Title: Exploring mitigation options to reduce vehicle-caused mortality of a threatened butterfly

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ABSTRACT
Roads that bisect habitat can lead to a decline in population size due to animal-vehicle collisions or interruption of key life history events. Along the Oregon central coast, Highway 101 divides breeding from nectaring habitat of the Oregon silverspot butterfly (OSB; Speyeria zerene hippolyta), a federally listed species. We evaluated which of several proposed management techniques for reducing vehicle-caused deaths of OSBs should be pursued further. We could not directly evaluate each, so we gathered information on behavioral ecology relevant to each management option. OSBs did not prefer the road or road-cut for basking or flying, suggesting mitigations to increase wind in the road would likely not be effective. Rather, OSBs crossed the road in areas that had more flowering plants along the verge; hence, vegetation management would likely be an effective mitigative measure. Because most crossings were concentrated in specific areas, barrier installation to increase flight height is also recommended. Reduction of traffic speed when road temperature is just over 19.0°C, a threshold temperature correlated with flight, also may reduce vehicle-related OSB mortality. We found gathering targeted ecological information was an effective approach for prioritizing management options.
INTRODUCTION

Many studies have documented the varied effects of roads and vehicles on terrestrial animals (1-3). Documented population-level effects include direct mortality (4, 5) and barrier effects through fragmentation or road avoidance (6), as well as other causes. Population-level effects are especially a concern for organisms with small populations. Small animals are estimated to be hit by vehicles much more than large ones (7), so small animals with small population size may be particularly at risk. More than half of the 201 listed threatened or endangered invertebrate species in the U.S. have the potential to be impacted by roads as well as 41 small vertebrate species (8).

Roads can affect behavioral patterns of animals (e.g., movements). Wildlife cross roads to access resources (9, 10), avoid predators (11 as cited in 6), and locate mates (6). Roadside verges serve as habitat for a wide range of species, including butterflies (10-13), and at times even support higher densities than adjoining landscapes (14). Roads and their verges may offer microhabitats, such as shelter from the wind, that may attract or keep individuals in the road corridor longer than expected. For example, roads may be warmer, warm up earlier in the day, or remain warm for extended periods of time; poikilotherms are attracted to these locations for basking (4, 6).

Effective mitigation techniques have rarely been developed and tested for small or flying organisms (but see, e.g., 15, 16). Mitigation for one species may not work effectively for others (e.g., 17). Moreover, due to expense and scale, it is prohibitive to test multiple mitigation options sequentially. Therefore, we explored whether gathering targeted ecological data would help prioritize mitigation options for a threatened species, the Oregon silverspot butterfly (*Speyeria zerene hippolyta*, hereafter, OSB). We studied OSB ecology in order to evaluate the likely success of mitigation options before funding was pursued for implementing or directly testing any of them.

At the Rock Creek Big Creek (RC-BC) site, the focus of this study, Highway 101 severs habitat connectivity between ideal oviposition locations on the west side of the highway and the nectaring and roosting sites on the east side (P. Hammond unpublished data). OSBs are thought to be hit by vehicles at this site as they cross or loiter in the road. In addition, they have been observed to use the road-cut area and to fly along specific routes (P. Hammond unpublished data).

In this research, we considered four potential mitigation measures including earthen berm removal; barrier installation; environmentally triggered, flashing speed-reduction-sign installation; and vegetation manipulation (Table 1). Because these management scenarios are not yet in play, we could not directly test them. Rather, we gathered data on the behavioral ecology of OSBs and the environmental conditions of the road compared to surrounding habitat to determine which mitigation measures would have the greatest potential for effectiveness. To inform mitigation options we examined six questions about environmental conditions across habitats or microhabitats and how these correlated with OSB presence (Table 1).

Ecological information can be linked to management options for OSBs. We hypothesized that the road would be warmer than the surrounding meadow and that OSBs would therefore use the road more than expected, particularly in the road-cut area where wind shelter may exist and encourage OSBs to loiter. If OSBs preferentially use the road-cut, a change in topography such as removal of earthen berms, which would increase wind, could be an effective solution. If OSBs frequently bask in the road due to higher temperatures or amounts of sun, shading the road could reduce its appeal. Second, we expected movement from the meadows into the road would be non-random across space. Installing barriers in key locations could encourage OSBs to stay in the meadows longer or force them to fly higher above vehicles when crossing the road. Both visual and physical barriers have been effective for flying organisms. Poles discourage royal terns (*Sterna maxima*) from flying low over a Florida bridge (16). Similarly, seasonally erected nets and UV guide lights prevent the milkweed butterfly (*Salatura genutia*) from colliding with vehicles on a highway in Taiwan (15). Third, we expected OSB flight to be influenced by environmental conditions as they need to be warm to fly (18, 19) and tend to be grounded when wind speeds exceed 6.3 m/s (14 mph) (N. Testa unpublished data). Installing a flashing speed reduction sign triggered by environmental variables associated with OSB flight could reduce the likelihood of collision. Speed reduction signs were used for the endangered Hine’s emerald dragonfly (*Somatochlora hineana*), milkweed butterfly, and Alkali bee (*Nomia melanderi*) to increase the success of evasive maneuvering for insects (20, 15, 21). Fourth, greater abundance of flowering plants adjacent to the road may draw more OSBs to the road corridor for nectaring. Manipulating vegetation could draw butterflies away from the road corridor. Roadside hedgerows were removed to manage bird species in Poland (22). Also, planting unpalatable plants adjacent to the road prism and preferred ones away from it reduced ungulate-vehicle collisions (23, 24 as cited in 25).
METHODS

Study Species
The OSB is federally listed as “threatened.” Populations of OSBs remain at five sites, four in Oregon and one in California; Washington populations have been extirpated (26, 27). The OSB requires meadows with the larval host plant *Viola adunca* (early blue violet), nectar plants, and forest fringe areas to roost (27). Adults emerge from July through late September, mate then lay eggs on or near *V. adunca*. Larvae hatch shortly thereafter and soon enter a winter diapause (27).

Two major management techniques are in play at the RC-BC site. First, it has been managed for *V. adunca* since 1985 with three annual mowing events that control non-native grass height, thatch accumulation, and woody species (28). One of the main factors attributed to the decline of OSBs is the invasion of non-native grasses and other plants that can limit ovipositing locations (27, 28). Mowing is not considered a long-term solution for non-native species management (27), however, as it reduces the abundance of nectaring plants for adults. Second, the Nature Conservancy and the Oregon and Woodland Park Zoos have been augmenting wild populations with captive-reared individuals since 1999 to maintain genetic variability and increase the likelihood of recovery (29, 30).

Study Site
The study was conducted south of Waldport along the Oregon central coast in a salt spray meadow that is intersected by a north-south segment of Highway 101. The study site extends from the mouth of Rock Creek south to 200 m beyond Big Creek (27). Twenty of the approximately 177.1 hectares at the site are considered meadow and are managed by the Siuslaw National Forest (27). In 2008 the average annual daily traffic (AADT) on Highway 101 near the study area was 2,100 vehicles (N. Testa, unpublished data). In general, the east side of the study area starts at a significantly higher elevation (340 feet) and with a steeper grade than the west side. In some sections of Highway 101 the road surface is markedly lower than the abutting meadow on both sides of the road. This major road-cut area encompasses plots 8 (partial), 9, 10, and 11 (partial).

Study Design

Study Plots
Within the study area, a 1.2 km section of Highway 101 was divided into sixteen 75m x 8m plots. This plot size accommodates the low encounter rate. Each plot was divided into 5 marked 15m x 8m subplots (Figure 1) to allow flexible data analysis, more precise OSB location data, and clean lines of sight. Each road plot was paired with a plot of the same dimensions in the surrounding meadow. We placed each meadow plot at the same latitude as the road plot but at a random distance from the centerline of Highway 101.

Butterfly Sampling Surveys
Surveys were conducted 17 August-19 September 2009, spanning peak flight, on road and meadow plots. Surveys were not conducted when it was raining to minimize zeros attributable to weather unsuitable for flight (18, 31). Butterflies could not be marked and preliminary observations indicated focal individual sampling of unmarked butterflies was not a reliable survey method. Therefore, we performed two types of surveys: Instantaneous Scan Sampling and All Occurrence Surveys (Table 1). We also opportunistically recorded all sightings of OSBs in the road.

Road-Meadow Comparisons: Instantaneous Scan Survey Instantaneous scan sampling determined spatio-temporal patterns of OSB presence and evaluated activity levels in the road plots relative to the surrounding habitat. We systematically surveyed each component subplot, starting at the south end, until a whole plot was scanned, then repeated (Figure 1). Upon completing ten replicate surveys of a road or meadow plot, we surveyed its paired plot using the same protocol. Three or four randomly selected pairs of plots were surveyed each day (weather permitting). Four replicates were conducted for each of the 16 pairs of plots, totaling 3200 scans across 32 hrs of observation each for the meadow and the road (i.e. 16 plots x 5 subplots x 10 scans x 4 replicates).

At the beginning of each subplot survey, we recorded date, time, and wind speed, temperature, and humidity using a Kestrel 4500 Pocket Weather Tracker. At the instant of each scan, we counted the number of butterflies engaged in any of seven behaviors: nectaring (proboscis extended while perched on a flower), basking (wings held lateral [open]) or dorsal [closed] to catch sunlight), perching (standing with folded wings not oriented to receive sunlight), flying (all flight behaviors, including flight between flowers), mating (terminal segments of the male and female abdomens joined), ovipositing (abdominal probing or egg laying), and interacting with conspecifics (two or more chasing or swarming)(32).
**Detection Probability And Inter-Observer Reliability** Detection probability surveys in meadow subplots were performed to quantify the effectiveness of detecting butterflies during instantaneous scan surveys in this visually heterogeneous habitat. These surveys were conducted 2 - 19 September 2009 in meadow subplots after the instantaneous scan surveys as time permitted. The observer scanned the series of five subplots as above but only once then zigzagged back toward the initial subplot to flush any butterflies missed during the scan, counting all butterflies encountered (n=192 subplot (42 plot) detection surveys (the zigzag walk was impossible in 18 subplot surveys due to brush)). Observers had a high detection probability, always > 97% (5 butterflies originally missed in 192 subplots). Therefore, detection rate is assumed to be representative of the actual OSB presence.

Inter-observer reliability was calculated for the two observers simultaneously performing detection probability surveys. The percent agreement between the observers was 91% (31/34) for initial scans and 97% (33/34) for zigzags.

**OSBs in Road Plots: All Occurrence Sampling** The all occurrence survey documented OSB activities in the road, thus greatly increasing number of OSB sightings. The observer stood at the south end of a designated road plot looking north and recording all OSB activity for 15 minutes. We observed each road plot four times throughout the season, totaling 64 15-minute observations (16 hrs).

For every OSB sighting in the road, we recorded the variables from the scan surveys plus: flight direction; flight height (estimated relative to a 3.5 m reference staff, marked in half meter increments, placed along the road edge at the plot’s midpoint [length]); and if a collision occurred.

**Opportunistic Sampling** We sampled opportunistically along the road between scans and before and after systematic sampling. We estimated 60 min/day of opportunistic sampling (40 min between scans and 20 min between systematic sampling) and 16 hours during the study (60 min/day x 4 days to survey the 16 road plots x 4 replicates). This sampling added information regarding OSB road use but was not included in statistical analyses.

**Vegetation Surveys**

Number of flowering plants was quantified for 15 road subplots. Five randomly selected subplots were sampled within 1m of the road from each of 3 levels of OSB crossing (0, 1-2, 3-7). We counted every flowering plant detected at each of the 100 points in a divided square meter frame placed at six randomly-located sampling areas (3 from each side of the road) in each 1x15m subplot.

**Statistical Analyses**

Throughout the paper, summary statistics are reported as mean ± standard error (SE) of untransformed data, unless otherwise noted. We determined if the data, once transformed, met the assumptions of parametric analyses using the Shapiro-Wilk test of normality and Variance Inflation Factor (VIF) and F-tests for equal variance. Data did not depart from the normal distribution when pooled across subplots, replicates, and individual scans (n=16; W always < 0.9, P always > 0.1 for both the road and meadow). However, a correlation plot and Shapiro-Wilk test of the 320 points (pooled data) from the road and the meadow suggested that the response data were not normally distributed. The road and meadow data have similar variance (F-Test: F =0.4793, P=0.1659). A lag test examined the possibility of spatial autocorrelation of the plots at lags 1 through 4; no linear relationships were found. A partial ACF test on the residuals of the linear model, plotting the relationship between OSB presence and plot number, indicated no strong spatial dependence among plots.

Data for logistic regressions examining the relationship between OSB flight and the environmental variables were pooled from the ten scans from each plot/day, yielding 320 groups (16 plots x 5 subplots x 4 surveys) for each the meadow and road plots. We averaged environmental variables with little loss in variability because we completed all scans within 30 minutes.

To determine whether OSB presence (log) and environmental variables (temperature (log), humidity, wind speed) differed between habitats, paired t-tests compared 16 road versus meadow plots (for sampling time closest to seasonal peak abundance of OSBs). To determine if the major road-cut area along Highway 101 reduced wind, increased temperature, or induced sheltering, we used student’s t-tests to compare the number of OSBs, wind speed, or temperature in subplots within the road-cut area (subplots 37-51) to values in an equal number of subplots to the immediate north (subplots 52-66) and south (subplots 23-36) of the road-cut. Data from the instantaneous scan and all occurrence surveys were pooled to analyze the change in OSB presence. Instantaneous scan data were used to
analyze the difference in wind speeds and temperature; this larger dataset better represents the variance of these environmental variables.

We used logistic regression to determine if any of the measured environmental variables explained variation in OSB habitat use. Only behaviors found in the road were included in the analysis. As above, scans were pooled across subplots each day, yielding n = 320 (16 plots x 5 subplots x 4 replicates). We performed separate logistic regressions of OSB abundance versus temperature, wind, or humidity for road or meadow data. The logistic regression models predicting presence based on environmental conditions performed suboptimally; percentage of the observations correctly classified by the models ranged from 58% to 72%. The critical values (thresholds for predicting OSB presence versus absence) were picked to maximize the explanatory power over random (kappa) of each model yet kappa was always < 0.2.

A linear regression determined if the number of OSBs crossing the road (log transformed) at the subplot level was a function of the number of flowering plants adjacent to the road.

RESULTS

Road Mortality

One confirmed account of an OSB-vehicle collision, a female, occurred in plot 7 at 11:02 hrs on 19 August 2009, during the seasonal peak of OSB flight (30). Another dead OSB was found on the walkway at the north end of the Big Creek Bridge (R. Miller unpublished observation). Nine instances of likely OSB-vehicle collisions (apparent mortality) could not be confirmed because in each case the vehicle was moving away from the observer so its grill could not be examined. The road and verge were inspected soon after the vehicle passed but no OSBs were found.

Environmental Parameters Correlated With Flight In The Road

Both temperature and humidity were correlated with OSB presence. More OSBs were sighted at warmer temperatures (road: \( z = 2.349, df = 318, p = 0.0188 \), and meadow: \( z = 4.711 df=319, P < 0.0001 \)). The threshold temperature determined for prediction of OSB presence was 19.0°C (66°F), and no OSBs were detected below 13.9°C (57°F; temperatures during surveys ranged from 9.7 – 25.4 °C). Temperature when OSBs were sighted averaged 19.1 °C ± 2.1. Fewer OSBs were found at higher humidity (road: \( z = -2.68, df = 318, p = 0.0073 \), and meadow: \( z = -4.390, df = 319, P < 0.0001 \)) and the threshold humidity value was 65.0%. Also, no OSBs were detected below 56.5% relative humidity or above 79.6% (surveys ranged = 47.7 – 95.2%). Mean humidity during periods when OSBs were present was 65.5% ± 15.0. Wind was not correlated with OSB presence in this dataset (road: \( z = -0.677, df = 318, p = 0.498 \); meadow: \( z = -1.835, df = 319, p = 0.758 \)), but no OSBs flew at wind speeds above 7.5 m/s (16.8 mph; survey range = 0 – 10.1 m/s). Mean wind speed when OSBs were present was 1.4 m/s ± 1.5 (3.1mph ±3.4).

Road Versus Meadow Plots

Environmental Conditions

Temperatures were not significantly different between the road and meadow (paired t=-0.93, n=16, P=0.3648), although the road was consistently slightly warmer (17.7°C ±1.01) than the meadow (17.4°C ± 1.01). Humidity was slightly lower in the road (70.5% ± 0.99 S.E.) than meadow (72.2% ± 0.99 S.E.; t = 1.75, n = 16, P = 0.0999). Mean wind speeds did not differ (road: 1.6 m/s ± 0.11; meadow: 1.6 m/s ±0.11; t=-0.37, n=16, P=0.7142).

OSB Behavior

Four behaviors were observed in the road: basking, nectaring, flying, and interactive. OSBs were not attracted to the road for basking: 6.1% road butterflies basked while 12.9% of meadow butterflies basked. Basking behavior was only observed a total of 3 times in road plots (1, 7, 8) always within 75 min of 12:00 PM. The one account of nectaring occurred where a flowering plant was hanging over the guardrail and pavement in plot 7. The predominant behavior in both the road and meadow was flying, accounting for 86.4% and 65.0%, in the road and meadow respectively. OSB presence was higher in the meadow than the road (paired t-test: \( t = -2.815, df = 15, P =0.013 \)), with ~3 times as many sightings of OSBs in the meadow (149 of 178 sighted doing behaviors that could occur in the road) than the road (49 sightings from scans).

Areas of Road Crossed Most

Five main locations of OSB road crossing, encompassing about half the plots, were apparent within the project area, (Figure 2; A qualitatively similar result is reached without the opportunistic sightings). OSB height of flight (relative
Road-cut
The road-cut subplots had significantly lower wind speeds than the subplots immediately adjacent to the north and south (mean wind speed in road-cut = 0.90±0.04) versus outside of road-cut = 1.06±0.03; t-test: t = 3.59, n = 45, p = 0.0006) and warmer temperatures (mean temperature in road-cut = 18.6±0.24°C versus outside of road-cut = 17.1±0.17°C; t-test: t=-4.76, n=45, p<0.0001). Nonetheless, no difference was detected between OSB presence in the road-cut subplots versus subplots to the immediate north and south (1.2±0.45 OSBs in road-cut (log), 1.3±0.32 OSBs surrounding road-cut; t-test: t = -0.27, n = 45, p = 0.7884).

Differences in Flower Availability
OSB presence in the road was positively related to flowering plants along the roadside. More OSBs were found in subplots that had more flowering plants (Figure 3; linear regression: r² = 0.51, t = 3.71, n = 15, F₁,₁₃ = 13.76, p = 0.003, y = 0.126X + 0.245).

DISCUSSION
Our data on the behavioral and spatial ecology of the OSB at Rock Creek-Big Creek suggest that this threatened butterfly is at risk from vehicle collisions but that several mitigation options could reduce this risk. A high proportion (0.22) of the total OSB observations occurred on the road. Risk of road mortality is likely most severe during August when traffic, temperature, and OSB abundance all peak (D. Dunn unpublished data, 33, 30); a traffic flow model at the RC-BC site for key OSB flight times would improve understanding of the probability of mortality across traffic volumes. During this study one instance of vehicle-caused mortality was confirmed (of 95 butterflies seen in the roadway across all methods of observation), nine apparent mortalities occurred (10%) for which vehicle-caused mortality was likely but death could not be verified, and one dead OSB was found along the roadside. We use the study findings on the ecology of these butterflies as a first attempt to identify which management options may be effective at reducing the risk of butterfly mortality due to vehicle-butterfly collisions.

Vegetation Manipulation – High Priority
Vegetation manipulation has been established as high priority as it offers a benefit at an assumed relatively low, albeit on-going, cost. Our data support several recommendations for manipulating vegetation. First, the verge could be cleared of flowering plants, especially during the season of OSB flight. More OSBs entered road plots that were lined with higher densities of flowering plants than plots with fewer flowers (Figure 3), and an OSB was found nectaring in the road. These data suggest OSBs would reduce their number of road entries if the roadside had fewer available nectaring opportunities. Other studies have documented change in butterfly movement rates and time in a microhabitat based on their motivation for that habitat type, including host plant abundance (34, 35).

Second, the timing of verge mowing could be coordinated with meadow mowings. The meadow is mowed periodically to control the mostly non-native grasses that outcompete the butterfly’s larval food plant (V. adunca). Two opportunistic observations are relevant: 1) the meadows had lower flowering plant diversity than the road, with the main flowering plant in the meadows being Hypochaeris radicata, and 2) the roadside appeared to have more patches of flowering plants per area than the meadow. Coordinated mowing would presumably decrease this disparity. Butterflies may be attracted to the road verge and therefore the road more often and for a longer time when the surrounding meadow has fewer or lower diversity of flowering plants.

In addition, we recommend increasing nectar and larval food plants in meadows away from the road, and adding hedgerow or forest fringe, for shelter, to meadows on both sides of Highway 101 so butterflies do not have to cross the road to access resources. OSBs seemed to seek shelter from the wind, so creating sheltered areas in the meadow may reduce the need for OSBs to cross the road to other shelter areas. Planting hedges has a lower potential for accidental “take” of OSB larvae relative to construction of a berm and would be less destructive to critical habitat.

Barrier Installation – High to Moderate Priority
Barriers are likely to be successful, but at a greater cost than vegetation manipulation. Even partial barriers have the ability to manipulate movement of wildlife. For example, the visual barrier of poles spaced 3.7 m apart along the
length of a bridge in Florida caused royal terns (S. maxima) to fly higher, thereby greatly decreasing mortality (16). Similarly, hedgerows served as a strong barrier to Fender’s blue butterflies (Icaricia icarioides fenderi) along a two-lane, paved road in Oregon that bisects butterfly habitat, with only 1.2% of butterflies flying over them (36).

Fences, netting, guardrails, and/or concrete (temporary or permanent) structures in key locations could manipulate movement of butterflies, ideally keeping OSBs in meadows longer or forcing them to fly higher over the road and vehicle turbulence than they otherwise would, while allowing access to all habitats. Four lines of evidence suggest this management would be effective here. First, butterflies were not seeking out the road to use as a habitat, except for nectaring on the verge: they basked less in the road and spent much less time in the road than the surrounding habitat. Second, height of flight above the road ranged from 0.5 m – 4.5 m and typically depended on the height of vegetation or land on either side of the road. Third, OSBs tended to follow the most direct route across the road. Fourth, five road segments (across seven plots) accounted for the majority (72%) of OSB crossings (Figure 2), suggesting that strategic placement of relatively narrow barriers could be effective. These plots had higher densities of flowering plants alongside, were adjacent to areas where captive-reared OSBs were released (and counts were historically high), and may be travel routes due to the topography and resource distribution. Thus, these areas have promise as potential locations for barrier placement, with higher priority of placement going to areas that have a negative slope on one side of the road and a positive slope immediately across the road to complete a continuous and natural path over the road (S. Jacobson unpublished data). It may be necessary to extend the length of barriers beyond prioritized plot locations to prevent circumvention of the barriers, such as with fences for ungulates (37). OSBs were observed following edges and flying into the road once they approached a break in the hedge. OSB census report data can be used as a guide for timing of temporary barrier placement to coincide with the peak of OSB flight (30). Further research is needed to evaluate barrier types and placement.

**Flashing Speed Reduction Signal – Moderate Priority**

An environmentally triggered flashing speed reduction sign as a mitigation option was considered moderate priority because uncertain effectiveness, inconvenience to travelers, and high cost may hinder feasibility. Animal detection systems along with speed reduction are being investigated in several areas to reduce large animal-vehicle collisions (38), but these systems are still considered experimental, and none have been used for invisible animals, or for animals whose danger to the driver does not motivate speed reduction. A speed limit of 15 mph was implemented for the Hine’s emerald dragonfly (Somatochlora hineana), a federally-listed endangered species that experienced impacts from vehicle and railway traffic (20). Driver response to speed limit reduction is key to success, but it is unknown if drivers will respond to an unusual, and invisible, reason for speed reduction. Linking speed reduction to timing and environmental conditions typical of OSB flight would reduce impacts to traffic and likely increase compliance.

This research examined thresholds for OSB flight in the road relative to environmental variables. OSBs were not observed either in the road or meadow at wind speeds above 7.5 m/s (17 mph). Similarly, other observations have found that wind speeds of 6.3 m/s (14 mph) inhibit butterfly flight (N. Testa unpublished data; 39).

OSB presence in the road increased with increasing temperature and decreased with increasing humidity. No OSBs were found in the road at temperatures under 13.9°C, a conservative threshold option. A possible alternative threshold is 14.9°C, which is two standard deviations below the mean temperature for which OSBs were present in the road. A third option would be to use the temperature threshold predicted for flight by the road logistic regression model, 19.0°C. The positive relationship between OSB presence and temperature over the road or meadow is consistent with other studies (18, 19). Most Speyeria require high body temperature to engage in normal activities and typically suspend flight unless there is full sun or the ambient air temperature is higher than 21°C (70°F) when it is cloudy (18). OSBs use solar heating to raise their body temperature when ambient air temperature is ≤16°C (60°F) to fly effectively; (18, 19).

Humidity may impact OSB flight as more water vapor in the air may cause higher rates of evaporative cooling and keep butterflies below the threshold body temperature to fly. Fog and rain, common at the Oregon coast, can also negatively affect butterfly flight (18, 27, 31). The threshold value from our logistic regression, below which OSBs were more likely to be active, was 65% relative humidity and no OSBs were detected below 56.5%. Humidity is correlated with temperature and statistical models for humidity were not as robust as for temperature.

Speed reduction to reduce OSB mortality is an intriguing mitigation option that warrants further study as little is known about the effectiveness of speed reduction to reduce mortality (38) or the effectiveness of engaging driver response to a benign target. A study examining the relationship between vehicle speed and butterfly mortality would help identify the maximum speed limit that could substantially decrease mortality. The ideal reduced speed to
alleviate OSB vehicle-kills is unknown, especially considering the fragility of butterflies in turbulent air caused by passing vehicles. Assuming a given speed reduction, reducing traffic speed when temperatures are above 19.0°C and wind speeds are below 7.5 m/s would minimize the amount of time speed reduction is implemented.

Removing Earthen Berms - Low Priority
The removal and addition of earthen berms as a mitigation option was established as a low priority because no “sheltering” effect of OSBs was detected in the road-cut, despite its lower wind speed and higher temperature, and OSB habitat is protected under the ESA as “critical habitat” (40). The difference in wind speeds and temperature may not have been great enough for the butterflies to identify the road-cut as shelter. In addition, although the mean wind speeds are different from the road-cut subplots to the adjoining subplots, this area does not necessarily represent a shelter from wind as air is funneled through the road-cut independent of prevailing wind direction (33,39).

Potential Risks Of Mitigation Suggestions
An in depth analysis on the potential negative impacts from mitigation measures is difficult when there are multiple unknowns. This fact makes monitoring necessary and adaptive management extremely valuable. Evaluation from the USFWS Endangered Species Biologist actively working to restore OSB populations indicated no major risks of mortality or negative effects are expected to be sustained by OSBs from the outlined management suggestions and the management may have a positive effect on OSBs in the long term, assuming monitoring is employed to assess project implementation and outcomes (A. Walker, unpublished data). Future research needs include testing the recommended mitigation measures for effectiveness (39).

CONCLUSION
Determining which mitigation measures should be pursued to minimize the impact of roads on the surrounding animal community is not always straight forward. We evaluated potential management techniques to determine which should be pursued further by gathering information on the behavioral ecology of our target organism. We found using ecological observations with mitigation options in mind was an effective technique for prioritizing management options and identifying what related future research is most needed. Vegetation manipulation and barrier installation were designated high priority to reduce vehicle-caused mortality to OSBs, whereas the removal of earthen berms in the road-cut area appears unjustified, as no sheltering effect was detected. This approach is likely to be effective for other taxa as well. As roads are already having large effects on some populations and likely will have more as indigenous organisms move in response to climate change, such approaches are needed to identify how best to respond.

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REFERENCES


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<td>Determine whether OSB presence can be predicted by environmental parameters</td>
<td>Create a statistical model to predict OSB presence in the road</td>
<td>Environmentally triggered flashing speed-reduction sign installation</td>
<td>32 -- -- --</td>
</tr>
<tr>
<td>Are OSBs using the road more than expected based on their use of surrounding habitat?</td>
<td>Determine if the road varies from the surrounding meadow in weather conditions and OSB use.</td>
<td>Survey paired road and meadow plots to compare weather and number and behavior of OSBs.</td>
<td>Mitigations to reduce attractiveness of road (not explored here)</td>
<td>32 32 -- --</td>
</tr>
<tr>
<td>What is the dispersion of road-crossings and is it correlated to environmental conditions?</td>
<td>Use OSB movement at the study site to determine where to put barriers along the Highway 101.</td>
<td>Identify location of OSB road crossings and document behavior and height of flight when in the road.</td>
<td>Barrier Installation</td>
<td>32 16 16</td>
</tr>
<tr>
<td>Does the road cut vary from surrounding corridor in its environmental conditions and OSB use?</td>
<td>Determine if the road cut area creates a wind sheltered or warmer area that is preferentially used by OSBs.</td>
<td>Compare wind speed, temperature and number of OSB sightings in the road-cut plots to an equal number of adjacent plots to the north and south of the road-cut.</td>
<td>Earthen berm removal</td>
<td>32 16 --</td>
</tr>
<tr>
<td>Is the abundance of roadside flowering plants correlated with OSB movement in the road?</td>
<td>Determine if OSBs are drawn to the road because of flowering plants.</td>
<td>Sample flowering plants adjacent to road plots and compare to number of OSBs.</td>
<td>Vegetation manipulation</td>
<td>32 16 16</td>
</tr>
</tbody>
</table>

<sup>d</sup>Instantaneous Scan Survey; <sup>b</sup>All Occurrence Surveys in the road; <sup>c</sup>Opportunistic Sampling in the road (not used in statistical analyses); <sup>d</sup>Data not taken or not used
LIST OF FIGURES

Figure 1. Schematic of study site. Road plots are in yellow, meadow plots are in green.

Figure 2. Vehicle and OSB interactions (no collision, unconfirmed, confirmed) by plot for all accounts of detection either during surveys (scan or all occurrence) or opportunistic sightings. Across plots, 49 observations were from Instantaneous scan sampling, 24 were from all-occurrence surveys, and 22 were from opportunistic sampling.

Figure 3. Linear regression of OSB presence and flowering plants in the road.
FIGURE 1 Schematic of study site. Road plots are in yellow, meadow plots are in green.
FIGURE 2 Vehicle and OSB interactions (no collision, apparent collision, confirmed collision) by plot for all accounts of detection either during surveys (scan or all occurrence) or opportunistic sightings. Across plots, 49 observations were from Instantaneous scan sampling, 24 were from all-occurrence surveys, and 22 were from opportunistic sampling.
**FIGURE 3** Linear regression of OSB presence and flowering plants in the road