Efficiency and Efficacy of DOC-200 Versus Tomahawk Traps for Controlling Small Indian Mongoose, Herpestes auropunctatus (Carnivora: Herpestidae) in Wetland Wildlife Sanctuaries

Authors: Roerk, Lisa S., Nietmann, Lindsey, and Works, Aaron J.

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Efficiency and Efficacy of DOC-200 Versus Tomahawk Traps for Controlling Small Indian Mongoose, *Herpestes auropunctatus* (Carnivora: Herpestidae) in Wetland Wildlife Sanctuaries[1]

Lisa S. Roerk,[2] *Lindsey Nietmann,*[2,3] *and Aaron J. Works*[2]

Abstract: Hawai'i's native waterbirds are conservation reliant and need active management including predator control for the foreseeable future. The small Indian mongoose (*Herpestes auropunctatus*) is a detrimental predator to Hawai'i's native waterbirds: mongoose prey upon eggs, chicks, and adults. An effective trapping and baiting regime is fundamental in the control of this invasive predator. We examined whether DOC-200 kill traps or Tomahawk live traps are more effective in capturing mongoose. We also compared the cost efficiency of DOC-200 and Tomahawk traps. Throughout the study 114 animals were captured, of which 49 were mongoose (28 males, 14 females, 7 unknown sex). DOC-200 and Tomahawk traps did not differ in the number of mongoose captured. The trapping regime where DOC-200 traps were checked once a week proved to be most efficient ($40.70/mongoose), regimes where DOC-200 traps and Tomahawk traps were checked three times a week cost $65.20/mongoose and $102.80/mongoose, respectively. The results from our study give insight on trap preference, which can be used in other management areas that are impacted by mongoose in Hawai'i, as well as providing cost effective trapping regimes for managers.

Keywords: predator control, DOC-250, live trap, Kawainui Marsh

The small Indian mongoose (*Herpestes auropunctatus*; hereafter 'mongoose') was deliberately introduced to 64 different islands and at least one continental mainland area for pest control (Barun et al. 2011). Introduction of the mongoose to Pacific islands has been detrimental to native bird, mammal, amphibian, and reptile populations, earning the designation as one of the world's 100 worst invasive species (IUCN 2000, Hays and Conant 2007). In 1883, the mongoose was introduced to sugar cane plantations on Hawai'i Island, then later intentionally introduced to O'ahu, Maui, and Moloka'i to control rat (*Rattus* spp.) populations (Hays and Conant 2007). This failed as a biocontrol as rats are facultatively nocturnal in the presence of predators, and mongooses are strictly diurnal, and normally do not climb unlike rats (Nellis and Everard 1983). Today, the apex predator is ubiquitous within those islands, yet remains absent from Kaua'i, Ni'ihau, and Lāna'i (Duffy et al. 2015).

Human invaders, human impact, habitat loss, and other pressures have caused the state of Hawai'i to have more endangered species than any other state (USFWS 2021). Before human contact, Hawai'i lacked terrestrial predators, and ground nesting waterbird populations bred without much interference (National Academy of Sciences 2004). Hawai'i's wetlands today provide habitat to five endangered and endemic waterbirds:

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[2]Hawai'i Department of Land and Natural Resources, Division of Forestry and Wildlife, 2135 Makiki Heights Drive, Honolulu, HI 96822, USA.
[3]Corresponding author (e-mail: lindsey.nietmann@hawaii.gov).

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Hawaiian Stilt (aʻeo, *Himantopus mexicanus knudseni*), Hawaiian Gallinule (ʻalae ʻula, *Gallinula galeata sandvicensis*), Hawaiian Coot (ʻalae keʻokeʻo, *Fulica alai*), Hawaiian Goose (nēnē, *Branta sandvicensis*), and Hawaiian Duck (koloa maoli, *Anas wyviliana*) (Underwood et al. 2013). All of Hawaiʻi's waterbirds are conservation reliant, and require active management, including predator control for the foreseeable future (Underwood et al. 2013). Mongoose control is one of the most important management objectives in Hawaiʻi's wetlands, since mongoose prey upon endangered waterbird eggs, young, and potentially adults at wetlands statewide (USFWS 2011, Harmon et al. 2021, L. Nietmann and A. Works, unpubl. data).

Currently in Hawaiʻi and worldwide, the predominant mongoose control strategy is trapping (Coblentz and Coblentz 1985, Smith et al. 2000, Barun et al. 2011). Predator-proof fencing, although effective (Christensen et al. 2021), is cost-prohibitive at most sites. Toxicants such as diphacinone have been effective in field trials (Smith et al. 2000), but the current United States Environmental Protection Agency (EPA) registry does not include any toxicants approved for use on mongoose. Other toxicants are being trialed for mongoose (Sugihara et al. 2018), but in the meantime wildlife managers need to design trapping programs to be maximally effective and efficient. One previous study found that DOC-250 traps killed more mongoose than Tomahawk live traps, however sample size was small and statistical analysis was not performed (Peters et al. 2011). Pitt and Sugihara (2008) found that food baits (e.g., fish, meat scraps, egg, hotdog, coconut) can elicit more bait station visits and captures than synthetic baits (e.g., fish sauce, fatty acid scent, civet musk, catnip, synthetic fermented egg); and food baits can attract mongoose away from their normal home ranges. In a comparison study between novel food baits, mongoose were generally non-selective between bait types and frequently visited bait stations with beef, fish, egg, sausage, or coconut (Pitt et al. 2015). Mongoose can be lured from farther distances to baits that emit strong olfactory cues, but visually attractive baits (egg) can attract mongoose to bait stations as well (Pitt et al. 2015). Our objectives were to determine (1) which trap is preferred by mongoose in a side by side comparison of DOC-200 kill traps and Tomahawk live traps, (2) and which trap type is the most efficient and cost effective.

METHODS

Study Area

The study was conducted at Kawainui Marsh State Wildlife Sanctuary (21° 22′ N, 157° 45′ W; hereafter 'Kawainui'), in Kailua on the east side of the island of Oʻahu, Hawaiʻi, USA. Kawainui is the largest freshwater wetland in the state of Hawaiʻi, and was listed as a Ramsar Wetland of International Importance in 2005. The State Wildlife Sanctuary is managed by the Department of Land and Natural Resources (DLNR), Division of Forestry and Wildlife (DOFAW). Kawainui provides habitat for the Hawaiian Stilt, Hawaiian Gallinule, and Hawaiian Coot. At Kawainui, predation by mongoose ($n = 6$) caused the failure of 29% of nests in 2020 (L. Nietmann, unpubl. data). Prior management at the restoration ponds at Kawainui employed Tomahawk traps or DOC-200 traps. DOFAW managers suspected that live traps were more effective, but the two trap types were never used concurrently; therefore any apparent differences in effectiveness could be due to seasonal variation or other extraneous factors.

The study area was restricted to the restoration ponds (16.2 ha). The restoration ponds are separated into two pond areas intersected by Maunawili Stream. Each pond has five or six terraced cells 0.16–1.66 ha in size separated by low earthen berms. The cells are arranged in a mosaic pattern and rely on rainfall and flooding of Maunawili Stream for water.

Trapping

Mongoose were trapped using Tomahawk live traps and DOC-200 kill traps. Traps were placed inside and outside of the fenced restoration pond area. Two trap pairs were stationed per pond-cell on the access road surrounding the ponds (Figure 1*A*). Each trap

FIGURE 1. (*A*) Trapping locations of DOC-200 and Tomahawk trap pairs on access roads at the restoration ponds at Kawainui Marsh State Wildlife Sanctuary, Kailua, O'ahu, Hawai'i, USA. (*B*) DOC-200 trap and Tomahawk trap spaced 2 m apart, with entrances facing each other. (*C*) Inside DOC-200 trap, trap entrance at bottom with 8 × 8 cm hole, leading into mesh screen with 8 × 8 cm hole in front of DOC-200, stainless-steel DOC-200 trap triggered when stepped on, followed by bait jar.

pair consisted of a Tomahawk trap and a DOC-200 trap spaced 2 m apart, with trap entrances facing each other (Figure 1*B*).

Tomahawk live traps (Tomahawk Live Trap, Hazelhurst, WI, USA) were 23 × 23 × 66 cm open-door cage traps. When an animal steps on the treadle on the inside of the cage, the door closes, trapping the animal inside. Animals caught in Tomahawks were euthanized with a 0.22 caliber pistol. DOC-200 traps (CMI Springs Ltd., Auckland, New Zealand) were 18 × 19 × 11 cm, housed in 24 × 24 × 41 cm wooden one-way tunnel box traps. Wooden boxes were affixed with a mesh screen on the front and back end, with a 8 × 8 cm hole at the entrance. The inside of the wooden box contained (in order from entrance to end of trap) a mesh screen with an 8 × 8 cm opening 13 cm from the entrance, a stainless steel DOC-200 predator trap, and bait (Figure 1*C*). The DOC-200 trap is a powerful and humane trap that euthanizes predators when the treadle is stepped on and triggered.

Traps were baited weekly, alternating weeks to introduce novelty and increase interest in traps between frozen fresh fish and dry cat food (Purina Friskies Seafood Sensations adult cat food, Nestlé Purina PetCare Company, St. Louis, MO, USA) mixed with salmon oil (TrapShed Supply Co., USA). Traps were checked Monday, Wednesday, and Friday every week from February 24 to June 9 of 2021. Data on trap status (empty, capture, false trigger), species trapped, sex, date, and bait type were recorded on a smartphone using the Esri ArcCollector application.

We calculated chi-square goodness of fit tests to compare the number of mongoose captured between trap types, bait types, and sex ratios. All statistical analyses were performed in R (vers. 3.6.1; R Core Team 2019) with an α of 0.05 to indicate statistical significance.

Measuring Efficiency

A subset of seven trap checks were timed to compare efficiency between trap types. Efficiency was measured as cost per mongoose. Actions in timed checks include baiting, checking traps, euthanasia/removal, and entering data.

The cost per mongoose calculation compared three different trapping regimes: (1) Tomahawk traps checked three times a week, (2) DOC-200 traps checked three times a week, and (3) DOC-200 traps checked once a week. In the regime where DOC-200 traps were checked once a week, we re-calculated the number of animals caught by only taking the first animal caught in the week, since DOC-200 traps can only catch one animal at a time. The trapping regimes used represented the feasible number of trap checks DOFAW managers could employ.

Based on the subset of timed trap checks, we estimated the total time for checking and baiting traps for the duration of the study. We timed how long it took to reset traps with a capture, which we refer to as "reset time". Reset time included euthansia, carcass removal, and trap resetting. We took the average reset time per trap, then multiplied that by the total captures for each regime. The total cost was the sum of the time for baiting and checking traps per regime and total reset time, multiplied by the hourly cost of a technician which is $15/hour. Finally, we divided the total cost by the number of mongoose captured under each trapping regime.

RESULTS

We captured 114 animals across 4,900 trapping days. DOC-200 traps caught 30 mongoose (0.012 mongoose/trap day) and Tomahawk traps caught 19 mongoose (0.008 mongoose/trap day). During the study a total of 65 by-catch animals were captured (Table 1). DOC-200 traps had a catch rate of 0.029 animals/trap day, and Tomahawk live traps caught 0.017 animals/trap day. Overall, more male mongoose ($n = 28$) were captured than female mongoose ($n = 14$; $\chi^2 = 4.67$, df = 1, $P = .03$). Tomahawk traps caught 13 males, 3 females, and 3 mongoose of unknown sex and DOC-200 traps caught 15 males, 11 females, and 4 mongoose of unknown sex (mongoose were either juveniles and sex was unidentifiable or mongoose were too decomposed to sex). There was no difference in mongoose captures between Tomahawk and DOC-200 traps ($\chi^2 = 2.47$, df = 1, $P = .12$; Figure 2). There was no significant difference in the number of mongoose captured between bait types ($\chi^2 = 2.06$, df = 1, $P = .15$).

The cost of using Tomahawk traps and DOC-200 traps checked three times weekly was $102.80/mongoose and $65.20/mongoose, respectively; DOC-200 traps checked once weekly cost $40.70/mongoose.

DISCUSSION

We found that Tomahawk live traps and DOC-200 kill traps were equally effective at removing mongoose. However, when labor costs were considered, DOC-200s were more cost efficient in capturing mongoose since they could be checked once per week with minimal decrease in mongoose catch rate. Tomahawk live traps required more skilled and intensive labor as they must be checked three times a week and need licensed staff for firearm euthanasia. Our data suggest that checking DOC-200 traps once per week offers wildlife managers a cost-effective

TABLE 1

Total Counts of Species Captured in DOC-200 and Tomahawk Traps at the Restoration Ponds at Kawainui Marsh State Wildlife Sanctuary, Kailua, O'ahu, Hawai'i, USA, from February to June 2021

Taxonomic Group	Species	DOC-200 Captures	Tomahawk Captures
Mammals	Mongoose	30	19
	Cat	0	3
	Pig	0	1
	Rat	5	0
Reptiles	Red-eared Slider	0	8
	Chinese Softshell	0	3
Amphibians	American Bullfrog	0	1
	Cane Toad	27	0
Fish	Chinese Catfish	1	1
Birds	Spotted Dove	3	4
	Red-crested Cardinal	3	0
	Common Myna	2	2
	Zebra Dove	1	0

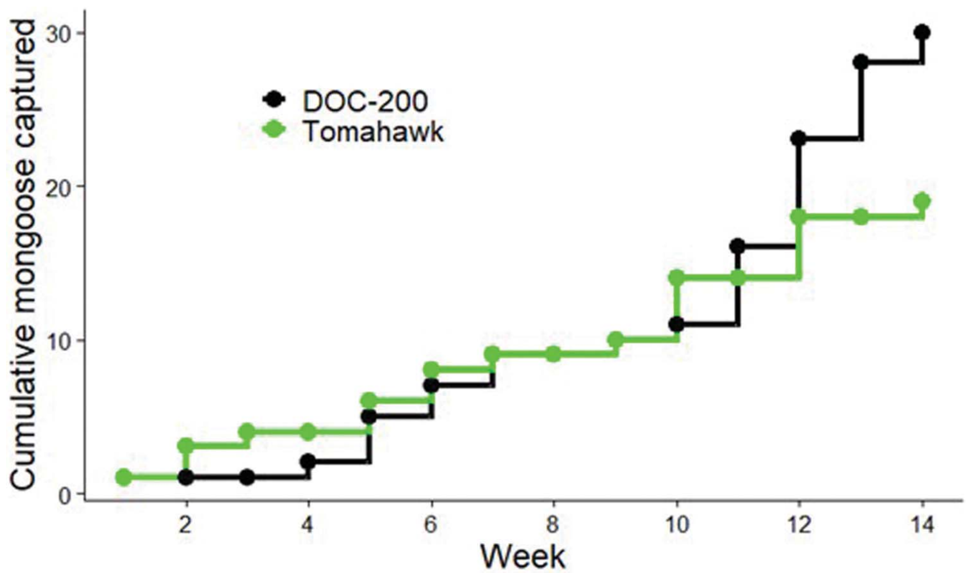

FIGURE 2. Cumulative mongoose captures for DOC-200 and Tomahawk traps per week at Kawainui Marsh State Wildlife Sanctuary, Kailua, O'ahu, Hawai'i, USA.

mongoose control option, however it may be important to occasionally introduce other trap types and/or toxicants to target individuals that are trap-shy and/or habituated to one trap type. Future studies should examine the resource response (e.g., waterbird nest success) of different mongoose removal strategies to ensure that different trapping regimes offer equal resource protection in addition to equal removal rates.

Male mongoose dispersal rates in Hawai'i increase from January to March, while females tend to disperse more from August to October (Hays 1999). Trapping at Kawainui was conducted between these two seasons (February to June), and both trap types captured at a similar rate until the last two weeks of the study. DOC-200 traps captured eight mongoose (5:1 female:male sex ratio) in the last two weeks of our study, whereas Tomahawk traps captured only two mongoose (1:1 sex ratio; Figure 2). Continuing our study for multiple years would reveal whether the observed increase in mongoose captures was spurious or driven by seasonal movement patterns.

We captured twice as many male mongoose as female mongoose during the course of our study. This may be because female mongoose have smaller home ranges than males (Pitt et al. 2015) and thus were less likely to encounter our traps. Alternatively, males may have simply been actively dispersing during our study's timeframe (Hays 1999) and thus more likely to encounter a trap. From a management perspective, adult female mongoose may be more valuable to capture, since they have an average litter size of 2.7 pups, and reach sexual maturity within 4–6 months of age (Nellis and Everard 1983). Determining how best to catch females (e.g., targeting trapping efforts around potential denning habitat and/or determining whether females have a preference for certain baits or lures) is an important management objective that should be pursued in future research.

In another small-scale study, Peters et al. (2011) found that DOC-250 traps appeared more effective at removing mongoose than Tomahawk traps. DOC-250 traps are similar to DOC-200 traps, except they have a more powerful spring mechanism that makes resetting the trap more difficult for field technicians. Since our DOC-200s were housed in plywood boxes similar to the housings used by Peters et al. (2011), we do not believe that the differences in these two studies was due to the use of DOC-250s versus DOC-200s. Instead, the conflicting results of our study with Peters et al. (2011) suggest that mongoose behavior and capture rates may be influenced by habitat type, seasonality, and/or interactions between these and other factors. Ultimately, more research on the factors influencing mongoose capture rates is needed both in Hawai'i, where land managers need to control mongoose for the foreseeable future (Underwood et al. 2013) and worldwide, where invasive mongoose are considered one of the most damaging predators (Hays and Conant 2007).

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