TO ANALYZE THE POST-2021 WILDFIRE EFFECTS ON THE OCCUPANCY OF THE
TOWNSEND'S SOLITAIRE DURING THE BREEDING SEASON BY CONDUCTING A
SINGLE-SEASON SINGLE SPECIES OCCUPANCY MODELING

A Thesis

Presented to the Faculty of the Graduate School

of Cornell University

in Partial Fulfillment of the Requirements for the Degree of

Master of Professional Studies in Natural Resources and the Environment

by

Shubham Shashikant Darveshi

December 2023

ABSTRACT

California wildfires have nuanced effects on the landscape of the forests and habitat of wildlife. Some species respond positively to ecological changes while some respond negatively to it. Our purpose was to investigate the effects of 2020 North Complex Fire of Sierra Nevada California on the Occupancy of the Townsend's Solitaire (Myadestes townsendi). Our hypothesis was that this bird species has benefitted from the patches around the recorder sites burned at high severity. So, we conducted a survey in this region and detected the calls of Townsends solitaire over its breeding season from May to July. We found that there is possibly a positive correlation between high severity fire and occupancy of Townsends Solitaire, negative correlation between elevation, burnt state and the occupancy but we did not find sufficient evidence to conclude that this bird benefitted from this particular wildfire as the models having occupancy covariates were having $\Delta AIC \leq 2$.

BIOGRAPHICAL SKETCH

Shubham is a passionate wildlife photographer and birder from Mumbai, India. He has completed his undergraduate degree in Electronics and Telecommunication Engineering from Mumbai University. Before joining Cornell, he has been associated with conservation organizations such as Wildlife Institute of India, Bombay Natural History Society and World Wildlife Fund-India. He is motivated by the drive to understand the ecology and behavior of birds and explore the applications of technology in the field of wildlife conservation. His primary interest lies in Ornithology and conducting research using quantitative methods and advanced technology like Bioacoustics, Machine Learning and GIS that leads to devising conservation plans and informing conservation agencies about the for the endangered species.

Dedication: To my parents who instilled the love for nature in me and always supported my passion for wildlife photography, bird watching and pursuing a career in wildlife conservation.

ACKNOWLEDGMENTS

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF ABBREVIATIONS

RAVG – Rapid Assessment of Vegetation Condition After Wildfire

USGS – United State Geological Survey

AIC – Akaike Information Criterion

SSP – Secondary Sampling Period

ARU – Automated Recording Units

LIST OF SYMBOLS

p_{ij} - *detection probability*

α - *the parameters to estimate for the detection probability p*

ψ_i - *occupancy probability*

β - t*he parameters to estimate for the occupancy probability ψ*

BACKGROUND

The response of the wildlife species to the wildfires is nuanced and idiosyncratic (Hutto and Patterson 2016). Some species respond negatively to the combinations of severity of fire while others respond positively. Forest fires have changed the landscapes in California's Sierra Nevada, the genocide of the indigenous people who used fire as a management tool (Taylor et al. 2016; Madley 2017), a century of fire suppression to support the timber industry and climate change have led to an increase in large and homogeneously severe fires that can threaten biodiversity (Steel et al. 2015; North et al. 2015). It has been projected that such instances of wildfires will increase in the future (Adams 2013; Wood and Jones 2019; Coop et al. 2020; Cova et al. 2023). It has become crucial to understand how wildlife species respond to these recurring disturbances in habitat caused by wildfires. Dr. Connor Wood found from the preliminary outputs of a model representing the species response to wildfire from his ongoing Sierra Nevada Bioacoustics Project in California that some species exhibit peculiar trends in response to fires. To understand the effects of wildfires on the bird species and inform its occupancy trends in response to wildlife, I collaborated with Dr. Connor Wood. He found one such peculiar species named Townsend's solitaire (Myadestes townsendi), hypothesized to show both colonization and extinction response to habitat changes caused by wildfire in Sierra Nevada region. It has been observed to prefer burned and open woodlands[4]. We speculated that open forest habitat post fire resulted in the burnt undergrowth and bushes might prove to be better habitat for Townsend's Solitaire. Hence, we analyzed the Townsend's Solitaire response to the post habitat changes caused by the North Complex Fire which took place in the Plumas National Forest during August 2020 to December 2020 using the detection data from the ARU's in this region and using Occupancy Modeling as a primary analysis tool. We used a very large-scale passive acoustic monitoring program to assess the relationship between high severity fire in the north complex region and the occupancy estimate of the Townsend's Solitaire bird species. In addition to that, our goal was to determine whether other observation factors and landscape covariates such as elevation would be supportive in terms

of informing the ecological effects of fire on the occupancy of this bird at the recorder sampling sites.

SURVEY AND METHODS

Study Area and Surveys

Dr. Connor Wood conducted passive acoustic monitoring surveys during the period from May to August 2021 at 167 sites located in the North Complex fire region of the Sierra Nevada, California. We selected the period of 10th May to 3rd July 2021 as a survey period for our analysis, which coincides with the peak breeding season of Townsend's Solitaire[5]. Our survey took place in the Plumas National Forest region of Sierra Nevada from the habitat mixed conifer forests and elevation 600m - 2200m.

Survey Data and Processing

We identified the Townsend's Solitaire vocalizations using the machine learning algorithm BirdNET, a deep convolutional neural network that is trained to recognize > 6000 species of birds worldwide (Kahl et al. 2021). We selected the detection threshold in the BirdNET analyzer for Townsend's Solitaire call to be 90% accurate. We also wanted to eliminate the false positives, so we used a detection filter to consider only those sites as occupied where the bird was detected for at least 3 separate days during the survey period and to compensate for the imperfect detections caused by the 90% threshold of the BirdNET. We only considered a detection to be valid if the survey effort of the recorder was greater than 0 hrs.

Observation and Habitat Covariates

To assess the post-fire effects and fire severity on the habitat & occupancy of the Townsend's Solitaire, we created two sets of fire covariates, one for whether the site was burnt and, if burnt, how severe the fire was quantified from the fire history at each site using a fire severity data from

the RAVG portal of USGS[6]. I also included effort hours per recorder for each secondary sampling period and first day of the each SSP i.e. date (Julian day of the year) as detection covariates to improve the detection probability estimate and support our predictions of the occupancy model. We also included elevation as a covariate to incorporate changes in the terrain of the landscape which might affect the occupancy of Townsend's Solitaire as it has been observed to prefer lower elevations of 300m-3400m[7].

Modeling Procedure

We used single-season single-species occupancy models in a frequentist framework to assess the associations between Townsend's Solitaire and both habitat and fire. Occupancy models rely on repeated surveys to correct for imperfect detection of target species (Mackenzie et al. 2002), and the single-season framework allows for the incorporation of random effects to account for spatial patterns. We used the month of May-July as our primary sampling period because it coincides with peak breeding period of this bird and avoids any migratory movements by adults[5]; thus, this survey period mitigates potential violations of the closure assumption of occupancy models (Mackenzie et al. 2002). We split our primary sampling period into five 7-day secondary sampling periods.

An occupancy model can be written as follows[8]:

$y_i|z_i \sim Bernoulli(p * z_i)$
$z_i \sim Bernoulli(\psi)$

$logit(p) = \alpha_0 + \alpha_1 * covariate_1$
$logit(\psi) = \beta_0 + \beta_1 * covariate_1$

Our detection model for all analyses was of the form:

$$logit\ (p_{ij}) = \alpha_{ssp[ij]} + \alpha_1 * effort\ hours_{ij} + \alpha_2 * date_{ij}$$

$$logit\ (\psi_i) = \beta_0 + \beta_1 * burnt_i + \beta_2 * high.severity_i + \beta_3 * elevation_i$$

I implemented all the models in the R Statistical Environment using the unmarked package. I derived the inference of the combinations of the models from the Dredge function of the MuMIN package.

RESULTS

1. We inferred that around 38% of the sites were occupied by Townsend's Solitaire with the 95% confidence interval between 0.3642384 & 0.4569536.

2. We observed a positive correlation between the sites burned at high severity and the occupancy of the Townsend's Solitaire.

3. We observed a negative correlation between probability of occupancy of the Townsend's solitaire and the burnt state and elevation of the study sites.

4. By the model selection criteria of using lowest AIC score of models. It was observed that the model with only detection covariates was better than model's the occupancy covariates.

5. The models with the addition of burnt, high severity and elevation site covariates were within $\Delta AIC \leq 2$.

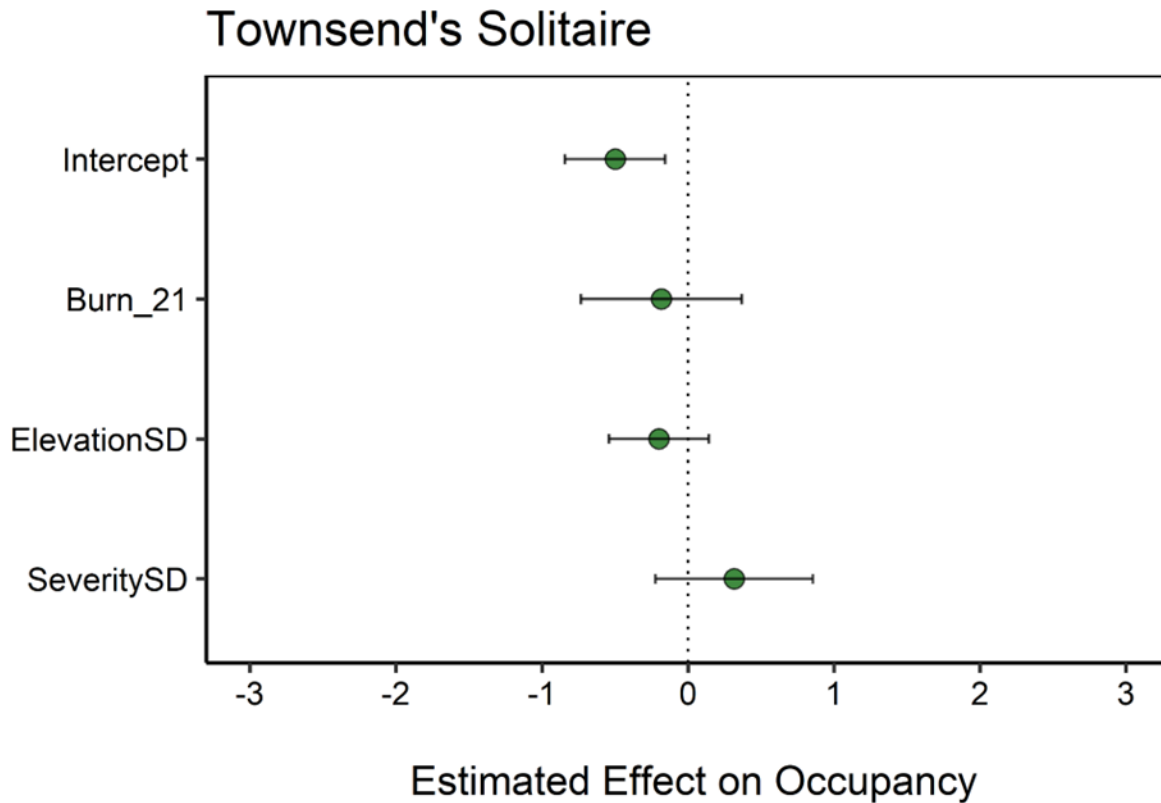Fig 1: Graph showing the effect of the site covariates on the Occupancy of Townsend's Solitaire

Naive Occupancy of Townsends Solitaire at the recording units in North Complex Site of Sierra Nevada Bioacoustics Project
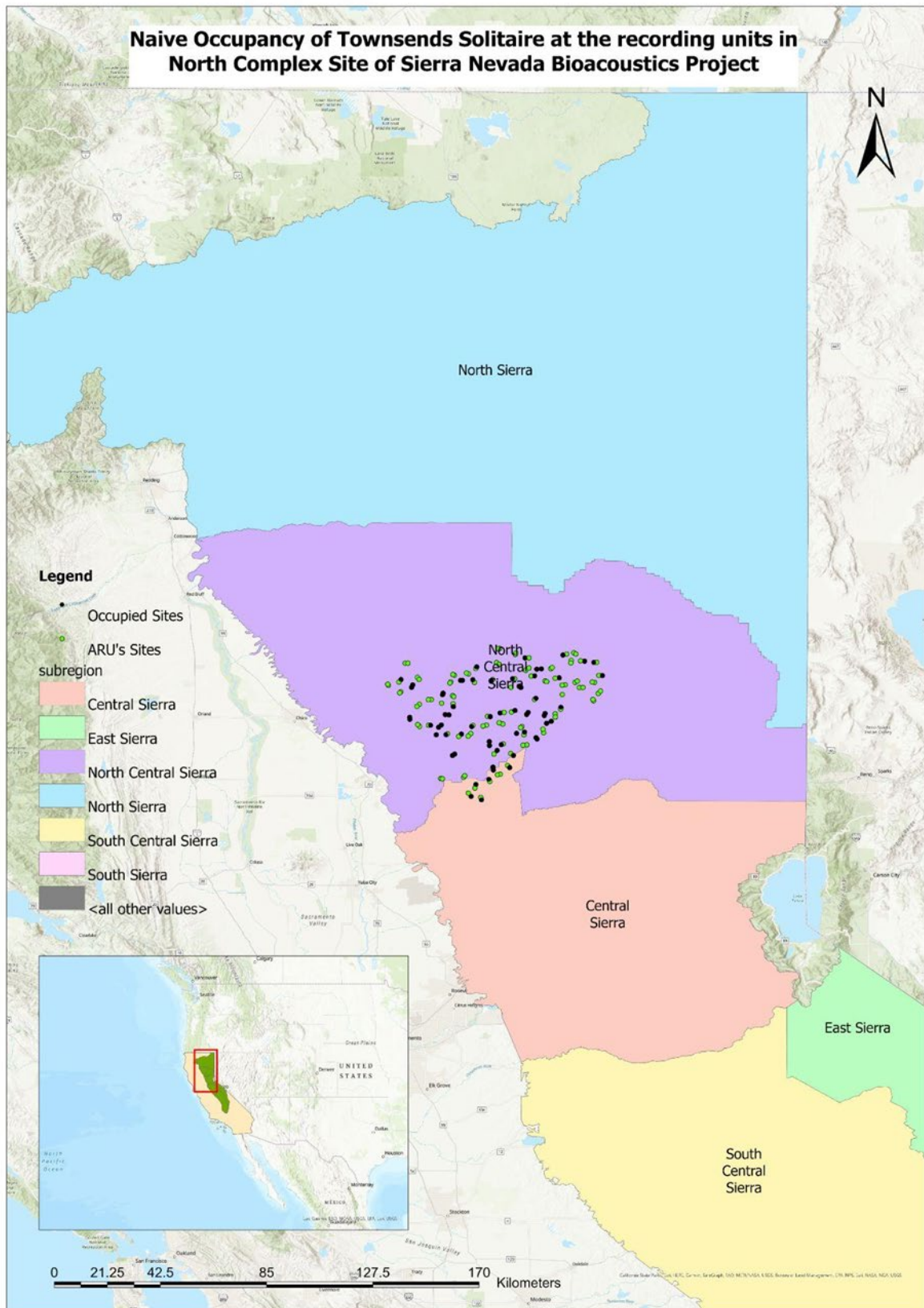
Fig 3: Relationship between proportion of sites burned at high severity and the probability of the Occupancy of Townsend's solitaire
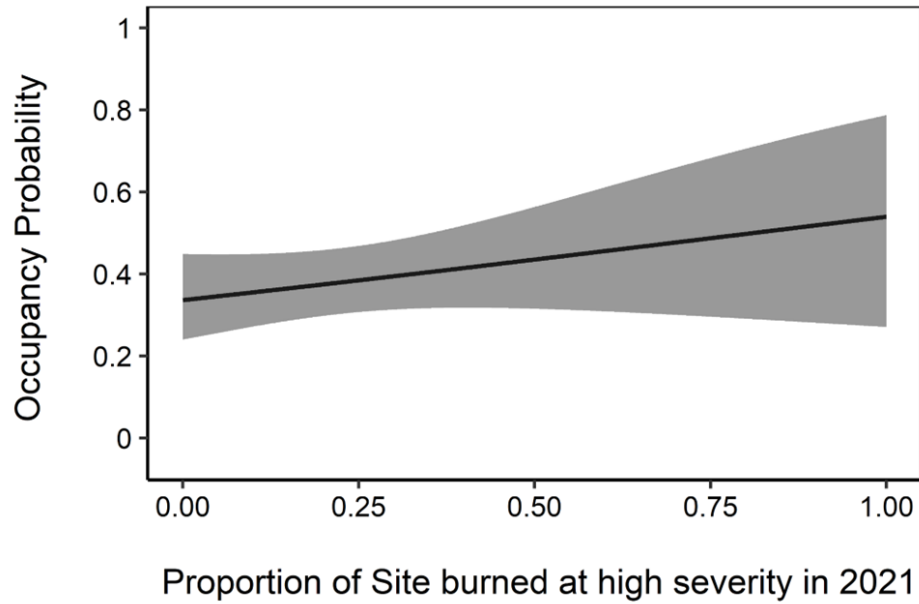

Fig 4: The output of statistical parameters of the combinations of occupancy models using the Dredge function in R

	p(Int)	psi(Int)	p(date)	p(eff_hours)	psi(burn_21)	psi(ElevationSD)	psi(SeveritySD)	df	logLik	AIC	delta	weight
4	-0.6598536	-0.4848799	-1.532534	1.435550	NA	NA	NA	4	-250.2381	508.4763	0.0000000	2.340802e-01
12	-0.6709033	-0.4924475	-1.529582	1.451230	NA	-0.2158120	NA	5	-249.4597	508.9193	0.4430442	1.875680e-01
20	-0.6642658	-0.4889477	-1.530532	1.441816	NA	NA	0.1910410	5	-249.6133	509.2266	0.7503746	1.608507e-01
28	-0.6767804	-0.4953549	-1.527766	1.458765	NA	-0.2053541	0.1791511	6	-248.9177	509.8355	1.3592157	1.186355e-01
8	-0.6596210	-0.4853341	-1.531956	1.436079	0.06815135	NA	NA	5	-250.1602	510.3203	1.8440274	9.309775e-02
24	-0.6625066	-0.4918880	-1.530228	1.439066	-0.19809516	NA	0.3415021	6	-249.3546	510.7091	2.2328666	7.664853e-02
16	-0.6733171	-0.4926787	-1.529136	1.454476	0.06620157	-0.2153253	NA	6	-249.3871	510.7741	2.2978656	7.419754e-02
32	-0.6741679	-0.4980430	-1.527791	1.455194	-0.18136278	-0.1985803	0.3172766	7	-248.7040	511.4081	2.9318046	5.404200e-02
2	0.5053144	-0.4977885	-1.645170	NA	NA	NA	NA	3	-258.2434	522.4868	14.0104786	2.123381e-04
10	0.5082919	-0.5066008	-1.643573	NA	NA	-0.2071164	NA	4	-257.5145	523.0291	14.5528176	1.619051e-04
18	0.5064947	-0.5023986	-1.643555	NA	NA	NA	0.1874823	4	-257.6381	523.2762	14.7999461	1.430860e-04
26	0.5091533	-0.5100312	-1.642351	NA	NA	-0.1948253	0.1739854	5	-257.0000	524.0000	15.5236973	9.964067e-05
6	0.5057415	-0.4983230	-1.644950	NA	0.06268624	NA	NA	4	-258.1771	524.3543	15.8780019	8.346422e-05
22	0.5059428	-0.5052357	-1.643330	NA	-0.20583303	NA	0.3440533	5	-257.3576	524.7153	16.2390018	6.968034e-05
14	0.5086440	-0.5069922	-1.643404	NA	0.05853343	-0.2059679	NA	5	-257.4573	524.9146	16.4383242	6.307074e-05
30	0.5086475	-0.5125345	-1.642073	NA	-0.19131964	-0.1884870	0.3200635	6	-256.7609	525.5219	17.0455921	4.655447e-05
3	-0.6094734	-0.4931161	NA	1.376664	NA	NA	NA	3	-281.1690	568.3380	59.8616878	2.347277e-14
11	-0.6149320	-0.4989735	NA	1.383725	NA	-0.2260432	NA	4	-280.3095	568.6191	60.1427858	2.039505e-14
19	-0.6119245	-0.4963122	NA	1.380004	NA	NA	0.1952350	4	-280.5147	569.0294	60.5531239	1.661196e-14
27	-0.6178204	-0.5012456	NA	1.387559	NA	-0.2152945	0.1825878	5	-279.7462	569.4925	61.0161888	1.317855e-14
7	-0.6104553	-0.4931660	NA	1.377966	0.07139960	NA	NA	4	-281.0833	570.1665	61.6902694	9.407904e-15
15	-0.6162234	-0.4989285	NA	1.385417	0.06850515	-0.2253725	NA	5	-280.2317	570.4633	61.9870480	8.110511e-15
23	-0.6108897	-0.4994176	NA	1.378629	-0.19648816	NA	0.3442613	5	-280.2581	570.5163	62.0399905	7.898632e-15
31	-0.6164812	-0.5040040	NA	1.385864	-0.18008388	-0.2089206	0.3194256	6	-279.5339	571.0678	62.5915642	5.994862e-15

LIMITATIONS

1. The responses of the birds to fire are nuanced and time dependent hence only one-year data analysis might not be sufficient to conclude any ecological relationship between fire and the occupancy of Townsend's Solitaire.

2. The sample size and the survey sites are limited to this specific region of Plumas National Park which is a tiny portion of the Townsend's solitaire range.

3. Use of 90% which might result in imperfect detections and false positives in the final sampling of the surveys.

4. Use of few covariates to establish a relationship between birds' occupancy and ecological parameters.

DISCUSSION

We found the relationship between occupancy probability and the high severity of the fire in our study region as we hypothesized i.e. the positive relationship between high severity and occupancy. But the AIC parameters indicated that this relationship is not informative to conclude our hypothesis and having any effect on the occupancy of Townsend's Solitaire. As we discussed in the limitations section, it might be due to multiple factors, and we need to survey for more than one year to get some conclusive evidence regarding the relationship between fire and occupancy of this bird.

It might be possible that Townsend's solitaire might not respond positively to fire in the immediate first year post-fire and it might also be the case that it might be preferring the location's several years after it is altered by the habitat change caused by fire. It might be worthwhile to conduct a field survey and do ground truthing of burnt & unburnt study sites which are most suitable for Townsend's Solitaire. We need to check other variables which give more information on the nature of the fire like severity data from other fire monitoring programs and sites with changed habitat several years post fire. Also, more specific habitat parameters like forest cover proportion, vegetation type can be utilized to infer the preference of Townsend's Solitaire.

More stronger evidence of the relationship between the preference of Townsend's solitaire to post-fire habitats can be established by having a Habitat data which shows the change of trends in the habitats after it was burnt. Alternatively, we need to check the relationship between occupancy of Townsend solitaire and the past historical fire severity data with periods like proportion burned 2-5 years, 6-10 years, 11-35 years after fire.

We also need to account for the population dynamics and phenological changes in the Townsend's solitaire breeding patterns and the shifts in summer migration locations caused due to climate change which might provide additional information on the probability of occurrence in the regions affected by fire.

CONCLUSION

From the results of our occupancy model analysis of this study we found that there is no conclusive evidence of Townsend's solitaire responding to the fire in a positive way or having any ecological effect because of the fire altered landscape as the ΔAIC between the models having the occupancy covariates are indicative of non-informative parameter's and do not support having any relationship with the occupancy of this bird.

REFERENCES

1. https://en.wikipedia.org/wiki/Plumas_National_Forest

2. Shaffer, Kevin & Jr, W.F.. (2006). Fire and Animal Interactions. Fire in California's Ecosystems. 118-144.10.1525/california/9780520246058.003.0007 .

3. https://en.wikipedia.org/wiki/North_Complex_Fire

4. https://www.audubon.org/field-guide/bird/townsends-solitaire

5. Shambaugh, N. (1987). The nesting ecology of the Townsend's Solitaire (Myadestes townsendi).

6. https://burnseverity.cr.usgs.gov/products/ravg

7. https://www.allaboutbirds.org/guide/Townsends_Solitaire/id#:~:text=Townsend's%20Solitaires%20inhabit%20open%20pine,where%20juniper%20berries%20are%20abundant.

8. https://kevintshoemaker.github.io/NRES-746/Occupancy.html

9. https://doi90.github.io/lodestar/fitting-occupancy-models-with-unmarked.html

10. Kahl, S., C.M. Wood, M. Eibl, and H. Klinck. 2021. BirdNET: A deep learning solution for avian diversity monitoring. Ecological Informatics 61: 101236. https://doi.org/10.1016/j.ecoinf.2021.101236

11. Kellner KF, Smith AD, Royle JA, Kery M, Belant JL, Chandler RB (2023). "The unmarked R package: Twelve years of advances in occurrence and abundance modelling in ecology." Methods in Ecology and Evolution, 14(6), 1408–1415. https://www.jstatsoft.org/v43/i10/.

12. Brunk, K.M., Gutiérrez, R.J., Peery, M.Z. et al. Quail on fire: changing fire regimes may benefit mountain quail in fire-adapted forests. fire ecol 19, 19 (2023). https://doi.org/10.1186/s42408-023-00180-9

13. Taylor, A.H., V. Trouet, C.N. Skinner, and S. Stephens. 2016. Socioecological transitions trigger fire regime shifts and modulate fire–climate interactions in the Sierra Nevada, USA, 1600–2015 CE. Proceedings of the National Academy of Sciences of the United States of America 113: 13684–13689. https://doi.org/10.1073/pnas.1609775113.

14. Madley, B. 2017. An American Genocide: The United States and the California Indian Catastrophe, 1846-1873. New Haven: Yale University Press.

15. Hutto, R.L., and D.A. Patterson. 2016. Positive effects of fire on birds may appear only under narrow combinations of fire severity and time-since-fire. International Journal Wildland Fire 25: 1074. https://doi.org/10.1071/WF15228 .

16. Steel, Z.L., H.D. Safford, and J.D. Viers. 2015. The fire frequency-severity relationship and the legacy of fire suppression in California. Ecosphere 6: 1–23. https://doi.org/10. 1890/ES14- 00224.1.

17. North, M.P., S.L. Stephens, B.M. Collins, et al. 2015. Reform forest fire management. Science 349: 1280–1281. https://doi.org/10.1126/science.aab2356 .

18. Adams, M.A. 2013. Mega-fires, tipping points and ecosystem services: Managing forests and woodlands in an uncertain future. Forest Ecology and Management 294: 250–261. https://doi.org/10.1016/j.foreco.2012.11.039

19. Wood, C.M., and G.M. Jones. 2019. Framing management of social-ecological systems in terms of the cost of failure: The Sierra Nevada, USA as a case study. Environmental Research Letters 14: 105004. https://doi.org/10.1088/1748- 9326/ab4033 .

20. Coop, J.D., S.A. Parks, C.S. Stevens-Rumann, et al. 2020. Wildfire-driven Forest conversion in western North American Landscapes. BioScience 70: 659–673. https://doi.org/10.1093/biosci/biaa061 .

21. Cova, G., V.R. Kane, S. Prichard, et al. 2023. The outsized role of California's largest wildfires in changing forest burn patterns and coarsening ecosystem scale. Forest Ecology and Management 528: 120620. https://doi.org/10.1016/j.foreco.2022.120620 .

22. Kahl, S., C.M. Wood, M. Eibl, and H. Klinck. 2021. BirdNET: A deep learning solution for avian diversity monitoring. Ecological Informatics 61:101236. https://doi.org/10.1016/j.ecoinf.2021.101236

23. Mackenzie, D.I., J.D. Nichols, G.B. Lachman, et al. 2002. Estimating site occupancy rates when detection probabilities are less than one. Ecology 83: 2248–2255.