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Article

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Posted Date: November 26th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-11368249/v1

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Additional Declarations: No competing interests reported.

LiDAR derived metrics reveal response of an invasive ungulate to lethal removal efforts

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Abstract

Invasion by nonnative species is among the five greatest threats to biodiversity globally, having the potential to not only impact individual species of flora and fauna but to disrupt entire ecosystem and cross-ecosystem processes worldwide. Wild pigs (*Sus scrofa*) are among the most destructive invasive invertebrates in North America and Oceania, causing agricultural and ecological damage as well as acting as reservoirs and vectors of disease. Current management efforts often employ lethal removal to reduce populations and remove wild pigs from specific areas; however, responses of wild pigs to activities associated with lethal removal are less understood. We examined LiDAR point cloud data in combination with locations from GPS-collared wild pigs to examine habitat selection in response to repeated lethal removal efforts in Hawai‘i, USA. Wild pigs altered how they selected habitat in response to removal efforts, selecting for more rugged terrain, greater canopy cover, and remaining farther from roads and closer to water. Our results suggest that management of wild pigs may be improved by applying

intensive management efforts within shorter temporal windows to reduce the possibility of wild pigs learning to avoid management activities. Alternatively, sustained removal efforts should account for shifts towards less accessible areas. While management of wild pigs will likely remain a complex, multifaceted process, additional data-driven resources can inform future management directives and improve effectiveness of management strategies to reduce damage from wild pig populations.

Keywords: feral swine, invasive, lethal removal, lidar, management, ungulate, wild pigs

Introduction

Invasion by nonnative species is among the five greatest threats to biodiversity globally and is a direct threat to 25% of the species considered threatened with extinction by the IUCN (Hogue and Breon 2022). Invasive species have the potential to impact individual species of flora and fauna and disrupt entire ecosystem and cross-ecosystem processes worldwide (Peller and Altermatt 2024). Further, introductions of invasive species have doubled in the past 50 years, accelerating loss of biodiversity (IPBES 2019). Economic impacts of invasive species have also increased greatly, with an estimated impact of USD 1.26 trillion from 1960 - 2017 on the North American economy alone and annual costs have increased from approximately USD 2 billion in 1960 to over 26 billion/year in the 2010s (Crystal-Ornelas et al. 2021) and, while invasive species impact economies globally, these costs were found to be highest for North America followed by Oceania (Cuthbert et al. 2022). While numerous invasive species have contributed to biodiversity loss and economic loss across North America and Oceania, among

46 the most impactful of these species is the wild pig (*Sus scrofa x* domesticus; VerCauteren et al.
47 2020).

48 Wild pigs (domestic pigs, wild boar, or hybrids), also referred to as feral pigs, feral swine,
49 wild boar, or other similar names, are among the most destructive invasive invertebrates in
50 North America and Oceania (Glow et al. 2020, VerCauteren et al. 2020). Recent estimates
51 suggest roughly 5 million wild pigs are present in 39 of 50 states in the U.S (Centner and
52 Shuman 2015). Several factors contribute to the widespread prevalence of invasive wild pigs
53 including high reproduction rates, adaptable biology, and a flexible, omnivorous diet (Bevins et
54 a. 2014) as well as intentional spread by humans to new regions (Giglio et al. 2024). Wild pigs
55 can have widespread ecological impacts due to their omnivory, rooting, wallowing, and
56 trampling, posing a threat to plant, invertebrate, and vertebrate species (Treichler et al. 2023,
57 Bergman et al. 2024). In addition, wild pigs can worsen water quality (Bradley et al. 2025), cause
58 agricultural damage (Fischer et al. 2019, Friesenhahn et al. 2023, Treichler et al. 2023), and pose
59 a threat to human health due to diseases and parasites that can spread to domestic livestock or
60 directly to humans (Palencia et al. 2023, Glow et al. 2020). Annual economic impacts of wild
61 pigs in the U.S. alone are estimated to be a minimum of USD 3.4 billion, although actual costs
62 may be far greater (McKee et al. 2026). As wild pigs are such a widespread and destructive
63 nonnative species in North America and Oceania, extensive management efforts have been
64 undertaken to mitigate the ecological, agricultural and health impacts of wild pigs.

65 Due to the prevalence of wild pigs, a variety of management techniques have been
66 proposed and employed to control the impacts; however, no single perfect solution exists, and
67 management is often insufficient or ineffective (Adams et al. 2019, Seward et al. 2004). Hunting

of wild pigs is a common approach to reducing populations although U.S. states are able to set their own laws in relation to wild pig hunting and, as such, practices differ widely across states, ranging from encouraged recreational sport hunting with few restrictions to strict laws on when, where and how many wild pigs may be harvested (Centner and Shuman 2015). Lethal removal efforts by management agencies often focus on aerial shooting operations or shooting within traps, in agricultural fields or over baited sites (Seward et al. 2004). Toxicants, currently used in Oceania in places such as Australia and New Zealand (Lapidge et al. 2012), can also be an effective tool at reducing populations of wild pigs; however, many current forms of toxic bait carry the risk of affecting non-target species (Snow et al. 2018), although newer formulas targeted specifically for wild pigs are being developed. Fencing can be used to exclude wild pigs from target areas although there are rarely truly pig-proof fences over the long term (Glow et al. 2020, Seward et al. 2004). Trapping, and in rare cases snares, are additional forms of removal that may be effective in reducing populations of wild pigs (Glow et al. 2020). Some successful management efforts have been undertaken to reduce damage by wild pigs, such as in Florida's wetland habitats (Engeman et al. 2007), or in the case of the larger effort to remove pigs entirely from Arizona's Havasu National Wildlife Refuge (Bergman et al. 2024); however, in many other states such as Hawai'i, the problem of wild pigs persists with continued impacts on local biodiversity (Snow et al. 2025).

Wild pigs first arrived to Hawaii with Polynesian voyagers around 1,220 C.E. (Mangan et al. 2026, Wilmshurst et al. 2011). The wild Polynesian pigs were significantly smaller in size than present day varieties, and represented a culturally significant resource that was managed from an animal-husbandry perspective pre-colonial settlement (Luat-Hu'eu et al. 2021, Ziegler 2002),

however; over time the Polynesian pigs began to interbreed with domestic swine and wild boar species introduced by European settlers (Tomich 1986), eventually resulting in a pig population dominated by European and Asiatic ancestry and a cultural shift towards a hunter-prey relationship (Mangan et al. 2026, Luat-Hu'eu et al. 2021). As wild pigs increased in size and population, they had increasingly devastating consequences on native Hawaiian biodiversity. Not only do wild pigs eat and trample native plant species, many of which evolved without herbivory, they also facilitate the spread of invasive plants by dispersing seeds and creating disturbed areas where invasives can thrive (Leopold and Hess 2017, Nogueira-Filho et al. 2009). Similar to the establishment of Havasu NWR in Arizona to protect migratory birds and other local wildlife (Bergman et al. 2024), U.S. Fish & Wildlife Services established Hakalau Forest National Wildlife Refuge to protect endemic plant, bird and invertebrate species in 1985 (USFWS 2010). This area has been intensively managed to remove invasive wild pigs with mixed success throughout the years (Hess et al. 2019). As such, management of wild pigs in Hawai'i could be improved by additional information on how wild pigs respond to management efforts, to better tailor future management directives.

Management of invasive species is essential to maintaining native flora and fauna; however, in the case of invasive wild pigs, management is often complicated by rapid reproduction, adaptable biology and intentional introductions by humans (Bevins et al. 2014, Giglio et al. 2024). Understanding how wild pigs respond spatially to management efforts is essential to informing future management actions and successfully achieving management goals. Our objectives were to examine habitat selection of wild pigs and, more specifically to assess whether wild pigs altered their habitat selection in response to lethal removal efforts. We

112 expected wild pigs to respond to repeated lethal removal efforts by altering their habitat
113 selection. We predicted wild pigs would attempt to avoid human presence on the landscape by
114 increasing use of terrain that is less accessible to humans (e.g. more rugged terrain, farther
115 from roads, more dense vegetative cover). Understanding how target species respond to
116 management efforts is essential for tailoring future efforts and improving effectiveness of
117 management actions. Further, in the case of wild pigs, by identifying patterns and behaviors in
118 response to lethal removal efforts, subsequent removal efforts could be better focused on
119 spatial and temporal windows that maximize the impact of the management efforts and
120 improve conservation of native species.

121

122 **Methods**

123 *Study Area*

124 We conducted this study in the Upper Maulua Unit of the Hakalau Forest National
125 Wildlife Refuge (HFNWR) on the island of Hawai‘i, USA, located on the windward slope of the
126 Mauna Kea Volcano (Fig. 1; LaPointe et al. 2016). HFNWR was established in 1985 to protect
127 endemic plant, invertebrate and bird species (USFWS 2010). Management efforts on HFNWR
128 are focused on removal of invasive ungulates and plant species that threaten native species
129 (Banko et al. 2014). About 5 years after the establishment of the refuge, the Upper Maulua Unit
130 was fenced off for the purpose of removing cattle and pigs from the unit (Hess et al. 2006). This
131 fenced off area covered approximately 7.77 km^2. This region was closed to the public and only
132 accessible to refuge and agency personnel with appropriate access. The region consists of

montane forest with elevation ranging from 750 – 2,000 m (Hess et al. 2010). The refuge consists of three main habitat types: high elevation pastures, low elevation closed forests and open forest in between (Guillaumet et al. 2016). The Upper Maulua Unit experienced a fire during the early 2000s (Yelenik 2017). Average temperature and rainfall vary seasonally at the Maulua unit with precipitation ranging from 64 mm in June to 238 mm in March with a mean of 206 mm and average temperature between 10.1°C in February to 13.5°C in August with a mean of 11.6°C (Lavelle et al. 2025). Forest in the region is dominated by koa (*Acacia koa*) and ʻōhiʻa (*Metrosideros polymorpha*; Banko et al. 2014).

Populations of wild pigs on Hawai'i are characterized by a high degree of interbreeding with European and Asiatic boars, resulting in larger and more ecologically destructive pigs. Management of invasive pigs has occurred on the Hawai'ian islands since the early 1900s and continues to present day, representing a significant ecological challenge for land managers and requiring substantial effort and monetary costs to manage (Hess et al. 2019). Wild pigs are found in all management units within HFNWR with populations approximated at around 300 pigs within the refuge.

Animal Captures

We captured and collared 30 wild pigs (15M & 15F) across two capture efforts (March 31, 2021 – April 06, 2021 & December 1 – 8, 2021) on the Upper Maulua Unit of HFNWR. Wild pigs were captured using either Pig Brig net corrals (PIG BRIG, Field Engine Wildlife Research & Management, Moodus, CT, USA), existing welded-wire corral and box traps, and novel, highly

154 portable box traps (Lavelle et al. 2025). Traps were baited using either stock feed (Producer's
155 Pride, Tractor Supply Co., Brentwood, TN, USA) or sweet corn, oats and barley (COB). Pig Brigs
156 can catch wild pigs continuously when set whereas the corral and box traps were triggered by
157 pigs entering the trap. Individuals heavier than 36 kg were immobilized using butorphanol-
158 azaperone-medetomidine (BAM; Wildlife Pharmaceuticals Inc., Windsor, Colorado, USA) at a
159 dosage of ~0.03 ml/kg (Ellis et al. 2019) delivered via intramuscular injection using a CO_2 dart
160 projector. Each captured individual was fitted with a GPS transmitting collar (VERTEX PLUS-2
161 Collar, VECTRONIC Aerospace GmbH, Berlin, Germany) that collected locations every 60
162 minutes. Before release, individuals were administered atipamezole as a reversal agent at a
163 dosage of ~0.7 ml/kg. All capture and handling methods were approved by the Institutional
164 Animal Care and Use Committee from the USDA/APHIS/WS/National Wildlife Research Center
165 (QA-3225) and all methods were performed in accordance with relevant guidelines and
166 regulations. Permission from respective authorities was obtained prior to conducting any
167 capture or handling of animals.

168

169 *Removal Efforts*

170 We conducted three removal efforts to remove wild pigs on HFNWR from November 30,
171 2021 – December 8, 2021, March 1 – 9, 2022, and April 23, 2022 – May 7, 2022 (Lavelle et al.
172 2025). The objective during removal efforts was to remove as many wild pigs from the area as
173 possible during those pulse periods. We captured wild pigs using the traps described above.
174 Older corral and box traps were considered 'immobile' traps whereas novel box traps and Pig

Brig corrals were considered ‘mobile’ traps and were relocated throughout the removal period. All trap sites were pre-baited weekly with either sweet COB, dry COB (Producer’s Pride, Tractor Supply Co., Brentwood, TN, USA), or 12% all stock feel beginning two weeks prior to removal periods. Baiting of trap sites was essential to allow wild pigs time to acclimate to sites and improve efficacy and efficiency of each removal period. Captured wild pigs were euthanized via cranial gunshot using a suppressed .22 caliber pistol or rifle in accordance with guidelines set by the American Veterinary Medical Association (AVMA 2020). In addition to trapping, lethal removal was conducted via ground shooting over bait piles during the last removal effort. Bait sites for shooting were positioned along travel corridors on the landscape and baited with ~ 20 kgs of bait (typically sweet COB). Shooting operations generally occurred in late afternoon/evening. Shooting was conducted using .243 and .308 caliber rifles. Collared individuals that were recaptured during the first removal effort were released. Collared individuals captured during the second removal effort were also released except in the case of a malfunctioning collar or for noticeably pregnant individuals. During the third removal effort, collared individuals were tracked and removed.

Analysis

We used LiDAR point cloud data to quantify landscape characteristics and evaluate habitat selection of wild pigs in relation to lethal removal efforts. LiDAR data was collected from January 30, 2018 – January 6, 2020, by Leica Geosystems, Inc. as part of the Island of Hawai‘i LiDAR NOAA 2017 B17 project and is publicly available from the National Oceanic and

196 Atmospheric Association (Office of Coastal Management 2018-2020). Point cloud data was
197 processed using the 'lidR' and 'lasR' packages in program R (Roussel et al. 2020, Roussel 2026, R
198 Core Team 2026). We derived a digital elevation model (DEM) to describe elevation as
199 vegetation communities vary with elevation in the region (Guillaumet et al. 2016). We also used
200 the DEM to calculate a topographical ruggedness index (TRI). We created a canopy height model
201 (CHM) based on normalized heights of points and calculated percent canopy cover by dividing
202 all first returns above 10 m by all first returns (Sergeyev et al. 2024). We speculated that dense
203 vegetation may act as secure areas for wild pigs during removal efforts and, as such, calculated
204 density of vegetation ≤ 2 m high using point counts. All rasters were created at 5 m resolution.
205 As bait stations were generally close to roads, we calculated the distance to roads for each GPS
206 location using the road network within the refuge. As water can be an important factor in
207 habitat selection for wild pigs, we also calculated distance to water for each GPS point (Snow et
208 al. 2022a). Hydrological features were obtained from the National Hydrography Dataset created
209 by the U. S. Geological Survey (USGS 2022).

210 We modeled habitat selection of wild pigs in response to lethal removal efforts using a
211 step-selection framework (Thurfjell et al. 2014) with conditional logistic regression models in
212 the 'survival' package in R (Therneau and Grambsch 2000). We considered 10 random steps for
213 each true step (Panzacchi et al. 2016). We restricted our analysis to all locations collected before
214 lethal removal efforts (from time of capture until November 14, 2021) and during the three
215 removal efforts, summarized as a Treatment variable (Pre = pre- lethal removal, T1 = first
216 removal effort, T2 = second removal effort, and T3 = third removal effort). We elected not to
217 include the two week pre-baiting periods as these periods included human disturbance on the

landscape but did not result in lethal removals and as such, did not fit within the pre-treatment period nor the treatments themselves. *A priori* candidate models contained different combinations of landscape variables as well as interactions between landscape variables and Treatment, to examine whether habitat selection changed with subsequent removal efforts. All models included ID-step as a grouping variable. To improve model convergence and for better comparison of effect sizes, all predictor variables were rescaled from 0 to 1 using the 'scales' package in R (Wickham et al. 2025). We evaluated competing models using an AIC_c model selection process (Akaike 1973). We created predictive plots based on the top model using the 'ggplot2' package in R (Wickham et al. 2016).

Results

Lethal removal efforts resulted in 206 pigs removed during the first effort (26.51 pigs/km^2), 79 during the second effort (10.17 pigs/km^2), and 150 during the third effort (19.30 pigs/km^2), for a total of 435 wild pigs euthanized across 162 capture events (Lavelle et al. 2025).

When examining habitat selection in relation to lethal removal efforts, we observed differences that suggested wild pigs became increasingly aware of human presence on the landscape and altered their selection of habitat as a result. Our top model included vegetation density, canopy height, canopy cover, elevation, distance to roads and distance to water, with an interaction between Treatment and each of the landscape variables. None of the other candidate models were within ΔAIC_c of 2.00 of the most supported model. In response to subsequent lethal removal efforts, wild pigs increased use of rugged terrain ($\exp(\beta) = 1.88$ [95%

C.I. = 1.38, 2.55] for Treatment 2 and exp(β) = 1.98 [95% C.I. = 1.19, 3.28] for Treatment 3) and selected for lower elevations (exp(β) = 0.09 [95% C.I. = 0.01, 0.65] for Treatment 2 and exp(β) = 0.05 [95% C.I. = 0.00, 1.21; α = 0.07]; Fig. 2 & 3.). Selection for canopy cover did not differ between the pre-treatment period and Treatment 1 or Treatment 2; however, by Treatment 3, wild pigs selected for increased canopy cover (exp(β) = 2.15 [95% C.I. = 1.25, 3.69]). We observed wild pigs selecting for lower canopy height during Treatments 2 and 3 (exp(β) = 0.57 [95% C.I. = 0.30, 1.10; α = 0.10] and exp(β) = 0.25 [95% C.I. = 0.08, 0.77]. Wild pigs selected for dense vegetation during Treatment 1 (exp(β) = 2.78 [95% C.I. = 1.39, 5.55], however, this effect reversed during Treatment 2 (exp(β) = 0.45 [95% C.I. = 0.21, 0.98]. Selection for distance to water did not differ between pre-treatment and Treatment 1 or Treatment 2; however, wild pigs selected for areas closer to water during Treatment 3 (exp(β) = 0.15 [95% C.I. = 0.03, 0.64]. We observed selection for areas closer to roads during Treatment 1 (exp(β) = 0.40 [95% C.I. = 0.24, 0.68]), no difference between pre-treatment and Treatment 2 in relation to distance to roads (exp(β) = 0.86 [95% C.I. = 0.49, 1.50]), and selection for areas farther from roads during Treatment 3 (exp(β) = 3.50 [95% C.I. = 1.47, 8.29]).

Discussion

As a widespread and often overabundant native and invasive species, wild pigs threaten biodiversity worldwide, particularly in areas with rare and vulnerable endemic species such as Hawai‘i, USA. We leveraged LiDAR data, combined with GPS locations of wild pigs, to examine the response of wild pigs to short duration, intensive removal efforts. Total numbers of removed pigs suggest abundance on Maulua had greatly increased since the mid-2010s, with older

estimates ranging from approximately 50 – 80 pigs (Leopold et al. 2015). We provide a novel perspective of how invasive ungulates may respond to management efforts. Our results show distinct shifts in the habitat selection of wild pigs in relation to lethal removal efforts, suggesting wild pigs are adept at identifying new threats on the landscape and alter their behavior to avoid risk. As a result, we expect that management efforts could lessen in effectiveness as remaining pigs improve in ability to avoid being captured or shot. As such, understanding the response of wild pigs to lethal removal efforts is paramount to maximizing effectiveness of management efforts. Our study builds upon previous knowledge on the effects of management on wild pig populations and how managed species respond to anthropogenic influences.

We observed the strongest effects related to selection for dense vegetation during the first treatment and for rugged areas in greater canopy cover and farther from roads during the final treatment. Selection for dense vegetation during the first treatment suggests pigs avoided managers and used dense vegetation as refuge. Similarly, selection for rugged terrain, farther from roads in denser canopy represents a shift towards areas less accessible to managers (Hidalgo-Toledo et al. 2025). The stronger magnitude of effect during the final treatment was not surprising as wild pigs had had more opportunity to become educated to the additional risk on the landscape and further, lethal removal was conducted on foot during the third treatment likely creating more disturbance than the initial two removal efforts. Studies on habitat selection of wild pigs in response to lethal removal have often provided inconclusive evidence. When reviewing literature regarding habitat selection by wild pigs in response to lethal removal, Keuling and Massei (2021) documented a shift in spatial behavior in 62% of prior studies while 38% were either inconclusive or found no effect of hunting on spatial behavior of wild pigs.

283 Overall patterns show an increased use of less accessible terrain; however, we observed some
284 conflicting results at the population level wherein pigs selected for lower canopy or less dense
285 vegetation in some instances, although the negative effect of vegetation density during the
286 second treatment was marginally significant. We interpreted these conflicting results as
287 potential instances of erratic movement to escape removal efforts that may have resulted in
288 unexpected patterns of habitat selection. Similarly, removal of wild pigs by trapping led to
289 remaining wild pigs shifting use of land cover types and reducing selection for areas rich in
290 vegetation (Bastille-Rousseau et al. 2020). These results also show population level trends
291 whereas the selection of individuals likely differed between individuals and/or sexes (Bengsen
292 et al. 2025, Bastille-Rousseau et al. 2020). Water availability has also been documented as an
293 important driver of habitat use by wild pigs (Cuevas et al. 2026, Clontz et al. 2021) and we
294 similarly observed wild pigs selecting for areas closer to water by the third removal effort,
295 potentially a result of them taking cover in resource-rich areas (Brewer et al. 2024). Many
296 ungulate species select areas farther from roads in response to anthropogenic influences
297 (Rezvani et al. 2024), consistent with our findings that pigs in our study area, with minimal
298 persecution prior to this study, also selected for areas farther from roads in response to lethal
299 removal efforts.

300 Recent studies have shown that removal of wild pigs can reduce and reverse pig-related
301 damage on the landscape (Treichler et al. 2022, Gaskamp et al. 2018); however, understanding
302 the impacts of removal efforts on the behavior of wild pigs is essential to informing
303 management strategies. Overall, we observed several shifts in habitat selection in response to
304 removal efforts within our study area, with shifts towards terrain less accessible to humans

(farther from roads, in denser canopy or more rugged). Our results suggest wild pigs rapidly became aware of anthropogenic disturbance and the associated risk and altered their behavior to reduce risk. Wild pigs that experienced negative anthropogenic stimuli exhibited less visitation to bait sites (Snow et al. 2022b). Similarly, wild pigs that did visit bait and trap sites, adjusted the timing of visits to reduce overlap with humans and increased use as time since human presence increased (Slezak et al. *in press*, Fischer et al. 2020). Further, in response to lethal removal efforts, wild pigs increased movement rates and altered behavior (Bastille-Rousseau et al. 2020, Koriakin et al. *in press*, Fischer et al. 2016, Campbell et al. 2012, Campbell et al. 2010). Our study adds to a growing body of literature on the responses of wild pigs to management efforts and further shows that management efforts have the potential to alter behavior of wild pigs (Keuling and Masseo 2021, Bastille-Rousseau et al. 2020, Koriakin et al. *in press*, Fischer et al. 2016) and provides additional evidence of how spatiotemporal changes in risk can influence behavior of a persecuted species (Tolon et al. 2009).

Our study suggests that pigs quickly become aware of lethal removal efforts and alter their habitat selection in response, thereby making it more difficult to effectively trap remaining individuals. Within a population of wild pigs where little or no recent shooting or trapping existed prior to the study, we observed distinct changes in space-use as a response to the presence of wildlife managers. While a large number of wild pigs were removed, likely representing a large portion of the population within our study area (Lavelle et al. 2025), the remaining wild pigs would have likely required far more effort, and at a greater cost, to remove as they had become increasingly aware of the removal efforts and remained in areas more difficult to access (Fischer et al. 2020). Our results therefore suggest that short-term, intensive

approaches of agency-led professional trapping and shooting would likely be more effective than repeated or continuous removal efforts, as wild pigs become increasingly difficult to locate and remove. Prior studies have shown that placement of bait/traps is more influential than the bait used (Snow et al. 2022b), suggesting that properly targeting management efforts is essential to the success of those efforts. In areas where wild pigs are more aware of persecution by humans, populations may be far more responsive to management efforts. Further, in areas with recreational or subsistence hunting of wild pigs, hunting may prove counterproductive for population control as the number of pigs removed is likely less than during concentrated removal efforts yet the anthropogenic presence on the landscape is far more pronounced, potentially serving to educate the remaining wild pigs. Future research may help to identify thresholds of how much management/disturbance is needed on the landscape to result in changing behavior by wild pigs.

As an ecologically and economically destructive invasive species, management of wild pigs will continue to rely on the integration of multiple techniques; though, understanding the response of wild pigs to management efforts can generally help to inform management directives. Our results provide new insight into how invasive ungulates respond to lethal removal efforts, showing that wild pigs increase use of rugged terrain, canopy cover, and remain closer to water and farther from roads. By accounting for these shifts in habitat selection, managers can either plan greater effort in advance before wild pigs have the opportunity to learn and adjust or plan on longer-term trapping/removal that accounts for shifts towards less accessible terrain. Using data-driven, focused management approaches can increase effectiveness of management and reduce ecological and agricultural damage from wild pigs.

Further, understanding how managed species respond to management efforts can help inform and improve future objectives and management approaches.

Acknowledgements: We are grateful to Seth Cook, Joseph Halseth, Carmen Antaky, Bethany Friesenhahn, Thomas McAuliffe, Robert Sugihara, Keely Kohen, Tom Cady, Donna Ball, Steve Kendall, Israel Leinbach, Shayne Veriato, Ryan Kiriu, Jeremiah Psiropoulos, Kathleen Urchek, and Darrin Phelps for all of their help in planning and conducting this study. We thank the US Department of Agriculture (USDA) Animal and Plant Health Inspection Service (APHIS) for funding this research. Mention of commercial products does not represent an endorsement by the US government. The findings and conclusions in this publication are those of the authors and should not be construed to represent any official USDA or US Government determination or policy.

Data Availability Statement: The datasets generated and/or analysed during the current study are not publicly available due to the animal GPS data being personal and protected information but are available from the corresponding author on reasonable request. Code used for the analysis can be found at the Github repository: https://github.com/MaksimSergeyev/SciRep_LiDARSSF_WildPigs_Code

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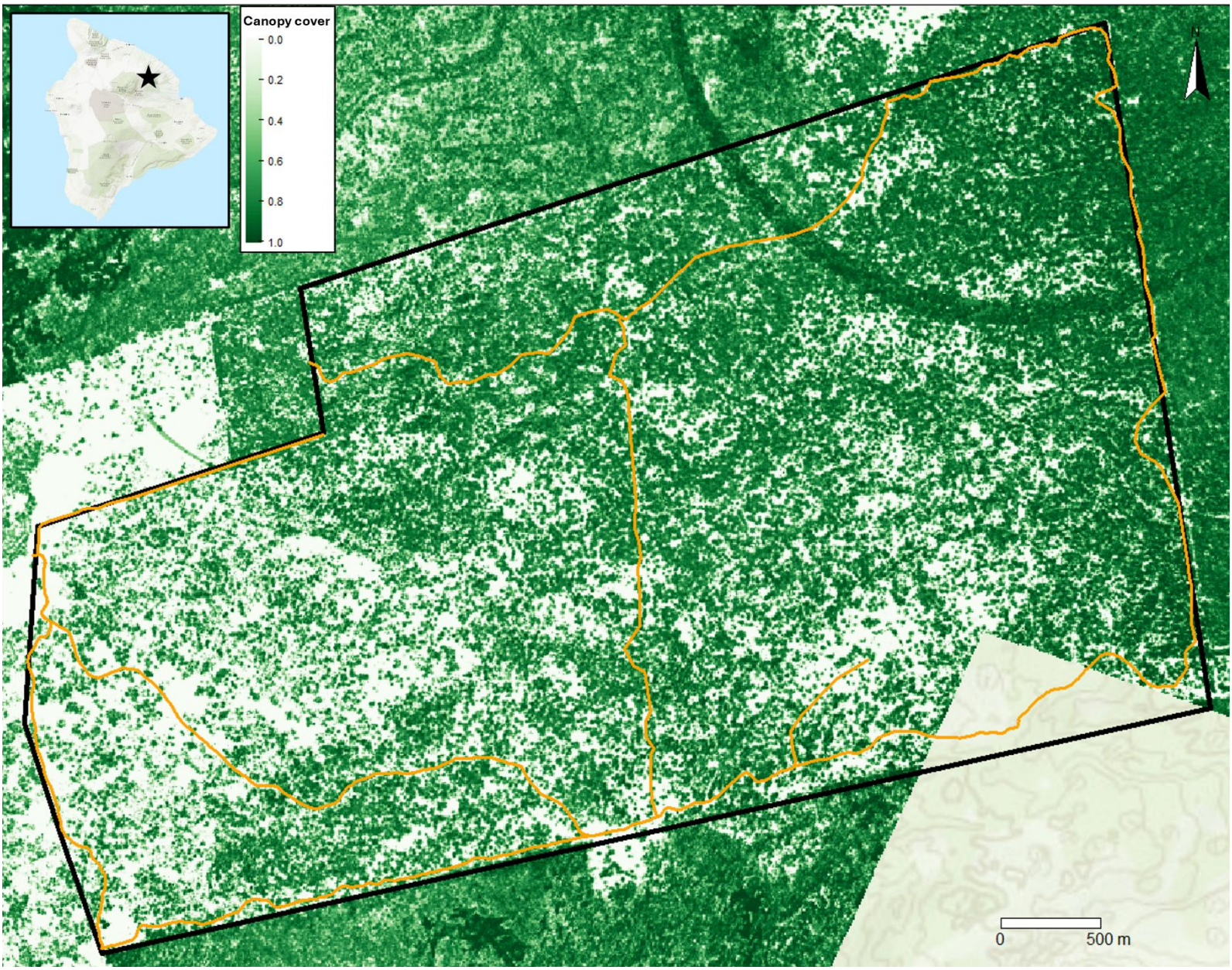
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Tables

Table 1. Model output from the top model of habitat selection by wild pigs on the Island of Hawai'i, USA following lethal removal events in 2021-2022. Model included ruggedness, elevation, % canopy cover, canopy height, density of vegetation below 2 m, distance to water, and distance to roads as well as an interaction between each variable and Treatment (T1, T2, and T3 refer to the lethal removal events. Table provides the coefficient estimate as well as the exponentiated coefficient and 95% confidence interval.

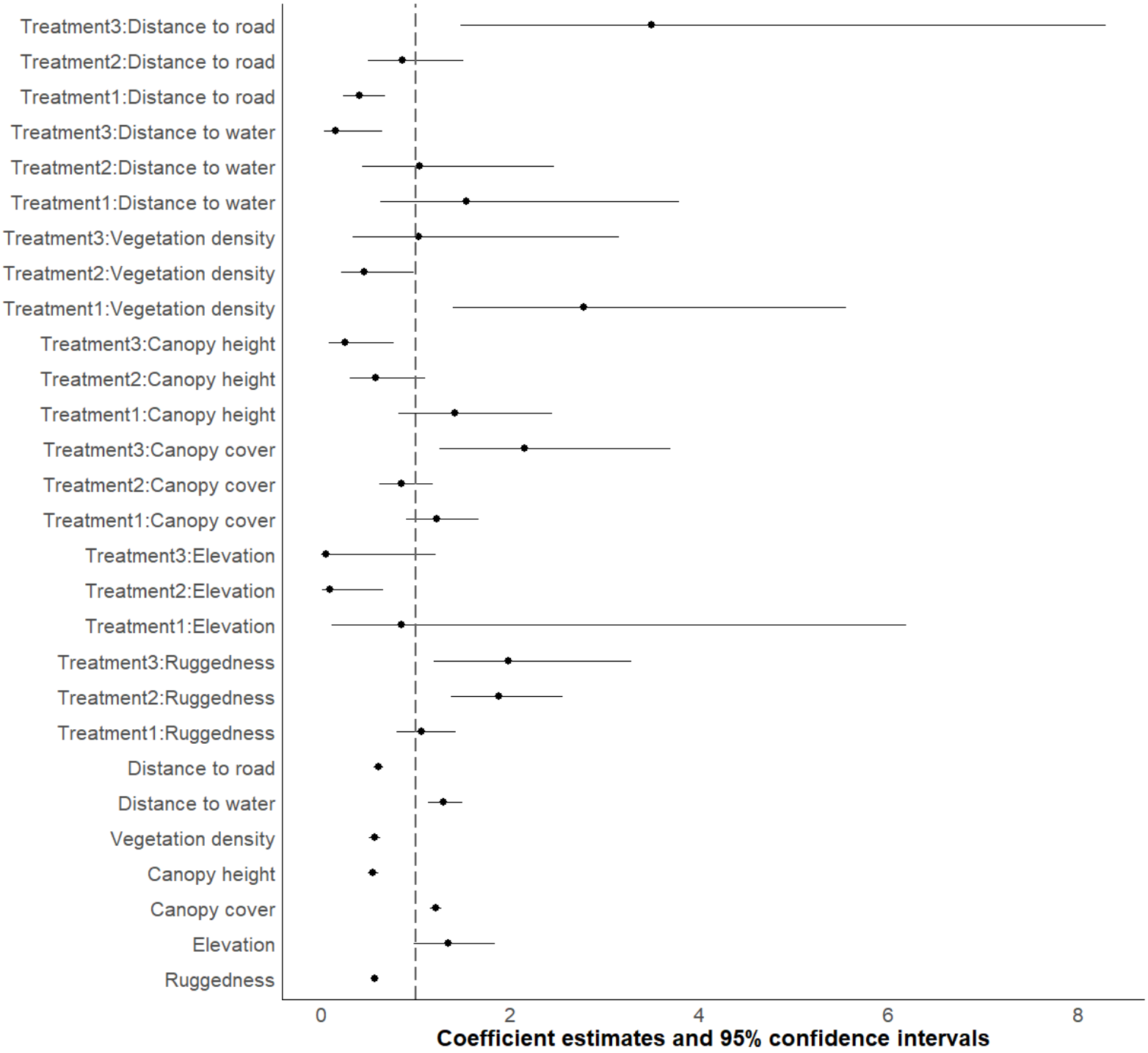
	β	exp(β)	95% C.I.
Ruggedness	-0.575	0.562	[0.537, 0.590]
Elevation	0.291	1.338	[0.975, 1.837]
Canopy cover	0.190	1.209	[1.152, 1.269]
Canopy height	-0.601	0.548	[0.500, 0.602]
Veg. density	-0.573	.0564	[0.507, 0.627]
Dist. water	0.260	1.297	[1.129, 1.490]
Dist. roads	-0.501	0.606	[0.558, 0.659]
T1:Ruggedness	0.061	1.063	[0.796, 1.420]
T2:Ruggedness	0.629	1.875	[1.376, 2.556]
T3:Ruggedness	0.681	1.976	[1.190, 3.281]
T1:Elevation	-0.170	0.844	[0.115, 6.188]
T2:Elevation	-2.436	0.088	[0.012, 0.653]
T3:Elevation	-3.042	0.048	[0.002, 1.207]
T1:Canopy cover	0.202	1.224	[0.900, 1.664]
T2:Canopy cover	-0.163	0.850	[0.612, 1.179]
T3:Canopy cover	0.766	2.150	[1.252, 3.695]
T1:Canopy height	0.344	1.411	[0.814, 2.447]
T2:Canopy height	-0.547	0.579	[0.304, 1.102]
T3:Canopy height	-1.370	0.254	[0.084, 0.766]
T1:Veg density	1.022	2.779	[1.391, 5.551]
T2:Veg density	-0.790	0.454	[0.209, 0.983]
T3:Veg density	0.026	1.027	[0.335, 3.146]
T1:Dist water	0.430	1.537	[0.624, 3.782]
T2:Dist water	0.036	1.036	[0.437, 2.459]
T3:Dist water	-1.904	0.149	[0.034, 0.644]
T1:Dist roads	-0.916	0.400	[0.236, 0.678]
T2:Dist roads	-0.148	0.863	[0.494, 1.508]
T3:Dist roads	1.251	3.495	[1.472, 8.298]

611 **Figures**



612

613 **Figure 1.** Map of the study area for examining the response of wild pigs to lethal removal
614 efforts. Black line denotes the fenced boundary of the Upper Maulua unit of the Hakalau Forest
615 National Wildlife Refuge, HI, USA; orange lines denote off-highway vehicle roads within the
616 refuge. Inset map provides the location of the refuge in the context of the Island of Hawai'i, HI,
617 USA. Missing portion in bottom right corner of boundary is due to missing coverage in the LiDAR
618 data set.



619

620 **Figure 2.** Exponentiated coefficients from the top conditional logistic regression model
621 examining habitat selection of GPS collared wild pigs in Hawai‘i, USA. Treatments refer to one of
622 three subsequent lethal removal efforts. Coefficients below 1.0 (vertical dashed line) signify a
623 negative effect while coefficients above 1.0 signify a positive effect.

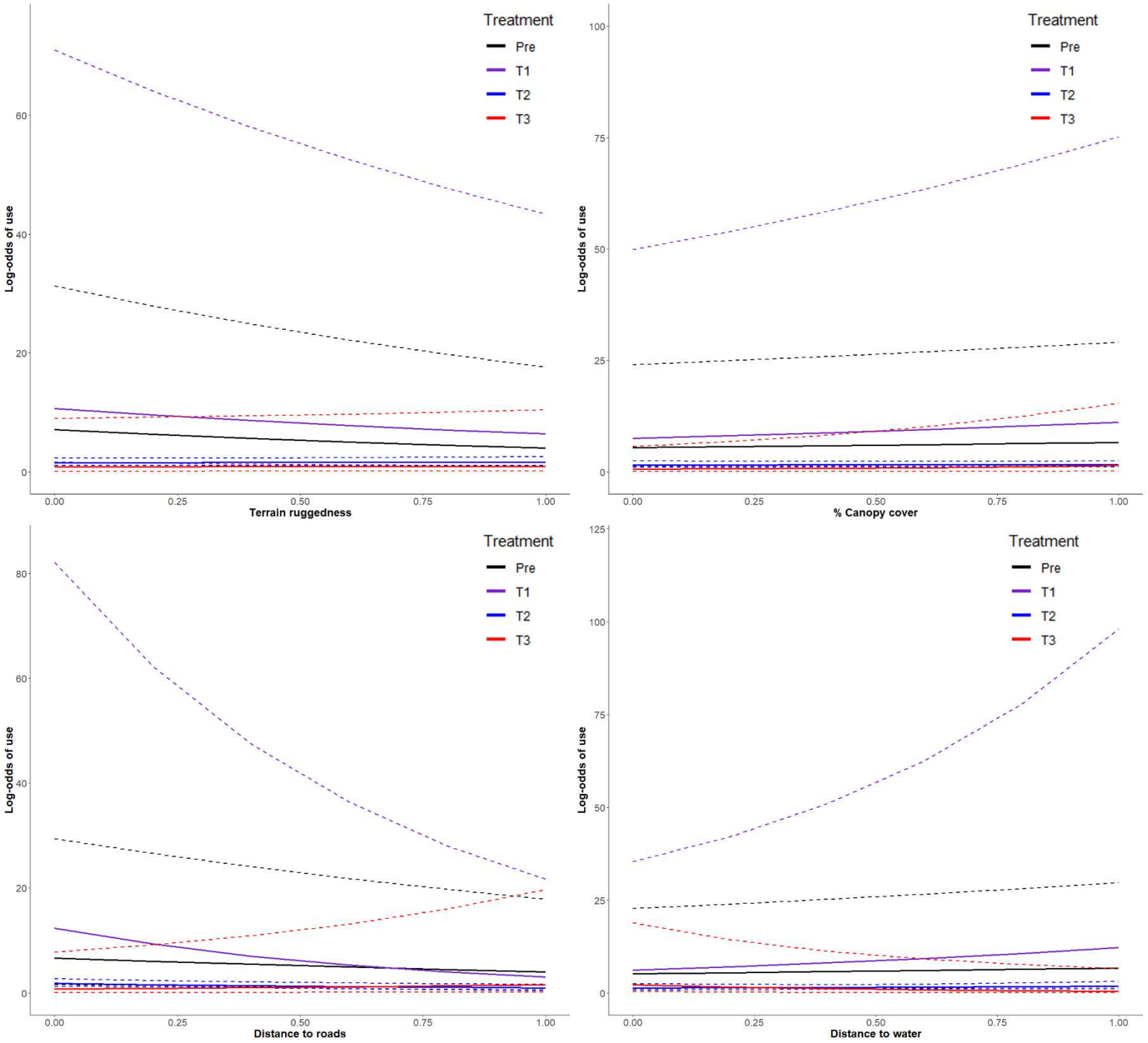


Figure 3. Predictive plots showing the effect of four significant variables (terrain ruggedness, % canopy cover, distance to roads and distance to water) in the top conditional logistic regression model examining habitat selection of wild pigs in Hawai'i, USA. Treatments refer to lethal removal efforts; "pre" refers to the period before pre-baiting began for lethal removal, T1-3 refer to the three lethal removal efforts undertaken. Solid lines show the model prediction while dashed lines show the 95% confidence interval. All variables are rescaled from 0 to 1.