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Tools and Technology

Use of Artificial Cavities by Humboldt Marten

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ABSTRACT Many species of wildlife require cavities in trees as locations for refuge or reproduction. In forests where the availability of cavities has been reduced, artificial cavities may provide surrogate locations. Artificial cavities are typically created using boxes and artificial cavity research has traditionally focused primarily on birds. However, there are numerous cavity-dependent species of mammals that are of regional and global conservation concern, such as the Humboldt marten (*Martes caurina humboldtensis*). Martens (*Martes* spp.) are small mustelids that often use cavities for daily resting and seasonal reproductive activities. During June 2013 to September 2015, we tested an artificial cavity design, modified from a design successfully used for European pine martens (*M. martes*), for the Humboldt marten in northwestern California, USA. We built and installed 16 artificial cavities ("marten" boxes) in marten-occupied areas that have been managed for timber production and likely have reduced cavity availability. We monitored each box with a remote-sensing camera for 2 years to evaluate visitation and use by martens and other cavity-dependent species. Eleven mammal species visited $\geq$1 boxes and 4 species entered the box to use it. Martens had the greatest number of box-use events, several martens used boxes for resting, and $\geq$1 female marten used a box for reproductive activities. Our results indicate that our boxes may provide artificial cavities for Humboldt martens in forests where natural cavities have been reduced due to timber harvest or severe wildfire.

KEY WORDS artificial cavity, California, mammal, marten, *Martes*, rest structure.

Tree cavities have been described as "keystone structures" and are critical habitat features for a suite of vertebrate species worldwide (Tews et al. 2004). Cavity use is most often associated with obligate cavity-nesting birds and small mammals such as squirrels (Cockle et al. 2011). However, some species of carnivorous mammals also use cavities, including the olingo (*Bassaricyon gabbii*) in South America, the common genet (*Genetta genetta*) in Europe, and the spotted-tailed quoll (*Dasyurus maculatus*) in Australia (Glen and Dickman 2006, Prange and Prange 2009, Carvalho et al. 2014). Carnivorous mammals may use cavities on a daily basis for resting, thermoregulatory benefits, protection from predators, and reproduction as secure locations for giving birth to and raising dependent young (Taylor and Buskirk 1994, Bull 2002).

Forest ecosystems are increasingly characterized by reduced availability of cavities, due to the loss of existing cavity-bearing trees and failure to recruit a new cohort of cavity-bearing trees (Lindenmayer et al. 2012). Recruitment of cavity-bearing trees is typically a slow process because trees must achieve sufficient age and diameter and also undergo cavity-formation processes, such as inoculation with heart-rot fungi, to develop cavities large enough to be useful for many vertebrate species (Cockle et al. 2012). Conversely, loss of cavity-bearing trees may occur over relatively short time periods as the result of anthropogenic (e.g., timber harvest) or natural (e.g., severe wildfire) disturbances (Lindenmayer et al. 2012). Timber harvesting in particular often removes large-diameter, old, live trees and snags; recruitment of additional large-diameter trees and snags may take decades to centuries (Stevenson et al. 2006, Gibbons et al. 2010). In western North America, cavity-bearing trees may take >100 years to develop in Douglas fir (*Pseudotsuga menziesii*) forests (Franklin et al. 2002), whereas timber harvest rotations in commercial Douglas fir forests may be as short as 60 years (Busing and Garman 2002). This disparity in time results in forests that are managed primarily for timber production having significantly fewer natural cavities than unmanaged forests (Cline et al. 1980, Lindenmayer and Franklin 2002).

In forests where natural cavities are rare or absent, artificial cavities may act as surrogates. Artificial cavity research has

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traditionally focused on birds, and "nest" box studies have been used for almost a century to investigate life-history traits of a suite of bird species (Møller 1989, Czeszczewik et al. 2008). Conversely, research on artificial cavity use by carnivorous mammals is extremely sparse. In one of few studies worldwide, Messenger et al. (2006) designed and deployed "den" boxes to support resting and reproductive activities of the European pine marten (*Martes martes*) on commercial forests in Scotland. In the initial trial, 40% of den boxes showed clear evidence of pine marten use within 14 months after deployment; den boxes are currently deployed for pine martens in England, Ireland, Scotland, and Wales (Vincent Wildlife Trust 2017).

In North America, several members of the family Mustelidae, including the American marten (*M. americana*), Pacific marten (*M. caurina*), and fisher (*Pekania pennanti*) also use cavities for resting and reproduction (Buskirk and Ruggiero 1994, Bull and Heater 2000, Zielinski et al. 2004, Slauson and Zielinski 2009). Cavity-bearing structures are often large in diameter and old in age (Raphael and Jones 1997, Bull and Heater 2000, Zielinski et al. 2004, Slauson and Zielinski 2009). Although martens and fishers may use a variety of locations for resting and reproduction, cavities potentially offer such benefits as optimized thermal buffering and increased protection from predators compared with other locations (Wiebe 2001, Maziarz and Wesolowski 2013, Green 2017). Cavities appear to be particularly critical for reproductive fishers and martens as locations for giving birth to, and rearing of, unweaned and poorly mobile kits (Ruggiero et al. 1998, Bull and Heater 2000, Lofroth et al. 2010, Raley et al. 2012).

The Humboldt marten (*M. c. humboldtensis*), a subspecies of the Pacific marten found only in northwestern California and western Oregon, USA, is of conservation concern because of significant range reduction and subsequent decrease in population size over the past century (Zielinski et al. 2001, Slauson et al. 2009). Throughout the majority of its currently occupied range, the Humboldt marten is associated with late-successional and old-growth Douglas fir forests (Slauson et al. 2007). Early- to midsuccessional forests are generally considered to be low-quality marten habitat because they typically lack large-diameter, cavity-bearing, live trees and snags, among other critical forest resources (Buskirk and Ruggiero 1994, Payer and Harrison 2003). Although the initial population decline of the Humboldt marten is likely attributable to unregulated fur trapping (Twining and Hensley 1947), the continued absence of the Humboldt marten from large portions of its historical range may be due to reduced availability of habitat as the majority of mature forest in the region has been harvested (Fox 1996, Thornburgh et al. 2000).

Reduced cavity availability, in particular, may act as a limiting factor for marten populations, given the importance of cavities for female marten reproductive activities (Ruggiero et al. 1998). To increase cavity availability for martens, we built and deployed artificial cavities, using a modified version of the Messenger et al. (2006) "den" box design. A comprehensive plan for Humboldt marten conservation is currently under development with objectives of increasing 1) overall population size, 2) number of populations, and 3) overall geographic distribution (Slauson et al. 2017). Long-term actions to achieve these objectives include re-establishment of martens in areas of currently available but unoccupied habitat, protection and restoration of habitat where it can benefit existing populations of martens, and restoration of habitat connectivity where it has been lost. In the short term, our boxes may increase the availability of locations supporting marten resting and denning activities, thereby improving habitat quality and accelerating marten recolonization of harvested forests. To assess the effectiveness of boxes, we evaluated visitation and use patterns by martens and other cavity-dependent wildlife species over a 2-year period.

STUDY AREA

Our research took place in Humboldt County in northwestern California, USA (Fig. 1), on private timberlands owned by the Yurok Tribe. The study area covered approximately 25 km^2, with elevation ranging from approximately 500 m to 1,000 m. Annual temperatures in this region averaged 7–15° C and annual precipitation averaged 750–3,000 mm (USDA Forest Service 2007). The study area was dominated by tanoak (*Notholithocarpus densiflorus*) and Douglas fir forest associations, with other common tree species including bigleaf maple (*Acer macrophyllum*), golden chinquapin (*Chrysolepis chrysophylla*), Pacific madrone (*Arbutus menziesii*), Port Orford cedar (*Chamaecyparis lawsoniana*), red alder (*Alnus rubra*), sugar pine (*Pinus lambertiana*), and western hemlock (*Tsuga heterophylla*).

METHODS

Our marten box design (Fig. 2a–d) incorporated the same dimensions and structural components as the European pine marten "den" box (see Vincent Wildlife Trust 2014 for full box specifications). Box dimensions were approximately 60-cm height × 55-cm width × 25-cm depth. Box structural components included 2 lateral entrances located on the bottom of the tree-facing side of the box (Fig. 2a), a central inner chamber created by 2 baffles (Fig. 2b), a lateral access shaft on either side of the inner chamber leading from each entrance to the chamber (Fig. 2b), and a sloping roof to shed water (Fig. 2c). The purpose of the 2 baffles was to increase heat retention in the inner chamber. Chamber size was based on average dimensions of natural cavities used for denning by female European pine martens (Messenger et al. 2006).

Our marten boxes incorporated a number of design modifications to the Vincent Wildlife Trust design to improve longevity and increase structural integrity. The coastal forests within the range of the Humboldt marten receive large amounts of moisture annually. To increase water resistance, we constructed boxes out of the most rot-resistant native wood species available, including salvaged old-growth redwood (*Sequoia sempervirens*) and commercial-grade western red cedar (*Thuja plicata*); connected all exterior wood joints using a strong construction adhesive (Liquid Nails®, Strongsville, OH, USA); and fastened all wood joints

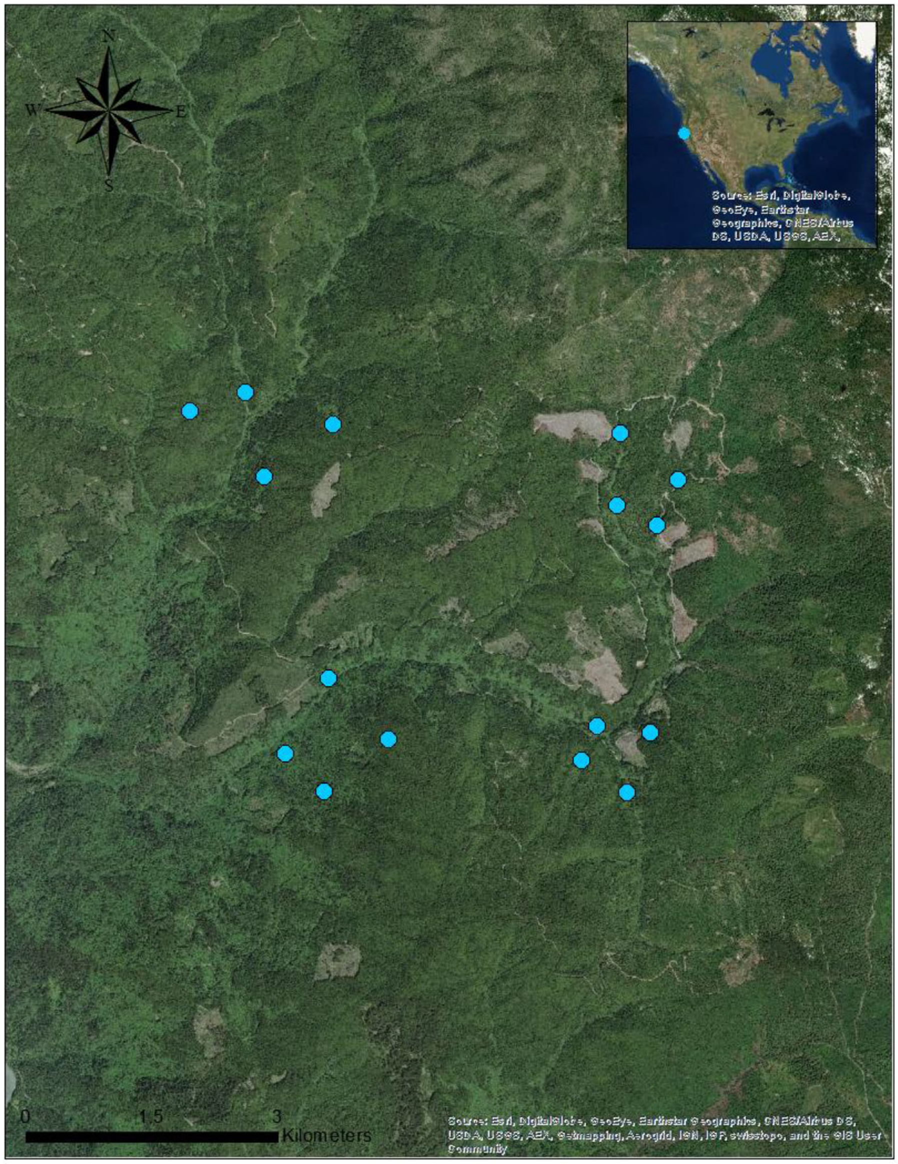

Figure 1. Location of Pecwan Creek study site in northwestern California, USA, where artificial cavity use of boxes by Humboldt martens was monitored during June 2013 to September 2015, including locations of 16 boxes (blue circles).

with 10–15-cm-long wood screws (TimberLok®, Fastenmaster Inc., Agawam, MA, USA). We increased wood thickness to 3.5–5.0 cm to minimize susceptibility of boxes to damage by American black bear (*Ursus americanus*). Finally, we decreased the size of box entrances to approximately 6.5-cm diameter, to reduce the likelihood of larger bodied marten predators (e.g., fisher; Hodgeman et al. 1997) entering boxes. This diameter is also the size of the entrance in the wooden "cubbies" commonly attached to the back of live traps to provide shelter for trapped martens (Wilbert 1992), and has been shown to allow unrestricted movement by both uncollared and radiocollared Humboldt martens while excluding larger bodied predators (K. M. Slauson, unpublished data).

In June and July 2013, we deployed 16 marten boxes in the Pecwan Creek watershed in northwestern California (Fig. 1) within the vicinity of telemetry locations for approximately 10 martens with very-high-frequency radiocollars (K. M. Slauson, unpublished data). We deployed boxes in groups of 4, using a 1-km^2 grid separated into 4 equal quadrants of 0.25 km^2 (i.e., 1 box deployed/quadrant), and a minimum spacing of $\geq$500 m between boxes. We sized grids similar to mean home-range size of female Pacific martens in California, with the intent of providing 4 boxes in each marten home-range-sized area (Martin 1987).

In each stand selected for deployment, we mounted boxes at a height of approximately 5 m on the largest diameter live tree available (Fig. 2d). We selected box-mounting trees that had an additional tree adjacent ($\leq$5 m) on which we installed a camera for monitoring purposes, and we oriented box entrances toward the camera. We designed our mounting system to minimize damage (e.g., girdling) to mounting trees as the trees age and increase in diameter. We used a paired wooden cleat system, with 2 cleats attached to each box (box

Figure 2. Humboldt marten box design for 16 boxes deployed at the Pecwan Creek study site in northwestern California, USA, between June and July 2013, including (a) tree-facing side of box including 2 lateral entrances; (b) box interior including 2 lateral access shafts and central inner chamber created by 2 baffles; (c) fully constructed box including attached roof; and (d) box mounted on a live tree.

cleats) and 2 corresponding cleats (tree cleats) attached to the mounting tree with 25-cm-long Timberlok (Fastenmaster Inc.) screws. We then placed box cleats on top of the tree cleats and bolted them together. Tree species used for box mounting were primarily Douglas fir but also included western hemlock (Fig. 2d).

We monitored animal activity at all boxes ($n=16$) with either Bushnell Trophy (Bushnell, Overland Park, KS, USA) or Reconyx HC500 (Reconyx Inc., Holmen, WI, USA) remote-sensing cameras. We mounted a single camera at approximately 2-m height on a tree upslope from the box, at a distance of $\leq$5 m from the box. Field of view for each monitoring camera included the upslope box portion, the upslope box entrance, and the adjacent upslope side of the tree bole. We set Bushnell Trophy cameras to record 10-s videos upon being triggered, with no delay between subsequent triggers. Reconyx HC500 cameras did not have video capabilities, and we set them to take photographic "bursts" (10 consecutive photographs) upon being triggered, with no delay between subsequent triggers. For the first 12 months of box monitoring (Jun 2013 to Jun 2014), we applied an olfactory lure (Gusto®, Minnesota Trapline Products, Pennock, MN, USA) near each box to increase the likelihood that martens would find the box, and we refreshed the olfactory lure at each revisit. We discontinued lure application for the remainder of the monitoring period (Jul 2014 to Sep 2015) to decrease bear activity at boxes and prevent potential box damage by bears.

We revisited boxes 8–10 times on approximately 12-week intervals from September 2013 to September 2015. During each revisit, we externally inspected boxes for signs of use (e.g., Messenger et al. [2006] commonly found scat deposits on the roofs of boxes that were used by European pine martens). We replaced memory cards and reviewed all photographic and video capture events at boxes. We considered discrete capture events to be 1) a single photograph or video of an identifiable mammal species or 2) a series of photographs or videos of an identifiable mammal species with no break between photographs or videos of >30 min.

We classified animal detections at boxes into 2 types of behaviors based on video or photographic evidence: visitation events or use events. A visitation occurred when an animal was photographed near the box or on top of the box but did not enter the box, or when an animal entered the box but exited in <20 min. A use occurred when an animal was photographed entering a box and remained in the box for >20 min. We assumed that animals remaining in the box for <20 min were "investigating" the box, rather than "using" the box for an activity such as resting. We only considered visitation and use events for species whose body size would allow them to enter the box, which excluded black bears. We were able to identify the majority (~90%) of animal visitation and use events to species. All methods were approved by Humboldt State University's Institutional Animal Care and Use Committee (Protocol 12/13.W.68-A).

RESULTS

We monitored animal activity at 16 boxes between June 2013 and September 2015 with remote-sensing cameras. We monitored boxes for a mean of 802 ± 4.5 (SD) days, resulting in approximately 12,800 camera-days of effort (no. of cameras × duration of monitoring). During our monitoring efforts, visitations were more common than events that demonstrated use. We documented 11 species visiting or using boxes, including 783 visitation events and 49 use events across all species (Tables 1 and 2). In addition, we detected black bears at 100% of boxes ($n = 16$) on 238 occasions.

Of the 6 carnivore species that visited boxes, martens visited the greatest number of boxes ($n = 14$, 88%), followed by fisher ($n = 11$, 69%), short-tailed weasel (*Mustela erminea;* $n = 2$, 13%), long-tailed weasel (*M. frenata;* $n = 1$, 6%), ringtail (*Bassariscus astutus;* $n = 1$, 6%), and western spotted skunk (*Spilogale gracilis;* $n = 1$, 6%). Total visitation events were greatest for martens ($n = 113$) and fisher ($n = 38$), with short-tailed weasel, long-tailed weasel, ringtail, and western spotted skunk rarely visiting boxes ($n \leq 5$ visits/species).

Of 5 noncarnivore species that visited boxes, Douglas squirrel (*Tamiasciurus douglasii*) visited the greatest number of boxes ($n = 15$, 94%), followed by northern flying squirrel (*Glaucomys sabrinus;* $n = 11$, 69%), chipmunk (*Neotamias* sp.; $n = 6$, 38%), mice (*Peromyscus* sp.; $n = 3$, 19%), and western gray squirrel (*Sciurus griseus;* $n = 2$, 13%). Visitation events were greatest for Douglas squirrel ($n = 428$) and northern flying squirrel ($n = 131$), followed by *Neotamias* sp. ($n = 43$), western gray squirrel ($n = 20$), and *Peromyscus* sp. ($n = 5$).

Martens used 3 boxes (19%; Fig. 3a and b), had the greatest number of box-use events ($n = 36$), and had the greatest ratio of box-use events to visitation events of any species (Table 1). Box use by species other than marten was limited. Three small mammal species used marten boxes: Douglas squirrel ($n = 11$), northern flying squirrel ($n = 1$), and *Peromyscus* sp. ($n = 1$). No carnivore species other than martens were documented to use boxes. Despite 38 visitation events at 11 boxes, fishers did not use boxes, and appeared to be excluded from entering boxes by the size of the entrance hole.

At least 2 individual martens appear to have used boxes—we could distinguish some individual martens because our study was contemporaneous with another study that radio-collared martens. Adult female marten F04 initially used box Pecwan Creek 5 (PC5) on 3 occasions in the nondenning season, during November and December 2013. F04 again used box PC5 on approximately 20 occasions between March and July 2015 and used a second box (PC8) on 7 occasions between June and July 2015. F04 appears to have used both boxes as maternal dens, determined by photographs of 1–2 kits with F04 on 1 occasion (9 Jul 2015) at box PC5 and on 7 occasions (between 21 Jun and 12 Jul 2015) at box PC8 (Fig. 3b). Martens typically defecate near natural cavities upon arrival and departure, and the presence of scat deposits on the roofs of both PC5 and PC8 offers further evidence of marten use of boxes. In addition, ≥1 unknown (i.e., not radiocollared) marten used box PC7 on 2 occasions between April and June 2015.

DISCUSSION

Our work has established that Humboldt martens will visit, enter, and use the boxes designed for both resting and reproductive activities. Among carnivore species, martens visited the greatest number of boxes and also had the greatest number of box-visitation events. Among all species detected, carnivore or otherwise, martens had the greatest number of box-use events as well as the highest ratio of box-use events relative to visitation events. At least 2 individual martens used ≥1 boxes; and martens used boxes for both resting and reproductive activities. This suggests that boxes may benefit martens on both a seasonal basis (as locations to raise dependent kits) and a year-round basis (as locations to seek refuge while resting).

Our boxes seemed to be well-sized to facilitate marten use while excluding use by larger bodied predators such as fishers, which was a critical measure of the success of our work. Weir et al. (2012) suggested that female fishers typically select cavities with entrances that are only slightly larger than their maximum skull width, providing them access to the cavity while preventing larger predator species from entering; martens likely select cavities in a similar manner. Box use by fishers could preclude use by martens (a marten may not enter a box that a fisher has previously entered), and fishers could also kill martens that are using boxes. It is likely that fishers were unable, rather than unwilling, to use boxes in this study because recent research has extensively documented fisher use of similarly designed, but larger sized boxes in British Columbia, Canada (Davis and Horley 2015).

Table 1. Box monitoring results for 6 carnivore mammal species at the Pecwan Creek study site in northwestern California, USA, June 2013 to September 2015. For each species, data reported include number of boxes visited (percent of total no. of boxes), number of visitation events across all boxes, number of boxes used (percent of total no. of boxes, if applicable), number of use events across all boxes, and approximate ratio of box-visitation events to box-use events (if applicable).

	Carnivore species					
Variable	Humboldt marten	Fisher	Short-tailed weasel	Long-tailed weasel	Ringtail	Western spotted skunk
Boxes visited	14 (88%)	11 (69%)	2 (13%)	1 (6%)	1 (6%)	1 (6%)
Visit events	113	38	2	1	1	1
Boxes used	3 (19%)	0	0	0	0	0
Use events	36	0	0	0	0	0
Ratio	3/1					

Table 2. Box monitoring results for 5 noncarnivore mammal species at the Pecwan Creek study site in northwestern California, USA, June 2013 to September 2015. For each species, data reported include number of boxes visited (percent of total no. of boxes), number of visitation events across all boxes, number of boxes used (percent of total no. of boxes, if applicable), number of use events across all boxes, and approximate ratio of box-visitation events to box-use events (if applicable).

	Noncarnivore species				
Variable	**Douglas squirrel**	**Northern flying squirrel**	***Neotamias* sp.**	**Western gray squirrel**	***Peromyscus* sp.**
Boxes visited	15 (94%)	11 (69%)	6 (38%)	2 (13%)	3 (19%)
Visit events	428	131	43	20	5
Boxes used	5 (31%)	1 (6%)	0	0	1 (6%)
Use events	11	1	0	0	1
Ratio	39/1	131/1			

We also concluded that box materials, construction, and mounting appeared sound. When designing our box, we were particularly concerned with preventing structural damage by black bears due to their large body size and strength. Despite instances of bears standing on, clawing at, and biting boxes, we identified only superficial damage to boxes by bears. We were also concerned with maximizing resistance of the boxes to moisture and rot. Over the course of the study, there was no apparent water damage to boxes; further, we did not identify any damage to boxes caused by other events, such as falling branches.

The use of olfactory lure offered both desired and undesired results. Martens appeared to be attracted by the lure—marten visitation events were greater in the first year of monitoring when olfactory lure was applied ($n = 81$ visits), compared with the second year after we had discontinued lure application ($n = 32$ visits). However, the olfactory lure also attracted black bears—during the first year of monitoring, we detected bears at all 16 boxes on 178 occasions. We chose to discontinue the lure application in the second year of monitoring to minimize bear activity at boxes and reduce the risk of bear damage; we subsequently detected bears at 13 boxes on only 62 occasions.

Marten use of boxes increased by >10-fold in the second year, despite an almost 3-fold decrease in marten visitation. However, much of this increase in use is due to a single marten, F04, who used 2 boxes on repeated occasions over a 5-month period in 2015. F04 appeared to have discovered ≥1 of the boxes as early as November 2013, but it is unclear why she did not use either box in the intervening time period between late 2013 and early 2015. It is also unclear why other martens visited boxes but did not appear to use them, although there are a number of possible reasons. We monitored boxes for a relatively short period of approximately 2 years; more time may be required for martens to find, investigate, and choose to use boxes. This is particularly true in the absence of olfactory lure or other mechanisms to attract martens to box locations. In addition, although our study site likely has reduced cavity availability as a result of intensive historical management for timber harvest, martens are not limited to using cavities within live trees and snags for resting and reproduction. Other potential cavities (e.g., logs, stumps, rock piles) may be of a sufficient quantity in our study site that martens do not need to use boxes.

Regardless, it remains important to consider what martens used boxes for, when they did use them; in other words, repeated use of boxes by a female marten for a critical life-history requirement (raising dependent kits) offers a promising result and may best indicate the potential value of boxes. Still, box use by martens should be evaluated over longer periods of time, at greater numbers of boxes, and at a larger geographic scale than was possible in this study. Continued and improved monitoring efforts at marten boxes may also better elucidate patterns of species visitation and use because estimates from this study are likely conservative for all species. For example, we were unable to identify approximately 10% of small-mammal visitation events at a taxonomic level more precise than the Family, and therefore excluded them from the data set. In addition, our monitoring efforts may simply have failed to document some use events. Monitoring cameras had a clear view of the upslope box

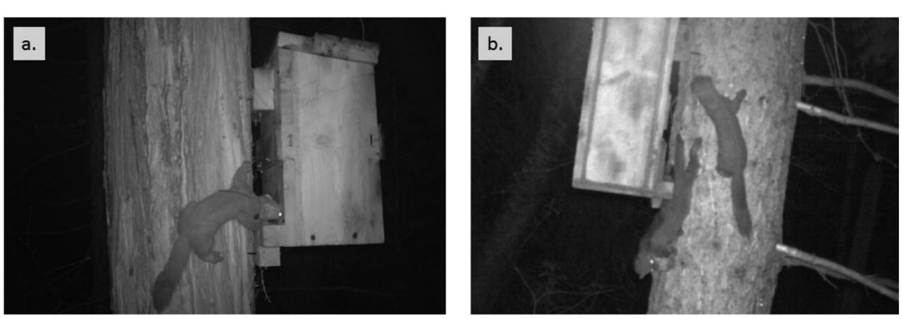

Figure 3. Examples of box use by Humboldt martens at the Pecwan Creek study site in northwestern California, USA, in 2015, including (a) an unidentified radiocollared marten investigating the entrance to box PC3 and (b) marten F04 at box PC8 with 2 dependent kits. F04 was photographed entering box PC8 on 7 occasions between 21 June and 12 July 2015 with 1–2 kits and appeared to be using the box as a maternal den.

entrance and the upslope side of the box mounting tree, but had an obscured view of the downslope entrance, and animals entering the box solely via the downslope entrance may not have been detected in certain instances.

Our study used a single remote-sensing camera to monitor animal activity at boxes. Future studies may choose to use multiple cameras simultaneously to provide better coverage of the box and its surroundings. Additional methods may offer further monitoring opportunities, such as integrating a hair-snare device into box entrances to collect genetic material from animals entering boxes, inserting an endoscopic camera into the box to investigate box contents or monitor kits in boxes, and incorporating a data logger into the box chamber to compare thermal properties of boxes with thermal properties of natural cavities.

Most of the forest within the historical range of the Humboldt marten has already been harvested (Fox 1996, Thornburgh et al. 2000); therefore, the fate of the Humboldt marten may be particularly dependent on improving the suitability of young, regenerating forests as potential habitat (Slauson et al. 2017). Several researchers have suggested that young forests may provide habitat for martens under certain conditions, such as if sufficient prey resources are available, or if sufficient structural complexity is retained (Baker 1992, Payer and Harrison 2003, Porter et al. 2005). Marten boxes may provide a critical resource, in the form of large cavities that support resting and reproductive activities where natural cavities are rare. Marten boxes could supplement existing natural cavities in areas that are marten-occupied and accelerate marten recolonization of forests with reduced or limited cavity availability.

Regardless of their potential applications, marten boxes will never perfectly replicate the conditions of natural cavities. It would be inappropriate to remove a natural cavity-bearing structure under the rationale that it can simply be replaced with a box. We suggest that, in the short term, forest management practices aimed at sustaining marten populations should focus on retention of late-successional forests where they still occur, including their associated cavity-bearing structures. Restoration of late-successional conditions in forests with reduced cavity availability and recruitment of a new cohort of cavity-bearing structures are long-term objectives that may benefit martens as well.

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