EXHIBIT D

MARTEN TRAPPING BAN PETITION

PUBLIC TESTIMONY RECEIVED AT MEETING

AUGUST 3, 2018

NOTE to ODFW Commission. The full peer reviews can be found here:

https://peerj.com/articles/4530/reviews/

I have pasted the rebuttal letters from the first round of review followed by the second round of review. This allows you to see comments and responses.

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12 January 2018

To the PeerJ team:

Thank you for considering our revised manuscript "**Density and population viability of coastal marten: a rare and geographically isolated small carnivore**" Article identification number (20529) for publication. We appreciate the helpful suggestions that we received from the reviewers and your facilitation of this manuscript.

Below are our responses to your comments and those of the reviewers. Our reply is written in italics and Times New Roman font with ">>" before our comment for ease of reading. We have attempted to clarify and revise our manuscript to accommodate all of the suggestions with a few exceptions that are explained within.

Thank you again for your time and consideration.

Respectfully,

Mark Linnell, Katie Moriarty, David Green and Taal Levi

Reviewer 1
Basic reporting
Generally looks fine to me (thanks, authors—written clearly is most places).

It might be helpful to include a layout of the trapping grid used for collaring, which I'll discuss below.

>> We have included the trapping grid in Fig. 1 and Fig 4.

L139—suggest "local convex hull (LoCoH)" and then using acronym rather than vice versa.

>> We have changed the text here per the reviewer's suggestion.

I suggest CRI rather than CrI as the acronym for Credible Intervals. In some places (e.g., L 249), you use plus/minus to denote a range—for clarity/ consistency, I would just stick with presenting CI or CRI for estimates rather than SE, and present means and range (rather than SD [? Not described]) when summarizing raw data.

>> We have changed raw data to mean and range, and changed estimates to mean with 95% CI or CRI where appropriate.

L256: the t-stat and p-value suggest no difference, but I think also presenting estimates of territory size by region with CI would give the reader a little more information.

>> Lines 262-266: We have included estimates of territory sizes using mean and ranges here, specifically because within our 4 groups (sex (m/f) x *study site (northern/southern)) we only have 2 individuals, we have just provided the values therein.*

Individual home range data are included in Table S1.

L290: The juxtaposition of the first two sentences in this paragraph is awkward. I think your point is that the observed anthropogenic mortalities, rather than evidence of a large population, instead suggest that the smaller population is at risk.

>> We agree this is awkward phrasing and have removed territory mapping from the paper entirely. The beginning of the discussion now reads (Lines 294-297):

"Our population assessment revealed that the central Oregon population of Humboldt martens likely has fewer than 75 adults divided into two subpopulations separated by a riverine barrier. Further, this population appears completely isolated with a lack of connectivity to the southern Oregon population. Based on the small population sizes of these subpopulations, our population projections suggest that even a small amount of human-caused mortalities will strongly increase the likelihood of extirpation over the next 30 years."

L301: Can you reword this? "Additional resolution" reads a little awkwardly.

>> We have removed reference to nesting birds and adult female mortality. This point is rephrased in the paragraph starting at Line 333 (Lines 336-351):

> *"Marten populations can be resilient to fur harvest when they are abundant, and if breeding females are harvested infrequently compared to males, particularly juvenile males (Robitaille 2017, Banci & Proulx 1999). Adult females in our study were observed more frequently than adult males at ratios of 1.5:1 (live-trapping) and 3:1 (SMR). Our results were atypical of ratios observed in other marten research studies and in harvested populations; these studies typically demonstrate higher male to female ratios (e.g., McCann et al. 2010; Payer & Harrison 1999; Robitaille 2017). Intolerance among same-sex individuals resulting in intrasexual territoriality typical of martens (Moriarty et al. 2017; Powell 1994) may require juveniles to disperse outside of the Oregon Dunes, especially if the long, narrow forested habitat resulted in elevated encounter rates between juveniles and resident adults. Alternatively, we spaced live-traps at a relatively fine-scale in our study compared to other studies which may have resulted in higher trap encounter rates by females. Regardless of the mechanism, resident breeding females appear to be extremely vulnerable to live-trapping in the Oregon dunes. We predict that limiting fur harvest to areas outside of the Oregon dunes would result in take of more dispersing juveniles and males compared to females, reducing the immediate risk of short term marten extirpation.*

L305: Rather than disproportionate, suggest saying greater or larger. Not sure why "nesting birds in plowed fields" needs to be explicitly included in this sentence.

>> We removed the reference to nesting birds, which was a factor increasing adult female mortality.

Generally, the discussion seems a little less fully formed than other sections of the manuscript. I'll revisit this in section three, but want to note it here because some issues with interpretation may simply be issues with the clarity and structuring of the writing.

>> We have completely re-written the discussion.

From looking at the code and the text, it's not clear to me how density is being estimated or when the masking is taking place: is D estimated as N-hat/Area with or without the masking of specific cells, or as the mean of the estimated point process intensity, or?

>> Density was calculated in the post-process by estimating the number of activity centers in suitable habitat in our study area. We defined our suitable habitat information (Lines 107-115) and then extrapolate the SMR results to only vegetation data (Lines 186-195, 212-213; Figure 3).

Lines 107-115: To distinguish vegetation cover (i.e., primarily forests) from open sand we used airborne light detection and ranging data collected at 1-m resolution. We defined vegetation cover as > 40% cover of pixels > 1 m in height within a 100-m circular radius moving window of each pixel. This process produced a raster layer that smoothed small gaps in vegetation cover (i.e., sand gaps >30 m) that martens could presumably move through but that excluded broad expanses of open sand that we assumed represented non-habitat for martens, particularly because of the presence of predators (Moriarty et al. 2015). The northern (i.e., north of Umpqua River, Fig. 1b) and southern (i.e., south of Umpqua River, Fig. 1c) study areas were comprised of 36.9 km^2 and 25.6 km^2 of vegetation cover, respectively.

The data is set up in a standard flat format, which is fine and easier to store: for transparency, I might just add a comment to the code file indicating that the input data needs to be manipulated prior to model fitting.

>> We have added the structure of our manipulated datasets to the supplementary material so that readers can fit our model using our data. However, we have altered the location data so the rare species is not in danger of trapping or other impacts.

Table 1: The input value for m here doesn't seem to have any connection to the studies you cite—typo?

>> We added a footnote to Table 1: "We choose m=1.5 assuming 3 offspring and a 50% sex ratio as reasonable as among the highest observed litter size that would be expected to be achieved at low population density. For instance, Strickland & Douglas (1987) reported that both pregnancy rates and numbers of corpora lutea in pregnant female martens in Ontario were stable, ranging from 91–100% and 3.19–3.53, respectively. Aune & Schladweiler (1997) reported pregnancy rates similar for 2 populations in Montana, ranging from 76–95% over 5 years, but a lower mean number of corpora (2.6) per adult female in the southwestern part of the state leading to an estimate of m = 1.1. Thompson & Colgan (1987) reported 2.74–3.46 corpora lutea in pregnant females. Flynn and Schumaker (2016) observed pregnancy rates of martens in Southeast Alaska averaging only 47% over seven years while litter size was 3.3, producing an estimate of m = 0.78."

Table 4: Could you present p0 parameters as p0[male] and p0[female]? It's not immediately clear which sex is which as presented.

>> We have included subscripts for male and female in this updated analysis, now displayed in Table 3.

Fig 1: Could you add an additional inset showing the distribution of cameras/traps? They don't show up well here.

>> We included insets in Fig. 1 to accommodate.

Fig 2: Instead of Mortality = x (which seems deterministic), how about Average Mortality = x?

>> We included average mortality in Figs. 5 and 6. Figure 2 was displaying remote camera photographs and does not include the word mortality.

Experimental design

I guess I interpret this part of the review as pertaining to methods/implementation. This is a clever design for answering the questions of interest, and the sampling effort (and the data collected) seem sufficient.

Several questions about how density was estimated. Throughout, I suggest describing this as a spatial mark-resight study rather than spatial mark-recapture (the same acronym is fine) because the model incorporates unmarked and marked detections.

>> We have used spatial mark-resight throughout.

1) A more detailed description of how unmarked observations and telemetry observations were integrated within the text is necessary for a reader to figure out what was performed without digging into code. Royle et al. use telemetry to get a better sense of habitat use (e.g., habitat/environment based changes in lam0 related to third order resource selection), while Sollmann et al. use telemetry exclusively to derive sigma (as performed here). The description of how of unmarked detections were integrated is similarly opaque (but seems to follow the likelihood described by Chandler and Royle in the 2013 AoAS paper). Please include some fundamental parts of the likelihood pertaining to these components of the model.

>> We have added more detail on the treatment of telemetry locations and unmarked individuals in the methods (Lines 196-204, and Supplemental Article S1).

"We followed Whittington et al. (2018) in their treatment of the sightings of unmarked individuals; the number of unmarked individuals detected at camera station j on night k (nU_{jk}) *was modeled as:*

$$nU_{jk} \sim Sum(yu_{1jk}, yu_{2jk}, yu_{3jk} \ldots yu_{ijk})$$

$$yu_{ijk} \sim Bern(pcam_{ijk})$$

where the number of sightings of unmarked individuals was modeled to be generated from a latent Bernoulli process of resight probability ($yu_{ijk} \sim Bern(pcam_{ijk})$)*, based on the same probabilities of resighting as defined previously* ($pcam_{ijk}$)*. The code for our SMR model can be found in Appendix 1."*

2) Could you provide more detail regarding the spatial configuration of the live-trapping effort in relation to the camera trapping effort? One assumption of SMR models is that the spatial distribution of marked and unmarked individuals is essentially the same, but it's tough to evaluate this without a sense of where the live-traps were placed. My sense is that this assumption is being violated (it seems like marked detections far outweigh unmarked detections, and that marked animals are much more exposed to sampling than unmarked animals), and it can lead to bias/poor coverage (see recent paper in Journal of Applied Ecology by Jesse Whittington et al. regarding "Generalized Spatial Mark-Resight" for a description of the issues and models to deal with them).

>> We have now incorporated the marking process directly into the spatial mark-resight likelihood to account for any issues in bias arising from differences in the probability of capture versus the probability of resighting following Whittington et al. (2018).

3) I'm generally all for integration of disparate data sources to improve estimate precision. But one risk of integrating different data sources to estimate a shared parameter is that if the parameter is not 'shared' between datasets, you're going to get a (precisely) biased estimate

(There's a paper "Balancing precision and risk" by Tabitha Graves et al. [2012] in Plos One that describes this nicely). I have some misgivings about integrating the telemetry and detection data in this case because I'd expect that baiting at cameras might be altering animal space use. Previous studies have suggested that incorporating telemetry data from a few individuals has basically no effect on estimates of density, but in this case, most of the data used to estimate sigma are derived from telemetry data: if 'telemetry sigma' is actually smaller than 'trap sigma' (which is what I'd surmise), shrinkage in estimates of the shared parameter might lead to overestimating marten density. Although Viorel Popescu's 2014 paper with fishers implies that there probably is no consequence of combining these data types, I guess I would feel more comfortable with integrating the telemetry data if you could provide some evaluation of their consistency or sensitivity to their consistency. Maybe the easiest way to evaluate sensitivity is to see whether estimates change very much if the telemetry data are removed.

>> *Martens are extremely territorial, traveling their entire territory in 4.6 days (Moriarty et al. 2016b; Moriarty et al. 2017). The sigma values based on the resighting information alone are likely to be inflated without the telemetry information because these martens live in such irregular habitat in coastal Oregon. When we ran the same model with and without telemetry data, the sigma values were in fact larger for martens without telemetry data included, but the sigma values for females were not significantly different (sigma female w/ telemetry (mean; 95% CRI) = 277.81 (266.46, 290.1); sigma female w/out telemetry = 302.969 (276.65, 336.4)), and males nearly overlapped (sigma male w/ telemetry = 1141.22 (1058.39, 1233.75); sigma male w/out telemetry = 1422.66 (1238.88, 1626.26)). If the sigma values were heavily influenced by the baiting, we might predict the sigma values to be smaller without the telemetry data included. This, however, was not the case. To help distinguish between the effects of baiting on sigma and the probability of capture, we have now also incorporated an effect on detection probability that takes into account the bait; we now estimate how the presence of bait or, rather, the quantity that is likely to remain, effects the probability of detection.*

4) The observation likelihood is off. Y is treated and described as a Poisson RV, but you seem to be imposing restraints to make it behave like a Binomial RV wherever possible (e.g., you're placing a natural limit on Y based upon the number of days a camera operated because defining Y as the number of days in which an individual was detected [the exact # successes in K trials that defines the Binomial distribution], and modeling variability in the intercept using a logit function). My guess is that you're forcing this as a Poisson observation model to allow the unmarked data to be integrated following Chandler and Royle 2013—but that observation model isn't necessary to integrate the unmarked data. I'd use a Binomial/Bernoulli observation model instead: the unmarked component of the model should look a little more like the what is described by Chandler and Clark 2014 (Methods in Ecology and Evolution 5[12]) or David Ramsey et al. 2015 in the Journal of Wildlife Management (79[3]). For consistency with the literature, use p[i,j,k] and p0 rather than lamda and lam0 when using a Binomial/Bernoulli observation model.

>> *We have now updated the observation likelihood for the camera resight data. We now model these based on the detections of individual i at camera j on night k using a Bernoulli process (Lines 198-203, Supplemental Article S1). We have also updated the naming of p and p0.*

5) Because the stations are baited, I think that incorporating a behavioral response to initial capture (probably a trap-specific behavioral response) using an indicator covariate is probably important. This is typically modeled using a Bernoulli encounter model. The Bernoulli likelihood will take a little longer to run, particularly with an imhomogenous point process model—here's a description of a tip that might help speed things up (https://groups.google.com/forum/#!topic/spatialcapturerecapture/v4KA8rSuX7Y). One caveat: in my limited experience working with unmarked Spatial Count type models, estimating a behavioral response has been tricky, and it may be impossible without additional information. I think the marked animals should provide sufficient info to allow a behavioral response to be modeled, but if you can't, I think presenting your results as conservative estimates of population size is probably ok.

>> We have now incorporated a behavioral response based on the days since baiting at each trap to investigate how these rewards may be influencing detection of martens on camera.

6) The chains used to generate MCMC samples seem short—in particular, the burn-in of 500 iterations seems insufficient. Are you sure that you are sampling from the stationary posterior distribution? The Geweke diagnostic might be useful for checking this.

>> In the updated analysis, we have increased the adaptation and burn-in period by more than 1000% to 6,000 iterations, and we also calculated posterior estimates based on 3,000 MCMC samples. This new analysis, in addition to examining the posterior chains by plotting and with the R-hat parameter, ensures that we are sampling from the stationary posterior distribution

7) Please provide a little more clarity regarding masking out habitat. As far as I can tell, you fit the inhomogenous point-process model without masking out anything, but masked out non-habitat when predicting? I think it is reasonable to mask out sand-dunes when predicting density into the other region (it doesn't look like the camera transect is really set up to capture the effect of forest cover on marten density all that effectively), but as noted above, it's a little difficult to figure out just how abundance and density estimates presented are is being derived here (it seems like it's derived from mu[g]). As noted below, if estimates reflect masking habitat out after the fact, comparison with other studies is a little trickier.

>> We have now added additional information about how we masked out habitat in the methods (Lines 107-115; 182-186). When determining the density of martens in our study area, we have simply masked out our state-space to 40% vegetation cover > 1 m forest cover. For our study, martens showed extreme choice for these areas (Figure 5). Thus, we believe this is an adequate representation for the suitable and available habitat for martens in Coastal Oregon.

Territory mapping: My sense is that demonstrating what you did within a graphic (perhaps adding onto to Fig. 3) might make interpretation easier. There seems to be disagreement within the text over what the territory mapping is estimating (carrying capacity, or actual population size). I'm not really convinced that this is a great method for doing either, and I don't see this as a necessary part of the paper, but maybe there's a compelling reason for keeping it that I'm missing. Regardless of how you prefer to interpret these predictions, if you keep this part, I think some discussion of the assumptions being made about marten space use and some justification for these assumptions is probably warranted.

>> We have removed territory mapping as it seems an unnecessary to communicate our main results.

PVA: generally seems fine, although I'm not qualified to review this with any technical depth. A couple minor questions regarding clarity/implementation. Why treat human-caused deaths as a Poisson RV, if only to later argue that anthropogenic mortality is not stochastic (Line 300)?

>> Please see next comment.

Given that the Poisson is skewed, maybe extinction at higher expected values is really being driven by sporadic but extreme mortality events? The modeled variation in anthropogenic mortality exceeds the range of observed harvest...is there sufficient empirical data to inform an alternative generating distribution for this variable? Could you add a little justification for choosing lambda values of 1,2,3 (e.g., we select these values to explore sensitivity to limited increases, or we assume that baseline mortality is higher because roadkill may go unreported, etc.)?

>> Human-caused mortality should be stochastic with some years associated with unusually high mortality and some with unusually low mortality. We assume 1, 2, or 3 deaths on average because observed mortalities are low, and to cover a range of average mortality that encompasses a reasonable range from likely persistence to near assured extirpation. All values of lambda > 3 produce a more dire outcome for the population, which is unnecessary to demonstrate. Because the values of lambda are small, both the mean and variance are small. Thus the probability of extreme events is quite low. For example, the probability that 5 or more individuals are killed when lambda = 1 is (1-Pr(X<=4)), where "Pr(X<=4)" is easily obtained from the cumulative distribution function using the ppois() function in R. Thus the probability of 5 or more individuals being killed is 1 - ppois(4,1) = 0.0037. When lambda = 2, this probability becomes 1 - ppois(4,2) = 0.053, and when lambda = 3 it becomes reasonably common for 5 or more mortalities to occur, 1 - ppois(4,3) = 0.18 but not as common for 6 or 7 mortalities (pr = 0.084 and Pr = 0.034). This distribution is precisely what we are hoping to model with our PVA. An average of 3 mortalities per year is likely to have a stochastic mortality associated with it leading to some years with 4, 5, or 6 mortalities, but 7 or more mortalities happen only 1 out of every 100 years. In reality, there is a reasonable probability that some years produce very large mortality events due to catastrophic disease, a spike in trapping effort, or an earthquake-induced tsunami (a major concern in coastal Oregon due to the Cascadia subduction zone).

Could you provide a more detailed justification for assuming these population as lacking immigration in the methods (on L312 you note barriers, distance, etc., but can these things be quantified and presented in the methods)?

>>We provided information in the introduction as well as a citation that previous extensive surveys have shown no evidence of an inland population of martens. We assumed that the nearest population (>50 straight-line km away) was not providing annual immigration but we

know of no citation that has estimated probability of an immigration event from that distance. Large barriers, including river-mouths also are likely to limit frequent enough movement between populations.

Finally, I think might be useful to incorporate uncertainty into the PVA projections (I think confidence intervals could be derived from non-parametric bootstrapping).

>> L242: The structure of the PVA is designed to cover a broad range of uncertainty, including uncertainty in the mean annual mortality rate (lambda = 1,2,3), uncertainty in the form of density dependence (theta = 1,2), uncertainty in carrying capacity (K = 20,30,40) and variation in the interannual growth and mortality across 1000 population simulations. Each gray line in Figs. 5 and 6 are one of 1000 separate realization of the model, and we report the proportion of runs that fall below the PVA in each of 18 scenarios (combinations of lambda, K, and theta). This strikes us as a very pretty thorough treatment of uncertainty to produce a probability of extirpation associated with each of the 18 scenarios, and the probabilistic output is itself a characterization of uncertainty.

Validity of the findings
I guess this section pertains to presentation/interpretation of the results.

L269: As presented in the methods, the territory mapping was used to estimate marten carrying capacity rather than abundance; here it is treated as an additional technique for estimating population size.

>> We have removed territory mapping from the manuscript to increase simplicity.

L278 & L285: I'd say 2-3 annual mortalities on average instead of 2-3 mortalities.

>> We replaced with "annual mortalities" throughout.

L299-315: Maybe this point belongs under basic reporting, but the focus here is unclear. The take-home of the PVA is that relatively low levels of anthropogenic mortality put these populations at risk. I'm not sure why juvenile recruitment is being mentioned here as another potential factor, and then summarily dismissed. I'd suggest focusing upon your own results a little more closely throughout the discussion.

>> We focus on juvenile recruitment and isolation within the discussion, focusing on our results (Lines 333-350):
Marten populations can be resilient to fur harvest when they are abundant, and if breeding females are harvested infrequently compared to males, particularly juvenile males (Robitaille 2017, Banci & Proulx 1999). Adult females in our study were observed more frequently than adult males at ratios of 1.5:1 (live-trapping) and 3:1 (SMR). Our results were atypical of ratios observed in other marten research studies and in harvested populations; these studies typically demonstrate higher male to female ratios (e.g., McCann et al. 2010; Payer & Harrison 1999; Robitaille 2017). Intolerance among same-sex individuals resulting in intrasexual territoriality typical of martens (Moriarty et al. 2017; Powell 1994) may require juveniles to disperse outside of the Oregon Dunes, especially if the long, narrow forested habitat resulted

in elevated encounter rates between juveniles and resident adults. Alternatively, we spaced live-traps at a relatively fine-scale in our study compared to other studies which may have resulted in higher trap encounter rates by females. Regardless of the mechanism, resident breeding females appear to be extremely vulnerable to live-trapping in the Oregon dunes. We predict that limiting fur harvest to areas outside of the Oregon dunes would result in take of more dispersing juveniles and males compared to females, reducing the immediate risk of short term marten extirpation.

L316-329: Two comments. First, I'm not sure that density estimates based on masking out non-suitable habitat are really comparable to density estimates reported by other studies. You're reporting density per sq. km of suitable habitat; other studies typically report density per sq. km of land. I'd at least note that this is likely to amplify your estimates relative to other systems.

>> When determining the density of martens in our study area, we have simply masked out our state-space to 40% vegetation cover > 1 m forest cover. For our study, martens showed extreme choice for these areas (Figure 5). Thus, we believe this is an adequate representation for the suitable and available habitat for martens in Coastal Oregon.

Secondly, do you think you could expand upon upon some of your predictions and alternatives here? An alternative is that rather than the distinct vegetation in this system mediating marten co-existence with other animal species, the animal community in the system is distinct (as you mention, year-round passerine birds). Or perhaps sympatric predators are less abundant in this system—martens in Newfoundland readily use beetle-kill and clearcuts that provide little cover, but sympatric predators are relatively rare (Hearn et al. 2010, Journal of Wildlife Management 74[4]). Presumably, the cameras provide some information about other carnivores in the study area?

>> We understand an influence from bottom up and top down impacts, but we do not have the data presented in this paper to firmly address the reviewer's comments. Instead we include this paragraph in our discussion (lines 323-332):

"Despite the adjacent high-density marten population, the mature forest east of the Oregon Dunes does not support a marten population. The reason for near complete marten absence to the east is unclear. We hypothesize that abundant berry-producing shrubs in the Oregon Dunes directly provide abundant food for martens, and indirectly support marten by increasing the abundance of frugivorous vertebrate prey. Moreover, dense understory vegetation likely mediates interactions with competitors and predators, and provided spaces to hunt and avoid predators similar to snow in winter (Andruskiw et al. 2008). Whether prey availability, habitat-mediated competition, or some combination of these factors limits martens from the extensive inland forests is largely unknown; these questions are key to address when considering the potential for population expansion."

L330-L335: I suggest avoiding any discussion of trying to manage inland forests to resemble coastal forests.

>>We agree with and have removed such discussions from the manuscript.

335-338: This is really the main finding of the study: this is an important but vulnerable marten population. I suggest that rather than ending with this sentence, you shift it earlier into the discussion and talk a little bit about how maintaining habitat and limiting mortality might be accomplished.

>>We have followed the reviewer's suggestion, emphasizing the uniqueness of this population in our first discussion paragraph (Lines 294-309):

"Our population assessment revealed that the central Oregon population of Humboldt martens likely has fewer than 75 adults divided into two subpopulations separated by a riverine barrier. Further, this population appears completely isolated with a lack of connectivity to the southern Oregon population. Based on the small population sizes of these subpopulations, our population projections suggest that even a small amount of human-caused mortalities will strongly increase the likelihood of extirpation over the next 30 years. Further, our analysis is likely an optimistic scenario for marten population viability because we assumed that marten populations would exhibit very high survival and fecundity at low population densities, which may not be the case. Despite these favorable assumptions, marten population viability was low given modest mortality estimates averaging 2-3 individuals annually, even when assuming higher than observed carrying capacities and assuming later onset of density dependence ($\theta=2$; Fig. 6). Moreover, we did not fully consider environmental stochasticity in our viability analysis. In particular, the extant central Oregon marten population is in a tsunami zone within the Cascadia subduction zone. The probability of a large earthquake and tsunami eliminating much of Oregon's near-coastal forests in the next 50 years is placed at 15 to 20% (Goldfinger et al. 2012). Such an event would be expected to eliminate the central coast marten population unless the population expands east of Highway 101."

Reviewer: Gilbert Proulx
Basic reporting

This is a well-written article. the authors used up-to-date references. I suggest that Buskirk et al (2012) in Aubry et al.'s book, be cited to support statements in lines 314-315.

>> We have included Thompson et al. (2012), which we assume the reviewer is referring to:

Thompson, I., J. Fryxell, D. Harrison, K. Aubry, W. Zielinski, M. Raphael, G. Proulx, and S. Buskirk. 2012. Improved insights into use of habitat by American martens. Biology and conservation of martens, sables, and fishers. Edited by KB Aubry, WJ Zielinski, MG Raphael, G. Proulx, and SW Buskirk. Cornell University Press, Ithaca, USA:209-230.

Experimental design

This is a well-designed scientific research with a proper inductive review of the problem. There is a bit of confusion regarding the habitat preferences of the Humboldt marten. The introduction indicates that the species is found in late-seral stages - and such stages are present in federal parks where the habitats are protected. However, there were no marten surveys in these parks. The martens are apparently found in 70-yr-old forests (study area). So it is incorrect to conclude that the species is a late-seral specialist (line 64). So the authors need to explain the discrepancy - either the species is wrongly believed to be a late-seral species, or the martens may use younger forests (as in the study area) - in the latter case, th presence of martens in young forests may be due to the fact that there is no other habitat at regional level or the food items are very abundant and the species is more flexible in its choice of habitats.

>>We have attempted to address these concerns within the introduction

Lines 45-55: Pacific martens (Martes caurina) are a small carnivore that is considered to be a habitat specialist closely associated with structurally complex forests with seasonal snow cover in the western United States (Buskirk & Ruggiero 1994; Zielinski 2013). Humboldt martens (M. c. humboldtensis) are a subspecies of Pacific martens that live in near-coast forests with limited or no snow cover at the southern edge of their distribution in coastal Oregon and California. Populations of Humboldt martens have contracted in the 20th century (Zielinski et al. 2001), prompting petitions to list them as threatened or endangered (Center for Biological Diversity 2010). Recent extensive distributional surveys suggest two or three potential populations in coastal Oregon and northern California (Moriarty et al. 2016a; Zielinski et al. 2001). The northernmost population of these populations is located in the central Oregon coast (Moriarty et al. 2016a), and it is also the most isolated population of Humboldt marten (i.e., > 50km from the nearest adjacent population).

Lines 63-66: Recent distributional surveys indicated this population likely occupies a <500m wide band of young (i.e., < 70 years old) forests growing on sand dunes along the margin of the Pacific Ocean west of Highway 101 and no evidence of martens > 3 km inland (Fig. 1, Moriarty et al. 2016a). Very little is known about population size, or spatial ecology of martens living in the central Oregon coast.

Methods are properly detailed. However, lease indicate the models and manufacturers of remote cameras.

>> *We modified lines **120-21**:* "using black-LED remote cameras (Aggressors, 2015, Bushnell, Missouri, USA; Fig. 2).

Why do they authors refere to "territory" instead of "home range"?

>> *We changed to home range throughout.*

Validity of the findings

The conclusions follow the data. The findings are significant and may play an important role in the conservation of the species

Comments for the author

Good work. the marten-habitat relationship needs to be better described and explained in the introduction. Please consider the following:

Line 58, martens instead of marten.

>> *We changed to marten's, martens, or marten populations throughout.*

Line 93 - The Oregon Dunes consist of...

>> We replaced this with a study area description (Lines 82-106):
Coastal forests within the Oregon Dunes consisted of a narrow north-south strip along the margin of the Pacific Ocean bounded by two large rivers to the north and south (i.e., Siuslaw and Coos Rivers), Highway 101 to the east, and bisected by the Umpqua River, which is 600-m wide at the confluence with the Pacific Ocean (Fig. 1). Much of the forested area there was the result of recent expansion over the last 70 years coincident with stabilization of near-coast beaches by European beach grass (Amophila arenaria) into mounded fore dunes, which limited sand deposition and facilitated vegetation expansion into previously shifting open sand (Christy et al. 1998).

Line 131 - 5 min instead of 5 minutes

>> We changed minutes to min.

Line 133 - hrs instead of hours.

>> We changed hours to hrs

Line 184 - within one (or 1) hour - no hyphen.

>> We replaced with one hr in 2 locations.

Lines 252 and 275 - >40% forest cover - please specify the cover (age and structure).

>> We clarified with:

Lines 109-117: To distinguish vegetation cover (i.e., primarily forests) from open sand we used airborne light detection and ranging data collected at 1-m resolution. We defined vegetation cover as > 40% cover of pixels > 1 m in height within a 100-m circular radius moving window of each pixel. This process produced a raster layer that smoothed small gaps in vegetation cover (i.e., sand gaps >30 m) that martens could presumably move through but that excluded broad expanses of open sand that we assumed represented non-habitat for martens, particularly because of the presence of predators (Moriarty et al. 2015). The northern (i.e., north of Umpqua River, Fig. 1b) and southern (i.e., south of Umpqua River, Fig. 1c) study areas were comprised of 36.9 km^2 and 25.6 km^2 of vegetation cover, respectively.

General note - your argument that, 'because of human-caused mortalities and limited habitat, the future of marten population may be jeopardized' relates to the level of resiliency of the species, a concept that has been developed by Banci and Proulx (1999- Mammal Trapping published by Alpha Wildlife Publications).

>> We added reference to Banci and Proulx (1999) within our discussion (lines 335-337) "Marten populations can be resilient to fur harvest when they are abundant, and if breeding females are harvested infrequently compared to males, particularly juvenile males (Robitaille 2017, Banci & Proulx 1999)."

NOTE to ODFW Commission.
The second round of review appears below.

21 February 2018

To the PeerJ team:

Thank you for the suggestions for the manuscript "**Density and population viability of coastal marten: a rare and geographically isolated small carnivore**" (Article identification number (20529).

We appreciate the helpful suggestions that we received from the reviewers and your facilitation of this manuscript.

Below are our responses to your comments and those of the reviewers. Our reply is written in Times New Roman font with ">>" before our comment for ease of reading. We have clarified and revised our manuscript to accommodate all of the suggestions.

Thank you again for your time and consideration.

Respectfully,

Mark Linnell, Katie Moriarty, David Green and Taal Levi

Although not a hard deadline, we expect you to submit your revision within the next 40 days.

With kind regards,

Andrew Byrne
Academic Editor, PeerJ

Editor's Comments

MINOR REVISIONS

Your paper has been reviewed again by both reviewers, and both recommend a minor revision to the manuscript. However, given the extensive nature of the technical comments made by reviewer 1 (Dr. John Clare), the manuscript may require additional analysis/rerunning of models. Please either clarify, address or rebut the points raised by Dr. Clare, or indicate whether further exploration of your dataset will be undertaken in other MSs.

Reviewer 2 highlights an issue around trapping of the martens, which should be commented on, or rebutted.

Both reviewers, and myself, commend the extensive work done on the paper after the first round of reviews.

Reviewer 1 (Anonymous)

Basic reporting

The one minor issue is that it looks like sigma and maybe some other greek symbols are being altered, which makes following some of the formulas difficult. For example, I can't quite figure out what's happening on line 187.

>>

Experimental design

```
lambdaresight[i,j,k] <- lam0.resight[i,j,k]*exp(-d. resight2[i,j]/(2*sigma2[Sex2]) )*z*(1 - marked[i]))
log(lam0.resight[i,j,k]) <- delta0 + delta1*Sex[i] + delta2*Baiting[j,k]
countu[i,j,k] ~ dpois(lambdaresight[i,j,k]
nU[j,k]~dsum(countu[1, j, k], countu[2, j, k].....etc.)
```

Alternatively, you might just look at presence-absence by station (i.e., there's >0 detections or not), in which case the likelihood looks a little different: the underlying encounter model for an individual follows the bernoulli model you have here, with the recorded presence-absences at a station = 1-(1-punmarked[i, j, k])^Nunmarked. Something like:

```
p_unmarked[i,j,k] <- lam0.resight[i,j,k]*exp(-d. resight2[i,j]/(2*sigma2[Sex2]) )*z*(1 - marked[i]))
```

>> This was a very helpful question.

We reviewed the camera data on the occasions where we detected an unmarked marten. Because we only ever saw 1 unmarked individual at each site on each day, there's no reason that this couldn't have arisen from a Bernoulli process. This essentially treats the unmarked individuals in the same way we treated the marked individuals-- weather or not they were seen at a station in a day. If >1 unmarked individual was seen at a camera on a day, then we'd use the above suggestion because we'd have to include some information regarding uncertainty of the sightings (e.g., was this the same marten or not).

All observations (photos) on a given occasion (day) were within a <19 minute sequence of each other and nothing about the animal changed to lead us to think otherwise (e.g. if it was male-sized, it was male-sized in all photos in the sequence). In my opinion, the most parsimonious explanation for this is that it is the same individual although we cannot be 100% sure of this because the animal is unmarked. We feel reasonably confident in our assertion that it was 1 unmarked animal for each occasion.

We further evaluated our photo identification data. We observed an individual marten at a camera station for 32.8 ± 67.0 (mean ± sd) photos per day with a median of 10. I checked again and we did have n = 14 occasions where the marten was unknown (3.5 ± 4.9 photos). This was less than 5% of the data set.

We included this in our methods (Lines 205-): Similar to the sightings of marked individuals, we assumed that a detection of an unmarked individual at our cameras on a day arose from a Bernoulli process. Unmarked individuals were seen infrequently on our cameras (n=14 sightings throughout the duration of the study), and identified as being present at the camera for a single bout typically <19 minutes. Thus, it was highly unlikely that more than 1 unmarked individual was captured on our cameras per day. The code for our SMR model can be found in Supplemental Article S1.

Validity of the findings

No issues.

Comments for the Author

The authors should be commended for putting a lot of work into revising the submission, and more generally, for attempting to tackle the underlying study problem with a high level of technical rigor. This is nice work, and I appreciate the thorough response to previous comments.

Reviewer 2 (Gilbert Proulx)

Basic reporting

Clear and unambiguous.

Experimental design

The text benefited from the comments expressed by Referee # 1 in the first review.

Validity of the findings

Very important findings.

Comments for the Author

I have a few comments only.

1. Considering that trapping may impact significantly on the population survival, I recommend that all forms of trapping be eliminated within and outside the area of concern. Accommodating trappers on the outside (so you capture more male juveniles than females) can still impact on the marten population in your study area. Martens have the ability to find baits set far away and these baits on the outside could cause displacement of some animals. Trap sets outside the study area could still impact on the population survival. Since we are talking about survival of a species, measures should be taken to avoid all deaths. You may not be able to stop vehicles, but you can remove trapping.

>> We changed to (Lines 357-):

Based on our data, a prudent consideration could limit fur harvest to areas outside of the Oregon coast range, reducing the immediate risk of short term marten extirpation.

2. The reference "Banci and Proulx 1999" is missing in Literature Cited:
Banci, V., and G. Proulx. 1999. Resiliency of furbearers to trapping in Canada. Pages 175-203 in G. Proulx, editor, Mammal trapping, Alpha Wildlife Publications, Sherwood Park, Alberta.

>> We added this citation.

3. Figure 1, legend = The verb tenses need to be reviewed. For example, you used the

past tense in "the study area was bonded..." and the present tense for "This area has extensive fragmentation...". I suggest the authors harmonize the verbs, and use the proper tenses. For example, the study area is bonded (and it still is!), but the area had extensive fragmentation (at time of study).

>> We made this change and looked through our legends.

4. Figure 2, legend. I think that lines 535-541 should be included in Methods, i.e., line 152.

>> We made this change and modified the methods at line 152.

5. Line 544 - Home ranges or territories?

>> We changed to home ranges throughout.

Marten background

Petitioned Federally Threatened within Northern California and Oregon Distinct Population Segment

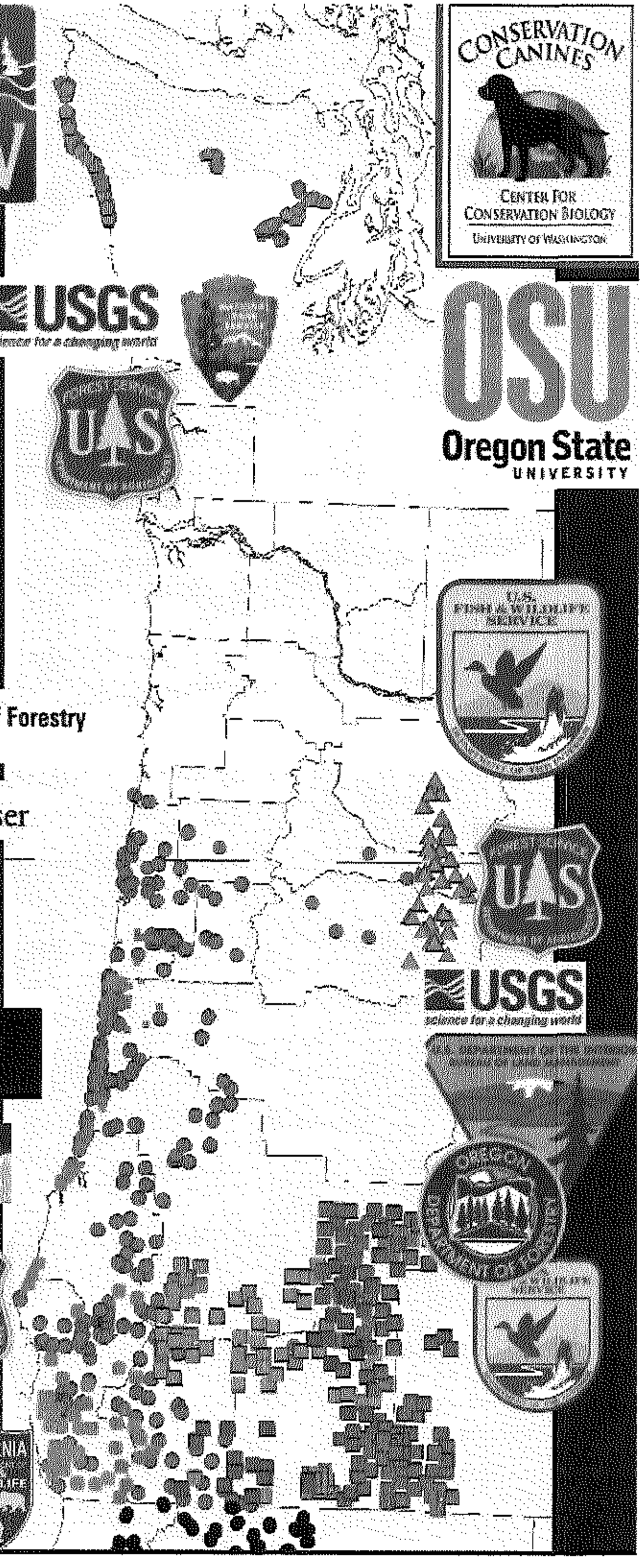
- 2010 Petition
- Apr 2015 Withdrawn
- Dec 2015 lawsuit
- Mar 2017 (partially) overturned, North District Court

- By Oct 2018 revised Proposed Rule by USFWS


Courtesy: Max Marquez

Carnivore distributions

- 8 projects in WA, OR, and CA ***since 2015***
- \>13 funding agencies
- \>60 collaborators
- 2,147 camera stations
  - 717 sample units
- ~ 4 million photographs



Oregon State UNIVERSITY | College of Forestry

Weyerhaeuser

Hancock Timber Resource Group

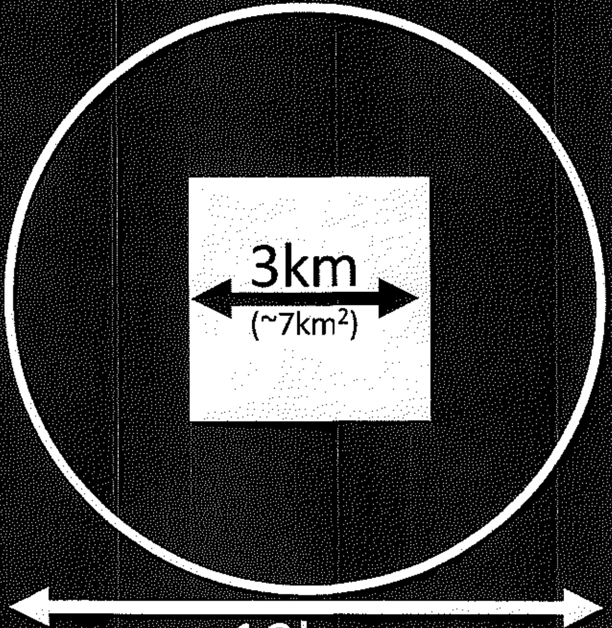
OFIC

ncasi

PORT BLAKELY TREE FARMS

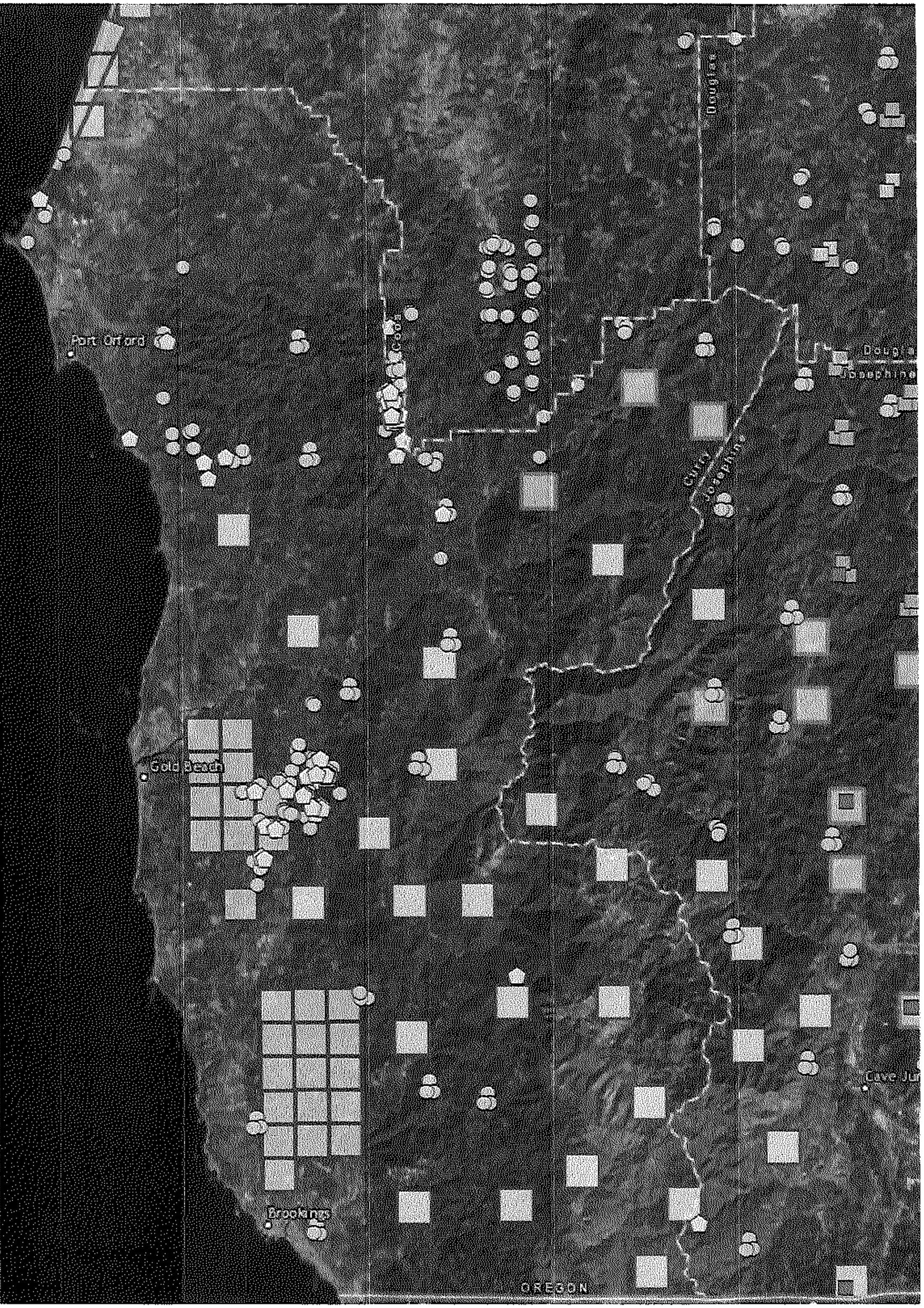
Detection dog teams

CONSERVATION CANINES
CENTER FOR CONSERVATION BIOLOGY
UNIVERSITY OF WASHINGTON



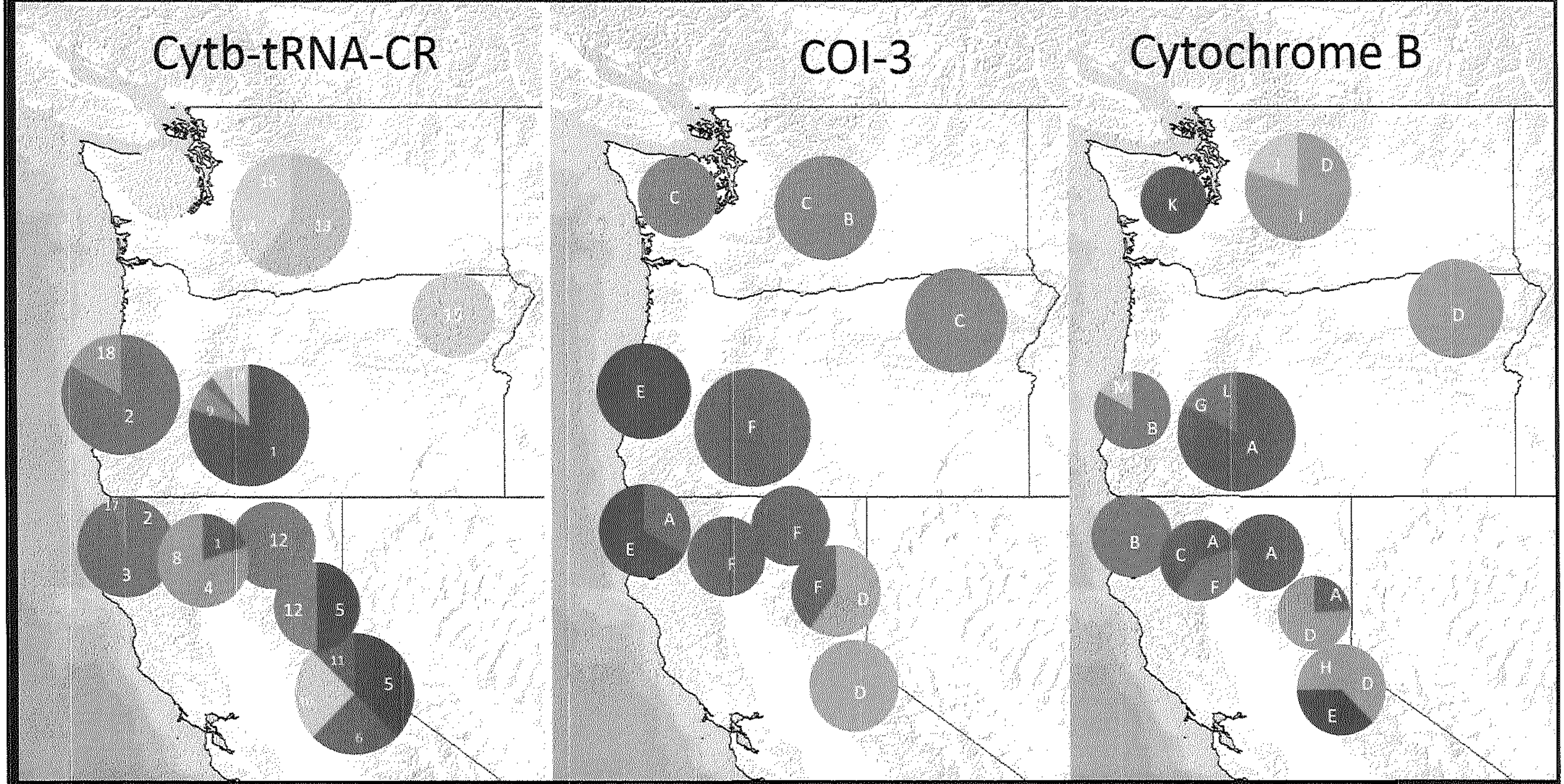
3km
$(\sim 7 \text{km}^2)$

10km



Marten effort/distribution - 2017

Humboldt marten genetic data

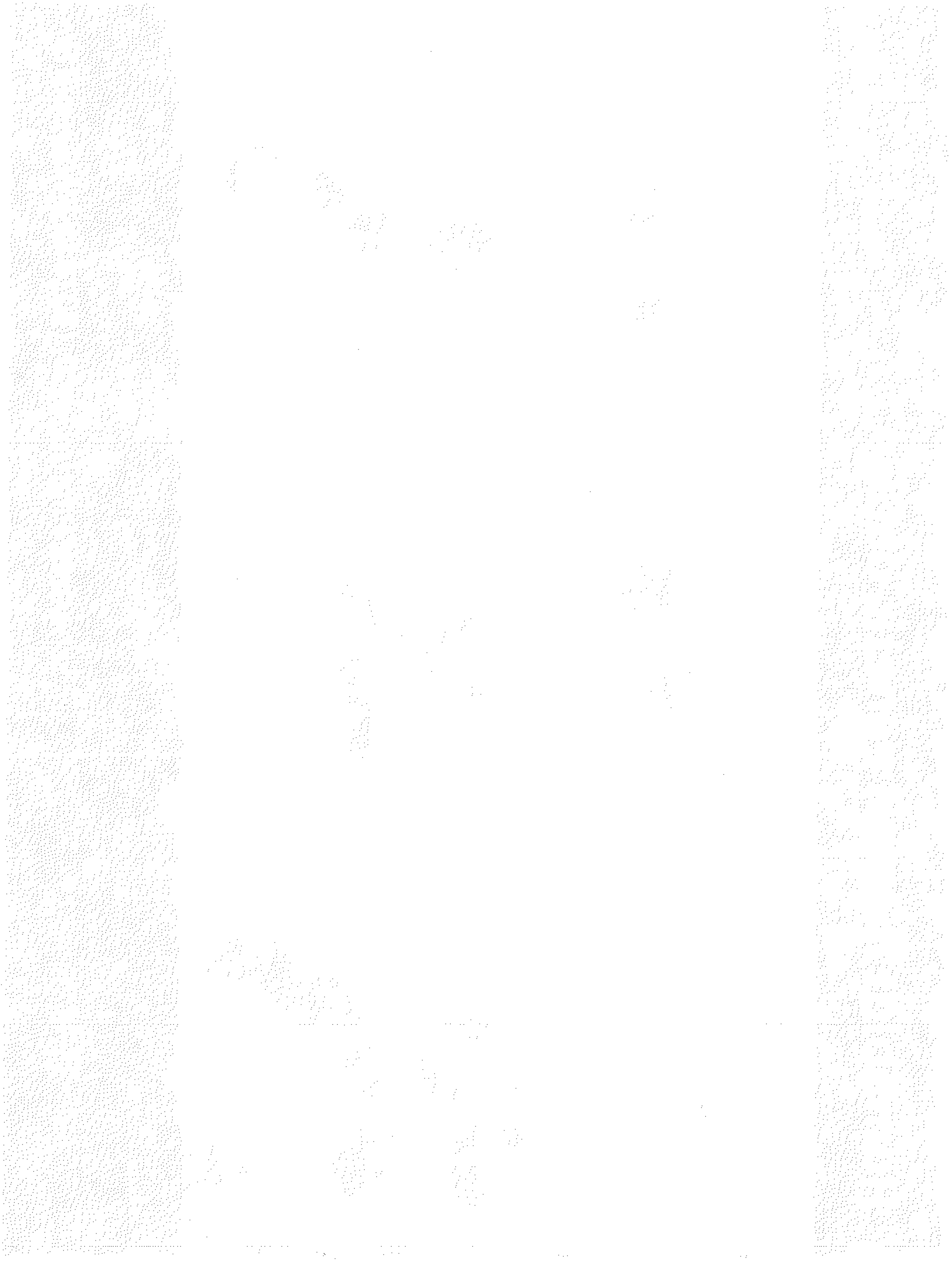


Cytb-tRNA-CR

COI-3

Cytochrome B

Schwartz, Pilgrim, et al. (2016 USFWS report)



opportunities due to random variation in birth and death rates). In studied wildlife populations, genetic diversity is strongly correlated with population fitness (increased survival and reproduction rates) and decreased extinction risk.

In addition to genetic effects, small populations are at great risk due to unpredictable changes in the natural environment such as droughts, fires, earthquakes, disease outbreaks, and changes in prey or predator populations. In small, isolated populations all or nearly all individuals can be impacted by such events. As populations get smaller they become more vulnerable to demographic variation, environmental variations, genetic drift, and inbreeding depression. Each of these effects can amplify the impact of the other effects, further reducing population size and accelerating the species towards extinction. The most recent Humboldt martin population estimate in California is fewer than 200 individuals, far below the population size necessary to ensure long-term viability of a wild population.

Habitat Essential for the Continued Existence of the Species - The Department considers all currently occupied Humboldt marten habitat, as well as suitable but apparently unoccupied habitat near the currently occupied habitat, essential for the continued existence of the species in California. Together these areas total less than 20% of the species' historical California range. However, even if the area was fully occupied by Humboldt martens, the maximum theoretical population would still be far short of recommended minimum viable population size. Therefore additional habitat that is not currently suitable but which could be restored within coming decades should also be considered essential to the recovery of the species over time.

Management Recommendations – The Department recommends maintaining and creating suitable habitat in and near the areas currently occupied by Humboldt martens in California, as well as actions to increase habitat connectivity and reduce barriers to dispersal. The Department also recommends balancing the conservation of Humboldt marten habitat with the need to attenuate potential habitat losses from severe wildfires through carefully designed fuel reduction actions. Finally, the Department recommends continued research on the Humboldt marten population size and distribution, the population's genetic diversity, habitat associations, and the potential threats to population persistence.

Recommendation - The California Endangered Species Act directs the Commission to determine whether a petitioned species' continued existence is in serious danger or is threatened by any one or any combination of the following factors: (1) present or threatened modification or destruction of its habitat; (2) overexploitation; (3) predation; (4) competition; (5) disease; or (6) other natural occurrences or human-related activities.

The Department provides this status review report, including its recommendation, to the Commission in an advisory capacity based on the best scientific information available. Through its evaluation, the Department has determined that historic trapping and habitat loss have extirpated Humboldt martens from significant portions of their range. Additionally, historic and ongoing habitat loss, habitat fragmentation, and associated elevated predation rates, coupled with unquantified, but potentially significant threats to the species from a small population size, disease, toxicants, wildfire, and climate change place the remaining California Humboldt marten population at risk of extinction. Therefore, the Department's recommendation to the Commission is that listing Humboldt marten as endangered under CESA is warranted.

Zielinski and Golightly 1996, Slauson and Zielinski 2004, Slauson et al. 2009b). Based on changes in estimated occupancy from surveys in the modern era the population appears to have declined by over 40% over the period 2000-2008, and then remained unchanged during the period 2008-2012 (Slauson et al. 2009b, USFWS 2015). In the only contemporary population estimate, Slauson et al. (2009b), estimated the extant Humboldt marten population in California consisted of less than 100 individuals. Since that time an additional population area has been discovered and estimates of the California population have increased slightly, but it remains below 200 individuals (Slauson et al. 2017). Moriarty et al. (2016) detected a minimum of 28 unique Humboldt martens in coastal Oregon during surveys in 2015, and concluded "martens in coastal forests are rare and likely limited by unknown factors, especially compared to their former range." Additional surveys in the central coastal Oregon shore pine population resulted in an estimate of 71 adult martens in that population alone (Linnell et al. 2018). It is not known if Oregon populations are in contact with California populations facilitating the exchange of genes between the two states.

Historically Humboldt martens appear to have been more common and widespread. Grinnell et al. (1937) stated that Humboldt martens were "fairly numerous" in "earlier years", though apparent declines in the Humboldt marten population, at least locally, were noted as early as the 1920s. The authors report a tale of one trapper capturing 50 Humboldt martens in a single winter near Fortuna, California. While no rigorous historical population estimate exists, one can reasonably infer from the recorded anecdotal information that the number of martens present at that time was larger than the population present in the 1990s when no detections of the species had been recorded for the previous 50 years (Zielinski and Golightly 1996).

THREATS

Trapping

Early trapping of Humboldt marten was intensive, with accounts of individual trappers taking 35-50 martens in a single winter (Grinnell et al. 1937). By the early 1900s annual harvest of Humboldt martens was already declining, prompting Joseph Dixon to call for closing the trapping season in California to prevent an extirpation; however, marten harvest continued until a partial closure was enacted in northwestern California in 1946, depleting populations and likely reducing genetic variation within the remaining population (Dixon 1925, Twining and Hensley 1947, Zielinski et al. 2001).

Today trapping of all martens is prohibited statewide (§ 460, Title 14, California Code of Regulations (CCR)), although it is possible that Humboldt martens could be inadvertently taken by trappers pursuing other fur bearers or nongame mammals that may be legally harvested for recreation, commerce in fur, or depredation. Trapping in California is highly regulated, and trappers must pass a Department examination demonstrating their skills and knowledge of laws and regulations prior to obtaining a license (Fish & G. Code § 4005). Additionally, only live-traps may be used to take furbearers or nongame mammals for recreation or commerce in fur and trappers are required to check traps daily and release non-target animals (*Id.* §§ 3003.1, 4004, and, 4152 and § 465.5, Title 14, CCR). With the passage of Proposition 4 in 1998, body-gripping traps (including snares and leg-hold traps) were banned in California for commerce in fur and recreational trapping (*Id.* § 3003.1). Trapping records indicate that there were no licensed fur trappers operating in Del Norte County from 2010 to 2016, and fewer than two trappers operating annually in Humboldt County in the same period suggesting a very low probability of Humboldt marten bycatch (California Automated License Data System 2018). However, some body-gripping traps may be used by licensed trappers for purposes unrelated to recreation or commerce in fur, including protection of property or by government employees, or their authorized agents, while acting in their official capacities (*Id.* § 3003.1 and § 465.5, Title 14, CCR).

Trapping of Humboldt martens remains legal in neighboring Oregon where trappers are required to obtain a trapping license and take an educational course (Hiller 2011). In recent years only four to eight trappers per year reported pursuing martens in Oregon (Hiller 2011). Oregon trapping records are organized by county making it difficult to determine if reported trapped martens were coastal Humboldt martens or interior *Martes caurina caurina*. Review of trapping record from 2007 to 2016 indicates that as many as nine Humboldt martens may have been trapped in Oregon (D. Broman pers. comm. 3/17/2017). Linnell et al. (2018) modeled Humboldt marten population viability in a coastal shore pine population and determined that the annual removal of two to three individuals from the population from human causes such as trapping and road kills would greatly increase the likelihood of extirpation within a 30-year period.

Trapping pressure on Humboldt martens was intense during the late 1800s and early 1900s, and very likely resulted in significant declines in population size as well as a dramatic reduction in range. There have been no studies on the population level effects of Humboldt marten trapping, but the loss of even a few adult martens, especially when combined with other mortality sources, could reduce the likelihood of long-term population viability (USFWS 2015). However, it is unlikely that trapping continues to threaten Humboldt martens in California due to the ban on trapping martens, the small number of active fur trappers, restrictions on the types of traps that may be used for other species, as well as requirements that licensed trappers check traps daily and release non-target animals.

Habitat Loss and Degradation

Changes in the structure and landscape configuration of Humboldt marten habitat can negatively impact survival, reproduction, and population connectivity of the species. In particular, timber harvest and other silvicultural treatments of older forests; wildland fires, salvage logging, and fuel reduction projects; development of coastal forests for human settlement; and the clearing of forests for the cultivation of cannabis can all lead to loss, degradation, and fragmentation of Humboldt marten habitat. The USFWS (2015) Humboldt marten species report concluded habitat loss and degradation from historical and current logging is the most plausible reason the marten is absent from much of its historical range, noting most of the remaining suitable habitat is located on federally owned land (Zielinski et al. 2001).

Forest conditions in the range of the Humboldt marten today have largely been shaped by a legacy of over 100 years of logging and timber management. It is estimated that the area of old growth conifer forest in the Pacific Northwest has been reduced by 72% since European settlement (Strittholt et al. 2006), and only 10% of the historical range of redwood forests remains in old growth stands today (Fox 1996). While timber harvest continues in the area, the logging of old growth forest stands on private and public lands has dramatically slowed from peaks in the second half of the 20th Century. Today, 33% of remaining old forest on federal lands in the Northwest Forest Plan area is fully protected from harvest, and 80% is afforded some level of management protection (Strittholt et al. 2006). The rate of timber harvest on private lands in the area has declined in recent decades due to more restrictive regulations and market conditions (Figure 5). Harvest on federal lands declined sharply following implementation of the Northwest Forest Plan in 1994 (Strittholt et al. 2006) (Figure 6). The area of older forests (forests with structural development typical of stands ≥200 years old) on federal lands in the coastal and Klamath mountains of northwestern California declined 8.4% from 1993-2012, largely due to wildfires, while the area of older forests on non-federal lands increased 1.3%, despite losses to timber

Figure 2. Historical and contemporary range of Humboldt marten in California with marten detections by date and minimum convex polygons around extant population areas.

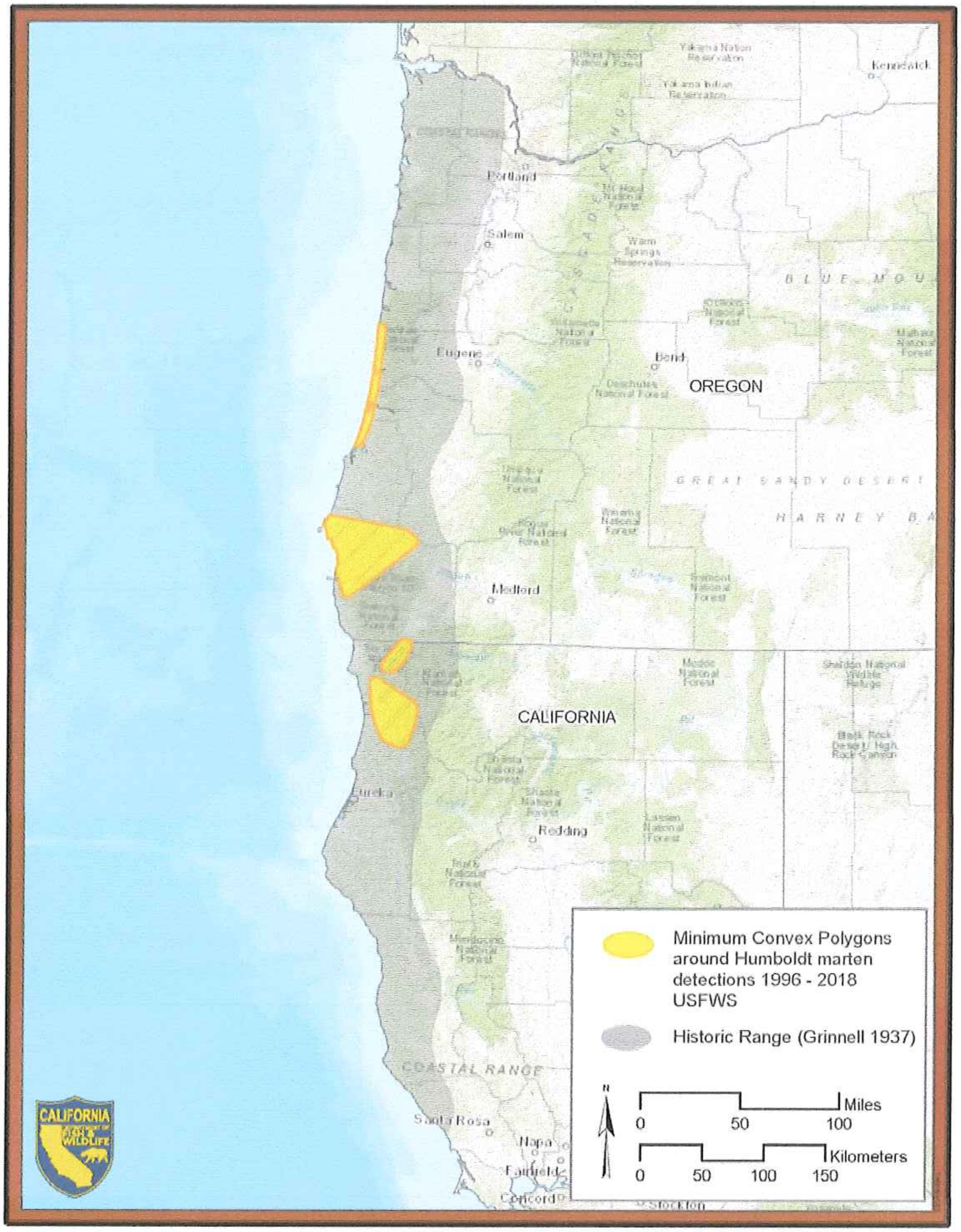


Figure 3. Humboldt marten extant population areas in California and Oregon (yellow polygons) imposed on historical range of Humboldt marten (shaded). Polygons are minimum convex polygons drawn around contemporary (1996 - 2018) verified groups of ≥5 Humboldt marten detections and buffered by 2 km.

Density and population viability of coastal marten: a rare and geographically isolated small carnivore

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ABSTRACT

Pacific martens (*Martes caurina humboldtensis*) in coastal forests of Oregon and northern California in the United States are rare and geographically isolated, prompting a petition for listing under the Endangered Species Act. If listed, regulations have the potential to influence land-use decisions on public and private lands, but no estimates of population size, density, or viability of remnant marten populations are available for evaluating their conservation status. We used GPS and VHF telemetry and spatial mark-resight to estimate home ranges, density, and population size of Pacific martens in the Oregon Dunes National Recreation Area, central coast Oregon, USA. We then estimated population viability at differing levels of human-caused mortality (e.g., vehicle mortality). Marten home ranges were small on average (females = 0.8 km^2, males 1.5 km^2) and density (1.13 martens/1 km^2) was the highest reported for North American populations (*M. caurina*, *M. americana*). We estimated 71 adult martens (95% CRI [41–87]) across two subpopulations separated by a large barrier (Umpqua River). Using population viability analysis, extinction risk for a subpopulation of 30 martens, approximately the size of the subpopulation south of the Umpqua River, ranged from 32% to 99% with two or three annual human-caused mortalities within 30 years. Absent population expansion, limiting human-caused mortalities will likely have the greatest conservation impact.

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Additional Information and Declarations can be found on page 16

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Keywords Density, *Martes americana*, Marten, *Martes caurina*, Population viability analysis, Spatial mark-resight

INTRODUCTION

Conserving wildlife while maintaining economic growth is one of the most pervasive conservation and policy challenges globally. This balance in the United States is enforced in part by the Endangered Species Act (ESA), which can regulate land-use on both public and private lands for the conservation of imperiled species. Forests of the Pacific Northwest of North America highlight challenges between land-use and endangered species

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conservation as demonstrated by the history with northern spotted owl (*Strix occidentalis caurina, Simberloff, 1987*). Now, decades after the conflict over listing the northern spotted owl, a distinct population segment of a forest-dependent small carnivore is a litigation target, petitioned for listing under the ESA (*Anonymous, 2017*).

Pacific martens (*Martes caurina*) are a small carnivore considered to be a habitat specialist closely associated with structurally complex montane forests with seasonal snow cover in the western United States (*Buskirk & Ruggiero, 1994*; *Zielinski, 2013*). Coastal populations of Pacific martens in Oregon and California, referred to as Humboldt marten (*Martes caurina humboldtensis*), are near the southern edge of their distribution and live in near-coast forests with limited or no snow cover. Recent extensive distributional surveys suggest two or three potential populations in coastal Oregon and northern California (*Moriarty et al., 2016*; *Zielinski et al., 2001*). These coastal populations of martens have contracted in the 20th century (*Zielinski et al., 2001*), prompting petitions to list a Distinct Population Segment as threatened or endangered (*Center for Biological Diversity, 2010*). The northernmost population is located in the central Oregon coast (*Moriarty et al., 2016*), and it is also the most isolated (i.e., >60 km from the nearest adjacent population).

The United States Fish and Wildlife Service determined that the coastal Distinct Population Segment of the Pacific martens in California and Oregon did not warrant listing as a threatened or endangered species under the Endangered Species Act in 2015 (*US Fish Wildlife Service, 2015*). The finding by the US Fish and Wildlife service, however, included two assumptions for which updated information now exists: (1) that coastal martens were abundant in central Oregon from the relatively high number of road-killed individuals there in the past three decades, and (2) extensive Late-Seral Reserves on federal lands provided habitat for these martens (*Slauson, 2015*). Recent distributional surveys indicated this population likely occupies a <500 m wide band of young (i.e., <70 years old) forests growing on sand dunes along the margin of the Pacific Ocean west of Highway 101, and that there is no evidence of martens >3 km inland (Fig. 1, *Moriarty et al., 2016*). With so little known about martens in the central Oregon coast, research needs including basic attributes of the population, such as population size, are urgently needed to inform conservation decisions.

Our objectives were to describe marten density, population size, and population viability in the central Oregon coast. Specifically, we used spatial mark-resight (SMR) models to evaluate density in a portion of our study area and then we applied our density estimate to coastal forests west of Highway 101 where martens resided to estimate total population size. We assumed that, (1) forest characteristics were similar across our study area, and (2) because martens are highly territorial, density would be static across study areas if home range sizes were similar between individuals. We then used a population viability analysis to quantify the potential effects of human-caused mortality on marten numbers (e.g., legal trapping, vehicle strikes). Finally, because density and home range size are often correlated with foraging resources (*Kittle et al., 2015*; *Mattisson et al., 2016*), we compared density and home range sizes of martens in coastal Oregon to other North American populations (*Martes caurina, Martes americana*) to infer year-round food resource availability compared to other populations.

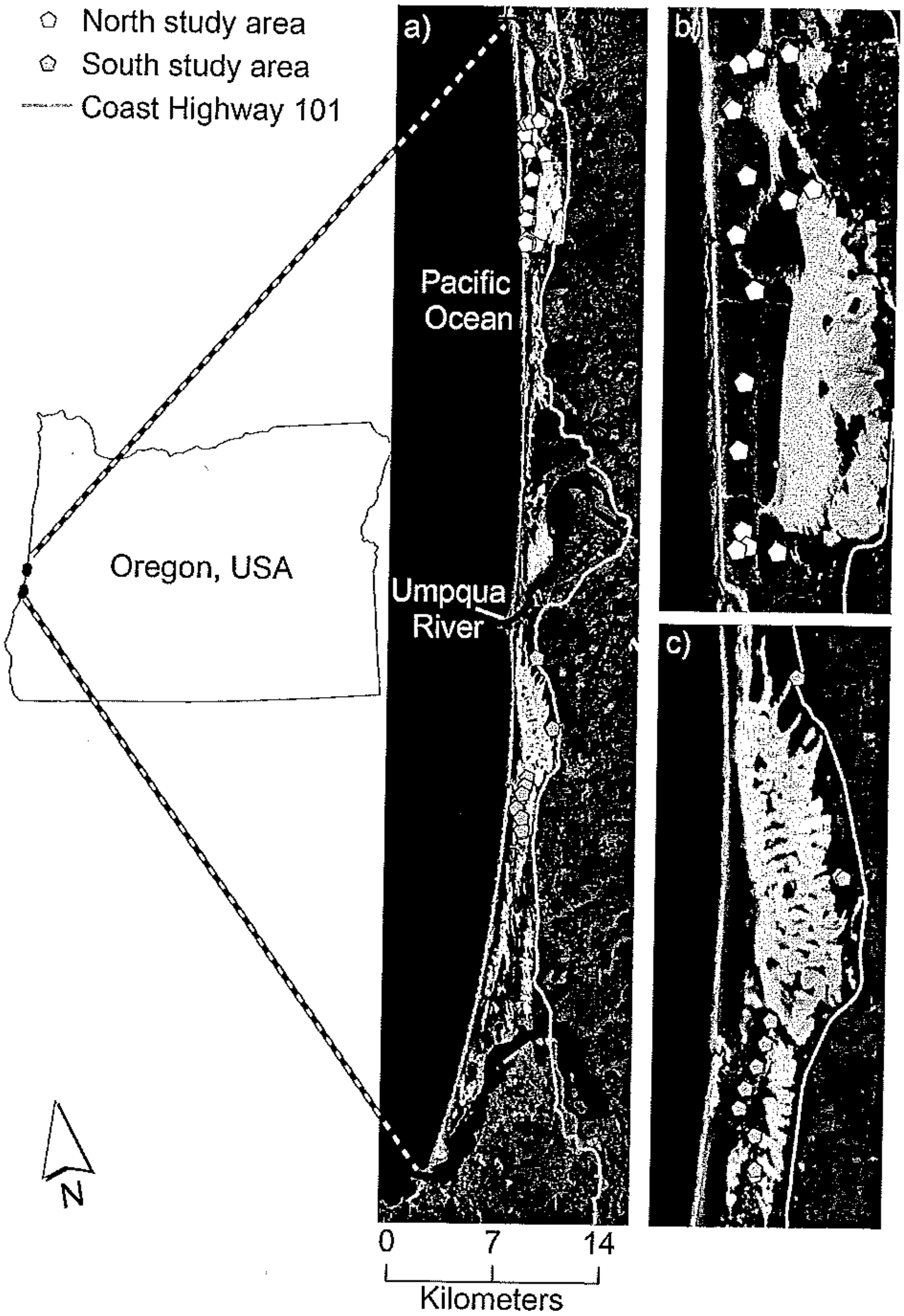

Figure 1 Our study area of coastal Pacific martens in the Oregon Dunes Recreation Area. We collected location data on coastal Pacific martens (*Martes caurina humboldtensis*) in the Oregon Dunes Recreation Area, west of Highway 101, Oct. 2015 to Jan. 2016. The study area is bounded to the north and south by the Siuslaw and Coos Rivers, respectively, and divided by the Umpqua River in the center, which is approximately 600 m wide where it meets the Pacific Ocean. Live-trap locations are represented by the white and orange pentagons in the north and south study areas, respectively. The complete study area is displayed in (A), and insets of the north and south study areas, specifically, are displayed in (B) and (C). Image data: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community.

Full-size DOI: 10.7717/peerj.4530/fig-1

METHODS

Study area

We surveyed the northernmost population of coastal martens along the central Oregon coast within the 125 km^2 Oregon Dunes National Recreation Area (hereafter, "Oregon Dunes"). Coastal forests within the Oregon Dunes consisted of a narrow north-south strip along the margin of the Pacific Ocean bounded by two large rivers to the north and south (i.e., Siuslaw and Coos Rivers), Highway 101 to the east, and bisected by the Umpqua River, which is 600-m wide at the confluence with the Pacific Ocean (Fig. 1). Much of the forested area was the result of recent expansion over the last 70 years coincident with stabilization of near-coast beaches by European beach grass (*Amophila arenaria*) into mounded fore dunes, which limited sand deposition and facilitated vegetation expansion into previously shifting open sand (*Christy, Kagan & Wiedemann, 1998*).

Coastal dune forests grew on nutrient poor sandy soils (*Christy, Kagan & Wiedemann, 1998*), and they were dominated by young (<70 years-old) shore-pine (*Pinus contorta contorta)* and Sitka spruce trees (*Picea sitchensis)*. The sub-tree canopy was dense, extended to >2.5 m in height, and it was dominated by willow (*Salix hookeri*), Pacific waxmyrtle (*Myrica californica*), salal (*Gaultheria shallon*), and slough sedge (*Carex obnupta*) on seasonally flooded sites, and berry-producing ericaceous shrubs (e.g., evergreen huckleberry *Vaccinium ovatum*, salal) on seasonally dry sites (*Christy, Kagan & Wiedemann, 1998*). Coastal forests differed substantially from inland forests east of Highway 101 in vegetation age, structure, composition, and their vertebrate communities (*Eriksson, 2016*). Inland forests were a mix of young (i.e., 0–80 years) and mature (i.e., >80 years old) Douglas-fir (*Pseudotsuga menziesii*) and Sitka spruce forests. Mature forests on federal lands were primarily managed as Late Successional Reserves to protect habitat for northern spotted owls (*Strix occidentalis)* and marbled murrelets (*Brachyramphus marmoratus, Davis et al., 2015*). Forests in the Oregon Dunes supported a high diversity of vertebrates, including several predators and competitors of martens (e.g., gray foxes *Urocyon cinereoargenteus*, coyotes *Canis latrans*, cougars *Puma concolor*; *Eriksson, 2016*).

To distinguish vegetation cover from open sand, we used airborne light detection and ranging data collected at 1-m resolution. We defined vegetation cover as >40% cover of pixels >1 m in height within a 100-m circular radius moving window of each pixel. This process produced a raster layer that smoothed small gaps in vegetation cover (i.e., sand gaps <30 m) that martens could presumably move through, but that excluded broad expanses of open sand that we assumed represented non-habitat for martens, particularly because of the presence of predators (*Moriarty et al., 2015*). The northern (i.e., north of Umpqua River, Fig. 1B) and southern (i.e., south of Umpqua River, Fig. 1C) study areas were comprised of 36.9 km^2 and 25.6 km^2 of vegetation cover, respectively.

Minimum and maximum temperatures in July and January were 10.1 °C and 20.3 °C and 3.2 °C and 10.2 °C, respectively. Annual precipitation averaged 176 cm, and occurred primarily between November and March (Western Regional Climate Center 1971–2016). Elevation within the study area ranged from eight to 80 m.

Live-capture and home range size estimates

We live-trapped and radio-marked martens from October to December 2015 using traps spaced approximately 1 km apart with some additional clustering of traps at <1 km (Fig. 1) using methods described in *Moriarty et al. (2017)* and *Mortenson & Moriarty (2015)*. We fit adult martens (i.e., >two years old) with a VHF (Advanced Telemetry Systems, Minnesota, USA; 29 g) or GPS/VHF collar (Quantum 4000 Micro-Mini GPS collars, Telemetry Solutions, CA, USA; 41–44 g; or G10 snap technology GPS, Advanced Telemetry Systems, Isanti, MN, USA; 27 g; Table S1). Each individual marten was marked with a unique pattern of reflective tape attached to the antenna of the radio collar, which we used to resight marked individuals using black-LED remote cameras (Bushnell Aggressor, model: 119776; Bushnell Corporation, Overland Park, KS, USA; Fig. 2). Most martens (80%) were captured only once prior to the spatial mark-resight survey and then re-captured after this survey was complete when we removed collars in January and February 2016. All capture and handling procedures were approved by the USDA Forest Service's Institute for Animal Care and Use Committee (USFS 2015–002) under an Oregon Department of Fish and Wildlife Scientific Take Permit (ODFW 119–15).

We programmed GPS collars to collect locations separated by 5 min, and only included locations in our analyses with predicted errors <30 m and time periods where data were collected for >72 consecutive hrs (details in *Moriarty et al., 2017*). We located individuals with VHF-only collars at least twice per week. We only used VHF locations where the variance of x and y was <400 m determined with Location of a Signal (Ecological Software Solutions LLC). We estimated 99% local convex hull home ranges, discarding 1% of the furthest dispersed locations (*Lyons, Turner & Getz, 2013*), using the t-LoCoH package in R. Local convex hulls were constructed using 35 neighboring locations ($k = 35$), regardless of time between locations ($s = 0$; *Lyons, Turner & Getz, 2013*; *R Core Team, 2017*). These parameterizations best reflected marten space use in our study (*Moriarty et al., 2017*) by limiting the formation of multiple activity centers, and they provided a smoothed outer contour boundary.

Spatial mark-resight

We monitored 31 sites for 39 consecutive nights in December 2015 and early January 2016 along a linear transect (henceforth, "SMR transect") that overlapped the area occupied by radio-tracked martens in the northern study area. Each site was distributed (mean ± 1 standard deviation) 311 ± 91 m apart within vegetation cover with a minimum goal of four sites accessible to each female (*Sun, Fuller & Royle, 2014*). Each site consisted of one remote camera placed 0.5 m high, 2–4 m from attractants (i.e., bait, olfactory lure) and a measuring strip, such that the camera field of view was centered on the attractants (Fig. 2). We placed bait, in the form of ~250 g of chicken and ~100 g of strawberry jam, at each site during setup and replaced it at each site on 3 visits. Visits occurred every (mean ± 1 standard deviation) 8.2 ± 1.5 days after setup. We reviewed photos for each site and occasion, which we defined as the 24-hour day, to identify marked or unmarked individuals. We had (mean ± 1 standard deviation [range]) 32.8 ± 67.0 [1–637] photos available per site and occasion to identify marked or unmarked individuals. We censored

Figure 2 Photographs of uniquely marked martens. Examples of uniquely marked individual martens (*Martes caurina humboldtensis*). (A) A female marten with GPS collar sniffing strawberry jam. (B) A male marten with two reflective bands (middle, end of antenna). (C) A female marten with three reflective bands. (D) A male marten with unique GPS collar with two antennas. Each station included an olfactory lure (Gusto, Minnesota Trapline Products, Pennacock, MN) and baits that were checked and replaced weekly. We set remote cameras (Bushnell Aggressor, model: 119776; Bushnell Corporation, Overland Park, KS, USA) 2–4 m from bait and we programmed them to record one photo after motion was detected with a one-second lag between consecutive photos.

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photos that we were unable to determine if the marten was marked or unmarked (<1% of all photos).

We estimated the density of martens from our photographic data using a generalized spatial mark-resight model (*Whittington, Hebblewhite & Chandler, 2018*; Code in Article S1) based on the methods of spatial capture-recapture (*Efford, 2004*; *Royle & Young, 2008*). Generalized spatial mark-resight models combine the latent processes that generate both the capture (i.e., marking) and resight data (i.e., cameras) to estimate the number of latent activity centers (s_i) within the study area (*Whittington, Hebblewhite & Chandler, 2018*). We defined our study area as a discrete state-space S of a 100-m grid within a 5-km buffer around camera stations, excluding cells in the Pacific Ocean.

We defined live-capture data as the binomially distributed random variable $ycap_{ij}$ representing the number of times that marten i was captured in trap j as a function of the probability of capture ($pcap_{ij}$) and the number of nights that trap j was open ($Ktrap_j$):

$$ycap_{ij} \sim Binom(Ktrap_j, pcap_{ij}).$$

We hypothesized that the probability of capture would vary by sex and the distance between the location of trap j and the activity center of marten i:

$$pcap_{ij} = p0cap_i \times e^{(-d_{ij}^2/2\sigma_k^2)}$$

where the average probability of capture $p0cap_i$ was modeled as a function of the sex of each marten ($\text{logit}(p0cap_i) = \beta_0 + \beta_1 \times \text{sex}_i$), a half-normal decay function where d_{ij} is the distance between the trap and the latent activity center of individual i (s_i), and the standard deviation of a bivariate normal distribution reflecting space-use varying by sex (σ_k). We parameterized σ separately for each sex (See Article S1).

We defined camera resighting data as the Bernoulli distributed random variable $ycam_{ijk}$ representing whether or not the previously live-captured marten i was resighted at camera station j on occasion k as:

$$ycam_{ijk} \sim Bern(pcam_{ijk})$$

where $pcam_{ijk}$ is a function describing the average daily rate of detecting martens on camera. Similar to the capture data, we hypothesized that the average daily rate of detection would vary by sex and the distance between the station and their latent activity center ($pcam_{ijk} = p0cam_{ijk} \times e^{(-d_{ij}^2/2\sigma_k^2)}$). We also hypothesized that the time since bait addition would influence the rate of detecting martens on camera, so we added a variable to test the effect of days since baiting at station j on occasion $k(\text{days}_{jk}) = (\text{logit}(p0cam_{ijk}) = \delta_0 + \delta_1 \times \text{sex}_i + \delta_2 \times \text{days}_{jk})$.

We modeled activity center locations using a non-homogeneous Poisson point process in S to examine whether locations of marten activity centers in the Oregon Dunes were associated with percent vegetation cover. We calculated the percent vegetation cover in each grid cell g in S, and used an intensity function following *Royle et al. (2014)* to model the probability of an individual being in grid cell $g(p_g)$ as:

$$p^g = \mu_g / EN$$

where μ_g is a function of an intercept (α_0), the linear effect of vegetation cover (α_1), and the size of the grid cell ($\text{area}_g; \mu_g = \text{area}_g \times e^{a_0 + a_1 \times \text{vegetation cover}_g}$), and is divided by the expected number of martens in the study area (EN). We incorporated telemetry data to increase the precision of our estimates for the movement parameters and the location of marten activity centers (*Royle et al., 2014*; *Sollmann et al., 2013*). Telemetry locations of martens were modeled as being generated from a bivariate normal movement model with a mean of s_i and a precision of $\frac{1}{\sigma_k^2}$ (See Article S1). Martens can travel to any point in their home range within one hr (*Moriarty, Epps & Zielinski, 2016*; *Moriarty et al., 2017*). Accordingly, we only used locations that were at least one hr apart to ensure independence of telemetry locations (*Sollmann et al., 2013*).

We followed *Whittington, Hebblewhite & Chandler (2018)* in their treatment of the sightings of unmarked individuals; the detections of unmarked individuals at camera station j on occasion k (nU_{jk}) was modeled as:

$$nU_{jk} \sim Sum(yu_{1jk}, yu_{2jk}, yu_{3jk}...yu_{ijk})$$
$$yu_{ijk} \sim Bern(pcam_{ijk})$$

where the number of sightings of unmarked individuals was modeled to be generated from a latent Bernoulli process of resight probability ($yu_{ijk} \sim Bern(pcam_{ijk})$), based on the same probabilities of resighting as defined previously ($pcam_{ijk}$). Unmarked individuals were seen infrequently on our cameras ($n = 14$ sightings throughout the duration of the study), and identified as being present at the camera for a single bout typically <19 min. Thus, it was highly unlikely that more than 1 unmarked individual was captured on our cameras per day. The code for our SMR model can be found in Article S1.

We fit our models using data augmentation (*Royle & Dorazio, 2008*; *Royle & Young, 2008*) and the Markov-Chain Monte Carlo (MCMC) methods of JAGS (*Plummer, 2003*) with the jagsUI package (*Kellner, 2014*) in R v. 3.4.3 (*R Core Team, 2017*). We used uninformative prior distributions for all parameters (See Article S1). We calculated estimates from 3,000 MCMC samples, taken from three chains run for 10,000 iterations, thinned by five, following a burn-in of 5,000. We assessed model convergence by examining trace plots and $\hat{R}$ values for parameter estimates (*Gelman & Hill, 2007*; *Gelman et al., 2014*). All $\hat{R}$ values were <1.1, indicating chain convergence. We estimated the density of martens in our northern study area by determining the number of martens with estimated activity centers located in vegetation cover in the state-space, excluding open sand.

To evaluate our assumption that home range sizes were similar, we compared home range sizes in the northern and southern study areas using a general linear model with two parameters: sex and study area. We interpreted test statistics from this model and lacking any significant differences, we assumed density could be extrapolated to estimate population sizes (*Moriarty et al., 2017*).

Population viability

We assessed the risk of extirpation for a marten subpopulation over the next 30 years in the context of threats from human activities (e.g., trapping, roadkill; *Gerber, Buenau & Vanblaricom, 2004*). We estimated the maximum intrinsic population growth rate using a modified Euler-Lotka equation proposed by *Skalski, Millspaugh & Ryding (2008)*

$$e^{ra} - e^{-M}(e^r)^{a-1} - ml_a = 0,$$

where r is the maximum intrinsic growth rate, a is the age at first birth, m is the fecundity constant (number of female offspring/female/year), e^{-M} is the probability of survival, and l_a is the probability of survival to maturity (survivorship). We obtained a range of parameter

Table 1 **Input values for coastal marten viability analysis.** Input values for coastal Pacific marten (*Martes caurina humboldtensis*) viability analysis in the Oregon Dunes Recreation Area.

Variable	Value	Justification
Age at first parturition	2	*Mead (1994)*
Average number of kits/year (m)	1.5[a]	*Aune & Schladweiler (1997)*, *Flynn & Schumacher (2016)*
Survivorship to first parturition (la)	0.35	
Kit survival (age 0–1)	0.49	*Johnson et al. (2009)*
Yearling survival (age 1–2)	0.7	Average for North American martens, *McCann, Zollner & Gilbert (2010)*
Range of adult survival (age 2+)	0.7–0.9	*McCann, Zollner & Gilbert (2010)*

Notes.

[a] We choose $m = 1.5$ assuming three offspring and a 50% sex ratio as reasonable as among the highest observed litter size that would be expected to be achieved at low population density. For instance, *Strickland & Douglas (1987)* reported that both pregnancy rates and numbers of corpora lutea in pregnant female martens in Ontario were stable, ranging from 91–100% and 3.19–3.53, respectively. *Aune & Schladweiler (1997)* reported pregnancy rates similar for two populations in Montana, ranging from 76–95% over five years, but a lower mean number of corpora (2.6) per adult female in the southwestern part of the state leading to an estimate of $m = 1.1$. *Thompson & Colgan (1987)* reported 2.74–3.46 corpora lutea in pregnant females. *Flynn & Schumacher (2016)* observed pregnancy rates of martens in Southeast Alaska averaging only 47% over seven years while litter size was 3.3, producing an estimate of $m = 0.78$.

Table 2 **Bracketing uncertainty with three maximum intrinsic growth rates (r).** Three estimates of maximum intrinsic growth rate (r) for coastal Pacific martens (*Martes caurina humboldtensis*) bracketing our uncertainty from most to least conservative life history assumptions of annual survival for population viability modeling.

Annual survival (e^{-M})	Female kits per year (m)	Age of first parturition (a)	Survivorship to age at first parturition (l_a)	Maximum intrinsic growth rate (r)
0.7	1.5	2	0.35	0.143
0.8	1.5	2	0.35	0.205
0.9	1.5	2	0.35	0.268

estimates associated with the maximum reproductive output of two closely related species of North American martens (*Martes americana, Martes caurina*) in wild populations from the literature (Table 1). Estimates of r are sensitive to uncertainty in annual survival, e^{-M}; we estimated maximum intrinsic growth rate assuming average, high, and very high survival rates (0.7, 0.8, 0.9 respectively, *McCann, Zollner & Gilbert, 2010*) to obtain three values of $r = 0.143$, 0.205, 0.268 (Table 2). We used the intermediate value of $r = 0.205$ in our population projections, but we also implemented a stochastic element with $\sigma = 0.06$ such that the low and high estimates of r would bracket one standard deviation from the mean.

We simulated the dynamics of a population beginning at carrying capacity using initial values of the population size (K) equal to 20, 30, and 40 to illustrate how estimates of extirpation risk depend on our uncertainty about the current population size, assuming that immigration between the northern and southern study areas was infrequent due to a large barrier (i.e., Umpqua River; see population estimates in *Results*). The density-dependent population dynamics are given by the discrete theta-logistic model with an annual mortality component:

$$N_{t+1} = e^{r\left(1-\left(\frac{N_t}{K}\right)^{\theta}\right)+\varepsilon} - H_t,$$

where $\varepsilon \sim N(0,\sigma)$, with $\sigma = 0.06$ based on the variation in our best estimate of r (Table 2), and mortalities resulting from trapping and road-kills as $H_t \sim Pois(\lambda)$. The rate parameter of the Poisson distribution, λ, defines both the mean and variance of the annual mortality through road-kills or trapping (H_t), which takes values of $\lambda = 1$, 2, or 3 martens in our models (36 martens harvested 1969–1995, 0–4/year; *Verts & Carraway, 1998*). We assumed a small density-independent harvest to illustrate how extirpation risk can be influenced by relatively low levels of human-caused mortality. We conservatively assumed a standard logistic population growth ($\theta = 1$), but we also assumed that density-dependent declines in per-capita growth occurred at higher population densities ($\theta = 2$), which is expected for long-lived mammals (*Boyce, 1992*). We simulated 1,000 population trajectories for each of three initial conditions ($K = 20$, 30, and 40), three stochastic human-caused mortality rates ($\lambda = 1$, 2, and 3), and two values of the strength of density dependence using theta ($\theta = 1$, 2). Finally, we report observed mortalities during our study period. Where appropriate, we report results as mean ± 1 standard deviation.

RESULTS

We live-captured and radio-collared seven females (four VHF-only, three GPS/VHF) and four male (all GPS) martens. Our GPS collars collected 1,139 ($\bar{x}$, range: 173–2,960) locations over 15.7 ($\bar{x}$, range: 4–44) days on 8 individuals (4 males, 4 females), and we collected 35 ($\bar{x}$, range: 23–37) locations over 75 ($\bar{x}$, range: 42–90) days for three females with VHF-only collars (Table S1). Home range sizes in our study areas were similar ($t = 0.5$, $p = 0.68$) for males: 1.7, 2.2 (northern, $n = 2$) vs 1.0, 2.2 (southern, $n = 2$), and females 0.59–0.84 ($\bar{x} = 0.67$, northern, $n = 4$) vs 0.71, 0.79 (southern, $n = 2$). Martens were primarily located in areas of high vegetation cover; vegetation cover within a 100 m moving window of telemetry locations averaged 75% (25–75% quantile range = 60–96%, $n = 11$ martens; Table S1, Fig. S1). Home range sizes were smaller and density was higher in coastal Oregon compared to other North American populations (Fig. 3, Table S2). Home range sizes were negatively correlated with density (Fig. 3).

Density and population size

We incorporated 79.3 ± 59.2 telemetry locations per individual into our SMR models. No marked individuals of the same sex were observed visiting the same camera station, and 1.1 ($\bar{x}$, range: 0.7–1.9) km and 4.7, 2.1 ($n = 2$) km was the furthest distance between camera station detections for females and males, respectively (Fig. 4).

We estimated marten density as (mean ± 1 standard deviation) 1.13 ± 0.15 individuals/km^2 (95% CRI [0.81–1.39]), or 9.75 ± 1.32 individuals within the SMR area. Assuming density was constant within vegetation in the 62.5 km^2 Oregon Dunes, we estimated a median population size of 42 (CRI = 30–51) north of the Umpqua River and 29 (CRI = 21–36) south of it. Sex did not have a significant effect on the probability of live-capture (Table 3), but female martens had a higher resight probability than males

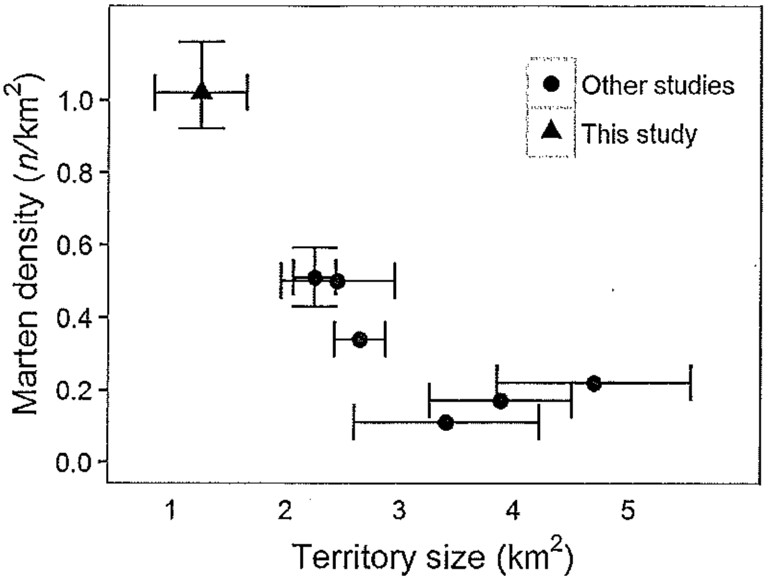

Figure 3 Density and home range size of North American martens. Technical articles that included the keywords "marten", "density", "territory", and "home range". Of the >75 papers reviewed for North American martens (*Martes americana, M. caurina*), four reported both home range sizes and density. Territories were estimated using either 100% Minimum Convex Polygons (MCP) or time-influenced Local Convex Hulls (t-LoCoH). Reported densities were either minimum known alive (MNKA) or calculated with spatial mark-resight. Mean and 95% confidence intervals reported if available in the study. Other studies were conducted in Maine, USA which included estimates from three study areas (*Payer & Harrison, 1999*), central British Columbia, Canada (*Poole et al., 2004*), New Hampshire, USA (*Sirén et al., 2016*), and Quebec, Canada (*Godbout & Ouellet, 2010*, Table S2).

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(Table 3). Days since baiting had a significant effect on resight probability; martens were more likely to visit baited cameras closer to a baiting event (Table 3). Percent vegetation cover had a significant effect on the distribution of activity centers (Table 3).

Population viability

We estimated that two or more annual human-caused mortalities on martens (e.g., trapping and road-kills) would lead to a substantial risk of extirpation, particularly at smaller population sizes (Figs. 5 and 6) and for $\theta = 1$ (Fig. 5) relative to $\theta = 2$ (Fig. 6). The likelihood of extirpation when $\theta = 1$ for a population of 30 individuals, which approximated the average of our estimates for each study area, was 32% and 99% with two and three annual mortalities, respectively. The probabilities decreased to 1% and 60% when $\theta = 2$ with two and three annual mortalities, respectively. The probability of extirpation increased to 89–100% and 65–100% for a population of 20 individuals with two or three annual mortalities.

DISCUSSION

Our population assessment revealed that the central Oregon population of coastal martens contains fewer than 87 adults divided into two subpopulations separated by a riverine

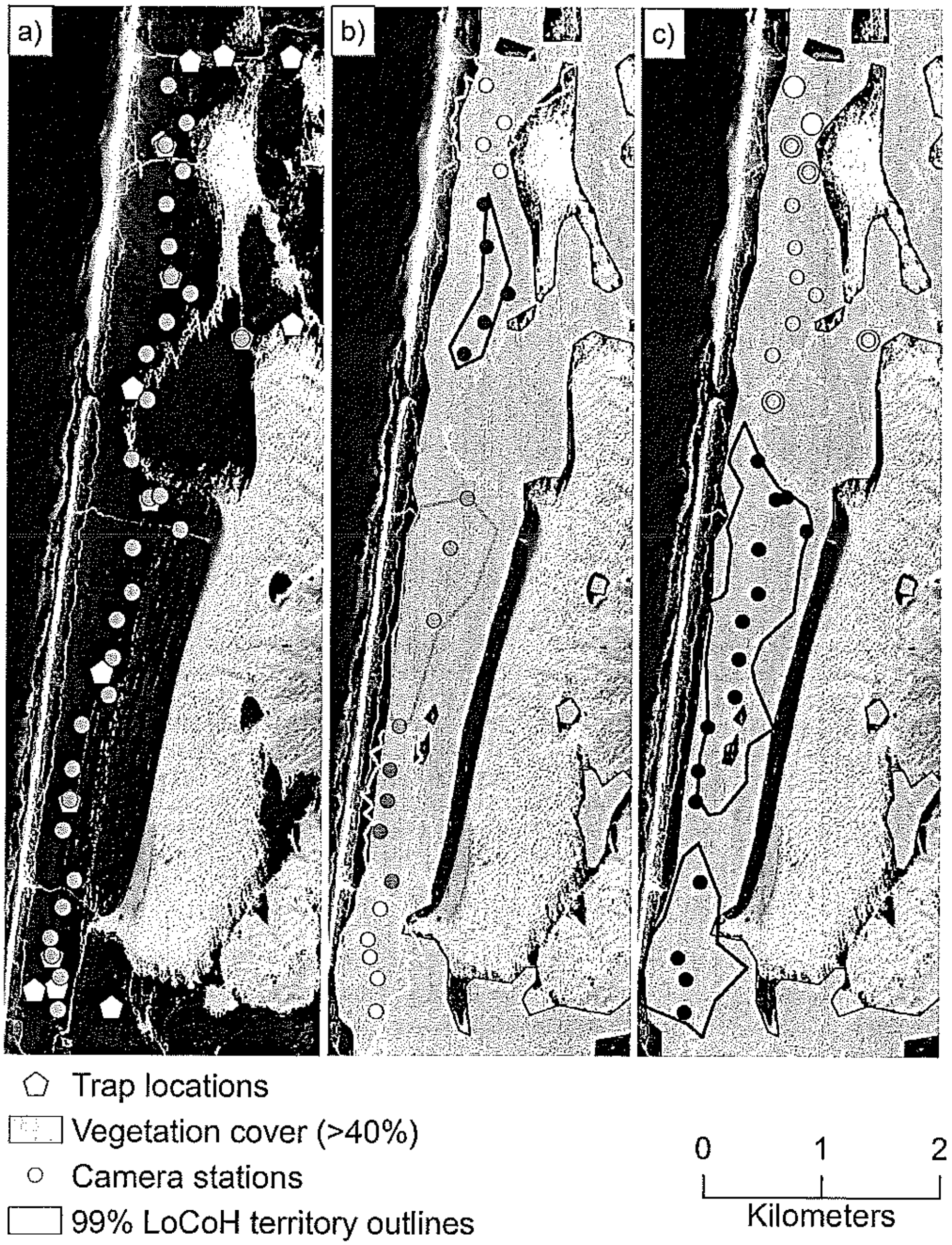

Figure 4 Our spatial mark-resight study area and coastal Pacific marten locations from remotely triggered cameras. We conducted a spatial mark-resight study using remotely triggered cameras and by marking the coastal Pacific marten (*Martes caurina humboldtensis*) with unique reflective strips on their collars (Fig. 2) in the northern portion of the coastal Oregon Dunes National Recreation Area from 4 December 2015 to 12 January 2016. Here, we show the (A) locations of all traps for live-capture (pentagons) and camera stations (orange circles), (B) stations that detected female martens, (C) stations that detected male martens, and unmarked martens (large white circles). For (B) and (C), individual martens are depicted by unique colored dots (camera station detections), and outlines (outer boundary of territories). The light blue shading depicts vegetation >1 m in height and with >40% cover within a 100-m circular radius estimated from a light detection and ranging canopy height model. Image data: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Air- bus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community.

Full-size DOI: 10.7717/peerj.4530/fig-4

Table 3 **Summary statistics of marten population density and detection rates using a spatial mark-resight (SMR) model.** Summary statistics from a spatial mark-resight model with telemetry data that estimated the density of the Humboldt subspecies of Pacific martens (*Martes caurina humboldtensis*) in our study area in the Oregon Dunes Recreation Area from October 2015 to January 2016. Significant effects (parameters with 95% CRI's not-overlapping 0), not including estimates of density, abundance, sigma, or intercepts, are indicated in bold.

Parameter	Mean (SD)	Credible Interval		
		2.5	50	97.5
Density (per km^2)[a]	1.13 (0.15)	0.81	1.15	1.39
Abundance (# martens)[a]	9.75 (1.32)	7	10	12
α_0—habitat intercept	−1.55 (0.76)	−3.29	−1.45	−0.38
α_1—effect of forest cover	**1.07 (0.53)**	**0.17**	**1.02**	**2.22**
β_0—capture probability intercept	−1.91 (0.53)	−2.98	−1.9	−0.94
β_1—female effect on capture probability	0.79 (0.6)	−0.36	0.79	1.98
δ_0—resight probability intercept	−1.26 (0.17)	−1.59	−1.26	−0.92
δ_1—female effect on resight probability	**0.75 (0.19)**	**0.38**	**0.76**	**1.11**
δ_2—days since baiting effect on resight probability	**−0.06 (0.02)**	**−0.11**	**−0.06**	**−0.02**
σ_{male} (m)	1,141.22 (45.27)	1,058.39	1,139.46	1,233.75
σ_{female} (m)	277.81 (6.17)	266.46	277.63	290.1

Notes.

[a] Based on the habitat mask within our state-space.

barrier. Further, this population appears completely isolated with a lack of connectivity to the southern Oregon population. Based on the small number of individuals in these subpopulations, our projections suggest that even a small amount of human-caused mortalities will strongly increase the likelihood of extirpation over the next 30 years. Further, our analysis is likely an optimistic scenario for marten population viability because we assumed that marten populations would exhibit very high survival and fecundity at low population densities, which may not be the case. Despite these favorable assumptions, marten population viability was low given modest mortality estimates averaging 2–3 individuals annually, even when assuming higher than observed carrying capacities and assuming later onset of density dependence ($\theta = 2$; Fig. 6). Moreover, we did not fully consider environmental stochasticity or catastrophes in our viability analysis. In particular, the extant central Oregon coast marten population is in a tsunami zone within the Cascadia subduction zone. The probability of a large earthquake and tsunami eliminating much of Oregon's near-coastal forests in the next 50 years is placed at 15 to 20% (*Goldfinger et al., 2012*). Such an event would be expected to eliminate much of the forests that the central coast marten population occupies.

Martens can be common in structurally complex high elevation montane forests with seasonal snow cover, but they are apparently rare and geographically isolated in coastal Oregon. Nonetheless, the Oregon Dunes supported the smallest home ranges and highest reported density of martens in North America (Fig. 3). North American martens inhabiting forests with seasonal snow-cover typically consume a narrow range of prey, especially during winter months (*Martin, 1994*), which can lead to substantial inter- and intra-annual variation in food availability (*Poole & Graf, 1996*), and presumably requires martens to defend large amounts of space within their home ranges to meet

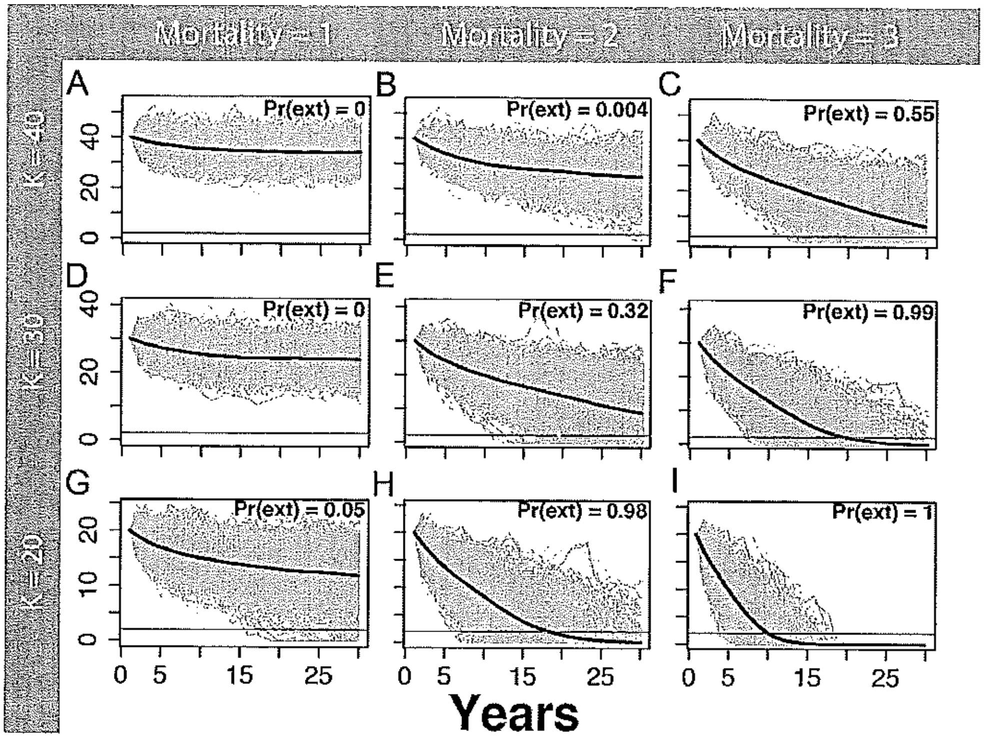

Figure 5 Marten population viability analysis, theta = 1. One-thousand density-dependent stochastic population projections (gray) for coastal Pacific marten (*Martes caurina humboldtensis*) from the theta-logistic model, assuming a linear relationship between per-capita population growth and population size (theta = 1) beginning at three values of carrying capacity (*K*; 20, 30, or 40), and three human-caused mortalities averaging 1, 2, or three marten annually. The mean population trajectory is given by the black line, and the red line signifies the pseudo-extinction threshold of 2 individuals. The proportion of trajectories falling below this threshold is the probability of extirpation Pr(ext). Stochastic mortalities averaging two or more marten lead to substantial extirpation risk within the next 30 years, particularly for smaller values of *K*.

Full-size DOI: 10.7717/peerj.4530/fig-5

nutritional requirements. In contrast, low-latitude coastal populations have a broad diet including foods such as late-season berries and over-wintering passerine birds, unavailable to montane and high latitude martens, particularly during winter (*Nagorsen, Morrison & Forsberg, 1989*) potentially facilitating the small home ranges observed in our study.

Despite the adjacent high-density marten population, the mature forest east of the Oregon Dunes does not support a marten population. The reason for near complete marten absence to the east is unclear. We hypothesize that abundant berry-producing shrubs directly provide abundant food for martens, and indirectly support marten by increasing the abundance of frugivorous vertebrate prey. Moreover, dense understory vegetation likely mediates interactions with competitors and predators, and provided spaces to hunt and avoid predators similar to snow in winter (*Andruskiw et al., 2008*). As such, maintaining contiguous tree and shrub cover—and limiting fragmentation and habitat loss—would benefit martens in areas where they persist. Whether prey availability,

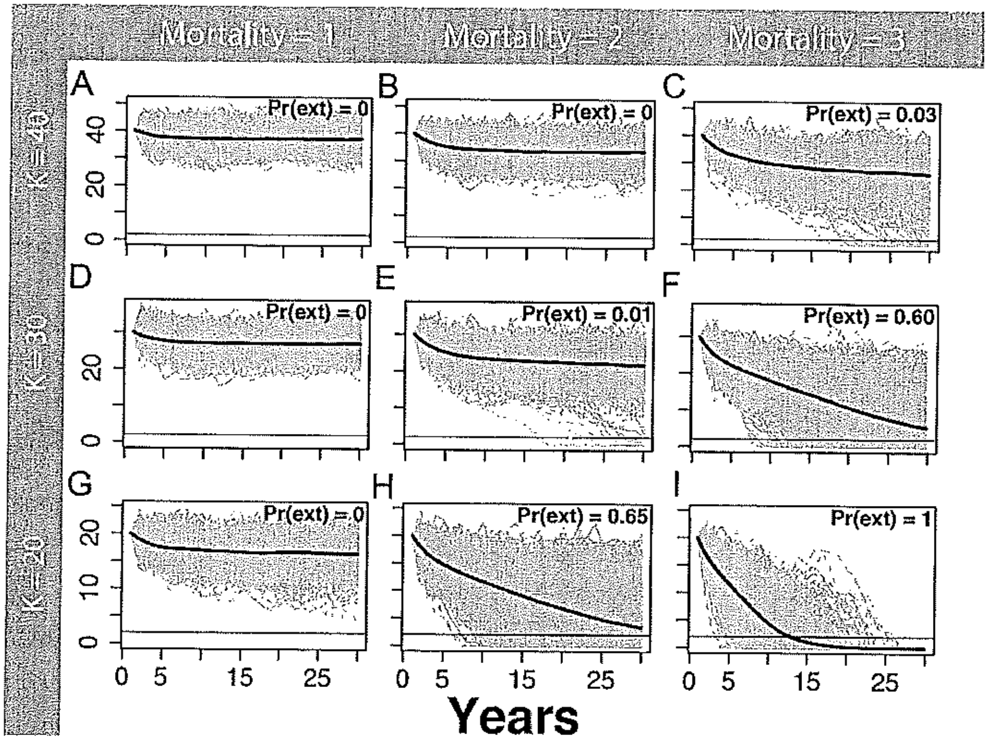

Figure 6 **Marten population viability analysis, theta = 2.** One-thousand density-dependent stochastic population projections (gray) for a coastal Pacific marten (*Martes caurina humboldtensis*) from the theta-logistic model assuming a convex relationship between per-capita population growth and population (theta = 2) beginning at three values of carrying capacity (*K*; 20, 30, or 40), and three human-caused mortalities averaging 1, 2, or three marten annually. A theta >1 may be more realistic for long-lived mammals, because the onset of density dependence likely occurs at higher population densities once crowding of territories occurs; assuming values where theta >1 is less conservative because the population will be more permissive to mortality or other mortality. The mean population trajectory is given by the black line, and the red line signifies the pseudo-extinction threshold of two individuals. The proportion of trajectories falling below this threshold is the probability of extirpation Pr(ext). Within the next 30 years, stochastic mortalities averaging two or more marten lead to substantial extirpation risk, particularly for smaller values of *K*.

Full-size DOI: 10.7717/peerj.4530/fig-6

habitat-mediated competition, or some combination of these factors limits martens from the extensive inland forests is largely unknown; these questions are key to address when considering the potential for population expansion.

In addition to vegetation structure and predation, harvest by humans can affect marten populations. It is currently legal to harvest marten throughout Oregon, including within this small, remnant, coastal population. Marten populations can be resilient to fur harvest when they are abundant, and if breeding females are harvested infrequently compared to males, particularly juvenile males (*Robitaille, 2017*; *Banci & Proulx, 1999*). Adult females in our study were observed more frequently than adult males at ratios of 1.5:1 (live-trapping) and 3:1 (SMR). Our results were atypical of ratios observed in other marten research studies and in harvested populations; these studies typically demonstrate higher male to female ratios of live-trapped and kill-trapped martens (e.g., *McCann, Zollner & Gilbert, 2010*; *Payer & Harrison, 1999*; *Robitaille, 2017*). Given the small population size and vulnerability to trapping, eliminating fur harvest in the central coast of Oregon would decrease immediate risk of marten extirpation.

We have provided a baseline estimate of population size that can be compared to future surveys, allowing the monitoring of population status and viability. Such additional monitoring efforts would inform whether these populations are declining or merely small (*Caughley, 1994*). Small population size, consistent annual human-caused mortality, and isolation indicate this coastal marten population is likely to remain vulnerable to extirpation.

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ADDITIONAL INFORMATION AND DECLARATIONS

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Competing Interests

The authors declare there are no competing interests.

Author Contributions

- Mark A. Linnell conceived and designed the experiments, performed the experiments, analyzed the data, contributed reagents/materials/analysis tools, prepared figures and/or tables, authored or reviewed drafts of the paper, approved the final draft.
- Katie Moriarty conceived and designed the experiments, performed the experiments, contributed reagents/materials/analysis tools, prepared figures and/or tables, authored or reviewed drafts of the paper, approved the final draft.

Oregon
Outdoor
COUNCIL

Oregon Fish and Wildlife Commission
4034 Fairview Industrial Dr. SE
Salem, OR 97302

August 3, 2018

Honorable Chair Finley and Oregon Fish and Wildlife Commission Members,

BEFORE THE OREGON DEPARTMENT OF FISH AND WILDLIFE
Petition to Initiate Rulemaking to Amend OAR 635-050-0110 to Prohibit Marten Trapping in Portions of Western Oregon

Sadly, and once again in a situation all too familiar to those of us who harvest furbearers and call Oregon home, battle lines are being drawn over how to best manage our state's indigenous wildlife. The most recent species chosen by environmental and animal rights' activists in their latest attempt to ban all trapping and timber harvest in Oregon's coast range is a secretive house-cat size forest dwelling furbearing carnivore known as the coastal marten.

The Center for Biological Diversity, Cascadia Wildlands, Environmental Protection Information Center, Klamath-Siskiyou Wildlands and Oregon Wild filed the aforementioned petition in an effort to ban trapping of marten in Oregon west of Interstate Five (I-5) from the California to Washington borders. The Petition states that the current regulated trapping of marten could put the coastal marten population at immediate risk of extinction if even two martens are lawfully harvested per trapping season. The petitioners reach their conclusion after one short and geographically limited study conducted in the Oregon Dunes National Recreation Area. It is interesting to note that the study also determined that the Oregon Dunes supported the highest reported density of martens in North America. Full text of the research can be found at: (Linnell MA, Moriarty K, Green DS, Levi T. (2018) Density and population viability of coastal marten: a rare and geographically isolated small carnivore. *PeerJ* 6:e4530 https://doi.org/10.7717/peerj.4530)

What is extremely troubling and quite ironic to Oregon trappers and hunters is the fact no coastal marten have been harvested by our conservation community over the last four years, and the scientists working under the auspices of ODFW's Wildlife Scientific Taking Permit No. 119-15 reportedly killed three during the study's very short timeframe. It is not lost on the trapping community that a marten trapping ban is the very first regulatory action requested by the petitioners, who have a very long track record of opposing science-based furbearer harvest regardless of Oregon furbearer species abundance and persistence.

Our conservation community has a long history of supporting and assisting the Oregon Department of Fish and Wildlife with responsible furbearer management through identifying and modifying trap standards and developing regulatory proposals such as the recent Eastern Oregon Red Fox seasonal harvest adjustment. Trappers and hunters as ardent conservationists generally feel that sound science, not the lack of, should craft wildlife policy decisions. The above referenced study has several glaring conclusions/declarations that cause our community to pause and ask some difficult questions of the researchers/petitioners.

1. If California banned trapping of coastal marten in 1946 (72 years ago) and the redwood marten population has not recovered, wouldn't it be reasonable to conclude that trapping was not the primary cause of the populations decline or remarkably slow recovery rate?
2. If a trap ban did not change the status of the California's coastal marten population for 72 years, why is it logical to conclude that an Oregon marten trapping ban west of I-5 would have any different species impact?
3. Aren't the petitioners prematurely asking for a regulatory conservation decision (trapping ban) while seeming to ignore this very specific declaration made in the study's introduction: "With so little known about martens in the central Oregon coast, research needs including basic attributes of the population, such as population size, are urgently needed to inform conservation decisions."
4. Shouldn't regulatory changes only be made after rigorous scientific analysis has been conducted, reviewed and concluded that a biological problem exists across the geographic range of the species of concern?

Staff provided extensive harvest records of marten harvest that confirms minimal interest in coastal marten by the trapping community. Coastal and Cascade marten pelts are not Alaskan grade. Pelt price is set by market demand for high quality, densely-furred prime pelts which are not customarily found at Oregon's lower coastal elevations. The low quality of coastal marten pelts self-regulates trapper interest/effort and associated harvest rate.

The furbearer harvesting community strongly believes that the current regulations which are reviewed every two years adequately ensure that the regulated harvest of marten in Oregon does not nor should not in the foreseeable future have a negative impact on the persistence of the species in Oregon.

The furbearer harvesting conservation community formally requests that the Oregon Fish and Wildlife Commission reject the petition in it entirety.

Stanley N. Steele, Chairman
Oregon Outdoor Council

OREGON HUNTERS ASSOCIATION

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Protecting Oregon's Wildlife, Habitat and Hunting Heritage

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August 3, 2018
Re: Marten Trapping Petition

Chair Finley, Commissioners, and Director Melcher,

The Oregon Hunters Association concurs with ODFW staff's recommendation to deny the APA petition to ban marten trapping throughout the vast region west of the I-5 Corridor in Oregon. We base our opposing position from both scientific and common-sense management principles which including these factors:

- The extremely low trapping effort put forth for this species in Western Oregon over the past 3 decades – with only 13 marten harvested, not even 1 marten per year, suggests that this is not a necessary ban – even if the petitioners claim is accurate that the Humboldt Marten population is only 71 individuals.
- Banning "tree-based trapping" on two National Forests (Siskiyou and Siuslaw), and all trapping in the Oregon Dunes National Recreation Area, is self-defeating for protecting both the marten subspecies discussed and other species of concern. Trapping is not just a detrimental action – it can, and does, have many positive influences on wildlife conservation and species protection through lessening undesired predation. Has there been an analysis of the enforcement aspect of banning only tree-sets on 2 large national forests?
- This petition speaks specifically about the need for a trapping ban, but it does not actually evaluate the ODFW trapping reporting data files, which lay out the causes of mortality over a 3-decade period.

In Sum, this petition lacks the scientific justification to make the suggested rule changes on a well-established and carefully monitored fur-bearer program. Please do not advance these recommendations into rule-making, it sets a bad precedent of eliminating an important management tool without adequate peer-reviewed scientific justification.

Sincerely,

Jim Akenson

Jim Akenson
OHA Conservation Director
541-398-2636

Marten Mortality 1989-2016

Coos, Douglas, Lane and Lincoln Counties

Year	Trap	Road Kill and other	Research Mortality	Total
2016	0	1	2	3
2015	0	2	1	3
2014	3	1	0	4
2013	3	2	0	5
2012	0	3	0	3
2011	2	1	0	3
2010	0	0	0	0
2009	0	0	0	0
2008	0	1	0	1
2007	1	0	0	1
2006	1	1	0	2
2005	0	0	0	0
2004	0	1	0	1
2003	0	0	0	0
2002	0	0	0	0
2001	0	0	0	0
2000	0	0	0	0
1999	0	0	0	0
1998	0	0	0	0
1997	0	0	0	0
1996	1	0	0	1
1995	0	0	0	0
1994	0	0	0	0
1993	0	0	0	0
1992	0	0	0	0
1991	0	0	0	0
1990	0	0	0	0
1989	2	0	0	2

This adds up to an average yearly mortality for these years of 1.04 marten per year. Trappers during those years took an average of 0.46 marten a year.

Please note in the years 2015 and 2016, 0 marten were killed by trappers and 3 were killed by researchers.