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Memorandum

September 17, 2021 **Project #4505-01**

To: **Julie Andersen, Senior Resource Management Specialist; Karine Tokatlian, Resource Management Specialist II; and Brad Pennington, Area Superintendent (Midpeninsula Regional Open Space District)**

From: **Dave Johnston, Ph.D. Associate Ecologist and Bat Biologist and Steve Rottenborn, Ph.D. Vice-President and Wildlife Ecologist (H. T. Harvey & Associates)**

Subject: **Analysis of E-bike Noise and Recommendations for Buffer Distances between Bike Trails and Bat Roosts/Nesting Birds**

Midpeninsula Regional Open Space District (MROSD) contacted H. T. Harvey & Associates to provide an analysis of high and low-frequency noises generated by e-bikes to help predict potential impacts to roosting bats and nesting birds in proximity of bike trails. Based on MROSD guidance, H. T. Harvey & Associates designed recording sessions of operating bicycles to determine what high-frequency noises are generated by three examples of e-bikes and two conventional bikes and to assess which bat species, if any, might be disturbed by these noises. Based on our subsequent communications with you, we have added the task of recording these noises on low-frequency recording devices as well, to help determine potential impacts to nesting birds. This memorandum provides the methods, results, and recommendations for establishing appropriate "buffer" distances between bike trails and roosting bats. We have also indicated the distances needed for e-bike and conventional bike (bike) sounds to attenuate to 20 decibels (dB), the approximate ambient noise level we recorded during our study, for purposes of determining the distance away from operating e-bikes and conventional bikes to reach this sound pressure, and to suggest "buffer" distances between all bike sounds and nesting birds in general. We are not prescribing a specific distance from trails to nesting marbled murrelets (*Brachyramphus marmoratus*) given the lack of consistent information on marbled murrelet disturbance tolerances. However, we recommend that site specific distances for marbled murrelets and other birds be explored and developed during the planning of trails.

Introduction

Sound pressure is reported in decibels (dB). Decibels are units based on human hearing; 1 dB is the lowest level of sound a human can hear, and each dB unit is the smallest increment in which humans can detect a difference in loudness. Kilohertz (kHz) is a unit of measurement for the frequency of sounds; higher frequencies correspond to higher pitches. While adult humans can detect sounds between approximately 0.015–18 kHz, most bats' hearing ranges from about 0.1–200 kHz (Altringham 2014). Avian hearing is similar to human hearing; birds are most sensitive to sounds from about 1 to 4 kHz although they can typically hear higher and lower frequencies (Beason 2004). No species of birds has shown sensitivity to high frequency sounds above 20 kHz (Beason 2004).

Bats typically have different roost sites for different activities. During the daytime, bats roost in crevices, caves, or foliage depending upon the species of bats, and sleep during this period. Usually at dusk or as early as just prior to sunset, bats leave their day roost, drink water, forage on insects, and night roost in an area that is typically warmer than ambient temperature. After night roosting for several hours, bats typically drink water again, forage again, and then return to their day roosts to sleep during the day. Bats are most sensitive to disturbance while day roosting during the maternity season when they are raising young.

Bats are acutely sensitive to changes in their sound environment and can react to even relatively quiet noise if it is foreign to them and stimulates a stress response (Altringham and Kerth 2016). Additionally, the frequency of the noise is also important because individual species of bats have different sensitivities to various noise frequencies (Johnston et al. 2019). Nearly all of California's bats are insectivorous, and with the exception of a few species such as the pallid bat (*Antrozous pallidus*), use high-frequency echolocation to detect prey and orient themselves within the landscape. Bats also use sound to communicate, especially while flying (Gillam and Fenton 2016). Different species of bats will respond differently to human-induced noise, and noise will affect certain bat behaviors, such as foraging versus roosting, differently (Caltrans 2016).

Potential adverse effects on bats from noise disturbances include roost abandonment and the interruption or impediment of bats' abilities to use echolocation for foraging or navigation. Noise disturbance and displacement of bats from roosts or important foraging areas can potentially result in reduced survivability of individuals from increased susceptibility to predation, reduced quality of thermal and social environments, and decreased foraging efficiencies. Although bicycling may generate a multitude of low and high frequencies to disrupt bats' foraging ability, and bats frequently use trails as foraging routes, bicycles and foraging bats are not usually operating at the same time. Bicycling is typically diurnal whereas bats forage during the twilight (crepuscular foraging) and at night (nocturnal foraging). Therefore, bicycling is not expected to disrupt bats foraging unless bicycles operate during twilight and nighttime hours.

On the other hand, bats are particularly sensitive to noise in proximity to maternity colonies. At a daytime construction project in a large urban park, a maternity colony of big brown bats (*Eptesicus fuscus*) tolerated high decibel (dB) levels of low frequency sounds (audible to humans) generated by chain saws (75–86 dB) and large graders (85–89 dB) within 100 feet of their maternity roost, but the colony abandoned their roost when workers used a high-frequency (19–28 kilohertz [kHz]) laser surveying instrument, inaudible to the human ear (Johnston et al. 2017). Such a disturbance so great as to cause a maternity colony to abandon its roost site likely reduces the survivorship of some of the young. Although high frequencies attenuate to ambient sound in shorter distances than lower frequencies, the noise from equipment should be measured for corresponding frequencies to which the bat species involved are most sensitive (Figure 1). For example, in order to determine appropriate buffer zones for operating equipment near an active big brown bat roost, it would be necessary to measure the dB of the 20-kHz frequency noise (the frequency that the big brown bat is most sensitive to) and the distance over which the noise would attenuate to ambient levels.

While adult humans can detect sounds between approximately 0.015–18 kHz, most bats' hearing ranges from about 0.1–200 kHz (Altringham 2014). Additionally, bats' sensitivity to noise is usually greatest at frequencies similar to those used for foraging. For example, the big brown bat's peak hearing sensitivity is at about 20 kHz (Figure 1), which represents the frequency of the bats' search calls with the most energy (Koay et al. 1997).

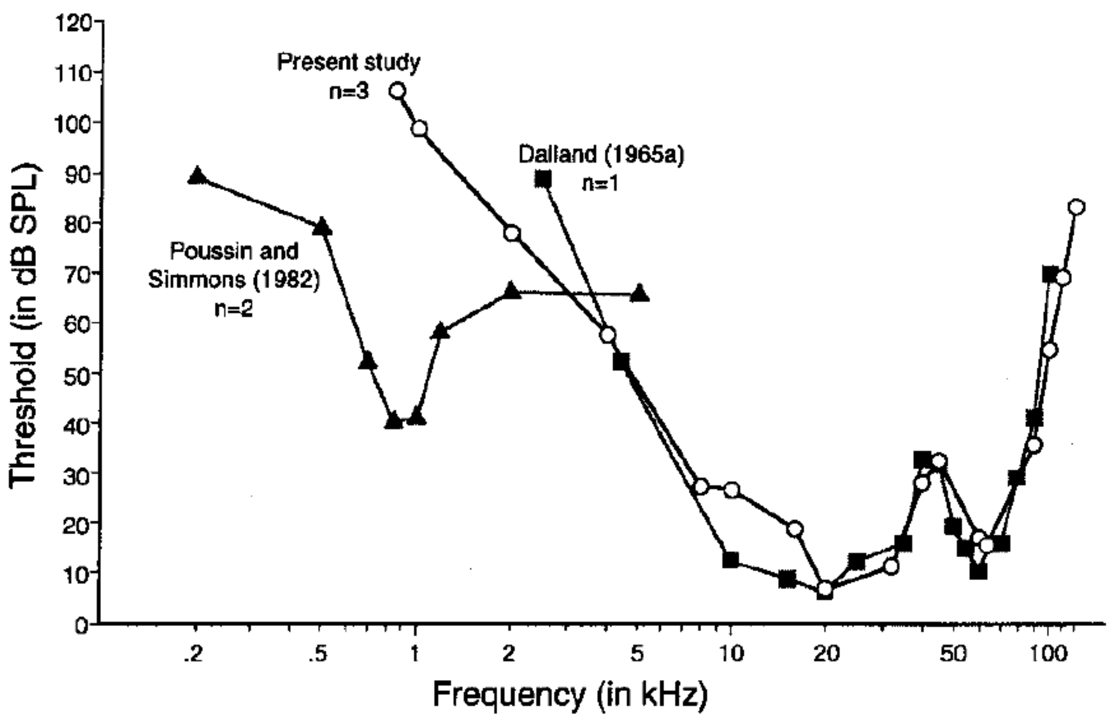

Figure 1. Hearing sensitivity in big brown bats (*Eptesicus fuscus*) as measured in three studies (Koay et al. 1997). Values shown depict the threshold of hearing for big brown bats for sounds up to 100 kHz.

Because bats' hearing is not as sensitive at lower frequencies compared to human hearing, the sound frequencies that disturb humans do not necessarily have a corresponding effect on most bat species, and vice versa. Humans may not be able to hear frequencies detected by bats. Therefore, we have used the frequency range of bats foraging calls to help determine which bats are sensitive to which frequencies.

Like bats, birds are most sensitive to noise disturbance when they are raising young. Birds' nesting season includes nest building, egg laying, egg incubating, and raising chicks until they have fledged. Birds have many different life histories, but most songbirds on MSORD lands nest in trees, shrubs, and grasslands; they are active during daylight hours and are sleeping during nighttime hours.

There has been much debate and controversy over the potential disturbance thresholds to marbled murrelets and what constitutes disturbance impacts to this species. While Hammer and Nelson (1998) recommended buffers greater than 100-meters between nesting marbled murrelets and any human activity, Long and Ralph (1998) reported that adult murrelets located in trees 10 and 25 meters from heavily used hiking trails showed "no visible reaction to loud talking near a nest tree." Hebert and Golightly (2006) later suggested that prolonged noise disturbance at nest sites could have unknown consequences. Additionally, the base ambient noise levels varied from one study to another, with some studies using 70 dB as the ambient noise level. We used a conservative 20 dB for the low frequency recordings because this was the measured ambient noise level at our recording sites. Therefore, we have determined the distance needed for the various noises generated by e-bikes and conventional bikes to attenuate to 20 dB, the approximate ambient noise levels determined during our low-frequency and high-frequency recording sessions.

Methods

On May 17, 2021 we positioned two low frequency sound recorders (Song Meter Mini recorders; Wildlife Acoustics, Concord, Massachusetts, United States) to record sounds in the low frequency (1 kHz – 10 kHz) range (Figure 2). One microphone was placed 10 feet and another 20 feet away from the Purisima Creek Trail at the Purisima Creek Redwoods Open Space Preserve in San Mateo County. We used this trail to record low frequency sounds because it was fairly typical of marbled murrelet nesting habitat. We recorded a Gary Fischer and a Specialized Rock Hopper to represent conventional bicycles and a Specialized 2020 Levo SL, a Santa Cruz 2018 Heckler, and a Specialized 2019 Levo to represent e-bikes. We recorded each e-bike and conventional bike as it was: 1) in power assist mode peddling slowly uphill, 2) in power assist mode peddling fast uphill, 3) coasting, and 4) braking.

Figure 2. Song Meter Mini used to record low frequency sounds propagated by e-bikes and conventional bikes.

On June 15, 2021 we set out four Song Meter bat detectors (Song Meter SM4 BAT recorders; Wildlife Acoustics, Concord, Massachusetts, United States) (Figure 3) to record high frequency sounds at distances 10 feet, 20 feet, 40 feet, and 80 feet from a trail located in mostly open grassland habitat at the Sierra Azul Open Space Preserve unit in Santa Clara County. We used this trail to record high frequency sounds because it was fairly typical of pallid bat foraging and roosting habitat. . We recorded a Gary Fischer and a Specialized Rock Hopper to represent conventional bicycles and a Specialized 2020 Levo SL, a Santa Cruz 2018 Heckler, and a Specialized 2019 Levo to represent e-bikes. We recorded each e-bike and conventional bike as it was: 1) in power assist mode peddling slowly uphill, 2) in power assist mode peddling fast uphill, 3) coasting, and 4) braking (Figure 4).

Figure 3. Song Meter SM4 Bat Detector used to record sound pressures from bikes.

Figure 4. Field recording of e-bikes. A Specialized 2019 Levo ridden by Jeff Smith (MROSD) while Dr. Dave Johnston (H. T. Harvey & Associates) notes the timing of each recording at the Sierra Azul Open Space Preserve.

We determined the specific sensitivity of each microphone and confirmed that all microphones' sensitivities did not vary by more than about 1% from the others. Further, the sound levels analyzed were calibrated using a recording of a "chirp" tone at 40 kHz generated by a Song Meter SM4 calibrator for each of the four deployed microphones. Based on the user guide for the SM4 calibrator, the chirp mode emits a 100-millisecond (ms) long, 40 kHz ($\pm$10 Hz) tone every 500 ms. The amplitude of this chirp is 104 dB sound pressure level (SPL) ($\pm$3 dB) at 10 centimeters. Using the recordings made at 10 feet (3.048 meters), the amplitude of the chirp is calculated to be 74 dB in amplitude using a standard geometric spherical spreading loss of 6 dB per doubling of distance. Figure 5 shows the spectral density and spectrogram of the calibration chirps used to analyze the conventional bike and e-bike recordings. All e-bike and conventional bike recordings made were typically 2 seconds in duration for the coast and brake modes of operation and about 8 to 10 seconds for the pedal fast/pedal slowly uphill modes. The difference in the duration times was due to the speed of the bike as it passed the microphones; bikes simply took more time to pedal uphill than they did to coast or coast and brake going downhill.

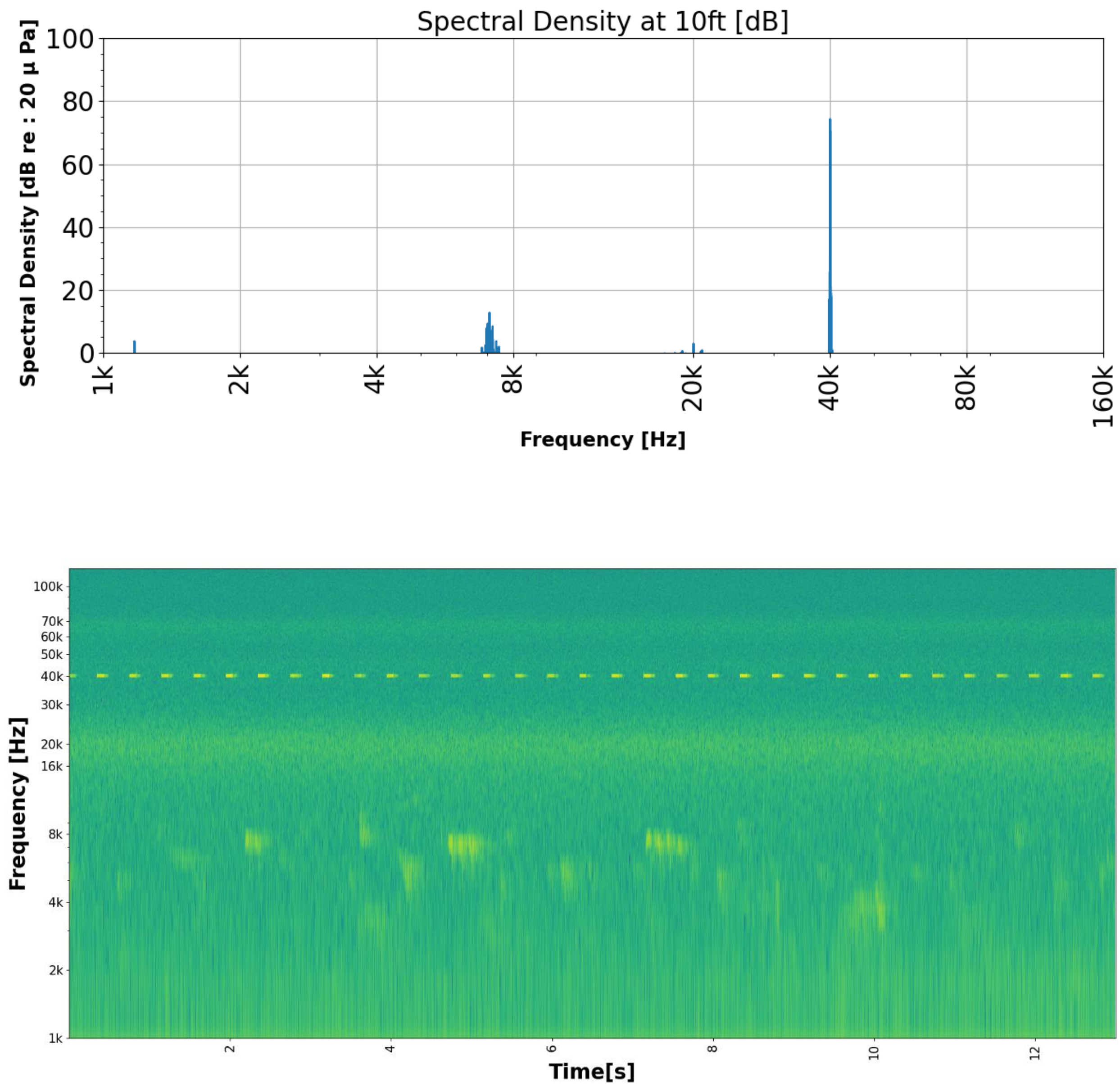

Figure 5: Spectral density plot and spectrogram for the calibration 'chirp' measured at 10 feet

A sound laboratory, Illingworth & Rodkin, Inc., analyzed recordings and was tasked with determining the distance-based rate of noise attenuation. For a generalized summary of all recordings, sound pressure levels in decibels were calculated for each bicycle and for each trial and separated into three frequency groups: all frequencies (1 – 128 kHz), medium and high frequencies (8 – 128 kHz) and high frequencies (16 – 128 kHz) (Table 1). For this summary, all frequencies were first combined and then reduced in a step-wise procedure when going from all frequencies to only high frequencies. For purposes of determining the distance-based noise attenuation for birds and each phonic group of bat species, noises were further grouped into categories representing species that are expected to regularly occur within the MROSD's geographic area. Therefore, we grouped the noise levels and attenuation rates into five phonic groups (Table 2). Illingworth & Rodkin, Inc. staff then computed the transmission loss rates for the loudest sounds propagating from the e-bikes for each phonic group to determine the distance for the sound to level off to ambient levels (20 dB).

Table 1. Phonic groups representing birds and bats

Frequency	1kHz – 5kHz	18kHz – 26kHz	27kHz – 35kHz	36kHz – 44kHz	45kHz – 55kHz
Phonic Group Name	Birds	20 kHz bats	30 kHz bats	40 kHz bats	50 kHz bats
Species Represented	Birds	hoary bat (*Lasiurus cinereus*) Brazilian free-tailed bat (*Tadarida brasiliensis*) Townsend's big-eared bat (*Corynorhinus townsendii*)	pallid bat (*Antrozous pallidus*) big brown bat (*Eptesicus fuscus*) silver-haired bat (*Lasionycteris noctivagans*) Long-eared myotis (*Myotis evotis*) Fringed myotis (*Myotis thysanodes*)	long-legged myotis (*Myotis volans*) little brown bat (*Myotis lucifugus*) western red bat (*Lasiurus frantzii*)	California myotis (*Myotis californicus*) Yuma myotis (*Myotis yumanensis*)

Results

Spectral Densities of the Different Modes for Representative Bicycles

The sound pressure levels for different modes of operation for each of the e-bikes and conventional bicycles are summarized in Table 2. No values are reported for pedaling slowly or pedaling fast for the Gary Fischer conventional bicycle, or pedaling fast for the Specialized Rock-Hopper conventional bicycle, because the sound pressures generated from these modes and models were likely too low to be recorded by the microphones. Generally, conventional bicycles were quieter. Note also that the loudest noises were propagated by pedaling slowly or fast uphill with the e-bikes. The loudest consistent noise, 90 dB, was generated by pedaling slowly uphill in the Specialized 2020 Levo SL e-bike, although the loudest sound recorded, 96 dB, was generated by braking hard in the Specialized 2019 Levo e-bike. Because braking hard generated very inconsistent results and is not a commonly occurring event for e-bike riders, we did not use this single 96-dB data point to help determine buffer distances. Likewise, we found inconsistent results from recordings of e-bikes pedaling slowly uphill, so we decided to determine appropriate buffer distances based on pedaling fast uphill.

Table 2: Summary of sound pressure levels for different modes of operation – conventional bikes and e-bikes measured at a distance of 10 feet

Bike name & type	Mode of operation	SPL dB* (1 kHz - 128kHz)	SPL dB* (8 kHz - 128kHz)	SPL dB* (16 kHz - 128kHz)
Gary Fischer - Conventional	Coast	52	52	52
	Brake	66	66	66
Specialized Rock Hopper - Conventional	Coast	61	61	61
	Pedal slowly uphill	83	81	81
	Brake	64	64	62
	Hard Brake	70	70	70
Specialized 2020 Levo SL - E-bike	Pedal fast uphill	81	81	81
	Coast	64	64	64
	Pedal slowly uphill	90	90	90
	Brake	82	82	82
Santa Cruz 2018 Heckler - E-bike	Pedal fast uphill	76	76	76
	Pedal slowly uphill	88	88	87
	Brake	54	54	54
Specialized 2019 Levo - E-bike	Pedal fast uphill	72	72	72
	Coast	88	87	86
	Pedal slowly uphill	41	38	38
	Brake	71	70	70
	Hard Brake	96	94	94

*SPL dB = sound pressure levels in decibels

Because sounds were loudest and more intact in their structure at 10 feet, Illingworth & Rodkin staff prepared spectral density graphs with dB for the continuum of frequencies along with frequency/time spectrograms based on the recordings made at 10 feet (Appendix A). Figure 6 shows spectral density plots on the left along with the corresponding spectrograms for the three e-bikes measured when the e-bike is operating in the 'pedal fast uphill' mode. For the Specialized Levo e-bikes, the frequency spectrum is relatively broadband as compared to the Santa Cruz Heckler e-bike, which has peaks between 16 kHz to 60 kHz. As seen from table 1 above, the Specialized 2020 Levo SL e-bike is the loudest of the three when operating in this mode, measuring at 81 dB when summed up logarithmically across the different frequency ranges taken into consideration.

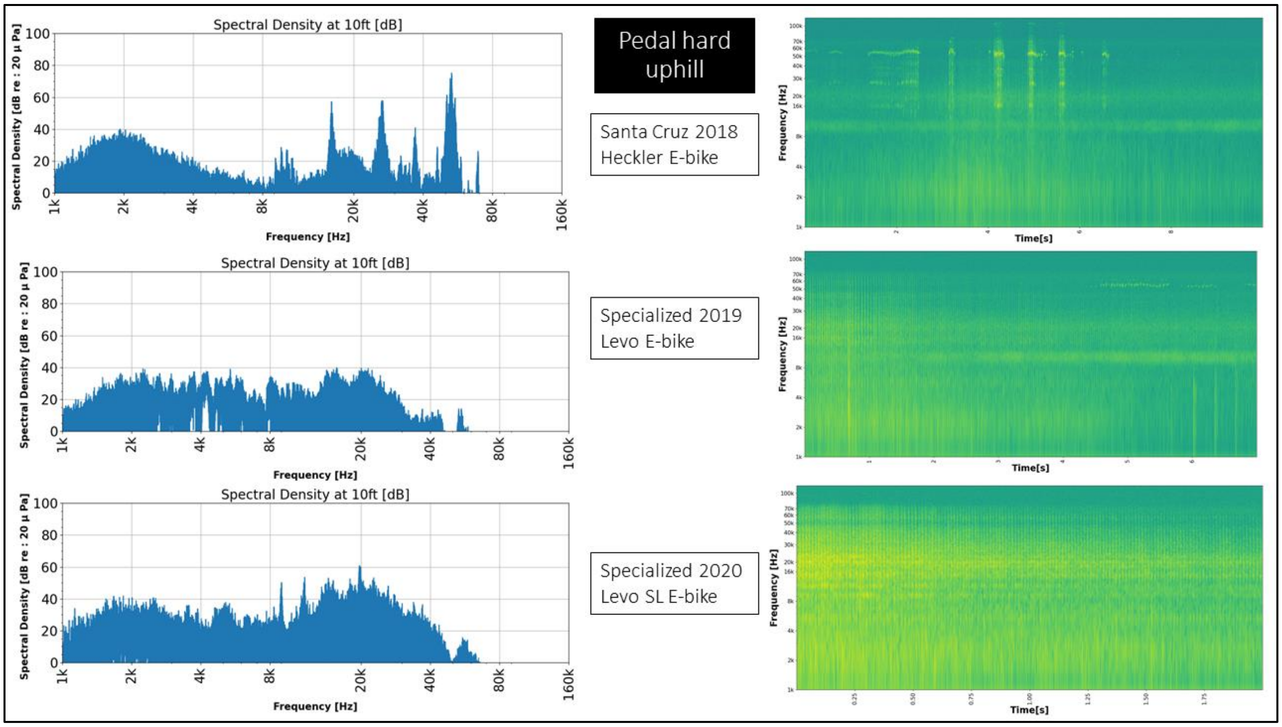

Figure 6. Spectral Densities of sound pressures and spectrograms of conventional bikes and e-bikes in pedaling fast uphill mode. This mode was chosen to determine appropriate buffers for various phonic groups of bats and birds as its own 1 kHz – 5 kHz group.

The 'coast' mode spectral density plots and spectrograms suggest that conventional bikes are quieter as compared to the e-bikes when coasting and the highest sound pressures were from between 8 kHz and 70 kHz (Appendix A1). The 'pedal slowly uphill' mode spectral density plots and spectrograms suggest that both the conventional bikes and e-bikes have substantial sound pressure from between 50 kHz and 70 kHz and the Specialized 2019 Levo e-bike is the quietest of all the bikes in this mode (Appendix A2). The brake mode spectral density plots and spectrograms suggest that the Specialized Levo e-bike showed the loudest levels while the quietest bike was the Santa Cruz Heckler e-bike (Appendix A3)

Recommendations

Buffer Distances

The Specialized 2020 Levo SL appeared to be the overall loudest e-bike out of the bikes measured; hence, sounds measured from this bike in the 'pedal fast uphill' mode were further analyzed to compute a sound transmission loss (attenuation) rate. A recommended buffer distance would therefore be based on the estimated distance from this operating e-bike needed in order to attenuate to an ambient noise level of 20 dB, the estimated ambient sound level of the environment at the time of recording. Figures 7 and 8 below show the spectral density and the spectrograms corresponding to the 2020 Levo SL e-bike operating in the 'pedal fast uphill' mode at distances of 10, 20, 40 and 80 feet captured by the Song Meter SM4 microphone.

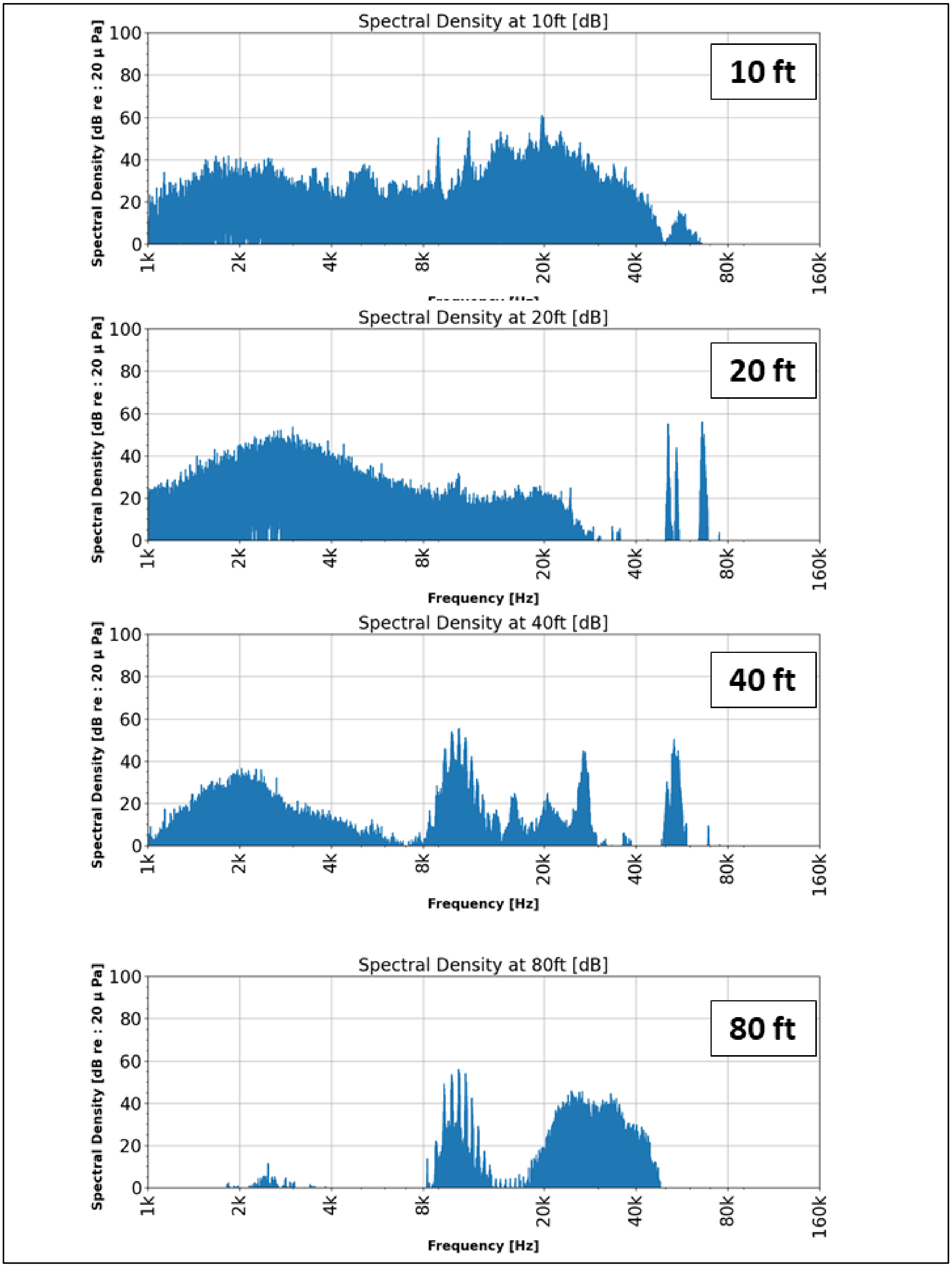

Figure 7: Spectral density plots for Specialized 2020 Levo SL e-bike in 'pedal fast uphill' mode of operation at different measurement distances from the source

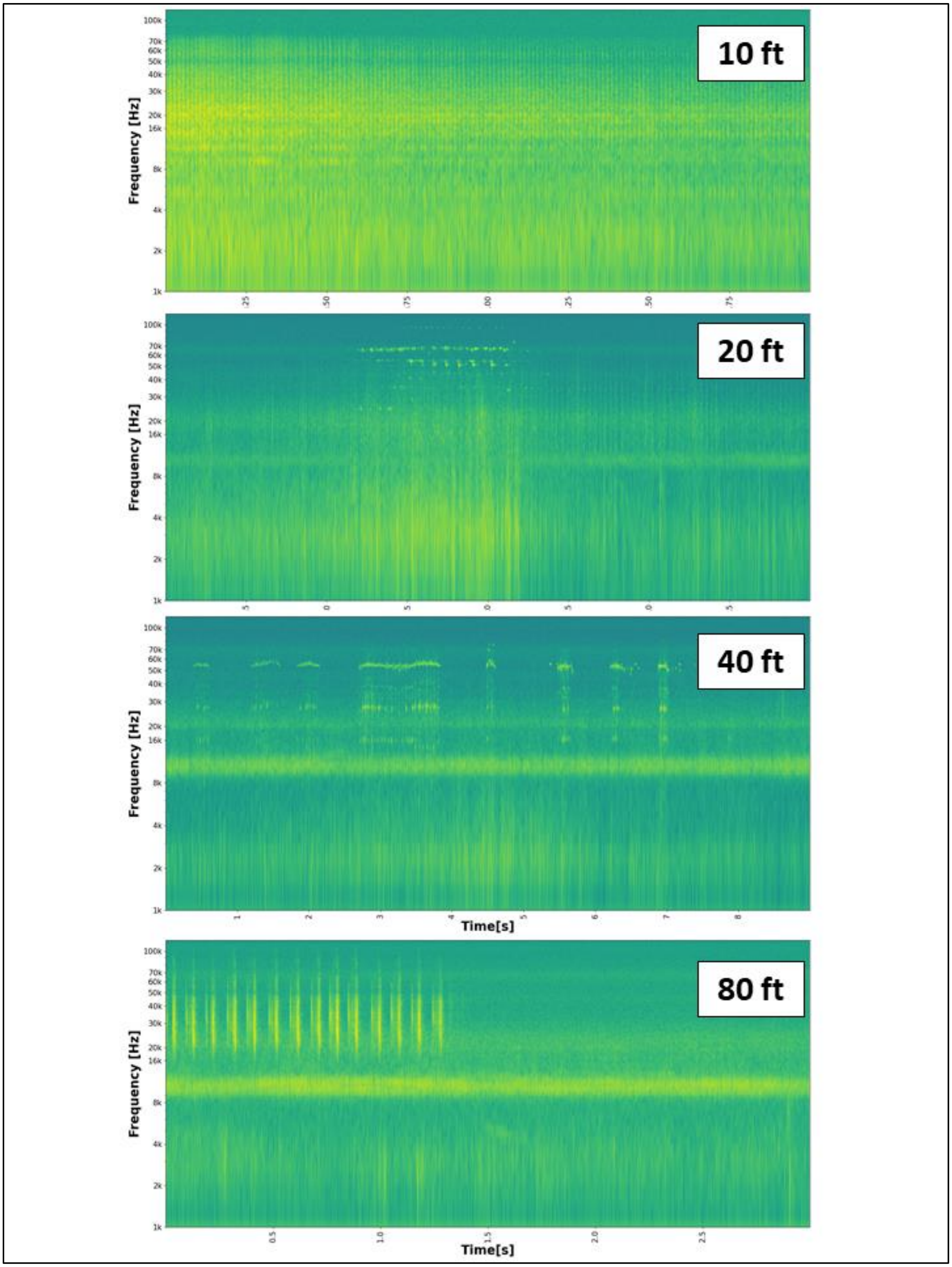

Figure 8: Spectrograms for Specialized 2020 Levo SL e-bike in 'pedal fast uphill' mode of operation at different measurement distances from the source

Calibration chirps at 40 kHz were also recorded at 10, 20, 40 and 80 foot distances along with e-bike sounds. The data from the above measurements for the Specialized 2020 Levo SL are summarized in Table 3 below. The sound levels shown in the table below have been summed up logarithmically between the phonic groups as previously described (Table 1).

Table 3: Summary of sound pressure levels summed for different frequency ranges along with computed sound transmission loss rates

Specialized 2020 Livo SL - E-bike	Sound Pressure Level, dB					
Distance (ft)	**Calibration chirp (40 kHz)**	**1kHz to 5khz**	**18kHz to 26kHz**	**27kHz to 35kHz**	**36kHz to 44kHz**	**45kHz to 55kHz**
10	74	61	66	73	78	72
20	47	48	61	51	50	46
40	61	8	57	42	37	33
80	No chirps in recordings	11	22	71	40	30
Transmission loss rate	-13.5 dB per doubling	-18.8 dB per doubling	-13.9 dB per doubling	-15.5 dB per doubling*	-12.8 dB per doubling	-13.9 dB per doubling

*using only 10, 20, 40 ft measurements

Using the transmission loss rates computed for the above frequency ranges, Table 4 below shows the computed distances required for sound to attenuate to an ambient level of 20 dB. As presented, the data suggest that the amount of sound pressure from e-bikes is not even across each of the phonic groups; rather, the amount of sound pressure is far greater in the 40 kHz phonic group than in other groups suggesting that bats such as the long-legged myotis, little brown bat, and western red bat may be more prone to disturbance from e-bike traffic than other bat species.

Table 4: Computed distances for e-bike sound to attenuate to ambient levels of 20 dB for different frequency ranges

	1 kHz to 5 kHz	18 kHz to 26 kHz	27 kHz to 35 kHz	36 kHz to 44 kHz	45 kHz to 55 kHz
Distance to ambient (ft)	45	100	107	231	134

We therefore recommend any bike (conventional bike and e-bike) trail that allows e-bike traffic, to have a minimum 100-foot distance from any roost site of Brazilian free-tailed bats, Townsend's big-eared bats, or hoary bats, although the latter is transient and does not produce young on MROSD lands. Active roosts of the 30 kHz phonic group of bats, which include pallid bats, big brown bats, silver-haired bats, long-eared myotis, and fringed myotis, should have a minimum buffer zone of 107 feet between an active roost and any bike trail; active roosts of the 40 kHz phonic group of bats, which include long-legged myotis, little brown bat, and western red bat should have a minimum buffer zone of 231 feet between an active roost and any bike trail; and active roosts of the 50 kHz phonic group of bats, which include California myotis and Yuma myotis, should have a minimum buffer zone of 134 feet between an active roost and any bike trail. Maternity colonies of pallid bats and Townsend's big-eared bats are extremely sensitive, and Townsend's big-eared bats are known to abandon young because of disturbances. Therefore, for a maternity colony of either of these species, we recommend a minimum buffer of 200 feet to any trail allowing any bike traffic.

Birds' sensitivities to noise disturbances are varied, and little is known about the tolerance of many species to noise disturbance; however, based on our data, these low frequency e-bike sounds attenuate to about 20 dB, the ambient noise level recorded, at 45 feet from the operating e-bike. The noises e-bikes make are primarily high frequency, so like humans, birds cannot hear these high energy, high frequency sounds and are not likely affected much from them. For reference, the United States Fish and Wildlife Service (USFWS) (2020) has recently published guidelines on the estimated disturbance distance (in feet) due to elevated action-generated sound levels affecting the northern spotted owl and marbled murrelet, by sound level (Appendix B). On the other hand, bats are going to be quite sensitive to e-bike noises. For a review of noise impacts on wildlife, see Blickley and Patricelli (2010).

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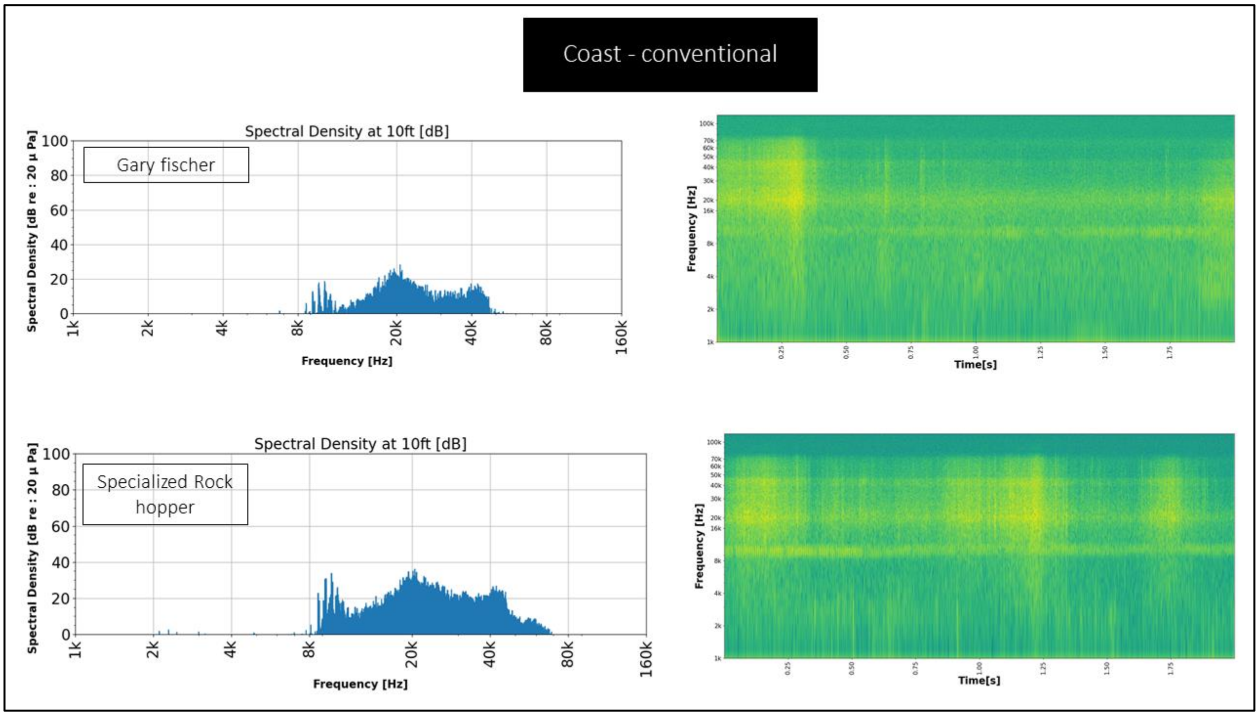
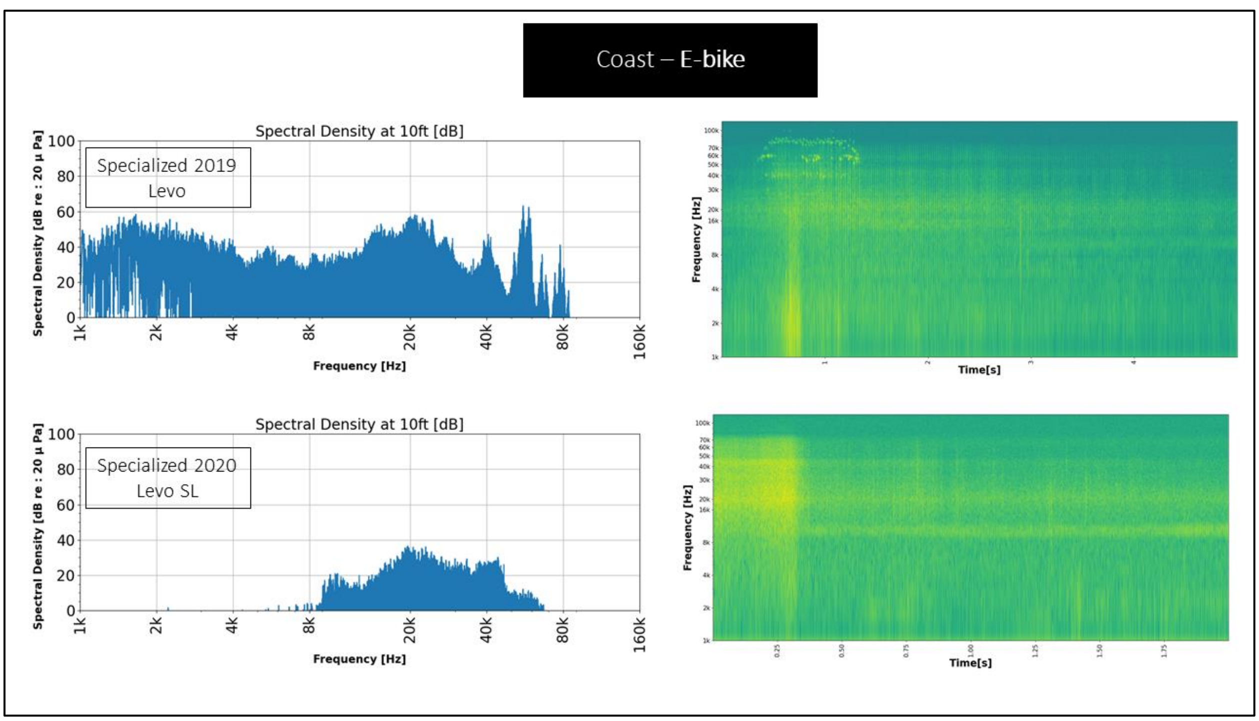
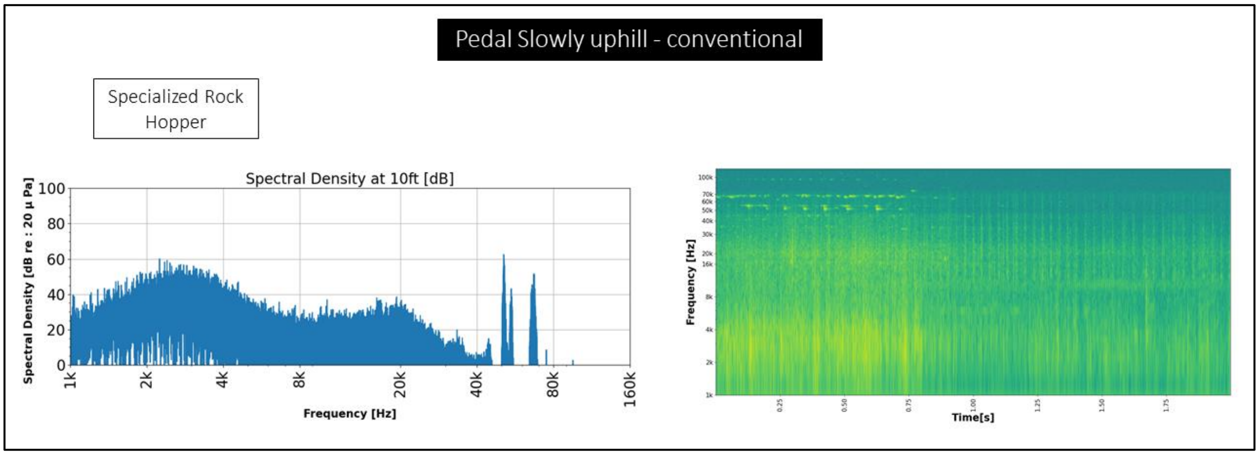
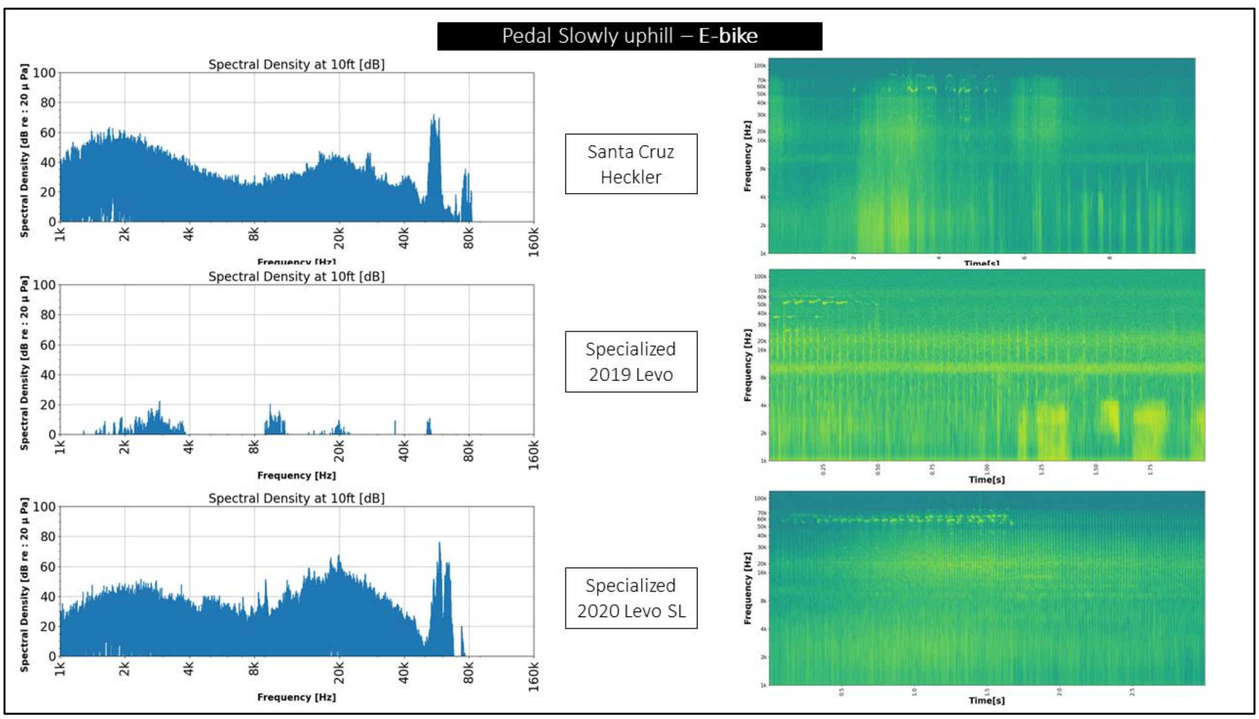
Appendix A1. Spectral density plots and spectrograms for conventional bikes and e-bikes when operating in the ‘coast’ mode



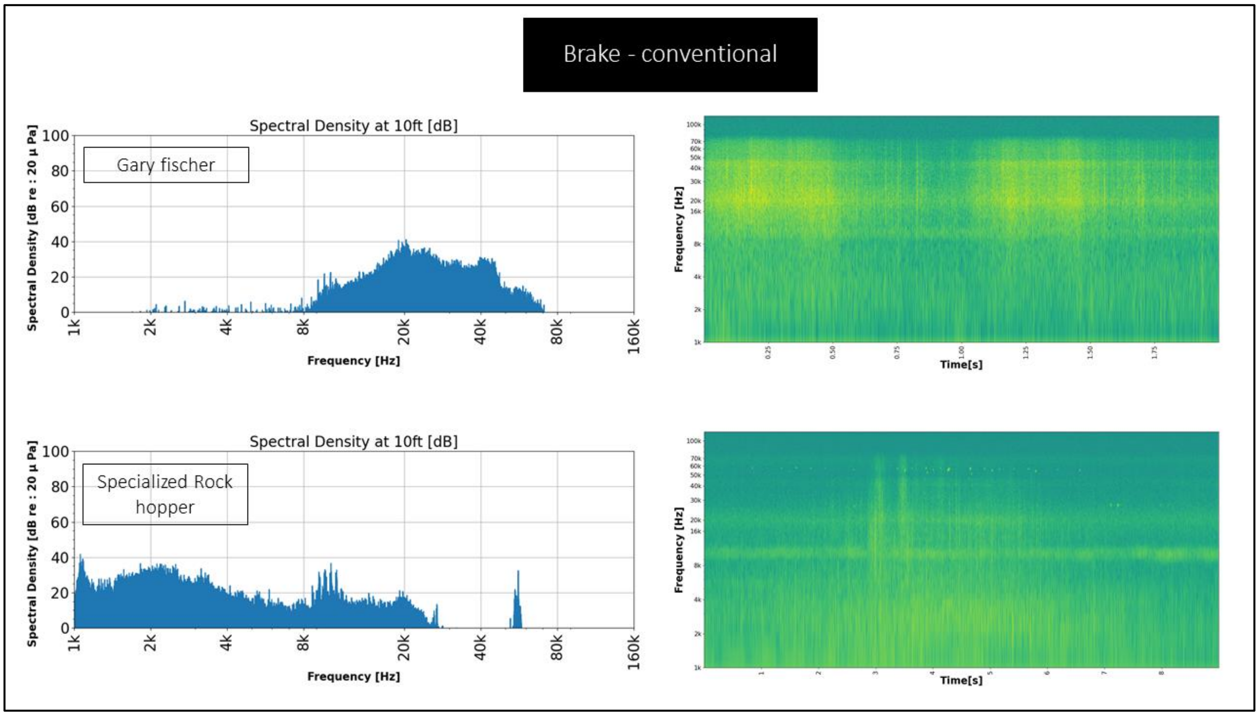


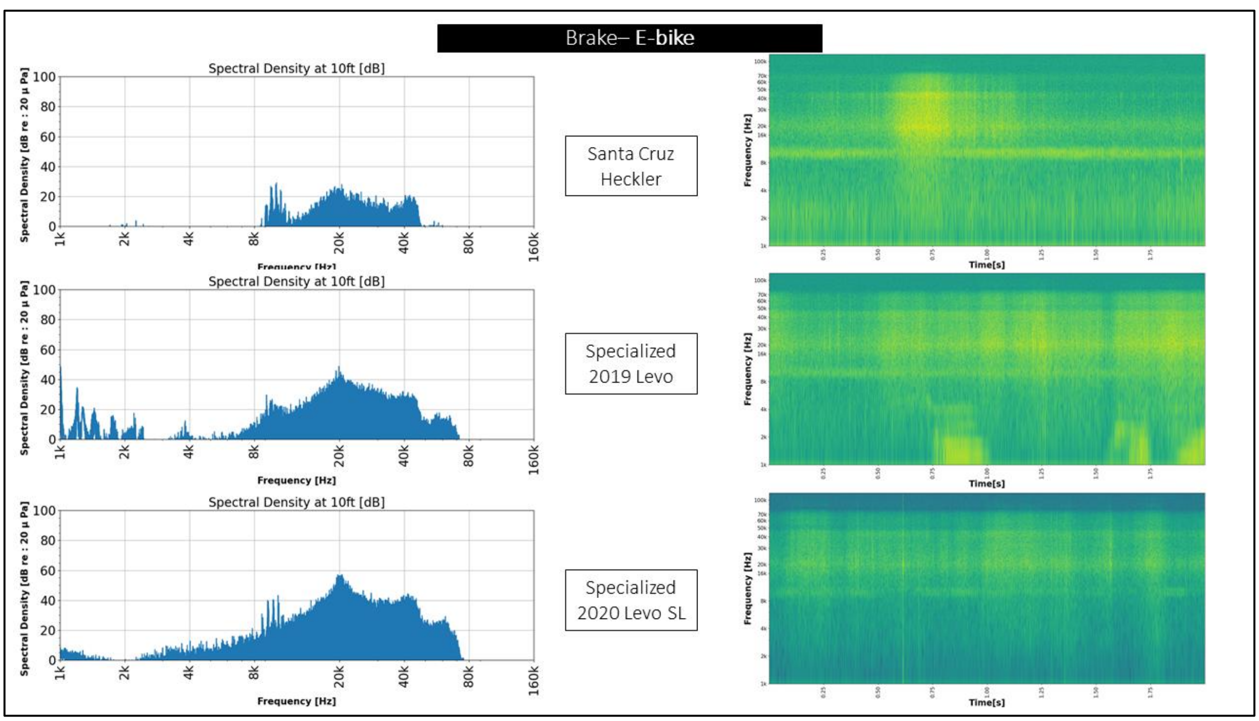
Appendix A2. Spectral density (left) and spectrogram (right) plots for conventional bikes and e-bikes in 'pedal slowly uphill' mode of operation





Appendix A3. Spectral density plots and spectrograms for conventional bikes and e-bikes when operating in the ‘brake’ mode.





Appendix B. USFWS guidelines for disturbance distances

Table 1. Estimated disturbance distance (in feet) due to elevated action-generated sound levels affecting the northern spotted owl and marbled murrelet, by sound level.

Existing (Ambient) Pre-Project Sound Level (dB) [1, 2]	Anticipated Action-Generated Sound Level (dB) [2, 3]			
	Moderate (71-80)	**High (81-90)**	**Very High (91-100)**	**Extreme (101-110)**
"Natural Ambient" [4] (< = 50)	50 (165)[5,6]	150 (500)	400 (1,320)	400 (1,320)
Very Low (51-60)	0	100 (330)	250 (825)	400 (1,320)
Low (61-70)	0	50 (165)	250 (825)	400 (1,320)
Moderate (71-80)	0	50 (165)	100 (330)	400 (1,320)
High (81-90)	0	50 (165)	50 (165)	150 (500)

[1] Existing (ambient) sound level includes all natural and human-induced sounds occurring at the project site prior to the proposed action, and are not causally related to the proposed action.

[2] See text for full description of sound levels.

[3] Action-generated sound levels are given in decibels (dB) experienced by a receiver, when measured or estimated at 50 ft from the sound source.

[4] "Natural Ambient" refers to sound levels generally experienced in habitats not substantially influenced by human activities.

[5] All distances are given in meters, with rounded equivalent feet in parentheses.

[6] For murrelets, activities conducted during the dawn and dusk periods have special considerations for ambient sound level. Refer to page 7 for details.