DE GRUYTER Noise Mapp. 2020; 7:303–315

Research Article

Greg Watts*, John Pearse, Ioannis Delikostidis, Johann Kissick, Brian Donohue, and Jeff Dalley

Tranquillity mapping in New Zealand national parks – a pilot study

https://doi.org/10.1515/noise-2020-0025
Received Jul 15, 2020; accepted Nov 03, 2020

Abstract: The tranquillity in national parks worldwide is currently under threat from intrusion of anthropogenic noise of a growing tourism industry and activity related to park management. This was addressed by creating informative tranquillity maps, where perceived tranquillity can be considered a key indicator of soundscape quality in natural areas. Tranquillity of an area can be assessed using TRAPT (Tranquillity Rating Prediction Tool), that has been developed and refined for assessing urban green spaces, national parks and wilderness areas in the United Kingdom. The subjective response to helicopter noise levels of a sample group of 35 people representing the general New Zealand population was obtained, based on visual and audio stimuli that were collected in Aoraki/Mt Cook National Park. These results were used to produce a revised TRAPT equation. It was discovered that levels under 32 dBA correspond to an excellent level of tranquillity. This threshold was used to produce a noise level exposure calculation for two national parks using noise prediction model AEDT (Aviation Environmental Development Tool). Contours representing tranquillity duration were then calculated and plotted, to serve as a planning tool for use by the Department of Conservation. A similar approach could be used for other national parks worldwide.

Keywords: tranquillity, noise mapping, helicopter noise

1 Introduction

1.1 Background

Anthropogenic noise in national parks worldwide has been identified as a growing issue of concern [1–3]. In the US a recent noise survey across 251 sites in 66 parks indicated that such noise was audible in 37% of recordings [4]. In New Zealand the Department of Conservation (DoC) has noted increases in the numbers of domestic and international park visitors that has resulted in a corresponding demand for their diverse expectations to be catered for [5]. Tourism operators along with DoC use mechanised transport to provide accessibility to areas otherwise only accessible on foot. The anthropogenic noise produced by these operations have an adverse effect on amenity values in national park settings, highly valued for their natural character and tranquillity [6]. The Resource Management Act (RMA) 1991 [7] allows territorial authorities to regulate activities on land and water that affect amenity values such as tranquillity yet, at present, it does not enable these authorities to control noise from airborne activities. In particular, DoC allocates rights for aircraft to land within national parks [8], but cannot specify flight paths. Natural areas that are accessed by aircraft also, by default, give them primary allocation of the natural soundscape and render it compromised to other visitors. Very little noise energy is required to substantially degrade listening conditions when the natural sound levels are already very low [9] – and such environments must be vigorously protected, as they are the most vulnerable to intrusion of noise.

Producing effective maps of tranquillity ratings in national parks can be a tool to aid national park management to better negotiate and develop policy for the protection of the natural setting. Factors that have been identified as statistically significant that affect the tranquillity of a place include the level of anthropogenic noise and the percentage of natural and contextual features in the visual scene [10]. The Tranquillity Rating Prediction Tool (TRAPT) has been designed to predict how, on average, visitors feel about their immediate environment using these factors [11]. This investigation looks into visualising the

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***Corresponding Author: Greg Watts:** Bradford Centre for Sustainable Environments, University of Bradford, Richmond Road, Bradford, BD7 1DP, United Kingdom;
Email: g.r.watts@bradford.ac.uk
John Pearse, Ioannis Delikostidis, Johann Kissick, Brian Donohue: University of Canterbury, 20 Kirkwood Avenue, Upper Riccarton, Christchurch 8041, New Zealand
Jeff Dalley: New Zealand Department of Conservation, Conservation House – Whare Kaupapa Atawhai, 18-32 Manners Street, Wellington 6011, New Zealand

effects of anthropogenic noise pollution caused by helicopters in Aoraki/Mt Cook and Westland Tai Poutini national parks in the form of tranquillity maps based on the rated tranquillity of a representative New Zealand population sample.

Throughout the world anthropogenic noise from a range of activities in national parks is expected to deteriorate the tranquillity of the natural setting. In Westland Tai Poutini and Aoraki Mt Cook national parks in New Zealand, helicopters are acknowledged as the predominant anthropogenic noise source and disturbance is set to grow with expected increases in visitor numbers particularly in the glacial valleys of Fox, Franz, and Tasman.

Tourism operators offer a range of helicopter-related activities in the region, from scenic flights, to glacier landings, and guided heli-hikes. DoC is tasked with overseeing landing concessions for commercial operations [12] but not overflights.

An immediate consequence of increased flying activity in and over national parks is the negative impact it has on many. Overseas research suggests scenery is more meaningful to people when there is less anthropogenic noise [13], as lower noise levels help visitors experience natural sounds and wildlife.

Series of visitor questionnaires performed in Franz Josef and Fox valleys found that approximately two thirds of participants (68%) were against increasing the number of helicopter flights to allow more people glacier access, and 67% agreed that ‘access to the glacier should remain as it is now’ [8]. At Fox Glacier, 1210 annual flights were recorded in 2013, and the number grew to 2849 in 2015, with the increase in visitor annoyance levels at Fox Glacier shown in biennial surveys [8].

Following the work of Herzog and Bosley [14] a tranquil place is defined as a quiet, peaceful, and attractive setting, a quality place to get away from “everyday life”. The perception of a tranquil place is conditioned by more than one stimulus type, combining inputs from two of the more dominant human senses: sight and hearing [11]. Rating the tranquillity of a place can be useful for evaluating its restorative value, and, in the context of a protected area, work as an effective decision-making tool to prioritise amenity values [15]. Further, this paper describes a novel approach to characterising soundscape quality in natural areas based on the concept of perceived tranquillity of a place. This is a novel approach and goes beyond mapping quiet areas based on a threshold noise level [16].

1.2 TRAPT

The tool enables prediction of tranquillity at any place within an area of investigation, given some known variables. Perceived tranquillity in a setting depends on three variables: the percentage of natural and/or contextual features, the level of anthropogenic noise and a moderating factor MF. The model derived from a wide range of environments both urban and rural in the UK was found to be:

$$TR = 9.68 + 0.041NCF - 0.146L_{Aeq} + MF \qquad (1)$$

Where TR is the predicted tranquillity rating on a 0 to 10 scale, from minimum to maximum tranquillity, respectively [11]. In rare cases, the calculated tranquillity rating can be negative due to the linear regression technique used to relate the variables. In this situation, the calculated value is set to 0. Similarly, when the calculation result is higher than 10, the TR value is set to 10.

NCF represents the percentage of natural or contextual features in the given setting and ranges from 0 to 100%. The benefits of natural or contextual features in an immediate visual scene and their quantification was first proposed by Pheasant *et al.* [11].

L_{Aeq} is the average sound pressure level representing exposure over a specified time period and ranged from 36.0 to 71.3 dB(A) in the laboratory experiment on which equation (1) was based.

MF represents any moderating factors that can influence the rating. In previous studies, it was shown that litter, graffiti, or the presence of other people decrease the TR [17]. It should be noted that the moderating factor is a minor adjustment and is unlikely to influence overall TR by more than 1 scale point.

Areas where the overall percentage of natural and/or contextual features in view is high and measures of anthropogenic noise levels are low would be predicted to give a high tranquillity rating. Conversely, areas featuring fewer natural or contextual elements in the field of view and higher levels of anthropogenic noise would return a tranquillity rating at the lower end of the scale. This work sought to calibrate the model for use in New Zealand national park setting.

1.3 Applications of GIS

Modelling anthropogenic noise is a common approach in urban areas, but also for areas under some form of environmental protection. Calculations of anthropogenic noise can significantly aid management and policy makers – and in turn advance scientific understanding of park ecosystems [18]. Detailed studies monitoring noise levels in national parks in America [19] and New Zealand [20] have taken place using purpose-built models for acoustic calculation through GIS (Geographic Information System) [21, 22]. There is also a noticeable direct focus on anthropogenic noise impacts on animal wildlife [22] as well as park visitors [23].

Essentially tranquillity mapping is an extension of traditional noise mapping. In this case, if the noise metric levels are substituted into TRAPT, ratings can be visualised in terms of contour at any location where the percentage of natural or contextual features is known. In a national park context, it is widely assumed that the percentage of natural features in view will be high, either at or close to 100% in the field of view.

The methods of anthropogenic noise management in national parks is a current concern [24]. Previous work has been guided by visitors of annoyance [20]. Tranquillity is considered a more appropriate measure of the impact of anthropogenic noise on park visitors as it addresses directly a key indicator of soundscape quality. Perception of tranquillity at a place depends on a number of factors, but those that have emerged as statistically significant are the presence of natural or contextual features in a setting, and level of anthropogenic noise. Combining subjective and objective factors in the same model, tranquillity predictions contribute in both a meaningful and measurable way to assess anthropogenic noise impacts in national parks [25].

Previous studies of tranquillity using TRAPT have mainly focussed on anthropogenic noise from road and rail transport. This investigation seeks to expand on this previous work by shifting the focus to other sources of anthropogenic noise, such as helicopters, in New Zealand national parks.

2 Method

The methodology of this investigation involves a series of steps that work towards an end result of tranquillity maps of Aoraki/Mt Cook and Westland Tai Poutini national parks. The methodology involves four phases: data collection, assessment of tranquillity using a representative sample of the New Zealand population, predicting noise levels, and developing tranquillity maps using GIS. Both the first and second phase are based on the methodology of Watts & Pheasant [25]. The second phase was adopted from a similar investigation into Westland Tai Poutini National Park [26].

2.1 Data collection

Sound level measurements and corresponding recordings were obtained in the field at Aoraki/Mount Cook National Park on the 16th June 2017. Prior acknowledgement of Tōponui sites that are sacred to Māori meant that they would not be included as locations in which to collect data. A Bruel & Kjaer (B&K) type 2250 sound level meter (SLM) was used for the measurement of sounds and the corresponding recordings were saved onto a secure digital SD card. Prior to making measurements and taking recordings of subjects at each site, the SLM was calibrated using a B&K type 4231 calibrator. A windshield was used for all measurements and recordings.

Eleven measurements were taken at four sites (Figure 1). The recordings consisted of:

(1) Helicopter noise at various positions of flight
(2) Natural ambient environmental sounds without presence of any anthropogenic noise
(3) A combination of (1) and (2)

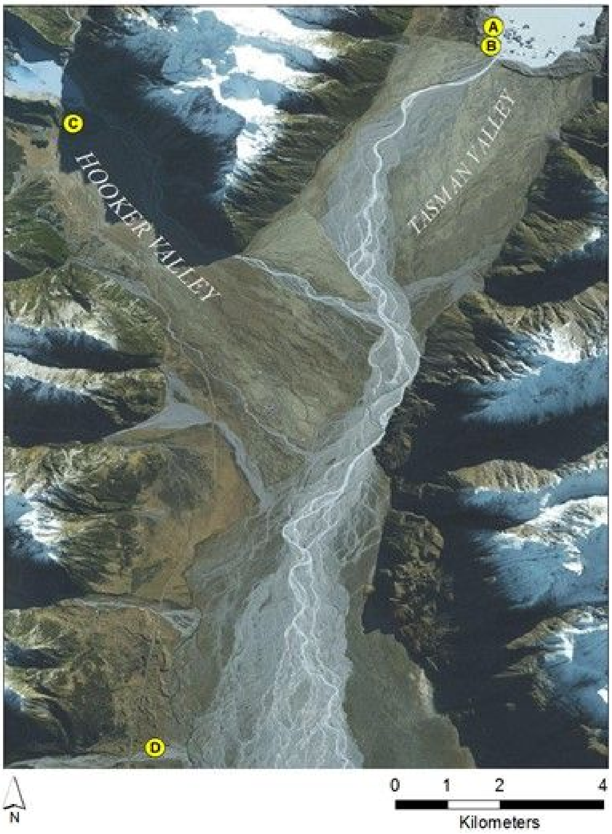

Figure 1: Location of measurements

The measurements varied in length, based on conditions such as the duration of a helicopter fly-by. The SLM was left unattended for several minutes to ensure a good quality reception of natural background noise. All measurements were recorded with the SLM mounted on a tripod set at the height of an average human ear.

Additional information, such as GPS (Geographic Positioning System) measurements, wind speed, cloud cover and any other observable weather patterns, were recorded at the same time as the acoustic measurements and audio recordings. Videos of the landscape were recorded at sites A and D in Figure 1, using an iPhone 6s (set at 4K resolution) mounted on a tripod.

2.2 Field data processing

The software suite Audacity was used to refine the eleven recorded audio clips into 30, 10-second truncated files and any contamination by other sound sources such as voices or footsteps were removed. The truncated files were further modified to fade in and out by 0.1 second in consideration for participant comfort. The sound pressure levels of the 30 truncated files were then calculated using digital post processing using B&K Pulse Reflex software, and then compared with real-time analysis using B&K Pulse LabShop Fast Track.

The 30 truncated files were refined to a selection of ten, ensuring that the range of sound pressure levels was a reasonable representation of spread of the levels that were measured.

The ten truncated audio files together with the visual stimuli were then made into 70 compilation videos using Adobe Premiere Pro. The randomised order of the audio files was determined using multiple 10 × 10 grid cell Latin square matrix distributions. Lastly, the compilation videos were designed to feature a 10-second countdown timer at the beginning to prepare participants for testing.

The audio stimuli were played as sequential 10-second clips followed by 10-second quiet intervals. The visual stimulus was a 10-second video loop recorded at location A (Figure 2), looking out over Tasman Lake (Figure 2).

During the quiet intervals the video was edited so as to have extremely low brightness and be out of focus in order to prompt participants that they should indicate the tranquillity rating, if they had not already done so, and prepare for the next sound.

2.3 Participants

Participants were gathered through means of online advertising and physical flyers posted around the University of Canterbury campus. A group of 35 was selected with a

Figure 2: Video image used in tranquillity assessment

range of individuals that reflected age and gender distributions from the New Zealand 2013 Census [27].

2.4 Listening room

The listening room used is IANZ accredited for the testing of hearing protectors [28] and as such provided a quiet, uniform, uninterruptable environment where participants could give their entire focus to the assessment of tranquillity. A calibration exercise of audio stimuli was performed before the testing phase. This was necessary to ensure that the audio of the test video was played at the exact sound level that was measured in the field environment. To achieve this, a 1 kHz calibration tone was played using Windows media player (12), with the audio feed being played through a set of Sennheiser HD 215 headphones that were fitted on a B&K type 4100 Head and Torso simulator, connected to the same computer that was running B&K Pulse LabShop. The volume output control on the computer was adjusted to 94.3dB to match the calibration tone. This procedure was repeated every day before testing participants, or whenever the computer entered sleep mode between tests.

Individual participants were asked to sit behind a small desk facing a 55” Sony Bravia 1080p flat screen monitor. Sennheiser HD 215 headphones were placed over the ears of the participant, and the tranquillity questionnaire and pens were set on the desk. Participants were briefed on the test structure and asked to imagine they were experiencing the national park first hand, and then left in isolation with minimal distraction. The perceived tranquillity test was performed by playing the compilation videos via the calibrated equipment, with the audio stimuli feed being delivered through the headphones, and visual stimuli being shown on a flat screen monitor. The layout of the listening room can be seen in Figure 3.

Each participant was played three compilation video files, with a different order as determined by a Latin square matrix. The first video file was designed as a practice run-through for the participants to familiarise themselves with the range of audio stimuli they would hear. Once the video file was played, the researcher entered the room to ensure the participant understood the task and completed the corresponding questionnaire page. This process was then repeated two more times. After completing the task, participants were rewarded with a coffee voucher.

The reported tranquillity of each stimulus of the second and third compilation video files played in the test sequence was averaged for each participant. The reported tranquillity of each stimulus was averaged again for the entire sample population. These averaged results of reported tranquillity were then compared to the measured L_{Aeq} of each of the 10 audio stimuli in a scatterplot graph, the relationship of which could be used to represent the general New Zealand populations’ perspective of tranquillity in national parks where helicopter noise was present. Both linear and fourth-order polynomial trend lines were observed to determine the nature of the tranquillity scale applied to the general New Zealand population. The equation relating to the linear relationship was then used to create a revised TRAPT equation.

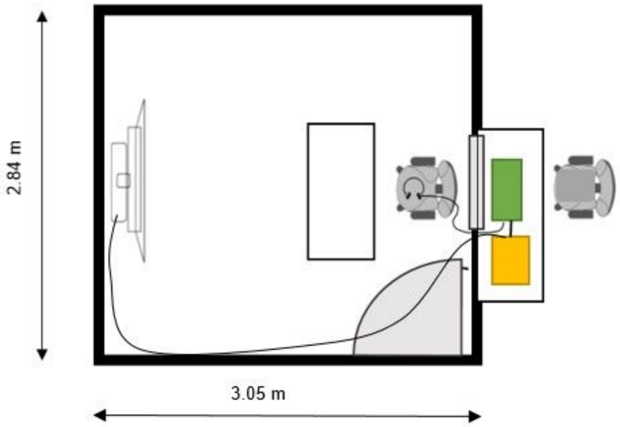

Figure 3: Listening room

2.5 Calculation of noise levels using AEDT

The Aviation Environmental Design Tool (AEDT) is a state-of-the-art software system developed by the Department of Transportation in the United States that is designed to model aviation related operations in space and time and determine noise, emissions, and fuel consumption [29]. It was the model of choice for the current work as it allowed noise level calculations over varying ground of varying height for a number of different aircraft including helicopters. In addition, a 15x15 metre resolution Digital Terrain Model (DTM) was sourced from Koordinates, originally recorded by the University of Otago National School of Surveying [30]. The geographic projection and terrain file format type were changed to provide compatibility with AEDT.

Flight records were taken by GPS recorders installed in helicopters that operate in the parks. Each helicopter follows a flight path reflecting an advertised product however no flight path is exactly the same as another. To compensate, the individual products were grouped into common flight ‘corridors’ and to minimise later processing, longitude and latitude flightpath coordinates were averaged, as well as horizontal aircraft speed, and vertical elevation.

The most appropriate noise metric outputted by AEDT was TA *i.e.* the time above a given A-weighted threshold level over the period of interest. In the present case the period of interest was a working day of 10 hours during which the helicopters would be expected to operate. From this the percentage of time below this level can be calculated as this was considered relevant to quantifying the period of excellent tranquillity. The level was set based on the Listening Room assessments that determined excellent tranquillity (see below).

A grid of noise-receiver points was set to be overlaid on top of the DTM, and as a noise source a Eurocopter AS350 Écureuil helicopter was selected from the AEDT/BADA aircraft library. This is a type of helicopter that is commonly used by New Zealand tourism operators.

The parameter for weather in AEDT was left to its default setting, which assumes a standard atmosphere in terms of temperature gradient atmosphere, pressure and air density.

AEDT has the additional functionality of being able to perform a calculation of noise propagation with consideration of topography. This feature is known as line-of-sight blockage or obscuration. However, when applied the computation time dramatically increases Zubrow and Hwang *et al.* [29]. Unfortunately, it was not possible within the time frame of the investigation to successfully implement this procedure. Further work will be needed to resolve outstanding issues that will require further dialogue with the software designers.

2.6 Tranquillity predictions

AEDT was set up to perform a calculation for both parks as they are adjacent and have a common boundary. Twenty-three types of operations, representing 423 flights from a Eurocopter AS350 Écureuil during a standard operational day were imported. Receptor or receiver nodes were evenly distributed in a 100 × 100 metre grid pattern.

Through the use of the recalibrated TRAPT equation, tranquillity levels representing the perspective of the general New Zealand population could be plotted as contours in maps of the two national parks that are the focus of this investigation. Following the recommendations laid out by Watts and Pheasant [10], tranquillity levels are considered to be excellent between 8 and 10 on the TR scale, which is considered appropriate for a national park environment. TRAPT was then used to determine the A-weighted levels when $TR \geq 8$. AEDT outputs of time above metric were obtained and then further calculations were performed to determine the time that receptor nodes noise levels were below this threshold representing excellent tranquillity.

2.7 Visualisation of results

The output tranquillity contours were exported from AEDT representing the length of time in increments of two-hour periods that the A weighted levels were below the value when $TR = 8$. Flight paths used as part of the AEDT calculations were also exported as a layer of polylines, and utilised in ArcMap to indicate where noise was expected to be highest and the resultant rating of tranquillity is expected to be lowest. Additional spatial information including the boundary for both national parks, helicopter landing sites (outside of the park), and key landmarks such as lakes and mountain ranges were used for labelling purposes, in order to improve spatial awareness.

As the focus of this investigation was entirely on two national parks, any noise calculations outside the park boundary were cropped from the final maps. Conventional mapping practices such as colour, transparency and labelling were applied to present the relatively unfamiliar concept of tranquillity to a varied audience.

ArcMap is optimised for producing maps in their simplest form: two-dimensional and static. The output tranquillity maps from this stage were designed to be used as report figures and in presentations.

The next evolutionary process of tranquillity maps was to enable audience interaction to improve understanding of the state of tranquillity in New Zealand national parks. ArcGISonline (My Map) was used as a platform to present tranquillity maps as well as enabling interactivity through the activation of layers providing the tools to navigate, zoom, and change aspect view angle of the tranquillity of the national parks.

3 Results and analysis

3.1 Field measurements

Table 1 presents the results of eleven measurements at four locations, each a combination of aircraft and background noise. An initial examination of the records indicated that Files M01, M09, M011 and M013 were mainly contaminated with extraneous noise events and were therefore unusable.

Table 1: Measurements in Aoraki/Mt. Cook National Park

Location	File	L_{Aeq} (dB)	L_{Amax} (dB)	L_{Amin} (dB)	Length (min. sec)	Description
site A	M02	34.0	48.4	31.9	2.02	Natural ambient noise. Small waves breaking on the shore of Lake Tasman
	M03	56.6	67.5	34.0	2.34	Predominant helicopter noise under the valley ridgeline
	M04	31.4	40.2	29.5	1.02	Natural ambient noise. Small waves breaking on the shore of Lake Tasman
	M05	40.5	54.5	31.8	4.33	Natural ambient noise with an approaching and passing helicopter
	M06	56.8	70.7	33.3	3.29	Natural ambient noise with an approaching and passing helicopter
Site B	M07	64.2	78.7	37.3	1.18	Fixed-wing flyby under the valley ridgeline
	M08	58.2	65.5	40.6	1.17	Helicopter flyby under the valley
	M10	78.1	89.8	37.2	2.50	A close approach and nearby hovering of a park management helicopter
Site C	M12	33.7	49.0	30.8	2.26	Natural setting with a few birds
Site D	M14	47.2	57.7	33.7	3.49	Natural ambient noise from cicada and occasional birdsong, with various fixed-wing and helicopters aircraft above the valley ridgeline
	M15	31.2	42.8	27.4	1.28	Natural ambient noise from cicada and occasional birdsong

Table 2: Audio stimuli used in tranquillity assessment

Location	Source file	Truncated file	L_{Aeq} (dB)	Description
Site D	M09	TT10	29.0	Ambient cicada noise
Site A	M03	TT4	32.9	Ambient waves breaking
Site A	M04	TT6	37.4	Helicopter at a far distance
Site A	M04	TT5	38.0	Helicopter at a far distance
Site A	M02	TT3	40.6	Ambient wind together with distant helicopter
Site D	M08	TT8	43.5	Cicada noise together with helicopter
Site A	M04	TT7	46.5	Helicopter noise
Site D	M09	TT9	47.6	Predominant helicopter noise with background cicada
site A	M02	TT1	51.3	Helicopter at closest point of passing
Site A	M02	TT2	55.3	Helicopter at closest point of passing

File M15, taken from site D, exhibited the lowest L_{Amin} level of 27.4 dB. This location was the furthest away from moving water such as waves and waterfalls, and the wind speed was low (<1 m/s). The highest noise level at L_{Amax} 89.8 dB was at site B (M10). This noise was due to a hovering helicopter, approximately 50 metres from the SLM. This measurement was omitted and not included, as the helicopter is a misrepresentation of typical daily activity: the helicopter was being used for equipment movement at the end of the summer season, which was not directly related to tourism operations.

Of the eleven measurements and recordings (not including calibration files recorded at each location) that were collected in Aoraki/Mt Cook National Park, five remaining recordings were considered acceptable for further processing. With careful consideration, ten truncated files lasting 10 seconds were made from these remaining five recordings, used as below (Table 2).

Table 2 shows the L_{Aeq} levels of ten truncated files and the source recordings that they originated from. The refined spread of the L_{Aeq} levels of the truncated file is 26.3dB, which reflects the range to be expected on the ground in the national park environment. Truncated files listed above were carefully selected, with the 10-second files not containing any distinguishable change in helicopter noise. Such as would be due to an approaching or departing aircraft. Measurements from sites B and C were omitted due to reasons of an unsatisfactory representation of anthropogenic noise, extensive contamination of background noise levels from footprints, voices and other form of interference from people. These truncated files are key to forming a common tranquillity rating and prediction for various levels, so the difference in L_{Aeq} should be greater than about around 3dB in order for participants to distinguish the audio files from one another.

3.2 Sample population demographics

The sample population consisted of 35 subjects. Which was a reasonable representation of the overall general New Zealand population. Table 3 shows the breakdown of demographics of the sample group compared with the results of the most recent census.

Table 3: Demographics of sample

AGE	18 – 25	26 – 40	41 – 60	over 61
2013 NZ Census	14.0%	25.0%	36.0%	25.0%
Sample Population	14.3%	25.7%	34.3%	25.7%

GENDER	male	female
2013 NZ Census	49.0%	51.0%
Sample Population	48.6%	51.4%

Alongside gender categories, four age groups were established. In this case, the largest deviation between the census population and the sample population was an underrepresentation of 1.71% for the age group 41-60 years. The gender distribution of the sample group and the census population was representative, with 17 males and 18 females making up the sample group. All participants were required to be New Zealand citizens, and represented a range of age groups and an almost exact reflection of gender, based on the latest 2013 Census information [27]. New Zealand citizens, rather than national park visitors were required because the Conservation Act (1987) is concerned with conservation of national parks for the benefit, use, and enjoyment of the New Zealand public [12].

3.3 Tranquillity calibration for the New Zealand national parks

The tranquillity assessment of the sample group of 35 people can be observed in Figure 4, where the average tranquillity of the ten stimuli can be compared to the L_{Aeq} levels of the stimuli. Test stimuli with higher levels of L_{Aeq} appear to return a lower average rating of tranquillity. It is shown however that there is an outlier to this trend: File TT5 is rated much lower than its neighbour TT6, despite having a higher L_{Aeq}. This can be a result of more factors than simply L_{Aeq} determining the outcome of tranquillity. For example, the acoustical character emitted by the noise source could further affect the state of tranquillity alongside L_{Aeq}.

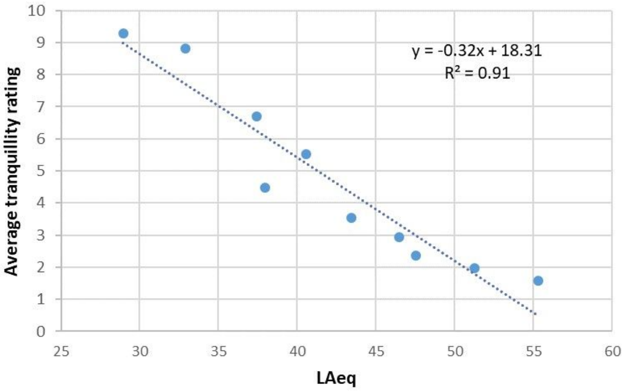

Figure 4: Tranquillity Ratings for National Parks

The relationship between average ratings of tranquillity and L_{Aeq} levels has $R^2 = 0.91$ which is statistically significant ($p < 0.001$). Therefore, using the linear equation, recalibration of TRAPT to accommodate the environments found in a New Zealand national parks with helicopter noise as the dominate noise source can be shown as:

$$TR = 18.31 - 0.322L_{Aeq} \tag{2}$$

As described above, TRAPT traditionally employs three parameters. However, in the context of a New Zealand national park environment, the parameter for percent of natural or contextual features (*NCF*) was set to 100% as no man-made features were visible. In addition, the moderating factor *MF* was set to zero since there was no litter or graffiti to degrade the tranquillity. This can be compared with equation (1) where *NCF* = 100 and *MF* is set to zero so the resulting equation becomes:

$$TR = 13.78 - -0.146L_{Aeq} \tag{3}$$

Figure 5 compares the predicted *TR* values for the UK and NZ studies using Eqs. (1) and (3).

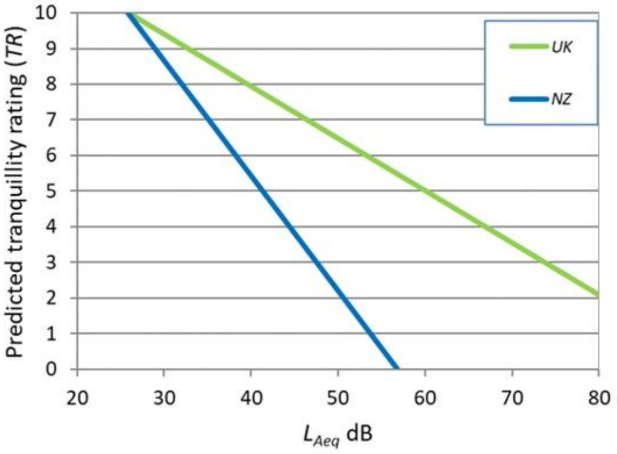

Figure 5: Comparison of trend lines from UK and NZ studies

The results of both investigations share the same trend of lower L_{Aeq} levels reflecting higher levels of tranquillity with a maximum rating of 10 at a noise level of 25.8 dB(A) for the NZ study and 25.9 dB(A) in the UK tests. However, in the New Zealand investigation tranquillity ratings exhibit a steeper decline with L_{Aeq} to that of the United Kingdom population. This can be mainly explained through the presence of a range effect, where there is a tendency for the maximum and minimum ratings on the subjective scale to be given to the maximum and minimum levels irrespective of what those levels might be [31]. Consequently, the smaller range of noise levels in the current New Zealand study of 26.3 dB(A) can be compared to the United Kingdom investigation where the range was considerably larger at 35.3 dB(A). This inevitably led to the steeper trend line of TR plotted against L_{Aeq}. However, the range of L_{Aeq} levels from the stimuli reflect for the most part the levels that are currently to be expected in the New Zealand national parks and so the recalibration is valid if used in context.

A further possible reason for variation from the United Kingdom setting is that the stimuli in this investigation was restricted to aircraft sounds while in the United Kingdom road traffic, aircraft and construction noise were included. If identical stimuli had been used for the NZ and United Kingdom population groups it is very likely that the results would show no significant difference. This was demonstrated in a recent investigation carried out in Hong Kong [17], where three groups (from Hong Kong, Mainland China and a diverse group from 16 different nations) were in close agreement when rating tranquillity for a range of identical tranquil and non-tranquil locations.

The findings of this investigation show, that under the newly calibrated TRAPT equation for the local conditions, for a *TR* rating of 8 or more A-weighted levels of ≤ 32 dB are necessary (under conditions of 100% *NCF* in the field of view). This is a difference of 7.5 dB when compared to the United Kingdom TRAPT equation where it can be shown from equation (3) that levels at or below 39.5 dB are required to sustain a *TR* rating of 8 or above.

3.4 Tranquillity maps

From flight records it was observed that operations in Westland Tai Poutini National Park (305 daily average) far exceeded the number of operations in neighbouring Aoraki/Mt Cook (86 daily average). Glacier tourism is known to be the cause of this phenomena, with many operations occurring in the Fox and Franz Josef areas on a daily basis.

Figure 6 presents the spatial distribution of hours of excellent tranquillity; a typical day of flying operations being 10 hours long. The map was produced with contours in distinctly identifiable colours spanning the entirety of the park. Helicopter flight tracks are presented in the foreground, with reference points added to assist the reader locate salient features.

The line-of-sight-blockage feature was not included as part of the calculation as the size of the investigation area was too large to be processed with current computing capabilities. Consequently, that tranquillity as depicted in Figure 6 would likely be higher beyond the valley side ridges due to direct-path blockage. This is not considered a setback to the investigation as the primary aim was to develop a transparent proof of concept that could be refined in a further study.

Some broad deductions can be made from the map, which shows that, for the most part, any form of helicopter activity in a space will result in a reduced number of hours of excellent tranquillity. Considering the amount of area that both parks encapsulate, there seems to be a significant imbalance in the distribution of the number of hours of excellent tranquillity. For example, approximately half of the park exhibits excellent levels of tranquillity for over eight hours. Two areas are of most concern: Fox and Franz Josef Glaciers in Westland Tai Poutini National Park, where most of the flights of frequent operation are clustered. The third area where excellent tranquillity levels are compromised is in the upper section of the Tasman Valley in Aoraki/Mt Cook National Park, probably as a result of glacier tourism.

Figure 7 illustrates the same tranquillity map, but on a web-based platform. As the map is no longer on a fixed

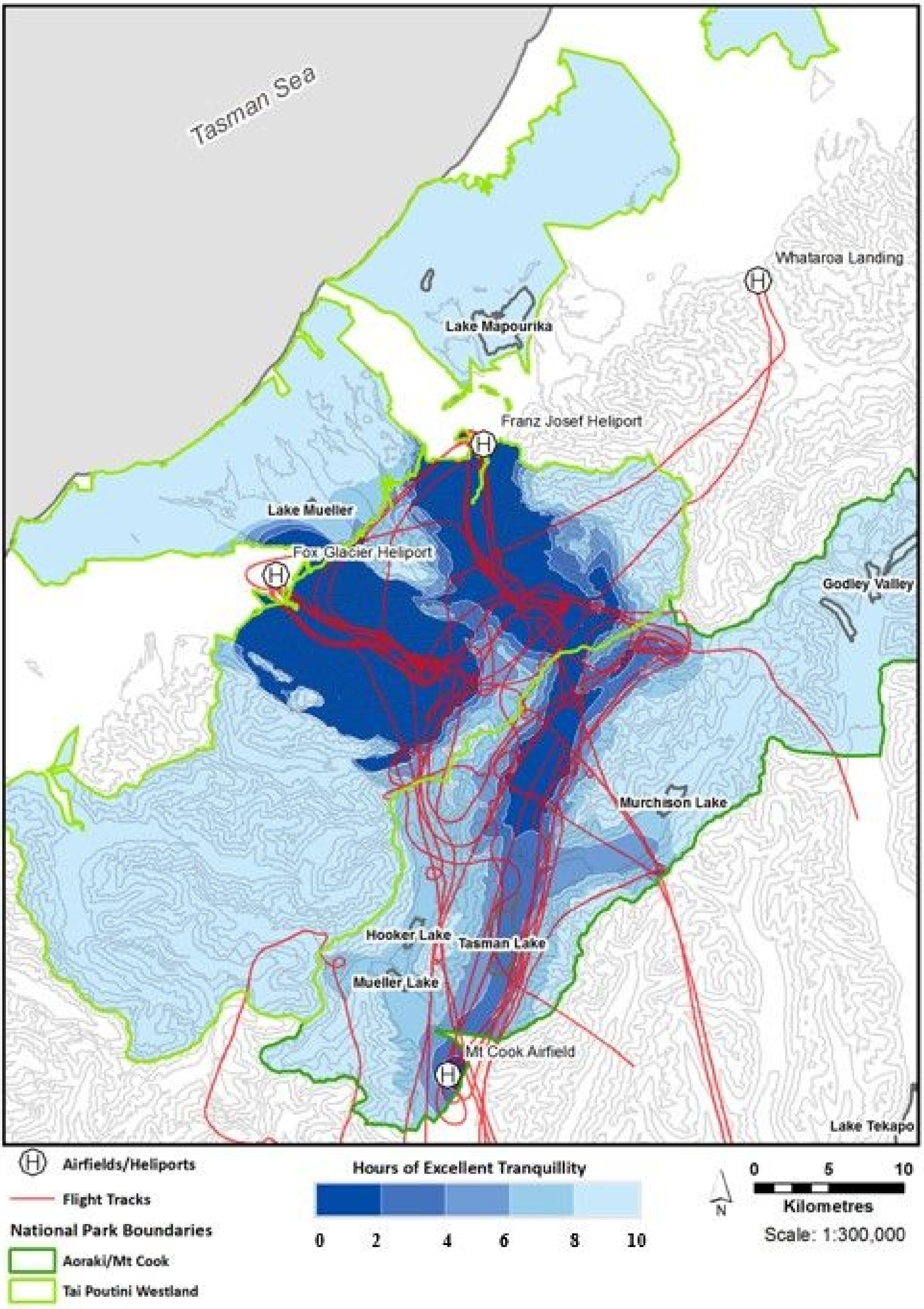

Figure 6: Tranquillity contour map showing hours of excellent tranquillity (TR ≥ 8)

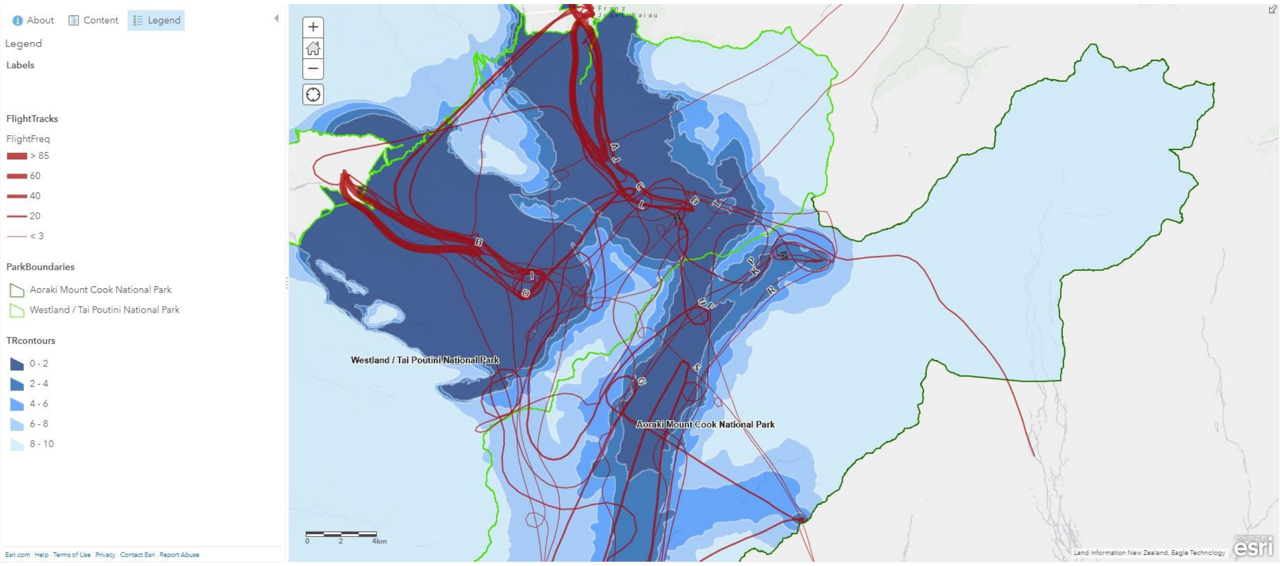

Figure 7: Interactive Web Map showing hours of excellent tranquillity (TR ≥ 8)

scale, readers are given the opportunity to interact with the map by panning and zooming to various sections.

As a result, labelling and overlapping of spatial information is not so accurately distributed. One such example is that the flight tracks are presented in varying thicknesses, depending on how many daily flights they accommodate. The benefit of this application is that thicker lines concentrate the readers' attention to areas that exhibit reduced levels of tranquillity. If chosen to be explored in more detail, the reader can disperse the overlapping flight paths by zooming into the map. The web version of the tranquillity map has further taken advantage of a dynamic platform through the use of labelling geographic features of importance at different scales. The web map can be accessed using the following link: https://arcg.is/04infP

4 Discussion and conclusions

The aim of this investigation was to develop a methodology for mapping tranquillity of New Zealand national parks based on the subjective response of a sample of the New Zealand population. The subjective testing results determined a relationship between sound level and tranquillity to be used as input to a tool for predicting tranquillity ratings (TRAPT). The approach for determining the parameters in the tool was based on prior studies carried out in the UK for a range of environments and noise sources. It was found that there was a close relationship between noise exposure from helicopters and ratings of tranquillity allowing a prediction of the noise level below which excellent tranquillity would be obtained. This predicted value was found to be 32 dBA, compared with a value of 39.5 dBA found in the UK study. However, at the maximum *TR* of 10 the results were in close agreement. The differences in *TR* values at higher noise levels can be largely explained by a wider range of stimuli in the UK study both in terms of noise levels and types of noise sources that were included.

The AEDT prediction package was used to predict noise levels. The package contains links to a European aircraft data base (BADA), a library of sound power values and directivity for a wide range of aircraft under different operating conditions. The library included data for the helicopters commonly used in the national parks (Eurocopter AS350 Écureuil). The helicopters operating in the study region were fitted with GPS tracking devices, making it possible to determine flight paths that could then be uploaded into AEDT to allow the prediction of noise levels.

AEDT allows for the calculation of various noise metrics at user defined positions in a geometric grid. Including the calculation of the time in an operational day that noise levels are above a given threshold (designated as TA or Time Above metric). This allows for the time that noise levels are below a certain threshold to be calculated. In the present case the value chosen was 32 dBA, corresponding to excellent tranquillity as determined by the subjective listening testing. Once the TA values were determined it was possible to plot their spatial distribution of excellent tranquillity as static and interactive online maps. The typical terrain of New Zealand national park environments calls for the additional need to include line-of-sight-blockage or obscuration to be implemented as part of a noise calculation. However, the final iteration of map generation did not include this variable due to issues with implementing the algorithm in the time available. This issue will be addressed in a further phase of the project.

The majority of anthropogenic noise in Aoraki/Mt. Cook and Westland Tai Poutini national parks originates from helicopter operations and subsequently this investigation only considered noise from helicopters. There are other sources of noise that are likely to have an impact on tranquillity, such as fixed wing aircraft, and other transport operations which will be considered in future work. It is expected that the findings from this work will be applied to assess the states of tranquillity in other national parks and conservation areas. The approach adopted could usefully be used in other conservation areas outside New Zealand.

Acknowledgement: The assistance of participants in completing the listening tests is gratefully acknowledged. The work was funded by the New Zealand Department of Conservation under the direction of Dr Jeff Dalley, Senior Technical Advisor, Design and Evaluation Team and was carried out at the University of Canterbury.

Conflict of Interests: The authors declare no conflict of interest regarding the publication of this paper.

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