

Conservation of rare and cryptic species: Challenges of uncertainty and opportunities for progress

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Abstract

Effective conservation of at-risk species presents a conundrum, often requiring rapid status assessments and timely actions regardless of the adequacy of best available information. Here, we present a case study on Humboldt martens (*Martes caurina humboldtensis*), a rare and cryptic carnivore listed as threatened in 2020 under the United States Endangered Species Act. Given their rarity, many aspects of Humboldt marten population ecology remain understudied. To help inform marten conservation, we conducted exploratory analyses to estimate population growth by incorporating empirically derived data into two demographic modeling approaches. Population growth rates from each approach exhibited substantial variability and were uninformative to evaluating population status. Our results highlight the inherent difficulties of studying cryptic animals and exemplify the issues of using sparse or uncertain data in potentially consequential circumstances. Considering the shortcomings of our findings, we provide a framework of reliable actions to improve future conservation outcomes for poorly-understood species.

KEYWORDS

coastal marten, cryptic species, demography, extinction, *Martes caurina humboldtensis*, mustelid, population dynamics, survival, threatened species

1 | THE CHALLENGES OF CONSERVING RARE, CRYPTIC SPECIES

Conservation of rare or at-risk species is of global interest, particularly considering escalating impacts of

contemporary human activities on the natural world (Díaz et al., 2019). Definitions of rarity vary, yet “uncommonness” (e.g., small population numbers or limited geographic range) is a frequently considered factor in wildlife conservation (Gaston, 1994; Orrians, 1997). The inherent difficulties of studying uncommon species are

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compounded when animals display cryptic behaviors (e.g., nocturnality; Grow, 2019), physical appearances (e.g., camouflage; Cuthill, 2019), or demographic attributes (e.g., low densities; Balme et al., 2009) that limit their detection or observation (Boonstra et al., 1992; Karp, 2020; McDonald, 2004). Although not synonymous with the seminal definition of cryptic taxa (i.e., Sáez & Lozano, 2005), crypsis can impede our understanding of species' life histories, habitat requirements, and population trajectories (Doak et al., 2015; Master, 1991). Rare animals that exhibit cryptic characteristics are often the focus of conservation efforts, such as threatened or endangered species listings (Chadès et al., 2008; Durso et al., 2011), yet knowledge of the conditions that enable their persistence is often lacking, despite being requisite to recognizing threats and assessing recovery prospects (Raphael & Molina, 2007).

A conundrum is presented when conservation actions to support at-risk wildlife occur in the absence of robust, empirical data, especially when the outlook appears dire if no action is taken (e.g., Bryant et al., 2016). Species management and policy decisions can often precede data availability (Merkle et al., 2019) and practitioners may need to rely on sparse, unreliable, or outdated information (Gibbs & Currie, 2012; Regan et al., 2005; Vogel et al., 2007). For example, listing decisions under the United States Endangered Species Act may be deemed warranted even though species' population size or distribution estimates are unavailable (Smith-Hicks & Morrison, 2021). Many regulatory agencies operate under “best available scientific information” frameworks, yet definitions of best available can be vague and inconsistent (Esch et al., 2018; Lowell & Kelly, 2016; Murphy & Weiland, 2016). Shortcomings of such frameworks have been widely noted (Bogert, 1994; Brennan et al., 2002; Joly et al., 2010) and litigation is a common outcome (Jesup, 2013; Langpap, 2021), further delaying conservation action. Timely assimilation of research into policy implementation may alleviate these issues, but requires better connections between scientists and other conservation professionals (Cook et al., 2010; Fabian et al., 2019).

2 | HUMBOLDT MARTEN: A CASE STUDY IN RARE SPECIES CONSERVATION

Humboldt martens (*Martes caurina humboldtensis*; synonymous with “coastal” martens), a subgroup of Pacific martens (*M. caurina*; Schwartz et al., 2020), exemplify the challenges of rare and cryptic species conservation. Martens are small-bodied, solitary carnivores that exhibit

high vagility (Moriarty et al., 2017), defense of relatively large territories (Buskirk & MacDonald, 1989), and avoidance of interspecific predators or competitors (Kautz et al., 2021). Although Pacific martens have a relatively widespread distribution throughout high-elevation, montane forests of western North America (Dawson et al., 2017), Humboldt martens uncharacteristically inhabit lower-elevation forests in coastal and near-coastal areas (Zielinski et al., 2001). The extant distribution of Humboldt martens in California and Oregon suggests that it is greatly reduced from historical conditions (U.S. Fish and Wildlife Service, 2018; Figure 1).

Humboldt martens were described almost a century ago as a “rapidly disappearing furbearer” due to overharvest (Grinnell & Dixon, 1926). Despite the establishment of a trapping ban in 1946 (Twining & Hensley, 1947), no verifiable records of Humboldt martens existed in California from 1942 to 1996 and they were assumed to be extirpated from the state (Zielinski et al., 2001). In 1996, a Humboldt marten was detected during surveys for fisher (*Pekania pennanti*), representing the first record in California in more than 50 years (Zielinski & Golightly, 1996). Nonetheless, the apparent absence of Humboldt martens from California for much of the 20th century raised substantial concerns for persistence throughout its range. Humboldt martens were petitioned for listing under the federal Endangered Species Act in 2010, based on the presumption that they occurred in small, isolated, and geographically limited populations (Center for Biological Diversity, 2010).

Following a decadal process of regulatory decisions (U.S. Fish and Wildlife Service, 2012; U.S. Fish and Wildlife Service, 2015) and litigation (Center for Biological Diversity vs. U.S. Fish and Wildlife Service, 2015), Humboldt martens were federally listed as threatened in 2020 as a “coastal distinct population segment” of Pacific martens (U.S. Fish and Wildlife Service, 2020). While conservation concern for the Humboldt marten was warranted, knowledge of population attributes such as abundance and distribution was, and still is, largely lacking. For instance, the number of Humboldt martens in each of four “extant population areas” in California and Oregon (U.S. Fish and Wildlife Service, 2018) is thought to be small, yet a formal estimate of population size is only available for one area (Central Coastal Oregon; Linnell et al., 2018). Estimates of population boundaries have continually expanded since 1996 following new detections – the area covered by the Northern Coastal California extant population area was estimated to be <200 km² in 2002 (Zielinski et al., 2001), 692 km² in 2010 (U.S. Fish and Wildlife Service, 2010), 1170 km² in 2018 (U.S. Fish and Wildlife Service, 2018), and >1500 km² in 2021 (J. Hutchinson, U.S. Fish and Wildlife Service, pers.

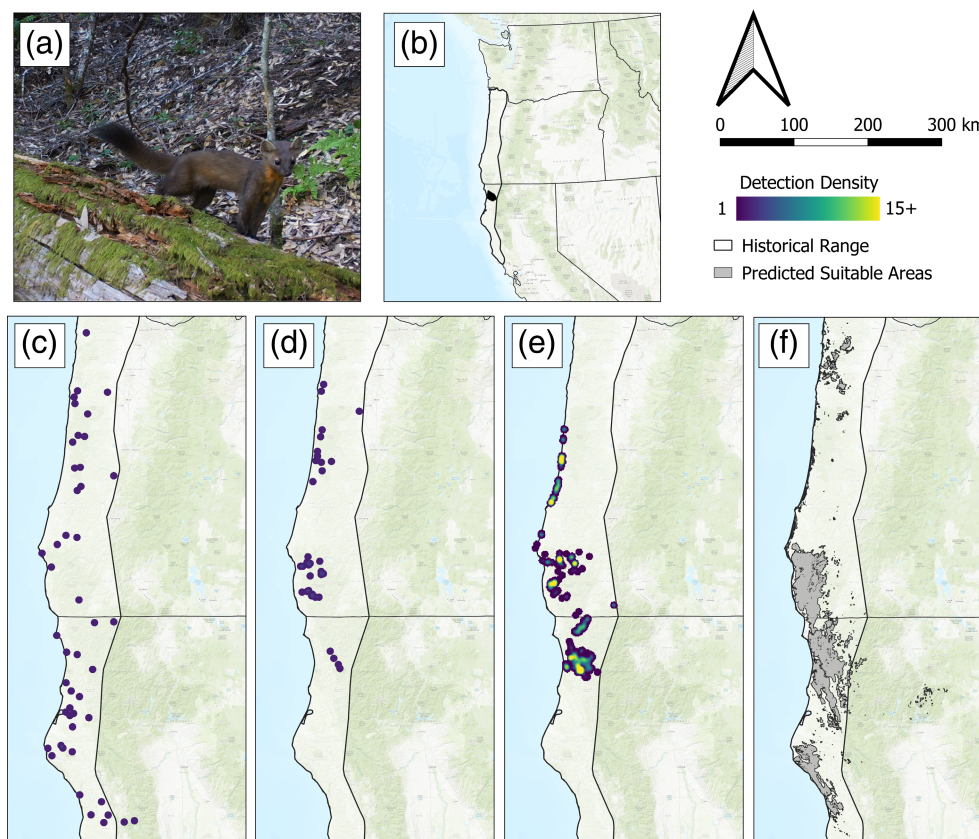


FIGURE 1 (a) Humboldt marten (*Martes caurina humboldtentensis*); (b) historical range of Humboldt marten in coastal and near-coastal forests of Oregon and northern California, USA (USFWS, 2018), indicating the location of contemporary research efforts in California (black polygon); (c) Humboldt marten detections from the early- to mid-20th century were sparse throughout the historical range and Humboldt martens were thought to be extirpated from California from 1942 to 1996; (d) Humboldt marten detections during surveys from 1989 to 1998 indicated a substantial range contraction, but also provided the first confirmed detection in California since 1942; (e) Humboldt marten detections from 1998 to 2018 suggested a broader distribution than surveys from 1989 to 1998, but still indicated a range contraction relative to historical conditions; (f) even with improved, contemporary data, disparities exist between where Humboldt marten have been documented to occur and where Humboldt martens could potentially occur based on predictive modeling (Moriarty et al., 2021). Points in panels c and d were digitized from Zielinski et al. (2001) and represent approximate (within 5 km) detection locations

comm.). While recent species distribution modeling efforts indicate predicted habitat exists outside of currently designated extant population area boundaries, it is unclear whether Humboldt martens occupy this habitat, as much of the historical range remains unsurveyed (Moriarty et al., 2021; Figure 1).

Given their newly established status as federally threatened, improved data remain acutely needed to guide and prioritize Humboldt marten conservation actions. In particular, continued uncertainty regarding fundamental species information (e.g., population growth trajectories) has been a stumbling block for determining the risk of population extirpation and whether intervention is warranted. As an exercise in evaluating the status of a Humboldt marten population, we used data collected from 2012 to 2017 within the Northern Coastal California extant population area to simulate population growth rate (λ) with two demographic modeling approaches. Our

first approach incorporated empirical Humboldt marten survival estimates derived from staggered entry Kaplan–Meier methods (Pollock et al., 1989) with fecundity estimates from the same population (Delheimer et al., 2021) into a deterministic stage-structured matrix demographic model that produced a range of growth rates (Caswell, 2001). Our second approach incorporated empirical Humboldt marten survival, derived from Cox proportional hazard methods (Cox, 1972), and fecundity estimates into a Monte Carlo sampling approach run for 5000 iterations that similarly produced a range of growth rates. Population growth rate estimates from each approach were highly variable ($\lambda = 0.84$ – 1.37 with deterministic matrix models; $\lambda = 1.23$ [0.93–1.53 95% CI] from Monte Carlo simulations; Figure 2), largely as an artifact of variable survival estimates (see Supplemental File S1 for detailed methods, survival estimates, and analytical code).

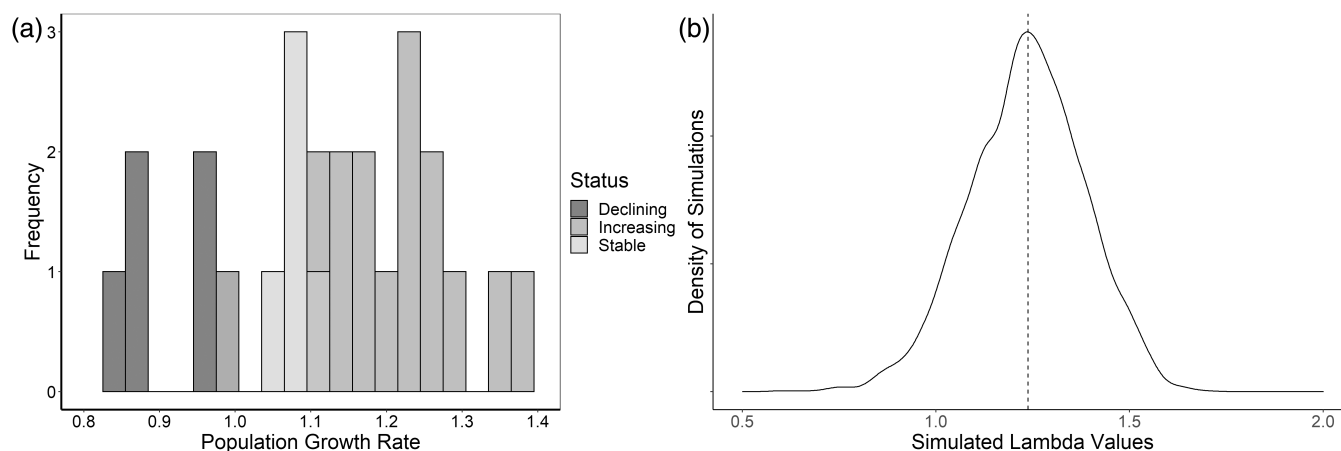


FIGURE 2 We used known-fates data collected from VHF-collared Humboldt martens (*Martes caurina humboldtensis*) captured from 2012 to 2017 within the Northern Coastal California extant population area to simulate population growth rate with two demographic modeling approaches. Our first approach (a) incorporated empirical Humboldt marten survival and fecundity estimates into a deterministic stage-structured matrix demographic model that produced a range of growth rates. Our second approach (b) incorporated empirical Humboldt marten survival estimates derived from Cox proportional hazard methods with fecundity estimates into a Monte Carlo sampling approach. Population growth rate estimates from each approach were highly variable, largely as an artifact of variable survival estimates

3 | MAKING PROGRESS WHEN “BEST AVAILABLE SCIENCE” IS NOT VERY GOOD

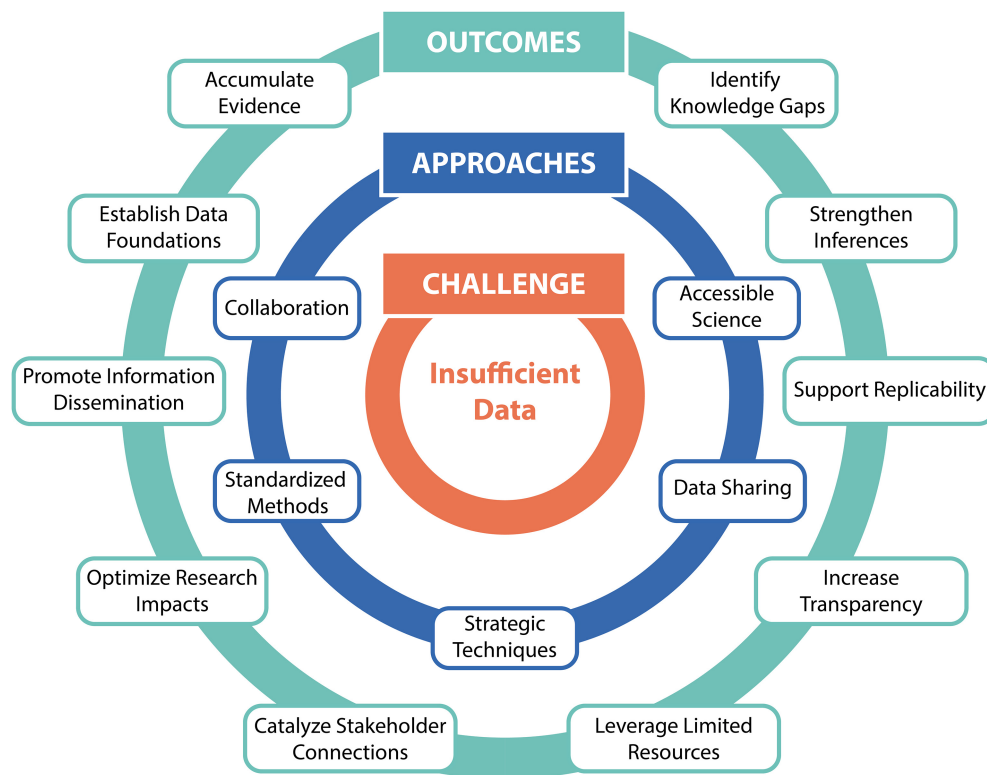
Our case study results yielded little insight into the status of the study population and are representative of the potential pitfalls of using sparse or uncertain information to inform conservation (Cheeseman et al., 2021; Holmes, 2001; Roberts et al., 2016). The case study also exemplifies the challenges of studying rare, cryptic species, given data collection was temporally and financially expensive, and resulted in capturing and tracking only 24 animals over a span of 5 years. Despite substantial financial and human capital investments, the resultant sample size was inadequate to produce precise survival estimates, which affected population growth rate estimates. Broad-scale, systematic, and long-term research can help address persistent data deficiencies (Hayward et al., 2015; Latif et al., 2018; Sanderlin et al., 2014), yet such efforts are uncommon despite their value and efficiency, because of biological, financial, logistical, or temporal constraints (Buxton et al., 2020; Ausband et al., 2014). Improved information and increased data availability remain imperative to conservation, despite inherent challenges, and hereafter we describe actions and approaches that can enhance progress and advance conservation of rare and cryptic species (Figure 3).

3.1 | Collaboration and inclusive science to strategically advance research

Given declines in support for long-term ecological studies (Vucetich et al., 2020), strategic advancement of research

is increasingly important to address critical information gaps (Jacobson et al., 2007). For example, wildlife studies often occur over relatively small geographic and temporal scales but extrapolating the findings from such efforts to broader geographies or time periods has been debated (e.g., Miller et al., 1998; Miller et al., 2004). Nonetheless, a suite of contemporary, open-access tools (e.g., Google Earth Engine) and remotely sensed data (e.g., Landsat) provide opportunities to collate and maximize the utility of data from disparate study locations to inform broader inference and conservation (Crego et al., 2022). Further, collaborative endeavors can overcome geographic and temporal limitations by joining separate entities interested in addressing common objectives (Hartel et al., 2019), identifying research priorities (Facka & Moriarty, 2017), leveraging limited resources (Merkle et al., 2019), and linking outcomes with management actions (Sands et al., 2012). An exemplar of the value of collaboration is the collective effort to better understand the status of the snow leopard (*Panthera uncia*), which has a small global population (<9000 individuals; McCarthy et al., 2016) spread across 12 countries (Rosen & Zahler, 2016). Some aspects of snow leopard ecology remain largely unknown (Riordan et al., 2016), yet recent research has rapidly improved knowledge due to collaborations that often spanned political or geographic boundaries (Atzeni et al., 2021; Bayandonoi et al., 2021; Rovero et al., 2020; Yang et al., 2021). Collaborative studies present opportunities to establish connections between diverse stakeholders, which can include government agencies, academic institutions, indigenous groups, non-profit organizations, and industry (Lamb et al., 2022; Miththapala et al., 2022). Further, efforts that engage community members and the

FIGURE 3 A conceptual diagram showing the central challenge in our case study with Humboldt martens: data insufficiency. Within this manuscript, we describe several approaches to addressing data insufficiency that can lead to a diversity of beneficial outcomes, thereby advancing conservation of rare and cryptic species



general public (e.g., citizen or community science) can be invaluable to democratizing research, promoting stewardship, increasing awareness, and ultimately creating lasting and impactful progress in conservation (de Sherbinin et al., 2021; McKinley et al., 2017).

3.2 | Standardized methodology that facilitates replication

Scientific evidence is best-supported when results are replicable (Nichols et al., 2021), but consistency in research design and application is often lacking among wildlife studies (Johnson, 2002). For example, camera traps are commonly used to investigate animal occupancy (Burton et al., 2015) and are particularly valuable in elucidating cryptic phenomena (e.g., Linnell & Lesmeister, 2020; Zhu et al., 2022). However, camera trapping methods can vary widely among projects, even for similar target species (Iannarilli et al., 2021). Methodological choices made during camera trapping can influence occupancy estimates at local (e.g., number of cameras installed; Evans et al., 2019) or broad scales (e.g., spatial resolution of a camera sampling grid; Tucker et al., 2021). Inconsistently applied methods can confound interpretations, whereas standardized or compatible methodologies allow for robust comparisons among studies and result in more powerful inferences (Fuller et al., 2020; Hayward et al., 2015; Matsuoka et al., 2014). Evidence that is

accumulated from smaller but complementary studies via standardized methods may offer the best proxy for larger research efforts that are often infeasible (Facka & Moriarty, 2017; Johnson, 2002; Nichols et al., 2019).

3.3 | Effective application of techniques and technology

Data collection techniques and technology should be selected to address research or monitoring priorities, but some approaches can be leveraged to simultaneously answer multiple questions (Tosa et al., 2021). For example, non-invasive techniques (e.g., hair snares, eDNA) that collect genetic material are a cornerstone of conservation genetics, which can be particularly effective when surveying cryptic species (Frankham, 2010; Lamb et al., 2019; Moss et al., 2022; Pauli et al., 2010). Genetic material has been widely used to assess population genetic health (Brook et al., 2002), but is increasingly applied to address topics ranging from individual-based identification to population-level demography (e.g., Ausband et al., 2015; Grauer et al., 2019; Kendall et al., 2016). Contemporary quantitative approaches that allow incorporation of data from different sources can further strengthen inferences and optimize conservation impacts of research (Fidino et al., 2022; Gilbert et al., 2021; Pearson et al., 2006; Stabach et al., 2017). For instance, collaborative and interdisciplinary efforts to

implement non-invasive genetic techniques with other approaches (e.g., camera traps) have greatly improved understanding of American marten (*M. americana*) abundance, distribution, and population viability in the Great Lakes region, offering a precedent of success that could be replicated elsewhere (Day et al., 2022; Manlick et al., 2017; Smith et al., 2021).

3.4 | Data sharing to increase availability

Synthesized data from multiple research efforts can offer an alternative when information collected during individual efforts is sparse, and data sharing via general public repositories (e.g., Dryad, <https://datadryad.org/stash/>; Mendeley, <https://data.mendeley.com/>; Zenodo, <https://zenodo.org/>) or repositories designed for specific data types (e.g., Movebank, <https://www.movebank.org/>; eMammal, <https://emammal.si.edu/>; Wildlife Insights, <https://www.wildlifeinsights.org/>; IsoBank, Pauli et al., 2017) can increase accessibility and inform conservation actions and priorities (Tulloch et al., 2018). Data sharing bolsters the integrity of the scientific process by supporting transparency and replicability of results, while allowing for new analyses of individual datasets or meta-analyses of combined datasets (Powers & Hampton, 2019; Vasilevsky et al., 2017; Warren, 2016; Wiens et al., 2021). Research efforts often go unreported, thus both published and unpublished datasets can provide valuable information (Chalmers & Glasziou, 2009; Haddaway et al., 2020). Data sharing mandates when publishing (e.g., by funding sources or journals) have increased as the importance of publicly available data is recognized (Tenopir et al., 2015). Though practitioners may have reasonable hesitations about sharing data due to concerns of unregulated access, misuse, or exploitation of intellectual property (e.g., Lindenmayer & Scheele, 2017), a variety of procedural (e.g., data encryption, redaction of locations) and legal approaches (e.g., memoranda of understanding) can be implemented to protect data (Lennox et al., 2020).

3.5 | Improving accessibility of scientific information

The urgency of improving access to science has been widely noted (Dienlin et al., 2021; McKiernan et al., 2016; Wilkinson et al., 2016) and choices made during the publication process can facilitate data dissemination (Tang et al., 2017). Posting submitted manuscripts to preprint servers allows researchers to rapidly share new findings, which can be critical to guiding timely regulatory decisions (Desjardins-Proulx et al., 2013). Preprints can also

improve the quality of published information, as feedback from the entire research community can be received and considered (Sarabipour et al., 2019). The ability to access published research is fundamental for conservation practitioners but can be impeded by journal paywalls, particularly for those unaffiliated with academic or governmental institutions (Alston, 2019). Publishing in open access journals largely eliminates this barrier and results in information that is free to readers, immediately available, and unrestricted (Laakso et al., 2011). The subject of open access publication is nuanced as costly publication fees can present an obstacle for those with limited financial support (e.g., scientists in developing countries or students at smaller academic institutions), although measures (e.g., fee waivers from journals or grants from professional societies) can be implemented to help alleviate this issue (Gossa et al., 2015; Peterson et al., 2019). Nonetheless, open access publishing increases the likelihood that results are accessed for management and policy applications (Fuller et al., 2014), which is critical for conservation of species which lack robust scientific information.

4 | CONCLUSIONS

Ensuring persistence of at-risk wildlife presents a substantial challenge in a changing world. Many species are affected by chronic threats that are difficult to mitigate, emerging threats that are poorly understood, or the interaction of multiple threats that may have dire consequences (Brook et al., 2008). In our case study, contemporary threats to small and disparate Humboldt marten populations include disease outbreaks (e.g., Smith et al., 2006), reduced genetic diversity (e.g., Lino et al., 2019), habitat loss due to increased wildfire (e.g., Abatzoglou et al., 2021), and exposure to anticoagulant rodenticides (e.g., Martin et al., 2022; Wengert et al., 2021). Addressing threats and supporting species recovery is imperative, but difficult when faced with limited funding, complicated logistics, and regulatory hurdles. While a dearth of data presents another barrier to species conservation, collaborative efforts, thoughtfully applied research, and publicly accessible findings can improve quality and accessibility of knowledge and offer a foundation for progress.

AUTHOR CONTRIBUTIONS

Marie E. Martin and Matthew S. Delheimer conceived the manuscript design with input from Katie M. Moriarty, Desiree A. Early, Keith A. Hamm, Jonathan N. Pauli, and Patricia N. Manley. Desiree A. Early, Keith A. Hamm, and Patricia N. Manley provided the raw data.

Marie E. Martin, Matthew S. Delheimer, Katie M. Moriarty, and Trent L. McDonald analyzed the data. Marie E. Martin and Matthew S. Delheimer wrote the manuscript. All authors reviewed and edited the manuscript and approved the final version.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

Data and code used for analysis will be made available through Dryad Data Repository and are available within Supplemental File S1.

ETHICS STATEMENT

Research was permitted by the California Department of Fish and Wildlife (SCP #4683) and capture and immobilization techniques adhered to guidelines for research with wild mammals established by the American Society of Mammalogists (Sikes et al., 2016).

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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