bird passing under the barrier and to the other side of the cage was counted as an incidence of defeating the barrier height. The lowest height defeated for each individual was used in our analysis. For the cages with three individuals present, if there was evidence indicating an individual had defeated the barrier, but no birds were physically present on the opposite side of the cage from where the birds began the trial, then we conservatively recorded just one bird had defeated the barrier. This meant that for some trials there was not a lowest height established for all three individuals in a group within a cage. The total individuals used in our analysis for blackbirds were n = 24 birds with three birds per cage, and n = 24 with one bird per cage, and for starlings were n = 21 birds with three birds per cage, and n = 27 with one bird per cage. An additional 12 blackbirds and 10 starlings were trialed but not used in our analysis because it was unclear if they ever defeated any barriers tested. Examples of such birds were those in a cage of three individuals where it was unknown how many passed beneath the barrier (see above), and single caged individuals where there was no evidence (e.g., droppings or food on the cage paper, or physical presence) that they visited the other side of the cage. Blackbirds were trialed from 12 February to 11 June 2020, and starlings were trialed from 12 June to 15 October 2020.

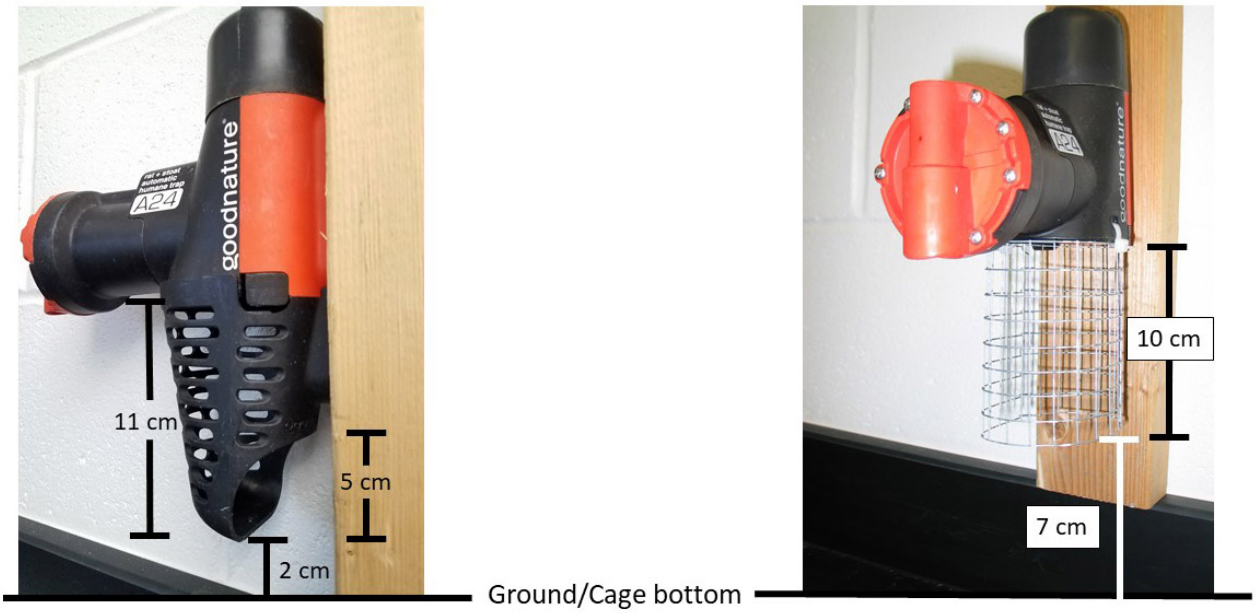

Figure 2. The two types of bird excluders tested against red-winged blackbirds and European starlings in our study at NWRC in Colorado during 2020–2021. Each excluder was attached to a Goodnature A24 rat trap, and the distances above ground (cage bottom) and total excluder lengths used in our trials are shown. Left image shows the plastic Goodnature excluder (currently available from Goodnature), and the right image shows the metal mesh excluder (home-made). Both pictured excluders also were tested against puaiohi in Hawaiʻi, where the distance to the ground for both excluders was different than shown and the length of the metal mesh excluder was 15-17 cm. Photographs by Danika R. Spock.

Trials with excluders attached to A24s

Two excluders that attach to the entrance of the A24 were trialed with blackbirds and starlings, including a Goodnature plastic excluder (hereafter plastic excluder) and a homemade metal mesh excluder (metal excluder) (Figure 2). The plastic excluder is 12 cm in total length but 11 cm when attached to the A24 due to a 1 cm overlap at the attachment point; we use the 11 cm length, hereafter, for reporting in our study. The plastic excluder's entrance is on the back of the excluder and is vertical, extending from the base of the excluder to 5 cm height where cylinder walls are entire. A perching lip is also present near the base of the plastic excluder (Figure 2). The metal excluder is 10 cm in total length when attached to the A24. The cylinder walls are entire and made of metal mesh (hardware cloth) with 1.27 cm-apertures and its entrance is horizontal (Figure 2). Both excluder types tested are cylindrical in shape and designed so that birds may not be able to shimmy up the cylinder excluders even if they can enter the excluder. Because trap height may influence a bird's likelihood of visiting a trap and defeating an excluder, we conducted trials where A24s were positioned low (see below) and high (83 cm trap height, 72 cm excluder height; where height was to the base of the trap or excluder) to the ground (cage bottom) (Figure 3). Heights were chosen based on the operational uses of these traps for rat control and otherwise were not influenced by our previous barrier trial results described in the previous section nor by trials by Crampton et al. (2022) investigating rat behaviors around A24s. A24s

Figure 3. Left picture showing a red-winged blackbird next to an (disarmed) A24 in high position (83 cm above cage bottom) without an excluder present. The right picture shows how the reward foods (e.g., four sunflower seeds, as pictured here) were suspended at the base of the metal mesh excluder to habituate the birds to the excluder. Incentive foods were placed up inside the A24, at the base of the trap entrance, when birds were challenged to defeat excluders during the test period. Photographs by Danika R. Spock.

without excluders attached, and positioned 11–12 cm above ground, were also tested. During operational use, A24s without excluders attached are most often placed low (10–15 cm) to the ground (Gillies et al. 2014; Shiels et al. 2019; Bogardus and Shiels 2020; Kreuser et al. 2022). Therefore, the greatest number of trials that we conducted were at low height. For the low height configurations, we secured the plastic excluders at 2 cm from the cage bottom (where the top of the excluder entrance was at 7 cm height above ground, and trap height was at 13 cm; Figure 2), and the metal excluders at 7 cm above ground (17 cm trap height; Figures 2, 3). These heights would likely prevent (metal excluder) or minimize (plastic excluder) dead rats clogging the entrance of the A24s and excluders, and therefore maintain functionality for rat control.

Blackbirds were trialed with A24s using two different excluder types and two heights from 19 March 2020 to 18 December 2020, and starlings were trialed from 3 January 2021 to 30 April 2021. All trials with A24s were conducted when the traps were disarmed, and they involved just one bird per cage. Thirty of the same type of stainless-steel cages used in the barrier trials were used in the A24 excluder trials. Birds used in the barrier trials were re-used in the A24 excluder trials. To encourage birds to interact with the A24s and challenge them with the excluders, for all A24 excluder trials, we used previously identified desired reward food items of black-oil sunflower seeds for blackbirds, and canine pellets (Mazuri Exotic Canine Diet) for starlings.

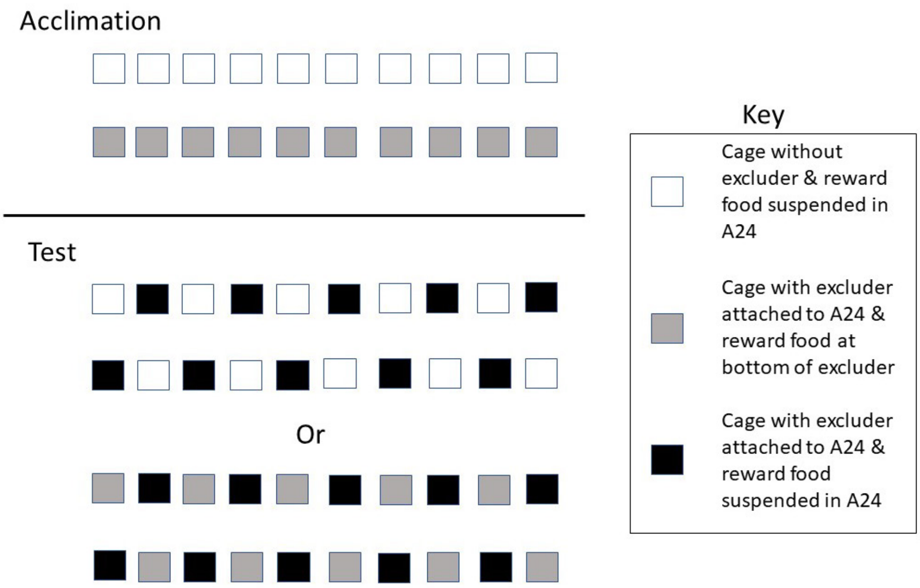

Figure 4. Diagram of experimental design for testing whether blackbirds and starlings could defeat excluders attached to A24s. Each trial included 10 cages, where each cage had one bird, and had an acclimation period and a test period. All 10 birds went through the acclimation period where excluders were absent from the A24s but a food reward was placed inside the A24s (white boxes), and where excluders were attached to A24s but the food reward was placed at the bottom of the excluder (grey boxes). During the test period, half of the cages received a treatment where the excluders were attached to A24s and the food reward was suspended inside the A24s, and the other half of the cages received treatment of a white box or grey box, as described above. After the first five had completed the black box treatment, treatments were swapped so the other five cages received the black box treatment. Each row in the diagram lasted approximately 1–3 weeks before the subsequent row began.

A cohort of 10 birds in 10 separate cages was trialed at a time using the same stepwise timeline described in a-d below and in Figure 4. A trial period included an acclimation period and a test period (Figure 4). The purpose of the acclimation period was to allow birds to become comfortable with the A24s and excluders in their cage. To facilitate acclimation, we placed food rewards in the A24s and at the bottom of the excluder to encourage the birds to explore these devices. As shown in Figure 4, all 10 birds went through a 2-step acclimation period before being tested to see if they could defeat an excluder. Each step of the acclimation and test period lasted about 1–3 weeks (5–15 days), and each week's activities would begin on Monday and end on Friday. On Tuesdays and Thursdays we withheld the dish of standard diet food to better encourage the birds to search for the reward food. Withholding the dish of food began at 16:00 Tuesday (or Thursday) and ended at 08:00 Wednesday (or Friday), thus lasting 16 hours each of the two days a week. For the other trial days (i.e., Monday, Wednesday, Friday), each bird always had access to a dish of food, and the reward food was always in the A24s or attached to the excluder (see Figure 3). In cases where air temperatures were extremely cold (< −5.5 °C), food was not withheld, and heat lamps were used to provide warmer temperatures in cages.

The general timeline for trialing each excluder (plastic and metal) and height (low and high) for each cohort of 10 birds was as follows, and b–d occurred using the food-withholding timeline (described above):

a) A24s were placed in cages for several days with birds present, a food dish was placed beneath the A24s and eight sunflower seeds (the reward food for blackbirds) or four canine pellets (the reward food for starlings) were placed on top of the food in the dish.

b) Four sunflower seeds (for blackbirds) or two canine pellets (for starlings) were set in a clear-plastic spoon suspended at the entrance of the A24s and seeds/pellets were checked daily for removal (shown as white boxes in Figure 4). Once any seeds/pellets were removed by a bird that bird/cage proceeded to the subsequent stage (step c below). All 10 birds would proceed to the subsequent stage at 3 weeks regardless if there were individuals that had not removed reward seeds/pellets.

c) An excluder (either plastic, or metal) was attached to the A24 entrance (as shown in Figure 2) and four sunflower seeds (or two canine pellets) were suspended inside the excluder at the base of the excluder (see Figure 3) and seeds/pellets were checked daily for removal (shown as grey boxes in Figure 4). Once any seeds/pellets were removed from the base of the excluder by multiple caged birds (ideally five), they would proceed to the test phase (step d below). All 10 birds would proceed to the test phase at 3 weeks regardless if there were individuals that had not removed reward seeds/pellets.

d) For five of the cages, four sunflower seeds (or two canine pellets) were moved to the A24 opening (entrance, just below the trigger), such that a bird would have to access the reward food by going up inside the excluder (shown as black boxes in Figure 4). Seed/pellet removal by the bird was quantified as removed (at least one seed/pellet missing) or not removed (no seed/pellet missing). This was the test of whether each bird could defeat the excluder. Meanwhile, the other five birds that were not being tested to see if they could defeat the excluder were either being tested to see if they could enter the A24 when an excluder was absent using methods in step b above and used in our statistical analysis to test Hypothesis 1, or they were subjected to the methods in step c above. Once a set of five birds were tested to defeat the excluder, the treatments were switched, and the other five birds were tested to defeat the excluder (as shown in Figure 4). This design enabled us to account for any deterrence that the A24s, excluders, or other environmental conditions posed at the time of the testing.

Four (blackbirds) or five (starlings) cohorts of 10 birds each were trialed using the a–d step progression for low excluder heights, and just one cohort (up to 10 birds) per species were trialed for high excluder heights. Low height trials were prioritized and always occurred before high height trials using the same individuals. The order of trialing metal or plastic excluders was randomized. Each bird was tested for 2–3 weeks (10–15 days) during step d above. There were some birds that died during the trials, likely due to cold weather, prior to their testing and therefore these individuals could not be included in our analyses. We consider any removal of seed/pellet from the A24s (as in step d above) to be evidence that the bird could be killed or injured, and evidence that the excluder was defeated.

Puaiohi trials

A24s were added to the puaiohi's aviary and were baited with frozen crickets, a highly favored food item. The frozen crickets were removed from the puaiohi's regular daily diet to increase the likelihood of the puaiohi interacting with the A24. A total of 81 trials were conducted with the single puaiohi. Each trial was monitored with a trail camera (Bushnell® Trophy) mounted inside the aviary, as well as an additional camcorder or hard-wired camera through an observation window. The cricket bait was placed in the disarmed A24 in the morning and left overnight. Each morning the number of crickets remaining was counted, and missing crickets were interpreted as the puaiohi successfully obtaining the bait within the A24. Camera footage was used to confirm whether the puaiohi was able to retrieve the missing crickets and how she interacted with the trap.

Initial puaiohi trials were conducted using the plastic excluder, with the trap mounted 11 cm from the ground, and the excluder touching the ground. Starting with the crickets placed on the outside of the trap and excluder, we sequentially moved the bait closer to the disarmed trigger of the A24 after each trial in which the puaiohi successfully obtained the bait. After 12 trials, an additional A24 was added to the aviary so that multiple excluder types and heights could be tested simultaneously. For each excluder type placed in the aviary, bait was added regularly until the puaiohi successfully obtained the bait from the trigger area (inside the A24s), or until the puaiohi stopped progressing towards taking the bait. While sequential testing and accumulated experience of this single bird could make it more likely that it would enter the trap than a wild bird, our aim was to determine if it was physically possible for this bird to access the trigger area under different trap and excluder conditions. In addition to the plastic excluder, two additional excluder types were presented: a metal mesh excluder with cylinder walls made of 1.27 cm hardware cloth (like the one used with the blackbirds and starlings, but the excluder length was 15–17 cm for the puaiohi); and a stiff, coiled wire tube (15.5 cm in length; Figure 5) that could be set up with either its small (6 cm diameter) or large (7 cm diameter) end as the entrance. For the coiled wire tube (hereafter coiled excluder), the height from the bottom of the excluder to the ground was either 0 cm or 16.5 cm. We also varied the height of the A24s to the ground from 11 cm to 50 cm, and some trials were conducted without an excluder (Table 2).

Statistical analysis

For the barrier trials, a *t*-test was used to compare blackbirds (n = 48) to starlings (n = 48) after determining the lowest barrier height defeated per

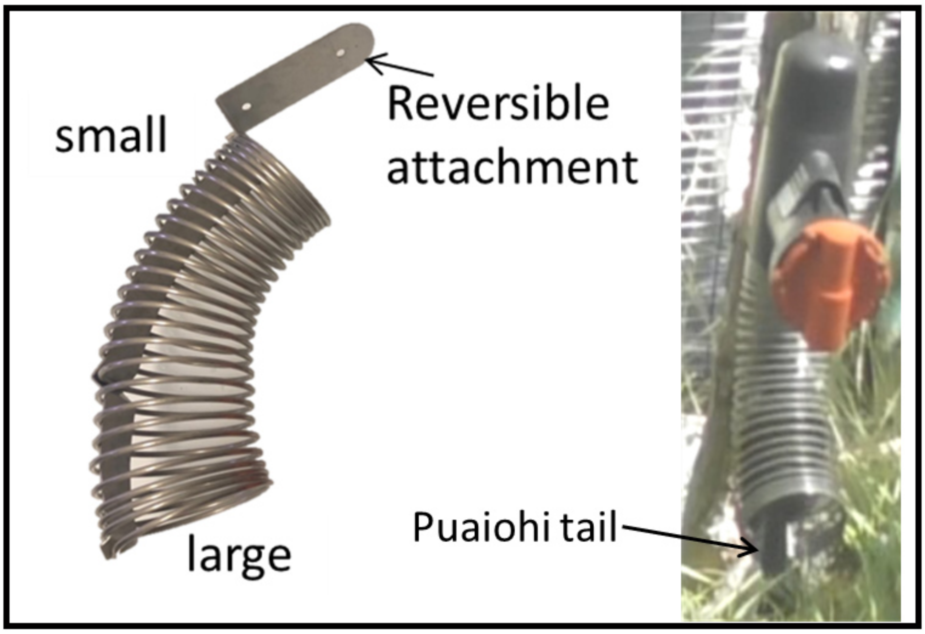

Figure 5. The coiled (wire tube) bird excluder that attaches to the A24 and was trialed with the puaiohi only. The small and large ends (opening) of the coiled excluder were each trialed as the entrance presented once attached to the A24. Note the puaiohi is pictured here inside the entrance of the coiled excluder.

Table 2. Different A24 excluder types, A24 heights above ground level, and excluder heights above ground level during which a baited, non-functioning A24 was provided to one puaiohi.

Excluder type (in order presented)	Height trap above ground (cm)	Height excluder above ground (cm)	Accessed A24 trigger area? (Y/N)	No. trials to access trigger area or trap deemed safe
Plastic Goodnature	11	0	N	10
No excluder	11	NA	Y	1
No excluder	50	NA	Y	1
Plastic Goodnature	50	39	Maybe-jumps up within 2.5 cm of trigger	19
Coiled wire tube, large to small	32	16.5	Maybe-walks inside, within 2.5 cm of trigger	20
Coiled wire tube, small to large	32	16.5	Maybe-walks inside, within 2.5 cm of trigger	3
Coiled wire tube, small to large	12	0	Maybe-walks inside, within 2.5 cm of trigger	3
Plastic Goodnature	15	4	Y	4
Plastic Goodnature	12	1	N	4
Metal mesh (17 cm length)	21	4	N	5
Metal mesh (17 cm length)	25	8	N	6
Metal mesh (16 cm length)	25	9	N	4
Metal mesh (15 cm length)	25	10	N	1

individual. Prior to the t-test, parametric assumptions (normal distributions and equal variances between groups) were confirmed. To test Hypothesis 1 (excluders are more effective at reducing or preventing bird entry into A24s than if excluders are absent) for the A24s trials, we used chi-square tests to compare the frequency that blackbirds and starlings entered A24s (and recovered reward food) with and without excluders, at both low and high heights. Because we prioritized low height trials (n = 25–40 individuals per group, depending on species and excluder type) over high height trials (n = 4–10 individuals per group) and high height trials always occurred after

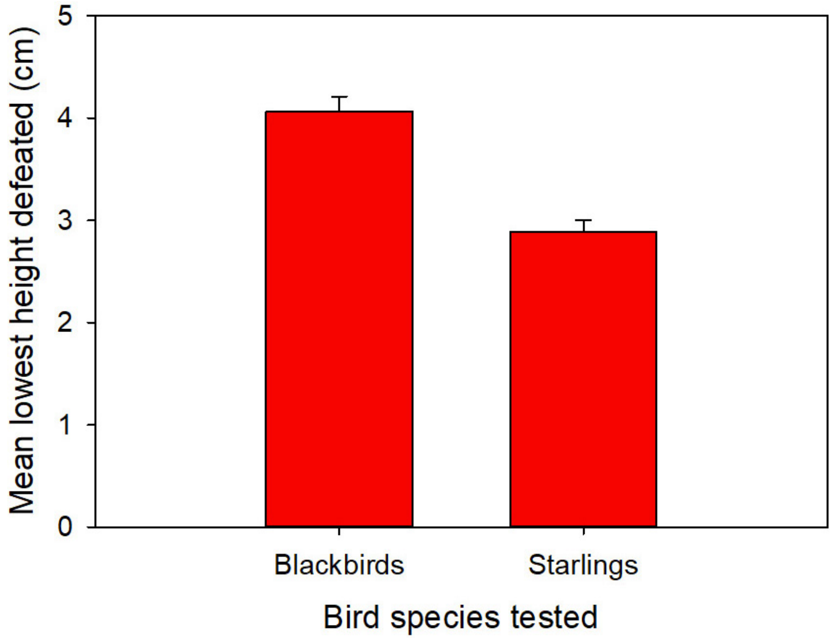

Figure 6. Mean (SE) lowest barrier heights defeated by red-winged blackbirds (n = 48 birds) and European starlings (n = 48 birds). Mean lower heights defeated were significantly lower for starlings than blackbirds (p < 0.0001).

completion of all low height trials rather than in a random order, we did not attempt statistical comparisons between low vs. high trap configurations. To test Hypothesis 2 (metal mesh excluders perform better than Goodnature plastic excluders for reducing or preventing bird entry into A24s), we conducted chi-square tests for blackbirds and starlings comparing the frequency of each bird species entering plastic vs. metal excluders for low and high heights. Statistical analyses were conducted in R version 3.4.1. and significance was based on $p < 0.05$. Because there was only one puaiohi individual available for trials, there were no statistical analyses performed for this species.

Results

Trials determining gap-heights below barriers for which birds cannot pass beneath

Starlings defeated barriers that were significantly lower (mean ± SE; 2.89 ± 0.11 cm; n = 48) than those that blackbirds defeated (4.06 ± 0.15 cm; n = 48) (t = 6.40, df = 94, p < 0.00001; Figure 6). The lowest barrier defeated by at least one individual was 1.91 cm for starlings (9 individuals) and 2.86 cm for blackbirds (3 individuals), and the most frequently defeated lowest barriers were those that were 2.86 cm (10 individuals each) for starlings, and 3.81 cm (16 individuals) for blackbirds (Figure 7).

Trials with excluders attached to A24s

Both blackbirds and starlings removed the reward foods from inside the A24s when the excluders were absent at low or high heights. Both types of

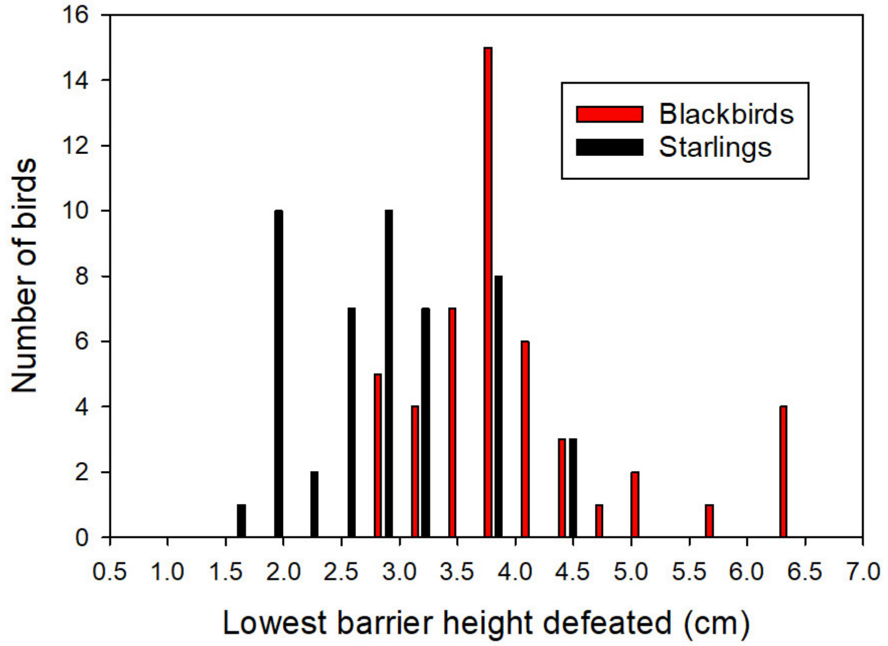

Figure 7. Lowest barrier heights defeated for red-winged blackbirds (n = 48 birds) and European starlings (n = 48 birds). The lowest barriers for which at least one individual defeated that barrier was 1.91 cm for starlings (9 individuals) and 2.86 cm for blackbirds (3 individuals).

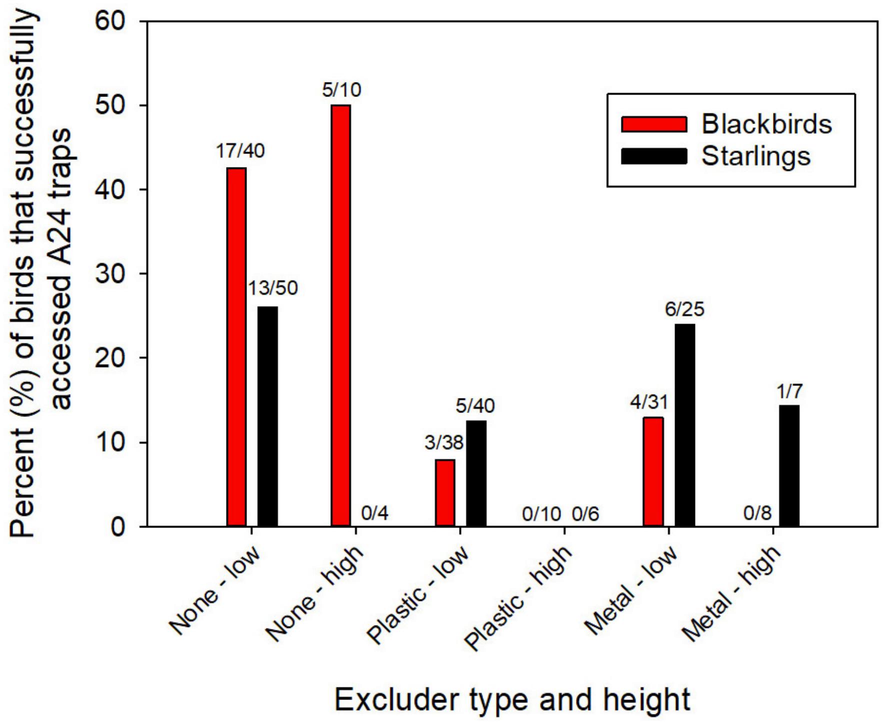

Figure 8. Summary results of the A24 trials with red-winged blackbirds and European starlings, where the percentage of birds that gained access to the A24 positioned at two heights (low and high) when excluders were absent (none) and with plastic or metal excluders attached to A24s. The number of individuals that successfully accessed A24s is shown out of the total number of individuals trialed for each excluder-height configuration.

excluders, at low (2 cm or 7 cm above ground) and high (72 cm) heights, prevented the entry into A24s of > 87% of the tested blackbirds; whereas 50–56% of blackbirds did not enter A24s when excluders were absent (Figure 8). When analyzed statistically (excluder present vs. excluder absent) at low height, the plastic excluders ($X^2 = 10.49$, df = 1, $p = 0.0012$) and the metal excluders ($X^2 = 5.99$, df = 1, $p = 0.0144$) were effective at reducing the frequency of blackbirds obtaining reward foods from the A24 triggering area (Figure 8). However, the plastic excluders were defeated by three of 38 (7.9%) blackbirds, and the metal excluders were defeated by four of 31 (12.9%) blackbirds, when attached to A24s at low height (Figure 8). Of the birds that defeated the excluders at low height, only one individual defeated both types; thus, five individuals defeated just one of the excluder types. No blackbirds defeated the plastic excluder ($n = 10$ birds) or the metal excluder ($n = 8$ birds) at high height, yet five of 10 blackbirds accessed the A24 reward food at high height (83 cm) when excluders were absent (Figure 8). With low samples sizes, plastic excluders ($X^2 = 4.27$, df = 1, $p = 0.0389$) but not metal excluders ($X^2 = 3.32$, df = 1, $p = 0.07$) significantly reduced blackbirds from entering the high height A24s relative to when excluders were absent (Figure 8).

Excluders (both types and at low and high heights) prevented the entry into A24s of >75% of the tested starlings (Figure 8). However, >73% of starlings did not enter A24s at either low or high heights when excluders were absent. Thus, when analyzed statistically (excluder present vs. excluder absent) at low height, neither the plastic excluder ($X^2 = 1.76$, df = 1, $p = 0.1849$) nor the metal excluder ($X^2 < 0.01$, df = 1, $p > 0.99$) were effective at reducing the frequency of starlings getting food rewards from the A24 triggering area (Figure 8). When excluders were in place, five of the 40 starlings (12.5%) defeated the plastic excluders at low height, and six of the 25 (24%) starlings defeated the metal excluder at low height (Figure 6). Of the starlings that defeated the metal excluders at low height, one individual had also defeated the plastic excluder. Only four starlings were tested when excluders were absent from A24s at high height, and none of the four birds obtained the reward food from the A24s. None of the starlings defeated the plastic excluder when positioned at high height ($n = 6$ birds), and there was no statistical difference between starlings accessing the A24s with and without the plastic excluder at high height ($X^2 < 0.01$, df = 1, $p > 0.99$). When A24s were placed high, one out of seven (14.3%) starlings defeated the metal excluder (Figure 8); this individual also had defeated the metal excluder at low height. Despite this one starling that defeated the metal excluder at the high height, there was no significant difference ($X^2 = 1.00$, df = 1, $p = 0.3169$) when comparing high height A24s having metal excluders to the high height A24s lacking excluders ($n = 4$ birds).

Plastic excluders did not differ in their ability to exclude blackbirds ($X^2 = 0.08$, df = 1, $p = 0.78$) or starlings ($X^2 = 0.74$, df = 1, $p = 0.39$) relative to metal excluders when positioned at low height or at high height ($X^2 < 0.01$, df = 1, $p > 0.99$ for each of blackbirds and starlings; Figure 8). Commonly the bird that defeated the excluder did so for multiple days in a row. One blackbird on 18 November 2020 was observed defeating the plastic excluder at low height by first hopping into the excluder (feet were on the lip of the excluder at the opening) and then extending its body to reach and remove the seeds up inside the trap. The reward food was placed up inside the A24 such that birds would not be able to insert their beak through the metal mesh excluder, or otherwise access the reward food from the outside of the excluder.

Puaiohi trials

The puaiohi was successful in obtaining bait placed in the trigger area of the A24s in three of 13 variations of different excluders, heights of the A24s, and height of the excluder to the ground (Table 2). These three instances included the only two situations in which no excluders were presented. During an additional four of 13 variations, the puaiohi may have been able to access the trigger area because it jumped and reached within 2.5 cm of the trigger (Table 2). In cases when the puaiohi was able to access the A24 trigger area, the puaiohi either jumped, stood, or walked up into the excluder. In contrast, two examples of when the puaiohi was not able to access the trigger area included: a) when she did not enter the excluder, likely because it was too close to the ground (i.e., plastic excluder was touching the ground), and b) when she accessed the bait by perching on the outside of the metal excluder. This behavior did not change when the metal excluder was shortened from 17 cm down to 15 cm, and so the trials were stopped prior to reaching the 10 cm metal mesh excluder length used in the trials with blackbirds and starlings.

For several trap-excluder configurations that were set up in new locations of the aviary or when a novel excluder type was trialed, it took upwards of 20 trials for the puaiohi to interact with the trap, presumably due to fear or hesitancy around the novel setup. By the end of the trap and excluder presentations, however, the puaiohi appeared to adjust more quickly to new setups, which may help explain the large discrepancies in number of trials needed between excluder types.

Discussion

Our first objective was to inform future A24 excluder designs by establishing the minimum heights below a barrier for which birds can pass beneath. Starlings defeated barriers that were significantly lower (≥ 1.9 cm) than blackbirds (≥ 2.9 cm). Although we had aimed to identify an A24 excluder (plastic, metal, coiled), positioned at high or low height, that prevented all bird entry into the A24s, none of the tested excluder-height configurations did so. Therefore, if 100% exclusion of small birds (including the endangered puaiohi) is desired while retaining ample A24 efficacy against target rodents, we recommend additional trials with a new method of preventing bird entry or a new excluder design that is not narrow or cylindrical yet incorporates an appropriate gap-height threshold, like the 1.9–2.9 cm gap-height determined from our barrier study. Our second objective was to test existing A24 bird excluders at two heights to determine which of these configurations is best to eliminate or minimize bird entry and their subsequent triggering of A24s. All three bird species entered the trap at low or high heights with no excluder and therefore would be at risk of injury. This finding is consistent with those from field operational use of A24s targeting rodents (Gillies et al. 2014; Crampton et al. 2022) and underscores that the absence of excluders may increase the risk to birds of injury or death from the A24s. We found support for Hypothesis 1 for blackbirds and puaiohi, as excluders greatly decreased bird entry into A24s, yet starlings entered traps with and without excluders equally. We did not find support for Hypothesis 2 because Goodnature plastic excluders were found to be equivalent or better than metal mesh excluders for preventing bird entry into A24s.

All three bird species in our study were physically capable of entering A24s lacking excluders, yet the single puaiohi and only 34% of the blackbirds and starlings gained access to the A24s (both heights and species combined) when excluders were absent. We expected more blackbirds and starlings to access A24s lacking excluders because we provided species-specific reward food items while withholding all other foods within their cages. However, A24s are designed to prevent some non-target entry even when excluders are absent. The diameter of the opening of A24s is 5.5–6.0 cm (slightly oval shaped), which is sufficiently narrow to prevent some large birds and mammals from gaining entry. In addition to body size, an important component of non-target entry to a trap is the specific behavioral characteristics of the species (Short and Reynolds 2001). For example, certain baits and lures are attractive to some non-target species but not others, as we found from our pre-trial reward food testing for starlings and blackbirds (data not shown). Height placement of A24s also can influence non-target visitation as some non-target species only forage on the ground (e.g., pigs) while others only visit the understory and not the ground (e.g., some birds). The temperament of bird species and individuals to novel, unnatural, or potentially dangerous stimuli also may have influenced our aviary study results (Réale et al. 2007). Therefore, managers should consider the characteristics of the non-target species at the site and lure used in the A24s to determine if addition of excluders is necessary.

Attaching plastic or metal excluders reduced entry into low-positioned A24s (relative to A24s lacking excluders) by > 75% for blackbirds yet did not significantly reduce starling entry due to their low overall entry into traps. Our prediction was that the plastic excluder would be less effective than the metal excluder because the lip at the entrance of the plastic excluder could facilitate perching and positioning to access the inner A24 trigger area where the reward food was placed. We observed an individual blackbird and the puaiohi use the lip of the plastic excluder as predicted. However, contrary to our prediction, the plastic excluder at low height tended to exclude about twice the proportion of blackbirds and starlings as did the metal excluder (10 cm excluder length, 7 cm above ground), but this result was not statistically significant. No consistent effect of excluder type was apparent for preventing A24 entry by the single puaiohi. Ultimately, these findings support the use of either plastic or metal excluders to reduce most small bird entry into A24s, yet other issues should also be considered by land managers (see below).

Elevating traps has prevented ground-dwelling birds from trap injury (Morriss et al. 2000), motivating our testing of A24s at high height. We found that when plastic and metal excluders were positioned at high height (72 cm) and compared to traps without excluders at high height, excluder presence (aside from plastic excluders with blackbirds) did not significantly affect A24 entry by blackbirds and starlings. A major limitation of this finding was the much-reduced sample sizes of birds used during high height trials. For example, only four starlings were trialed without excluders attached to A24s, and the greatest number of individuals of blackbirds or starlings tested during any high height trial was 10. Fewer trials were run at high height than low height for blackbirds and starlings because 1) the puaiohi repeatedly defeated the plastic excluders at high height (39 cm) and 2) trappers most often use the low height for A24 rodent control. While elevated traps with either excluder type tended to have relatively low entry by blackbirds and starlings, we cannot recommend elevating the traps with excluders rather than putting them at low height for the protection of small birds at this time, particularly because: 1) the small samples sizes used for high height testing, 2) statistical analysis was unsupportive of either excluder consistently reducing bird entry to traps at high height relative to excluders being absent, and 3) the puaiohi defeating the plastic excluder at 39 cm height. An additional consideration for deciding whether to elevate A24s into the understory is that elevating A24s may elicit a greater suite of birds to the traps, particularly those that reside in the understory and do not frequent the ground. Elevating A24s also has led to beak injury of large native ground-dwelling birds in New Zealand (Williams 2018). The inconsistent level of protection offered to birds from elevating the A24s with and without excluders is unfortunate, especially given recent field trials by Crampton et al. (2022) showing that elevated A24s (50 cm above ground) that lacked excluders did not deter target rat entry when compared to A24s positioned at the standard (low) height, and elevating traps may reduce ungulate interference with traps.

We found that seven out of the 13 trap and excluder configurations tested with the puaiohi were potentially dangerous. The bird displayed different behavioral tactics in some trap situations than others. For example, the puaiohi accessed the bait with metal excluders by sticking her beak through the side of the mesh, so she was technically excluded from the danger of the trigger area. Over time and with experience with different excluder configurations, the puaiohi appeared to need fewer trials to approach and interact with traps and retrieve the reward food item. Such a pattern could suggest that any traps placed in the wild may become more attractive and therefore more dangerous over time if birds gain any rewards from interacting with them. Time to adjust to traps may be one reason that none of the 147 incidences of birds interacting with A24s (with and without plastic excluders) resulted in individuals accessing the trigger areas during a five-month study in Canada (Ryan 2021), and the passing of several years after the initial deployment of hundreds of A24s in puaiohi habitat before any wild birds were killed by traps. Furthermore, the bird kills occurred soon after a new automatic lure pump (ALP) that continually provides fresh lure by pressing it out above the trigger and through the traps was used in these A24s, leading to the concern that puaiohi were gaining rewards from these traps (Crampton et al. 2022).

Despite the need to prevent unintentional injuries and mortalities of non-target species, A24s with bird excluders should not deter target rodents entering and triggering the trap due to the physical presence of the excluder or by failure of rodent carcasses to clear from the trap and excluder entrances. Small birds, like those that we studied, are more difficult to exclude from A24s while still enabling access by target rats than are large birds (e.g., crows, and parrots like the 675–1000 g kea; Gajdon et al. 2006); this difficulty is mainly a consequence of the body size overlap between many passerines and invasive rats (*Rattus* spp.). Trap excluder designs by Short and Reynolds (2001) prevented entry of several non-target species, but they unintentionally excluded some target species from entering traps including *Rattus norvegicus* Berkenhout, 1769. Early field observations using A24s with plastic excluders positioned 0–1 cm above ground suggested that rat carcasses would not freely clear from the excluder opening. Thus, subsequent rats could not enter A24s until a scavenging animal removed the carcass from the excluder entrance (Vickery et al. 2020). However, Crampton et al. (2022) found no significant difference between rat kill rates from A24s with plastic excluders (positioned 0–2 cm above ground) compared to traps without excluders, and both of these trap treatments had significantly greater kills than traps with metal excluders (16 cm in length, positioned 8 cm above ground) in an Oahu forest. In Kauai forests there were slight, but not significant, reductions in rat kills when the plastic excluder was attached to A24s compared to A24s without excluders (Crampton et al. 2022). Furthermore, in the Oahu forest, rat carcasses were usually scavenged within a few days, even after initially clogging traps. On Kauai, carcasses were typically either scavenged or decomposed before a new rat visited the trap (unpublished data from trail cameras). Based on our results combined with those of Crampton et al. (2022), land managers in Kauai have decided to use the plastic excluders positioned 0–2 cm above ground to protect native birds from the risk of A24s at many sites.

Ensuring 100% protection for birds from A24s may require determining the minimum heights beneath a barrier that each bird species can pass beneath. Although our study has demonstrated a methodology to complete this for blackbirds and starlings, determining the minimum heights for which each bird species of interest can pass beneath may be unrealistic. Starlings and blackbirds can act as surrogates for species like puaiohi that are too rare to be adequately tested. Starlings are notorious for accessing small crevices and holes (Ingold 1998) and are probably the most difficult to exclude from A24s of the three species included in our trials. Indeed, more starlings than blackbirds defeated both excluder types, as we had expected. The shortest gap-height below barriers defeated by starlings was 1.9 cm, and the nine individuals that were successful at passing under such gaps represented 19% of the population tested. Although starlings are larger than blackbirds (e.g., starlings weighed an average of ~ 14 g more than blackbirds during our trials; Table 1), the shortest gap beneath barriers that blackbirds passed under was 2.9 cm (3 individuals). Other morphometric characteristics also may influence a bird's ability to pass under such gaps, and the large legs of puaiohi (~ 5 mm longer than starlings and blackbirds; Table 1) may be one characteristic that influences their abilities to duck under barriers. Using barriers with minimal gaps that birds cannot pass beneath, like the 1.9 cm for starlings and 2.9 cm for blackbirds, could be an improved future strategy for designing A24s excluders. Figure 9 represents such an untested A24 excluder that could have the gap height adjusted for prevention of the small birds of interest while still allowing rodent access and preventing rodent carcasses from blocking the A24 entrance. Unlike the narrow cylinder designs of the plastic and metal excluders that we tested, the prototype design (Figure 9) allows target rodents to drop to the ground unobstructed when killed by the A24, and therefore clear from the A24 entrance. Scavengers could freely reach under and pull carcasses out of the interior area of the excluder that surrounds the A24. One potential problem is that it may be difficult to maintain the barrier height (distance between barrier and ground) of such a wider diameter excluder in uneven terrain. However, a potential solution to this scenario may include elevating the A24 and fastening a platform (e.g., wooden plank; as in Baldwin et al. 2022) just below an excluder such that a constant barrier height can be maintained. Although barrier heights could become too low for target rodents to defeat, and such minimum gap sizes have not been determined for invasive rodents to our knowledge, individuals of *Mus musculus* L., 1758 and *R. rattus* L., 1758 passed through 1.3 cm and 2.5 cm holes, respectively (R. Sugihara, *unpubl. data* within Pitt et al. 2011), suggesting

Figure 9. A prototype bird excluder that has not yet been tested. The height from ground to base of the metal mesh excluder could be adjusted to 1.9–2.9 cm (heights based on our study; see Figure 7), or another empirically derived height, to ensure that the bird species of interest could not successfully duck under the excluder, yet the enclosed space beneath the A24 is large enough that killed rodents would not block the entrance. Scavengers could freely reach under and pull carcasses out of the interior area of the excluder that surrounds the A24. The A24's gas canister and lure would be serviceable without having to remove the excluder. Photograph by Aaron B. Shiels.

that the 1.9–2.9 cm starling-blackbird gap heights would be within the height range that invasive rats and mice could defeat.

Management implications

The use of Goodnature A24 rat-stoat traps may be increasing worldwide (B. Calder *pers. comm.*; Automatic Trap Company *unpubl. data*), and while reports of non-target bird mortalities have been infrequent, they may have substantial consequences and be concerning for a wide suite of native bird species. The effectiveness of the plastic and metal excluders at reducing passerine entry into A24s in these aviary trials is sufficient to recommend the use of these excluders around sensitive birds that frequent the ground or lower understory (≤ 50 cm trap height) in the field where it is not possible to conduct such controlled trials. In most cases, elevating A24s is not recommended over securing traps low (11–12 cm above ground without excluders or 0–2 cm above ground with excluders) due to our findings and limited trials with elevated traps. Based on our trials and recent field uses of these excluders, the plastic excluder tended to perform best for preventing trap entry of all three bird species if positioned 0–2 cm above ground. However, if 100% protection from A24 injury and death is desired for birds, additional testing appears necessary, and this may require a new excluder design with a wider diameter and a gap-height threshold appropriately sized for the sensitive bird species in the A24 deployment area. A major trade-off for using excluders is that they may significantly reduce rodent control, as Crampton et al. (2022) determined. Such findings suggest managers should consider using excluders when rare or sensitive non-target species are likely to frequently visit and explore the inside of A24s, while balancing the possible decrease in efficacy of target species control. Such decisions will probably be site- and species-specific.

Acknowledgements

We thank United States Department of Agriculture (USDA) Wildlife Services Operations staff and S. Werner in Colorado for providing blackbirds and starlings for this study. Thanks to Kauai Forest Bird Recovery Project/Hawaii Division of Forestry and Wildlife for donating non-functioning A24 traps for the trials, and the U.S. Army Natural Resource Program on Oahu for donating plastic Goodnature excluders. All trials involving starlings and blackbirds were approved under the USDA National Wildlife Research Center's Institutional Animal Care and Use Committee (IACUC) study protocol QA-3189. Puaiohi care was conducted under U.S. Fish and Wildlife Service Native Endangered Species Recovery Permit TE060179-6, State of Hawaii Division of Forestry and Wildlife Protected Wildlife Permit WL19-26, and San Diego Zoo Wildlife Alliance IACUC protocol 19-004. Mention of a company or commercial product does not mean endorsement by the U.S. government.

Authors' contribution

ABS, LHC, LB, and BM conceptualized the study; all authors participated in sample design and methodology; ABS, DS, AG, and KE collected the data; ABS analyzed the data; ABS and BM obtained ethics approval; ABS, LHC, LB, and BM acquired the funding; ABS wrote the original draft; all authors reviewed and edited the paper.

Funding declaration

Funding for this research was provided by Hawaii Division of Forestry and Wildlife (DOFAW), San Diego Zoo Wildlife Alliance, and the United States Department of Agriculture (USDA). The funders' staff had a role in the study design, data collection and analysis, decision to publish, and preparation of the manuscript. Mention of a company or commercial product does not mean endorsement by the U.S. government.

Ethics and permits

All trials involving starlings and blackbirds were approved under the USDA National Wildlife Research Center's Institutional Animal Care and Use Committee study protocol QA-3189. Puaiohi trials were approved under the San Diego Zoo Wildlife Alliance Institutional Animal Care and Use Committee protocol 19-004.

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