Lauren M. Kuehne and Julian D. Olden, School of Aquatic and Fishery Sciences, Box 355020, University of Washington, Seattle, Washington 98195

Military Flights Threaten the Wilderness Soundscapes of the Olympic Peninsula, Washington

Abstract

Noise from military aircraft over the Olympic Peninsula (Washington, USA), has increased in recent years with changes in operations from nearby facilities. Further increases in training activities are proposed, but lack of any data that describe current noise levels has hindered assessment of impacts on humans and wildlife. Over a one-year period, we monitored three primary and two supplemental sites to document current noise contributions of military aircraft to the soundscape.

We found that currently, 88% of audible air traffic is military. Flight training activities were concentrated during weekdays and in daytime hours, with hourly percent time audible averaging 14 to 42%. The duration of time that military aircraft were audible in any hour was correlated across sites up to 51 km apart, and the site outside the operations area experienced substantial noise, signifying a noise footprint extending well beyond the operations area. Maximum loudness of flyover events exceeded 82 dBA (A-weighted sound pressure level), and a median increase of 3 to 4 dBA (i.e., a doubling of existing acoustic energy) from ambient periods was typical in most sites and seasons. Comparison of spectral power densities indicates that military aircraft largely impact frequencies below 1.2 kHz, averaging a 20-dB increase (i.e., quadrupling of loudness) in this frequency range compared with ambient samples. Our results demonstrate that changes in military operations will play a dominant role in dictating the future soundscape of the Olympic Peninsula, and offer an empirical basis for inquiry into how the proposed increases will impact people and wildlife in this region.

Keywords: soundscapes, passive acoustic monitoring, noise pollution, wilderness, national parks

Introduction

Military activity over the Olympic Peninsula (western Washington) has changed substantially over the past decade due to changes in operations and training for personnel out of the nearby Naval Air Station Whidbey Island (NASWI). Although naval flights have been operating in the area for decades, the transition from Northrup Grumman EA-6B Prowler to Boeing EA-18G Growler aircraft has increased the noise experienced by residents and visitors to the Olympic Peninsula. Concurrently, national consolidation of all Growler training to NASWI has increased the fleet from 82 to 118 aircraft, resulting in increased flight activities already in effect on Whidbey Island (US Dept of the Navy 2019a) and currently proposed for the Olympic Military Operations Area (US Dept of the Navy 2019b). The recent Northwest Training and Testing 2019 Draft Supplemental Environmental Impact Statement (NWTT EIS) proposes increases of 62% in electronic warfare and 13% in air-to-air training, the primary activities of Growlers in the Olympic Military Operations Area (US Dept of the Navy 2019b). However, lack of any monitoring and quantitative assessment of the current noise from military aircraft makes it nearly impossible to evaluate the implications of these increases for humans and wildlife.

The Olympic Peninsula is a historically, culturally, and ecologically unique place. Olympic National Park, which encompasses a large range of geologically significant and unique features, receives more than 3 million visitors every year and has been designated as a World Heritage Site. Eight Native American Tribes call the Peninsula home, with strong historical and current connections and dependencies with wildlife (e.g., salmon, whales) for subsistence and culture. The geologic history of the region has supported creation of unique biota, and over two dozen species or sub-species...
of mammals, birds, amphibians and fish are found only on the Peninsula (Gavin and Brubaker 2014). Extensive swaths of intact forests and largely free-flowing rivers with protected headwaters also provide important habitat for forest-dependent species, including multiple species listed under the US Endangered Species Act (ESA), and some of the healthiest Pacific salmon runs in the state.

The science of “soundscapes” has emerged around the recognition that noise can be a critical form of disturbance for wildlife and people, and that the acoustic environment is part of and an indicator of the overall health of ecosystems (Pijanowski et al. 2011). Although this particular case impacts one region, it is part of a broader national and international problem of increasing noise in wilderness and protected areas (Lynch et al. 2011). For example, Buxton and colleagues (2017) found that close to two-thirds (63%) of protected areas are impacted by anthropogenic noise at levels that are known to interfere with visitor experiences and wildlife behavior and fitness. This case also exemplifies a common management problem—that noise sources often stem from regional or national policies that are outside the reach of any local jurisdiction to address (Lynch et al. 2011, Dumyahn and Pijanowski 2011b, Barber et al. 2011). Since 1982, when Congress defunded the Office of Noise Abatement and Control, noise control is the responsibility of state and local governments. Exceptions to this are regulation of noise in areas around airports (i.e., the Aviation Safety and Noise Abatement Act of 1979), and management of local noise sources in national parks (National Parks Air Tour Management Act of 2000, National Park Service Management Policies 2006).

Concerns about noise disturbance stem from its myriad effects on human health and well-being (Basner et al. 2014). The majority of research into the effects of aircraft noise on human health has been for commercial versus military aircraft (Pepper et al. 2003, Basner et al. 2017). Therefore, the basis on which to estimate health consequences related to military overflights, which differ in loudness, duration, and frequency of occurrence, is currently very limited. However, based on comprehensive reviews of studies that considered diverse noise sources, negative health effects begin to manifest (typically as annoyance and related stress responses) at levels above 40 dBA (Smith and Pijanowski 2014). Concentration, memory, cognition, and mental health status can be impaired when noise levels reach 40 to 55 dBA (Stansfeld et al. 2005, 2009; Smith and Pijanowski 2014; Fox and Morris 2017), while levels above 55 dBA are associated with serious cardiovascular health effects, including hypertension, stroke, and risk of ischemic heart disease (Smith and Pijanowski 2014, Fox and Morris 2017). When noise is experienced in wilderness areas, annoyance can be exacerbated precisely because of the expectation of quiet (Mace et al. 2004, Bruce and Davies 2014), as well as by intermittence and lack of predictability of events (Kjellberg 1990).

Diverse impacts of noise disturbance on wildlife are also increasingly recognized (Francis and Barber 2013). A recent comprehensive review summarized the varied consequences of noise from 119 studies on birds, mammals, fish, reptiles, amphibians, and invertebrates (Shannon et al. 2016). These documented impacts include: avoidance of noisy areas, changes in behavior, increases in physiological stress, reductions in reproductive success, declines in abundance and occupancy of sites, and changes in species communities and interactions. Research at community and ecosystem scales has demonstrated that noise can result in shifts in entire bird communities (Francis et al. 2011, Herrera-Montes and Aide 2011) and even alter and disrupt ecosystem functions (Francis et al. 2012). Although studies that examine impacts on fitness (versus behavior) of animals are rarer, at least four studies have documented reductions in breeding success of birds due to different types of noise disturbance (Halfwerk et al. 2011, Schroeder et al. 2012, Kight et al. 2012, Kleist et al. 2017). Notably, a comprehensive field study that examined the impacts of simulated off-highway vehicle noise on the ESA-listed Threatened northern spotted owl (Strix occidentalis caurina) found evidence of increased physiological stress and reduced fledging success (Hayward et al. 2011). Similarly, Threatened marbled murrelet (Brachyramphus marmoratus) can be sensitive to
disturbance by humans and transportation (Long and Ralph 1998), although the impact of aircraft on marbled murrelet has not been explicitly studied. Changes in physiology and behavior of larger animals (i.e., caribou, mule deer) in response to low-altitude military aircraft have also been documented (Weisenberger et al. 1996, Maier et al. 1998). Given that research studies on military activity are often opportunistic and less common than for industrial and transportation-associated noise (Pepper et al. 2003, Shannon et al. 2016), there are substantial knowledge gaps in evaluating the impact of intermittent and periodically intense overflight events on wildlife.

Protected and wilderness areas around the world continue to grapple with the challenge of managing acoustic environments that are integral to landscape uses by wildlife and people (Barber et al. 2011, Buxton et al. 2019). The goals of this study were to establish baseline noise levels for the Olympic Peninsula from military and other aircraft. This study seeks to answer two questions: 1) What are the current noise levels and contributions of different aircraft on the Olympic Peninsula soundscape? and 2) How might these levels change with proposed increases in military training and operations? Answering these questions will facilitate a realistic appraisal of impact to residential communities, visitors, and wildlife, and thus better inform management and mitigation.

Methods

Study Sites and Data Collection

We selected three primary locations on the west side of the Olympic Peninsula for monitoring between June 2017 and May 2018 (Figure 1). Sites were monitored simultaneously in four periods (i.e., summer, autumn, winter, and spring) to ensure robust sampling and account for seasonal differences in the soundscape. Two of these sites (Third Beach, elevation 64 m; River Trail, elevation 199 m) were selected to replicate monitoring conducted in 2010 and 2011 as part of a soundscape inventory by the National Park Service (Lee and MacDonald 2016). The third site (Hoh Watershed, elevation 28 m) is adjacent to the national park boundary near the southern region (i.e., Oil City). Distances between the three sites are 22 km (Third Beach–Hoh Watershed), 40 km (Hoh Watershed–River Trail), and 51 km (Third Beach–River Trail). In addition to seasonal sampling of the three primary locations, we did opportunistic monitoring of the Third Beach site and two additional locations (Forks, elevation 284 m; Clearwater, elevation 78 m) for one 6-day period in late summer of 2017 (Figure 1); distances between the supplemental monitoring sites are 18 km (Third Beach–Forks), 30 km (Forks–Clearwater), and 38 km (Third Beach–Clearwater). All monitored sites are within the Olympic Military Operations Area (MOA) except for River Trail, which is 1.8 km outside of the MOA boundary.

We collected acoustic data at each site using Songmeter SM4 or SM2 recording units (Wildlife Acoustics Inc., Maynard, MA), which are designed to capture a broad range of frequencies. For this study, the most important distinction between the SM2 and SM4 units is the higher quality microphones of the latter, resulting in a lower noise floor. Based on manufacturer specifications and the gain settings applied, we anticipated distortion (i.e., “clipping”) to occur at approximately 84 dBA. However, in practice, distortion occurred at approximately 82 dBA with both units. Although aircraft events above this noise threshold were not common, this limitation in measurable range means that we were not able to describe the maximum events. Units were deployed at each site for a minimum of two weeks in June 2017, September 2017, January 2018, and April 2018. We used single-channel recording (sampling rate = 44.1 kHz) to maximize recording time, and batteries were changed as needed. Recording was continuous at all sites and periods with the exception of Hoh Watershed in the June 2017, September 2017, and January 2018 periods, where the SM2 recorder was scheduled to be off from 2 to 4 am to extend battery life.

Data Processing and Analysis

We processed ten days of audio files from each seasonal period: 22 June 2017 to 01 July 2017, 25 September 2017 to 04 October 2017, 01 January 2018 to 10 January 2018, and 22 April 2018 to 01
May 2018. A total of 2,813 hours of audio files were processed from the three primary sites and four sampling periods. The difference from the number of continuous hours during that period (24 hrs × 10 days × 3 sites × 4 periods) is due to the recorders being turned off from 2 to 4 am in three periods at the Hoh Watershed, and one equipment failure that led to loss of 6.5 hours of audio in the same location. Fifty minutes of audio were also lost at the Third Beach location due to a problem during battery change. Six days of data (11 August 2017 to 16 August 2017) were processed from the supplemental monitoring period, equaling 420 hours of audio files (the SM2 recorder at the Clearwater site was turned off from 2 to 4 am).

To process files, we visually inspected spectrograms to identify potential aircraft events. The start and end times of events were annotated by listening for the points at which the aircraft became audible and then disappeared relative to background noise. If flight activity was partially discontinuous (i.e., included periods of interspersed quiet and audibility), we considered an interval of 5 seconds of quiet to designate a new event. Each event was classified as “military”, “commercial”, and “propeller” (or “helicopter”) by listening to the event until the listener was confident of the identification (Figure 2). If there was uncertainty in identification, listeners could classify events using a first and second choice (e.g., “1-commercial” and “2-military”). Less than 1% (n = 107) of all flight events were identified using a double classification, and the majority of these were approximately evenly divided between “military-commercial” and “commercial-military”. “Helicopters” could also be difficult to distinguish from “propeller”, but were rare events. About half of all audio files were first processed by trained volunteers, and then validated by the project lead to ensure continuity in identification and delineation.

We conducted all data analyses in R (version 3.5.3; R Development Core Team 2019). Selections of aircraft events (i.e., start and end times) were used to calculate the duration and time of day of events, and these were assembled into a database for analysis of the number of flight events by location, sampling period, date, and hour of the day. To evaluate the geographic extent of impact

Figure 1. Locations of acoustic monitoring sites, the Olympic Military Operations Area, and Olympic National Park. River Trail and Hoh Watershed sites (black circles) were monitored in four 10-day periods from June 2017 to May 2018. Forks and Clearwater sites (grey circles) were monitored for one 6-day period in August 2017; Third Beach (black with grey circle) was monitored in all periods. The Third Beach and River Trail sites are within Olympic National Park, and were monitored by the National Park Service as part of a soundscape inventory in 2010 and 2011. Designated critical habitat for (terrestrial) species listed under the Endangered Species Act are also shown.
across the three monitoring sites at any given point in time, the summed duration of time that military aircraft were audible in each site × date × hour were tested for correlation using Pearson’s r. We also calculated the percent time that military aircraft were audible in each hour (i.e., total duration/actual recording time); because military aircraft were primarily detected on weekdays (consistent with current NASWI policy of operating only as needed on weekends), we excluded weekend data to calculate this metric.

To test the relationship between our observations of military aircraft in the Olympic MOA and activity at NASWI, we summarized information from the weekly notification schedule for Flight-Carrier-Landing Practice (FCLP) out of NASWI for comparison with our recorded data (US Dept of the Navy 2019c). FCLP training is conducted on Whidbey Island from two airfields: Ault Field and Outlying Field Coupeville (OLF Coupeville). FCLP training is not explicitly related to the electronic warfare training conducted on the Olympic Peninsula. However, it is currently the only publicly available indicator of the timing of elevated military aircraft activity expected in and around the Olympic MOA. According to the NASWI Complex Growler Final Environmental Impact Statement, 83% of current operations at Ault Field are Growlers (US Dept of the Navy 2019a); the flight notifications for Ault Field should be a reasonable surrogate of when Growler training is expected. Similarly, because aircraft are not housed at OLF Coupeville, a relationship with FCLP training for that airfield was not expected. The number of published time frames for FCLP training were summed for each day (e.g., “Night to Late Night” = 2 time frames) and each airfield over the one-year monitoring period (28 May 2017 to 27 May 2018), and tested for correlation with the mean number of flight events recorded across the three sites on each day.

We next applied the methodology outlined in Merchant et al. (2015) and corresponding PAMGuide software to generate calibrated sound levels from the recorded audio data. We extracted all selections classified as “military” or “commercial” as separate audio clips using the tuneR package (Ligges et al. 2018). To contrast sound pressure levels for the different aircraft with ambient levels, we selected corresponding audio clips from periods with no aircraft activity. This was accomplished by selecting 20-min intervals from that site × date until the total number of seconds with no aircraft activity matched those associated with “military” events for that day. These selections were preferentially made during daytime hours (9 am to 5 pm) to best match the periods of military activity. If it was not possible to obtain a sufficient number of intervals with no aircraft from daytime hours, then later or earlier hours were used to supplement. We used the Meta.R batch processing procedures in PAMGuide to generate 1/3 octave bands for all audio clips, using the following specifications for the micro-
phone and recorder: microphone sensitivity = –36 (SM2) or –35 (SM4), vADC = 1.414 vM (SM2)
or 1 (SM4), and gain = 48 (SM2) or 42 (SM4) dB. We used the 1/3 octave bands to calculate the
A-weighted sound pressure level (dBA) for each second of all audio clips. A-weighting is a method
of weighting sound pressure levels in decibels (dB) across frequencies considered most relevant
to the range and sensitivity of human hearing to create a single metric of loudness. Although it
has been criticized for not properly integrating acoustic energy, particularly in low-frequency
transportation noise, it is the standard metric in outdoor community noise monitoring (Houser
et al. 2017). We used kernel density estimation (a smoothing technique) to visually contrast and
statistically compare the distributions of dBA for each site and season, using a permutation approach
in the sm package that tests for equality of two densities (Bowman and Azzalini 2018). The me-
dian, 5th and 95th percentiles of dBA were also calculated for each site and season.

Because A-weighting downweights much of
the sound from the lowest and highest frequen-
cies that can be of importance to both humans
and wildlife (Persson et al. 1990, McKenna et
al. 2016), we also used PAMGuide to compare
the spectral probability density (SPD) of military
aircraft with that of ambient selections (the number
of commercial aircraft samples was too low for
meaningful contrast). To facilitate interpretation
of the contrasting SPDs, we selected a single
site and season (Hoh Watershed, autumn) that
had stable weather and relatively low amounts
of background noise.

Results

Temporal and Geographic Patterns of
Military Aircraft Activity

Across the primary monitoring locations and
periods, we identified 4,768 flight events. Of
these, 88% (n = 4,227) were military, 5% (n =
234) commercial, 6% (n = 281) propeller, and
less than 1% (n = 26) were helicopter events. Di-
ferent types of aircraft events had highly similar
mean duration (range: 122 to 139 secs), although
the variance was much higher for military flight
events (min – max: 5 secs – 23 mins, 36 secs) as
compared with other aircraft (Figure 3). Military
aircraft constituted the largest majority of audible
aircraft at most hours of the day, representing
88% of the total duration of time aircraft noise
was recorded; propeller/helicopter and commer-
cial aircraft represented much smaller, similar
percentages (7% and 5% respectively) of the
total time audible (Figure 4). Although recording
days included an approximately normal ratio of
weekend days and weekdays (1:4), only 8.4% of
the total time military flights were recorded was
on weekends. Three-quarters (74%) of the total
duration of recorded military aircraft occurred
between 9 am and 5 pm, 19% was between 5 and
10 pm, and 7% between 10 pm and 9 am (Figure
4). The relative contributions of different aircraft
and temporal patterns were highly similar during
the supplemental monitoring of three locations in
late summer 2017. Military aircraft also comprised
88% of all audible aircraft during that period,
with the same strong emphasis on activity during
daytime and early evening hours (Supplemental
Figure S1, available online).
For the one-year period from 28 May 2017 to 27 May 2018, FCLP training was scheduled at Ault Field on 118 days (Supplemental Figure S2, available online), overlapping with recording and processing days by 55%, or 22 out of 40 recording days. The number of active time frames published for Ault Field and the average number of flights recorded in that day across the three primary sites was correlated \((r^2 = 0.57, P < 0.001; \text{Figure 5A})\); the correlation is stronger if data from the supplemental monitoring period are included \((r^2 = 0.60, P < 0.001)\). By contrast, days where FCLP training was scheduled out of OLF Coupeville overlapped by only 15% (6 out of 40 recording days), and there was no significant correlation with active time frames \((r^2 = 0.02, P = 0.36)\).

The correlation between active time frames at Ault Field and the number of flight events at individual locations varied in strength, being weakest for River Trail \((r^2 = 0.30, P < 0.001)\) and strongest at Hoh Watershed \((r^2 = 0.58, P < 0.001)\). On the busiest days, we recorded an average of 75 to 90 flight events per location (Figure 5A). The distribution of flight events recorded at individual locations was slightly left-skewed, tending to cluster around 25 to 50 events on recorded days (Figure 5B). The maximum number of military flight events recorded on a single day at each location was 79 (Third Beach), 81 (Hoh Watershed), and 107 (River Trail).

The daily patterns in military flight activity were similar in all locations (i.e., strong peak during the middle of the day) but varied in the total percent time audible (Table 1). On weekdays between 9 am and 5 pm (when the large majority of military
activity occurred), military aircraft were audible for an average of 72 minutes daily at each of the two coastal locations (mean: 15%; range: 10 to 21% of any hour), and an average of 57 minutes at River Trail (mean: 12%; range: 9 to 16% of any hour). Similar daily totals (mean: 85 minutes site\(^{-1}\)) and hourly percentages (mean: 18%, range: 3 to 42% of any hour) were observed during the supplemental monitoring period (Supplemental Table S1, available online). By contrast, propeller aircraft were audible 5 to 12 minutes daily (depending on the location) during daytime hours, and noise from commercial aircraft was audible < 1 min for any site during the same period. The duration of time that military aircraft were audible in each day and hour was significantly (\(P < 0.001\)) correlated across the three locations: Third Beach–Hoh Watershed (\(r^2 = 0.61\)), Third Beach–River Trail (\(r^2 = 0.19\)), and Hoh Watershed–River Trail (\(r^2 = 0.36\)). Correlations between hourly data were also significant (\(P < 0.001\)) for the supplemental monitoring sites: Third Beach–Forks (\(r^2 = 0.68\)), Third Beach–Clearwater (\(r^2 = 0.38\)), and Forks–Clearwater (\(r^2 = 0.75\)). These correlations across distances indicate the large geographic extent of impact in any given hour.

### Sound Pressure and Noise Levels

Kernel density estimates of dBA differed significantly (\(P < 0.001\)) within all sites and seasons, indicating that the 1-second sound samples classified as ambient, commercial, and military do not have the same distributions. (Note: Because the general patterns were similar across most seasons, we present the results for one season [autumn 2017] here, and all other seasons in the Supplemental Information). In all sites and seasons, the median dBA of military aircraft samples was higher than ambient samples (Figure 6, Supplemental Figures S3–S6, available online). The magnitude of the increase varies somewhat across sites and seasons (Supplemental Table S2), reflecting variation in ambient conditions and the amount (and relative loudness) of aircraft activity. During the primary monitoring periods, a median increase of 3–4 dBA (an approximate doubling of the existing acoustic energy) was typical for the two coastal sites except during winter, when higher ambient noise levels (i.e., due to heavy rains) were evident (Supplemental Table S2 and Supplemental Figure S4).

Though still present, increases in median dBA were less apparent at the River Trail site, where ambient conditions are louder due to consistent influence of the nearby Hoh River. This site is also just outside the MOA and during daytime hours has the lowest percent time audible (Table 1), indicating less frequent and/or greater distance from overflights. The maximum median increase of 7.7 dBA was observed at the Forks location during the supplemental monitoring period; this relatively large increase reflects the quiet ambient conditions at this (inland) site and the higher elevation, which results in louder received dBA from overflights. In many sites and seasons, the

<table>
<thead>
<tr>
<th>Site</th>
<th>Hour of day</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Third Beach</td>
<td></td>
<td>1.0</td>
<td>0.2</td>
<td>1.4</td>
<td>0.7</td>
<td>0.6</td>
<td>0.0</td>
<td>0.1</td>
<td>0.1</td>
<td>3.2</td>
<td>13.5</td>
<td>13.1</td>
<td>12.6</td>
<td>15.3</td>
</tr>
<tr>
<td>Hoh Watershed</td>
<td></td>
<td>0.4</td>
<td>0.2</td>
<td>12*</td>
<td>2.1*</td>
<td>0.8</td>
<td>0.1</td>
<td>0.0</td>
<td>0.1</td>
<td>2.2</td>
<td>14.2</td>
<td>13.5</td>
<td>15.4</td>
<td>17.9</td>
</tr>
<tr>
<td>River Trail</td>
<td></td>
<td>0.4</td>
<td>1.4</td>
<td>2.0</td>
<td>2.5</td>
<td>1.0</td>
<td>0.3</td>
<td>0.4</td>
<td>0.2</td>
<td>3.2</td>
<td>10.6</td>
<td>12.1</td>
<td>10.6</td>
<td>13.2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Site</th>
<th>Hour of day</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
<th>17</th>
<th>18</th>
<th>19</th>
<th>20</th>
<th>21</th>
<th>22</th>
<th>23</th>
</tr>
</thead>
<tbody>
<tr>
<td>Third Beach</td>
<td></td>
<td>20.1</td>
<td>13.9</td>
<td>17.3</td>
<td>10.1</td>
<td>4.9</td>
<td>6.7</td>
<td>6.1</td>
<td>3.3</td>
<td>3.9</td>
<td>0.7</td>
<td>0.3</td>
</tr>
<tr>
<td>Hoh Watershed</td>
<td></td>
<td>20.7</td>
<td>12.3</td>
<td>16.6</td>
<td>11.8</td>
<td>7.6</td>
<td>8.5</td>
<td>7.3</td>
<td>5.4</td>
<td>4.9</td>
<td>0.8</td>
<td>0.3</td>
</tr>
<tr>
<td>River Trail</td>
<td></td>
<td>16.0</td>
<td>11.7</td>
<td>12.7</td>
<td>8.5</td>
<td>5.0</td>
<td>7.6</td>
<td>5.3</td>
<td>3.9</td>
<td>3.8</td>
<td>1.5</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Downloaded From: https://bioone.org/journals/Northwest-Science on 30 Nov 2020
Terms of Use: https://bioone.org/terms-of-use Access provided by University of Washington
increase in median dBA was accompanied by a change in the shape from the ambient distribution, which often exhibited bimodal (or even trimodal) peaks. In contrast, military sound samples were almost exclusively unimodal, indicating greater homogeneity (Figure 6; Supplemental Figures S3–S6). Commercial aircraft are associated with smaller differences from ambient conditions in most sites and seasons (Supplemental Table S2). Depending on the ambient conditions, this shift represents a decrease or increase, reflecting the smaller number of commercial sound samples being contrasted with ambient.

The spectral probability densities of ambient and military sound samples differ, with military aircraft strongly impacting the lowest frequencies (Figure 7). In ambient samples, the root mean square sound pressure (RMS; i.e., an average sound level) ranges from 20 to 30 dB across all frequencies (Figure 7A), and this average is approximately 20 dB greater in the frequency range from 0 to 400 Hz for military aircraft (Figure 7B). The RMS of military samples declines from 400 to 1000 Hz, with the profile becoming similar to ambient samples above 1200 Hz. Examination of the percentiles indicates that 90% of the sound pressure from military aircraft is between 22 to 53 dB (below 1000 Hz), in contrast with ambient where 90% of the sound pressure occurs between 13 to 33 dB (below 1000 Hz).

**Discussion**

We used on-the-ground acoustic monitoring to document the spatial and temporal extent and impact of a new anthropogenic disturbance on the Olympic Peninsula soundscape. Prior to this
study, no empirical data existed to describe current noise levels from military air training, which is proposed to increase by 62% for electronic warfare training and 13% for air-to-air combat training, commencing in 2020. Three of our sites (Forks, Third Beach and Hoh Watershed) are proximate to the largest communities on the Peninsula, including the Quileute Tribe and Hoh Nation, offering an estimate of current impact on residents and people of those tribal nations. Our primary monitoring sites also include some of the most highly visited areas of Olympic National Park, and therefore reflect the range of exposure that more than 3 million visitors to the region will experience.

Alongside the direct impacts on residents and visitors, persistent aircraft noise and a permanent alteration of the soundscape have profound implications for the management of Olympic National Park. Like all national parks, it is managed under an overarching mandate established by the Organic Act of 1916 which is to conserve park resources as to leave them “unimpaired for the enjoyment of future generations.” This mandate has been strongly reaffirmed over time by legislation (the Redwood Amendment of 1978) and case law that has consistently prioritized the Park Service’s responsibility for preservation and resource conservation, even over public enjoyment or other interests (Keiter 2011). Further, 95% of Olympic National Park is designated as Wilderness by Congress; this means that, among other criteria, the Park Service is required to manage this area so “the imprint of man’s work [is] substantially unnoticeable” and “for solitude or a primitive and unconfined type of recreation” (Wilderness Act 1964). The noise levels that we document in this study—and the proposed increases—arguably create an unresolvable burden that undermines the fundamental mission and purpose of the Park.

We found that military aircraft are a dominant contributor to the soundscape of the Olympic Peninsula, representing 88% of the total time aircraft are audible. The lack of commercial traffic in the area is consistent with the low number of routes (FAA 2019a) and the fact that commercial traffic is likely to be rerouted around an active MOA (FAA 2019b). The contribution of military aircraft to the soundscape could be measured in most sites and seasons as a median increase of 3 to 4 dBA over ambient conditions. Given that decibels are on a logarithmic scale, this is an approximate doubling of the existing acoustic energy in the environment. Because our ambient samples were
drawn from daytime hours when most human noise is generated, the increase in the median is above ambient levels that include other common noise sources (e.g., vehicles, people talking; Lee and MacDonald 2016).

The maximum loudness of military jet events was greater than anticipated, and indeed, at times exceeded the measurable range of our equipment. Although we were not able to characterize the very loudest events, they certainly exceed 82 dBA. Since these events are rare, exposure to these acute noise levels will not be for long periods; however, they exemplify the stark contrast of high-intensity aircraft with the rural and wilderness setting of the Olympic Peninsula, which is otherwise relatively free from anthropogenic noise. Based on national noise modeling, natural ambient sound levels in this area are very low (median: 32 to 34 dBA), with only small increases of < 2.7 dBA expected from anthropogenic sources (Mennitt et al. 2017). These models are consistent with a soundscape inventory of Olympic National Park in 2010 and 2011, which reported that the Third Beach and River Trail sites experienced natural sounds 83% and 91% of the time (Lee and MacDonald 2016).

Loudness is only one metric of importance when evaluating the impact of noise pollution. Studies have shown that other important characteristics of aircraft noise that determine annoyance include percent time audible, predictability, and type of aircraft (Mace et al. 2013, Rapoza et al. 2015, Basner et al. 2017). Listeners also interpret and react to noise through the lens of whether the sound is expected (i.e., bears a relationship with the landscape) (Bruce and Davies 2014). Despite the surprising loudness of some individual events, our results suggest that impacts on people and wildlife are more likely to stem from the chronic nature of the noise. Percent time audible was persistent and substantial, averaging more than an hour daily during weekday, daytime hours. However, considerable daily variation was evident, where military aircraft were audible as much as 2.5 to 3.5 hours on some days. Because flyovers are intermittent, the actual period when people hear aircraft noise is over several hours in a day, and will be experienced as punctuated and unpredictable events; our data show that individual locations can currently experience more than 100 events in a single day. To put this in perspective, a park visitor on a 6-hour hike will likely hear jet noise for close to an hour, interspersed throughout their visit. For residents experiencing these levels of noise on a large number of weekdays, the combination of chronic noise, unpredictable patterns, and lack of ability to control exposure or source are likely to exacerbate annoyance and stress responses (Mace et al. 2004, Basner et al. 2014). In areas where residents and tourists have an expectation of quiet, these types and levels of noise are likely to occur as even more intrusive or disruptive than in urbanized settings (Mace et al. 2004, Bruce and Davies 2014, Smith and Pijanowski 2014). Future research in this region might focus on establishing dose-response relationships of military aircraft noise with park visitor responses and use (e.g., Rapoza et al. 2015). Whereas studies of impact on residents should emphasize the potential effects of chronic exposure, including sleep disturbance, annoyance (and related stress responses), and interference of learning for school-age children (Basner et al. 2014, 2017).

The impacts of noise pollution on wildlife are less well studied than in humans (Pepper et al. 2003, Shannon et al. 2016). Unlike for humans, impacts cannot be readily surveyed but must be assessed through comprehensive studies of animal behavior and physiological responses (Goudie 2006, Francis and Barber 2013). Despite this, we know that responses of wildlife to noise can include avoidance and physiological stress, resulting in reduced reproductive success and declines in habitat use (Francis and Barber 2013). Depending on the frequencies that are impacted, noise can physically mask (i.e., drown out) signal communications between animals and reduce their detection space; both of these features play important roles in mate discovery and selection as well as hunting and foraging efficiency (Francis and Barber 2013, Shannon et al. 2016). Our data show that military aircraft largely affect frequencies below 1.2 kHz, but the impacts in this range are considerable, with an average increase of 20 dB (i.e., a quadrupling in loudness) below 400 Hz. For contrast, increases of only 3 dB and 10
**Impact of Military Flights on Olympic Soundscape**

**1. Introduction**

Impact of Military Flights on Olympic Soundscape

199

dB will reduce detection space by 50% and 90%, respectively, for many vertebrates (Barber et al. 2010). Recovery time of wildlife from high-impact noise events can also be considerable (Goudie and Jones 2004). The temporal and geographic patterns of military aircraft events that we document should help guide assessment of species-specific impacts and/or design of future research to evaluate responses.

Audible events were uneven across different locations, with consistently higher percentages in the two coastal locations (Third Beach and Hoh Watershed) as compared with the most interior location just outside of the MOA (River Trail). Though based on the shorter supplemental monitoring period, the highest percent times audible were observed in the center of the MOA at the Forks and Clearwater locations (whereas Third Beach during the supplemental period remained consistent with other periods). With only three locations monitored at any given time, it is impossible to know how operations are distributed across the entire MOA, but our results show the impacts are not localized. The distance at which an individual aircraft can be detected depends on speed, altitude, and power, as well as terrain and atmospheric conditions. Anecdotal information from residents that live around NASWI suggests that Growlers might be audible up to 14 to 19 km away in some conditions. This does raise the possibility of simultaneous detection of aircraft events in our data collection and processing, particularly for the two sites that were 18 km apart. However, hourly audibility was significantly correlated across both sets of monitoring sites, and between locations up to 51 km apart, indicating the broad geographic scope of activities in any given hour. Repeated monitoring over larger areas would better establish whether there are indeed “hotspots” in the MOA where communities, visitors, and wildlife may experience greater exposure to aircraft events.

The geographic extent of impact is important for two reasons. First, our monitoring demonstrated consistent impact to an area outside of the MOA, with the River Trail location averaging nearly an hour daily of audible activity (mean: 9 to 16% of daytime hours, with a maximum of 52% recorded on one sampling day-hour). The Airspace Noise Analysis for the Olympic Military Operations Area (Appendix J) in the NWTT EIS (US Dept of the Navy 2019b) states that pilots typically plan to complete maneuvers within 3 nm (5.5 km) of the boundary of the MOA. If so, our data indicate that jet noise is routinely detectable at distances of at least 7 km, making the noise footprint of the MOA substantially larger than the MOA itself, and potentially impacting a large proportion of Olympic National Park (Figure 1). Second, the geographic spread of impact means that residents and visitors (or wildlife) seeking a wilderness experience or refuge from jet noise would have to relocate well outside the MOA. This is not only impractical, but relates to an important psychological factor of annoyance with noise pollution, which is whether a person feels that they possess some control over sources and exposure (Mace et al. 2004). Our results demonstrate how difficult this will be for residents or visitors to the region.

Another important outcome of this study was demonstrating feasibility in identifying different types of aircraft from audio recordings, which were processed using widely available software. In this way, our study differs from the only other acoustic monitoring available for this area, which was the 2010 and 2011 soundscape inventory by the National Park Service (Lee and MacDonald 2016). Though we replicated two of those locations, our study goals and methods differed: audio processing protocols used by the National Park Service are based on evaluation of 10-second subsamples, which is highly appropriate for the purpose of conducting an inventory of all sounds (i.e., human versus natural) but were not intended nor conducive to classification of aircraft events. Conversely, our protocols, which involve listening to entire events, were specifically intended to distinguish aircraft types. However, a strength of passive acoustic monitoring is the creation of a permanent audio record, and either of these datasets could conceivably be revisited to better contrast the two periods.

Our data show that current impacts are considerable, and further increases in military training
activities out of NASWI are likely to dramatically alter the character and quality of the Olympic Peninsula soundscape. Our results also allow a more pointed inquiry into how the proposed increases of 62% in electronic warfare training and 13% in air-to-air training will be realized. For example, given knowledge that daytime percent time audible currently approaches or exceeds 20% on a consistent basis in some locations, we can ask if additional operations would increase that percentage. Alternatively, more hours of the day and/or numbers of days per year (i.e., weekends) could be impacted. Geographic extent already seems to be widespread, but areas that are currently less impacted might see more activity.

By demonstrating workability of this approach, we hope to promote on-the-ground monitoring as a critical evaluation and mitigation strategy. Clearly, it is impossible to mitigate impacts that are not quantified. By documenting the realized contribution of military aircraft to the Olympic Peninsula soundscape, we can bring the focus to possible mitigation strategies. These include relocating some training or periods of activity to a different regional MOA, and/or working with residents to set upper limits on the total percent time that military aircraft will be audible, and monitoring use against that threshold. Alternatively, noise monitoring could be used to communicate and set expectations for a community, such as informing tourists about the noisiest areas and times of day, allowing them to adjust their activities. Critically, on-the-ground monitoring evaluates the impact of combined users on a space. For example, although NASWI may not be the sole contributor to the aircraft noise in the Olympic MOA, residents, tourists, and wildlife experience the totality of disturbance, regardless of the specific source. To evaluate impact based on contribution of a single user (e.g., the NWTT EIS) invites the tragedy of the commons, and runs counter to the need to manage soundscapes as other types of common-pool resources are managed (Dumyahn and Pijanowski 2011a).

**Acknowledgments**

This study would not have been possible without the invaluable work of Sally Kamae (University of Washington’s Program on the Environment Capstone Program), Laura Giannone (intern with Quiet Parks International), as well as other community and UW student volunteers that assisted with initial processing of audio files. We are very grateful to Megan McKenna with the US National Park Service Natural Skies and Night Sounds Program, and Ruth Scott with Olympic National Park, for their advice and logistical support. Comments from two anonymous reviewers improved the final manuscript. Site permission was granted by the National Park Service, the Washington State Department of Natural Resources, and The Nature Conservancy. We are also grateful for several grants that made this project possible, namely from The Suquamish Foundation (Appendix X Award 2017Q1773), the One Square Inch of Silence Foundation, and the University of Washington School of Aquatic and Fishery Sciences.

**Literature Cited**


FAA. 2019a. IFR Enroute Aeronautical Charts and Planning. Federal Aviation Administration, Aeronautical Information Services, Silver Spring, MD.


Impact of Military Flights on Olympic Soundscape 201


SUPPLEMENTAL TABLE S1. Weekday percent time audible for military aircraft by the hour of the day for supplemental monitoring sites. Calculations are based on the recording time for that location and hour; “na” is used to indicate hours when the audio recorder at the Clearwater location was turned off to extend battery life. Hours between 9 am and 5 pm (“daytime” hours) are shaded.

<table>
<thead>
<tr>
<th>Site</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
<th>17</th>
<th>18</th>
<th>19</th>
<th>20</th>
<th>21</th>
<th>22</th>
<th>23</th>
</tr>
</thead>
<tbody>
<tr>
<td>Third Beach</td>
<td>0.0</td>
<td>0.0</td>
<td>0.8</td>
<td>3.5</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.5</td>
<td>14.5</td>
<td>20.3</td>
<td>15.3</td>
<td>20.6</td>
<td>31.3</td>
<td>8.8</td>
<td>1.8</td>
<td>2.5</td>
<td>10.3</td>
<td>3.5</td>
<td>12.3</td>
<td>1.7</td>
<td>1.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Forks</td>
<td>0.0</td>
<td>3.7</td>
<td>3.8</td>
<td>11.1</td>
<td>4.3</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>2.9</td>
<td>23.9</td>
<td>22.8</td>
<td>19.3</td>
<td>30.4</td>
<td>42.3</td>
<td>19.4</td>
<td>4.7</td>
<td>10.3</td>
<td>21.8</td>
<td>4.9</td>
<td>28.4</td>
<td>7.6</td>
<td>5.4</td>
<td>0.0</td>
<td>2.6</td>
</tr>
<tr>
<td>Clearwater</td>
<td>2.4</td>
<td>2.9</td>
<td>na</td>
<td>na</td>
<td>2.1</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>1.0</td>
<td>17.4</td>
<td>23.9</td>
<td>16.6</td>
<td>19.3</td>
<td>32.3</td>
<td>14.7</td>
<td>7.4</td>
<td>6.4</td>
<td>19.8</td>
<td>2.8</td>
<td>21.8</td>
<td>17.6</td>
<td>8.3</td>
<td>2.0</td>
<td>1.0</td>
</tr>
</tbody>
</table>
SUPPLEMENTAL TABLE S2. Summary statistics of distributions of A-weighted sound pressure levels (dBA) for sites, seasons, and aircraft type. Median dBA, 5th and 95th percentiles were calculated from the 1-second sound samples classified as ambient, commercial, and military for each site and season. Each site and season was based on 10 days of audio recordings, except for “Late Summer”, which was based on only 6 days.

<table>
<thead>
<tr>
<th>Site</th>
<th>Season</th>
<th>Ambient</th>
<th></th>
<th>Commercial</th>
<th></th>
<th>Military</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>5th percentile</td>
<td>median</td>
<td>95th percentile</td>
<td>5th percentile</td>
<td>median</td>
<td>95th percentile</td>
</tr>
<tr>
<td>Third Beach</td>
<td>Summer</td>
<td>26.7</td>
<td>33.6</td>
<td>49.8</td>
<td>26.5</td>
<td>33.1</td>
<td>43.9</td>
</tr>
<tr>
<td></td>
<td>Autumn</td>
<td>26.3</td>
<td>35.0</td>
<td>46.1</td>
<td>30.3</td>
<td>35.0</td>
<td>41.1</td>
</tr>
<tr>
<td></td>
<td>Winter</td>
<td>36.4</td>
<td>44.4</td>
<td>59.6</td>
<td>35.1</td>
<td>40.6</td>
<td>57.5</td>
</tr>
<tr>
<td></td>
<td>Spring</td>
<td>28.0</td>
<td>36.4</td>
<td>49.9</td>
<td>29.6</td>
<td>37.7</td>
<td>53.5</td>
</tr>
<tr>
<td>Hoh Watershed</td>
<td>Summer</td>
<td>31.5</td>
<td>33.2</td>
<td>40.1</td>
<td>31.7</td>
<td>34.2</td>
<td>39.5</td>
</tr>
<tr>
<td></td>
<td>Autumn</td>
<td>31.4</td>
<td>33.2</td>
<td>40.6</td>
<td>31.3</td>
<td>33.5</td>
<td>35.7</td>
</tr>
<tr>
<td></td>
<td>Winter</td>
<td>35.1</td>
<td>42.0</td>
<td>50.8</td>
<td>33.5</td>
<td>40.5</td>
<td>49.8</td>
</tr>
<tr>
<td></td>
<td>Spring</td>
<td>31.3</td>
<td>33.8</td>
<td>39.1</td>
<td>31.7</td>
<td>35.7</td>
<td>42.3</td>
</tr>
<tr>
<td>River Trail</td>
<td>Summer</td>
<td>37.4</td>
<td>39.4</td>
<td>44.7</td>
<td>36.8</td>
<td>39.5</td>
<td>42.6</td>
</tr>
<tr>
<td></td>
<td>Autumn</td>
<td>36.5</td>
<td>37.7</td>
<td>43.5</td>
<td>37.2</td>
<td>38.2</td>
<td>42.4</td>
</tr>
<tr>
<td></td>
<td>Winter</td>
<td>41.6</td>
<td>43.0</td>
<td>48.3</td>
<td>41.8</td>
<td>43.1</td>
<td>46.9</td>
</tr>
<tr>
<td></td>
<td>Spring</td>
<td>38.8</td>
<td>39.8</td>
<td>48.5</td>
<td>38.7</td>
<td>40.2</td>
<td>45.0</td>
</tr>
<tr>
<td>Third Beach</td>
<td>Late Summer</td>
<td>28.0</td>
<td>35.6</td>
<td>45.3</td>
<td>25.4</td>
<td>30.6</td>
<td>50.7</td>
</tr>
<tr>
<td>Forks</td>
<td>Late Summer</td>
<td>22.6</td>
<td>24.9</td>
<td>32.8</td>
<td>22.6</td>
<td>27.0</td>
<td>36.2</td>
</tr>
<tr>
<td>Clearwater</td>
<td>Late Summer</td>
<td>31.0</td>
<td>31.4</td>
<td>34.7</td>
<td>31.1</td>
<td>32.4</td>
<td>49.6</td>
</tr>
</tbody>
</table>
Supplemental Figure S1. Contribution of different aircraft to the duration of recorded audible time by hour of the day. Total duration is the number of seconds summed across the three supplemental data collection sites during the period of 11 August 2017 to 16 August 2017. Aircraft types are coded as: Commercial (COMM), Helicopter (HELI), Military (MIL), and Propeller (PROP).
Supplemental Figure S2. Periods of acoustic monitoring in relation to activity at Ault Field, Naval Air Station Whidbey Island. Black bars show the number of active timeframes published for Ault Field each day from 28 May 2017 to 27 May 2018. Grey shading indicates the four 10-day periods of monitoring of three primary sites (June 2017, October 2017, January 2018, and April 2018) and one 6-day period of opportunistic monitoring in supplemental sites (August 2017).
Supplemental Figure S3. Probability distributions of A-weighted sound pressure levels (dBA) by site and aircraft type recorded in summer of 2017. Kernel density plots of dBA for all 1-second sound samples classified as ambient, commercial aircraft, or military aircraft. Dashed lines and labels indicate the median dBA for the site. Note: the dynamic range of the recording units was approximately 22-82 dBA for the SM4 (Third Beach, River Trail) and 30-82 dBA for the SM2 (Hoh Watershed).
Supplemental Figure S4. Probability distributions of A-weighted sound pressure levels (dBA) by site and aircraft type recorded in winter of 2018. Kernel density plots of dBA for all 1-second sound samples classified as ambient, commercial aircraft, or military aircraft. Dashed lines and labels indicate the median dBA for the site. Note: the dynamic range of the recording units was approximately 22-82 dBA for the SM4 (Third Beach, River Trail) and 30-82 dBA for the SM2 (Hoh Watershed).
Supplemental Figure S5. Probability distributions of A-weighted sound pressure levels (dBA) by site and aircraft type recorded in spring of 2018. Kernel density plots of dBA for all 1-second sound samples classified as ambient, commercial aircraft, or military aircraft. Dashed lines and labels indicate the median dBA for the site. Note: the dynamic range of the recording units was approximately 22-82 dBA for the SM4 (Third Beach, River Trail) and 30-82 dBA for the SM2 (Hoh Watershed).
Supplemental Figure S6. Probability distributions of A-weighted sound pressure levels (dBA) by site and aircraft type recorded in late summer 2017. Kernel density plots of dBA for all 1-second sound samples classified as ambient, commercial aircraft, or military aircraft. Dashed lines and labels indicate the median dBA for the site. Note: the dynamic range of the recording units was approximately 22-82 dBA for the SM4 (Third Beach, Forks) and 30-82 dBA for the SM2 (Clearwater).