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THE PREDICTION OF ENVIRONMENTAL NOISE, USING ARCMAP, (NMSIM-GIS) AND ISO 9613, FOR COMMERCIAL JET BOAT OPERATIONS

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ABSTRACT

In this paper the effects of anthropogenic noise in protected natural areas is considered. In particular, noise in relation to commercial jet boat activities on rivers in New Zealand's National Parks is addressed. The focus of this paper was a particular point of interest on the Dart River called Chinaman's Bluff. Noise measurements taken at Chinaman's Bluff are compared to the predicted noise levels at selected positions along the Dart River using the model NMSIM-GIS, and ISO9613, with the results discussed. This paper looks at noise contour mapping and determining whether the software accounts for the effects of terrain. This allows for the development of conservation protocols by the Department of Conservation (DOC) for managing natural soundscapes in a marine context.

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Keywords: *insert here from 3 to 5 keywords separated by a comma (no bold, no capitalized letters, italic).* ***Note that the keywords insertion is mandatory.***

1. INTRODUCTION

Humans have encroached upon nearly every corner of the planet, and wherever they go, they inevitably bring along the noise they generate - this is known as anthropogenic noise. Back in 1902, Muir [1] made a hopeful statement suggesting that certain untouched areas still existed, such as the ocean, the polar regions, and the Grand Canyon, which were beyond human influence.

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However, looking at this in 2023, it is clear that Muir's assertion no longer holds. Humans have now spread far and wide, and with this their presence brings various forms of pollution, and noise is one of them. This noise pollution can be categorized into mechanical and non-mechanical types [2] and this paper considers the noise pollution from the use and operation of jet boats.

In the context of New Zealand, a country renowned for its natural beauty, this issue becomes particularly relevant as New Zealand has 13 National parks encompassing approximately 10,000 Ha. The protected areas cover about one-third of the country's land area. These National parks are not only cherished for their pristine landscapes but also serve as popular tourist attractions. However, the increasing popularity of these parks brings a downside as the influx of visitors introduces various forms of pollution, one of which is noise pollution.

The impact of noise pollution, particularly from activities such as jet boating on the natural environment, needs to be better understood. Understanding the extent of noise pollution can help understand its possible effects on the ecological balance within these protected areas which is crucial for developing effective conservation protocols. By conducting a study on the noise emissions of jet boats, researchers can evaluate the potential effects on wildlife, the quality of the natural soundscapes, and the overall sustainability of such activities within New Zealand's National parks.

In order to assess the impact of commercial jet boat operations, a specific location of interest was identified at Chinaman's Bluff, situated on the Dart River at Paradise, north of Glenorchy near Queenstown.

2. NOISE IN THE ENVIRONMENT

2.1 Noise and People

Numerous national and international standards have been established to define metrics for assessing exposure limits and regulating noise emissions. However, in New Zealand, there are currently no specific standards for safeguarding natural quiet. This is in contrast to other countries where regulations exist for the protection and management of public land, which includes preserving natural quiet as a valued attribute and expectation.

It's important to note that natural quiet does not imply complete silence. Rather, it encompasses the sounds of nature, such as flowing water (rivers, streams, waterfalls, rain), wind, wildlife, birds, and insects.

2.2 Noise and Wildlife

Combining the disciplines of acoustics and biology has led to the emergence of a new field called bioacoustics, which supports conservation efforts. No studies have been conducted in the specific context of New Zealand, although there have been small-scale studies focused on certain species.

Studies in New Zealand have examined the behavioural effects on specific underwater species from boats, aircraft, and tourism activities. These studies often considered noise in conjunction with other potential sources of disturbance, such as visual effects, movement, or boat wake. Several whale and dolphin species, including Sperm whales, Dusky dolphins, Bottlenose dolphins, Common dolphins, and Hector's dolphins, have been subjects of behaviour studies in relation to noise [3, 4, 5, 6].

The effects of noise on birds in New Zealand has been studied, indicating that activities involving loud noise and sudden movement, such as power boats, jet boats, off-road vehicles, and aircraft, are the most disruptive. Species-specific behavioural responses have been observed in relation to disturbance caused by recreational activities. For example, black shags have been identified as particularly sensitive to human activity, with reduced species diversity and population changes observed during times of high disturbance [7, 8, 9, 10, 11].

Research conducted at Lake Rotoiti and Lake Rotokare in New Zealand showed similar results, with black shags being the most affected bird species, taking flight and not returning until boats left. However, other bird species like the mallard and the New Zealand scaup appeared unaffected. Controlled experiments with the New Zealand dabchick, or weweia, demonstrated that boat passes significantly influenced their behaviour, with increased disturbance frequencies leading to more pronounced changes [12].
Although the observed behavioural changes were relatively short-lived, they could potentially impact the birds' energy balance and cause displacement into neighbouring territories [13].

Studies also focused on the impact of boat traffic on birdlife in the Waitangiroto Nature Reserve in South Westland, particularly the white heron or kötuku, and other bird species [14]. Observations showed that boat-related disturbance caused most herons to fly away, affecting their feeding and flying patterns, and boat traffic significantly reduced the presence of several bird species in the area [15]. Stakeholder opinions regarding disturbance scenarios varied, but the absence of chicks and negative effects on adult herons were considered unacceptable.

Bioacoustic research offers valuable insights into the impacts of noise on wildlife, but further studies are needed to understand the specific effects of noise pollution in the New Zealand context and its potential implications for a broader range of different species.

2.3 Jet boating and visitors at Chinaman's Bluff

The vicinity of Glenorchy is home to two rivers that flow into Lake Wakatipu: the Dart River and the Rees River. These rivers are connected by a popular walking track where trampers can traverse one river on their way up, and the other river on their way down. While private jet boaters have unrestricted access to the lower Dart River, any commercial operators must obtain resource consent from the Operative Transitional District Plan of the Queenstown Lakes District Council.

Glenorchy serves as the hub for all commercial operations on the Dart River, where a small harbour facilitates the launching of jet boats, and a small jetty allows for the loading of passengers. A short journey across Lake Wakatipu brings visitors to the mouth of the Dart River. In its lower sections, particularly the 8 or 9 kilometres below the Dart River Bridge, the Dart River displays the characteristic braided pattern more commonly associated with rivers in Canterbury. Near Mount Alfred, the Route Burn intersects the Dart River with a walking track through beech forest to Lake Sylvan within Mount Aspiring National Park. Continuing northward, the track extends to the Rock Burn and eventually loops back to the car park on the Route Burn Road. Dart River Safaris Ltd holds a resource consent allowing them to conduct up to 20 jet boat trips per day, to this area, with each trip lasting approximately two hours.

During an Environment Court proceeding, the Department of Conservation expressed concerns about the potential adverse effects of jet boating activities on the outstanding intrinsic values and characteristics of the Dart River and its surrounding environment, including the riverbed bird species. These concerns have been raised in relation to the unique braided river system of the Dart River, which is only found in the eastern South Island and Alaska. These river systems owe their existence to the deposition of significant amounts of eroded material from high rainfall areas onto drier land regions [16].

The wrybill, black-fronted tern, and banded dotterel, bird species that heavily rely on braided river habitats, have been identified as being under threat. Bird counts conducted on the Dart River have revealed varying population trends among different species over time, without any discernible pattern. The wrybill, black-fronted tern, and banded dotterel are considered rare due to their limited distribution and specialized habitat requirements. The decline in their populations poses a significant vulnerability, putting them at risk of becoming endangered [16].

The braided river system below Chinaman's Bluff on the Dart River holds exceptional value for wildlife conservation. With an extensive area spanning approximately 2,000 hectares on the braided riverbed, this site remains relatively unaffected by introduced plant species, further enhancing its ecological importance and importance of the development of conservation protocols in this region [16].

3. METHODOLOGY

In New Zealand, there is limited research on quantifying the effects of watercraft on both the flora and fauna, both above and below the waterline. One area of concern to tourists in wilderness areas is the absence of bird-song in tramping routes along, or close to, waterways where jet boats operate for another sector of tourism. Two examples where complaints have been made are the Dart River in Otago, and the Whanganui River in Taranaki. In this paper the annoyance caused by jet boating noise on the Dart River, specifically focusing on the area of interest known as Chinaman's Bluff, is explored.

The method involved comparing actual noise measurements taken at Chinaman's Bluff to the predicted noise levels at selected positions along the Dart River. The study utilized a combination of two models, namely NMSIM-GIS, a noise prediction model in ArcMap, and ISO9613, an international standard for attenuation of sound during propagation outdoors.

3.1 Chinaman's Bluff Noise Measurements

To determine a feasible method for the measurement of the sound power of jet boats necessary for accurate noise prediction, an initial exploratory study was conducted at Chinaman's Bluff in March 2018. The project objectives included preliminary explorations of jet boat noise on a river where tourism-related jet boat activity is well established in order to determine the suitability of applying the construct of tranquillity in developing a new protocol for allocating and managing natural soundscapes. In order to assess the impact of commercial jet boat operations, five wave-file recordings at Chinaman's Bluff were collected.

Data was collected along a straight section of the river with a flat shingle shoreline in a remote location well away from extraneous anthropogenic noise sources and significant water sounds. As a straight channel, it had minimal water turbulence and so was the preferred site for data collection, as jet boats could reach their maximum speed (Figure 1).

The equipment was set up on the shoreline with both the sound level meter and video recorder mounted on tripods. The sound level meter used was a Bruel and Kjaer Type 2250 Sound Investigator, which was mounted at a height of 1.5m above ground level. The meter was set to measure the maximum A-weighted level, L_{Amax}. The pass-by speed of the boat was measured using a radar speed meter at a distance of 26 metres.

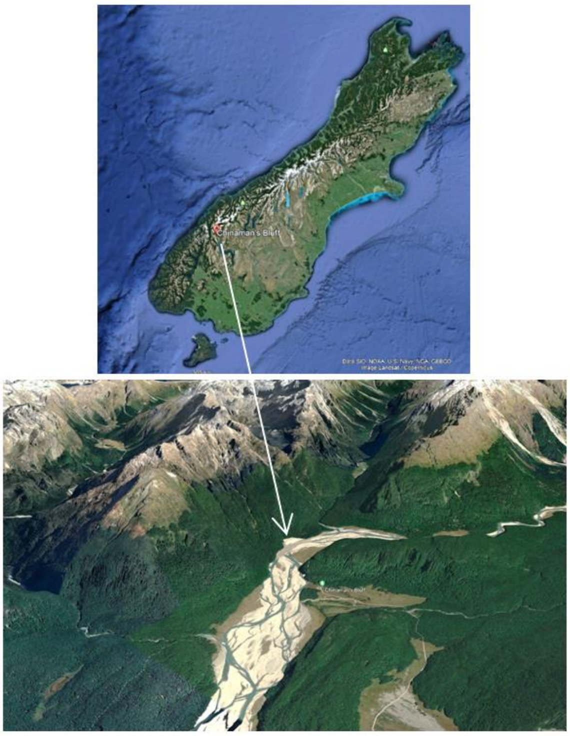

Figure 1. Chinaman's Bluff, Otago, NZ (*Google Earth*)

3.2 ISO 9613-2 Predicted Noise Levels

ISO 9613 is a standard that provides guidelines for calculating the attenuation of sound between a source and a receiver in outdoor environments. The standard includes different methods for predicting sound attenuation, one of which is the point source method.

The point source method is used to predict sound levels in the far field of a single, omnidirectional source of sound, such as a jet boat. This method assumes that the sound source is small enough and the distance between the source and receiver is large enough that the sound can be considered a spherical wave. This means that the sound level decreases as the distance from the source increases, following an inverse square law.

To calculate the sound level at a given distance from the source, the point source method uses an attenuation factor that takes into account the sound power of the source, the distance between the source and receiver, and the atmospheric conditions (e.g. temperature, humidity, wind speed). The attenuation factor is calculated using a series of equations and tables provided in the ISO 9613 standard.

The point source method is widely used in environmental noise assessments, particularly for predicting the noise impact of single, stationary sources. However, the method is limited, particularly when applied to complex, dynamic sound environments with multiple sources and reflective surfaces.

3.3 NMSIM-GIS Predicted Noise Levels

NMSIM-GIS is included as part of an ArcMap toolbox, developed by Sasha Keyel from Colorado State University. This toolbox comprises scripts designed to simulate sound propagation. The sound propagation model incorporates factors such as terrain elevation, ground type, travel path coordinates, vehicle sound power, and atmospheric data to generate representations of environmental data. This paper looked at using NMSIM-GIS for noise contour mapping to accurately predict sound levels to determine whether the software accounted for the effects of the terrain at Chinaman's Bluff (Figure 2).

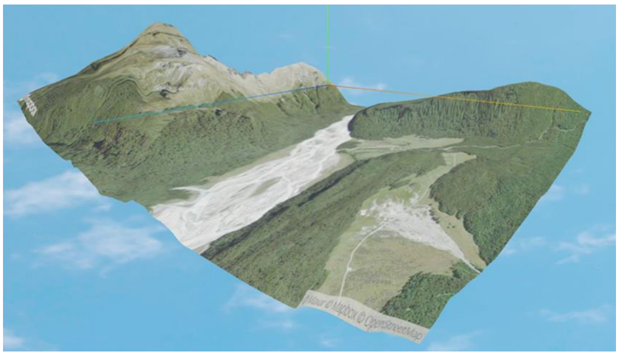

Figure 2. 3D Model of the Terrain

A zone 400 metres in length along a section of the Dart River was selected. This comprised of four data points, 50 metres apart, up and down stream of the measured site, totalling 9 positons of interest (Figure 3). Distances radiating out East and West of the data points were selected of 20, 60, 100, 200, 300, 420 and 500 metres. This was to account for as many variables that could influence the propagation of noise, ensuring a comprehensive representation of the areas affected by jet boating activities and broad comparsion to ISO9613.

Figure 3. Position of points of interest along the Dart River

This methodology allowed for the evaluation of the potential impact of jet boating noise on the Dart River, enabling a quantitative assessment of the annoyance levels experienced by visitors and nearby residents. This tool is expected to contribute to the development of conservation protocols for managing natural soundscapes in a marine context.

3.4 Chinaman's Bluff Noise Measurements

The research team collected wave-file recordings of sound consisting of a calibration signal, ambient sound, and noise from upstream, and downstream operation of the jet boat. This project converted the wave files to spectral data using Audacity software (V 2.2.1), where, after some data analysis, the A-weighted levels (L_{Amax}) were found to be: calibration tone, 94 dBA; averaged ambient, 55 dBA; jet boat pass-by going upstream, 81 dBA; and 67 dBA and 58 dBA going downstream. The A-weighted levels were found by exporting the data from Audacity to Excel as frequency plot spectra, and adding 94 dB to the dB scale, (as this was the full-scale value for calibration). Audacity scales the data relative to full scale and therefore the values come out as negative dBs'. The resulting decibel scale was converted to sound pressure units of Pascal and using octave band frequencies, the data was assigned to respective bands and the summed for each band. These summed pressures were then converted back to decibels and A-weighted, using one-third octave band centre frequencies. The A-weighted values calculated from the wave-files were compared with the sound level meter values and found to agree.

3.5 ISO 9613-2

The sound pressure level measured in the vicinity of an outdoor source is influenced by the medium through which the sound propagates. Normally occurring variations in meteorological conditions can easily result in sound pressure level variations of the order of 20 dB or more [17]. The ground effect in particular, has a strong influence on the measured sound pressure levels. Small changes in source orientation can also affect the measured sound pressure levels when the source exhibits directional radiation characteristics. In order to obtain accurate, reproducible data, it is imperative to understand and consider the influence of environmental variables on the measurement of sound pressure level. Sound propagating outdoors through the atmosphere generally decreases in level with increasing distance between source and receiver. This attenuation is the result of several mechanisms, most notably geometrical divergence from the sound source, absorption of acoustic energy by the air through which the sound waves propagate, and the effects of the environment. The environmental effects principally arise from propagation close to different ground surfaces in the presence of ambient atmospheric conditions, especially wind and temperature.

The equivalent continuous downwind octave-band sound pressure level at a receiver location down wind, $L_{ft}(DW)$ is calculated for each point source, and for the eight octave bands with nominal midband frequencies from 63 Hz to 8 kHz, from equation (1)

$$L_{fT}(\mathrm{DW}) = L_W + D_c - A \tag{1}$$

Where L_w is the octave-band sound power level (dB) produced by the point source, D_c is the directivity correction which for an omnidirectional point sound source radiating in to free space, D_c = 0 dB, and A is the octave band attenuation (dB) that occurs during propagation from the point sound source to the receiver.

The total attenuation, in decibels, in each octave band is approximated by:

$$A = A_{div} + A_{atm} + A_{gr} + A_{bar} + A_{misc} \tag{2}$$

The first three terms give the attenuation from three principal effects - geometrical divergence (A_{div}), atmospheric absorption (A_{atm}), and the ground effect (A_{gr})· A_{bar} is the attenuation due to barriers, however for this study A_{bar} = 0. The last term (A_{misc}) covers attenuation from additional effects that arise only in specific cases, and we therefore set $A_{misc} = 0$ for this study. For atmospheric absorption data, an ambient temperature of 10°C and an atmospheric pressure of 1 atm., with 70% relative humidity was used.

Figure 4 below represents the attenuation of a 100 dBA sound source with distance during propagation outdoors, following ISO 9613. It should be noticed that at a distance of 100 metres or so, the sound would be indistinguishable from the background.

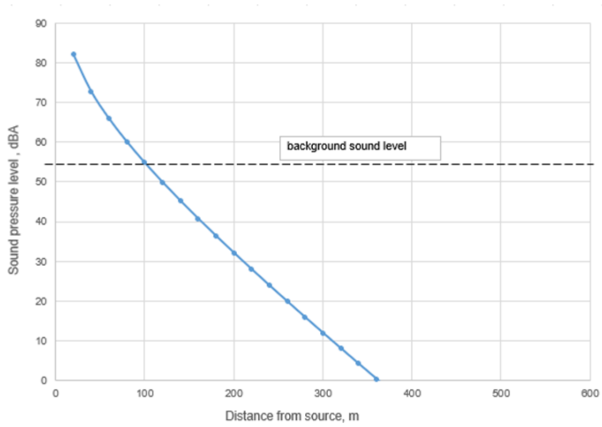

Figure 4: ISO9613 attenuation of sound during propagation outdoors at specified distances from a single source

3.6 NMSIM-GIS

The Chinaman's Bluff terrain map mosaic was obtained from the Land Information New Zealand (LINZ) LIDAR Digital Surface Model (DSM) database in TIFF format [18]. It utilized the NZ 8 m Digital Elevation Model (2012), employing the NZGD 2000 New Zealand Transverse Mercator map projection. The model's components were also aligned with this projection. The data had a default resolution of one metre. The same environmental conditions were used as those for the ISO9613 calculations.

The Aviation Environmental Design Tool (AEDT) is a software package developed by the USA's Federal Aviation Administration (FAA) and replaces the package INM. NMSim was a package developed by the same technical team but was specifically designed for the USA's National Park Service for prediction of noise propagation in extreme terrain – for example, the Grand Canyon in Arizona, USA.

In the AEDT software, to create a new sound source you take an existing source and edit it. The option to create a new source in NMSIM to represent a jet boat was not explored in this project, instead an existing sound sources in NMSIM was used. For the sound source information, an SRC file and its associated AVG files are required to define and specify a noise source for the model calculations. Within NMSIM-GIS, there are six folders of different sound sources including, fixed wing aircraft, helicopters, INM (Integrated Noise Model), ground sources, military vehicles, and a miscellaneous category.

Results were created in the form of rasters, showing A-weighted sound levels for each defined point. The results from the output rasters in NMSIM-GIS are summarised in Figure 5 and 6 below.

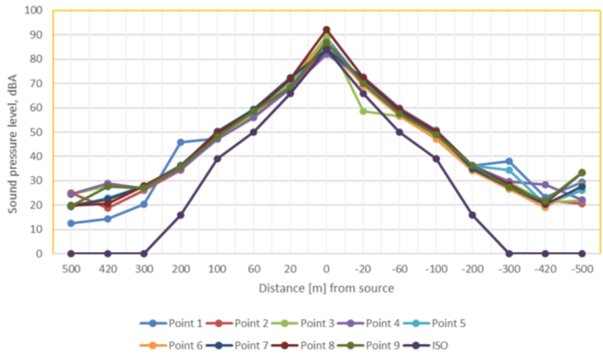

Figure 5: NMSIM-GIS model prediction of sound pressure level for a jet boat sound source in comparison to ISO9613 outdoor sound propagation

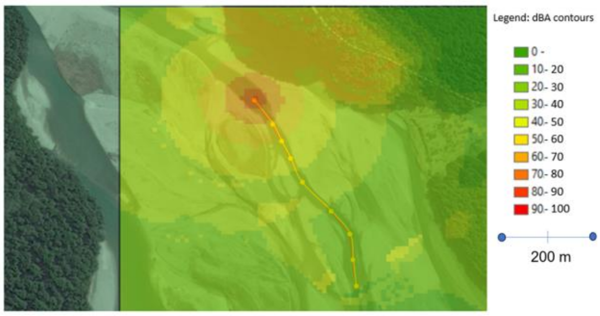

Figure 6: NMSIM-GIS noise contours for point, overlaid on terrain (*Google Earth*)

4. Conclusion

This paper aimed to provide insights into the predicted noise levels due to jet boating activity and their potential impact on the surrounding environment.

NMSIM-GIS modelling was utilised to predict the noise levels generated by jet boating activity in a study area. The predicted noise levels provided an estimation of the sound pressure at various distances from the jet boat source. The analysis shows that the jet boating activities resulted in elevated noise levels, with a predicted maximum of 92 dBA at close proximity (10 metres). Simply using ISO 9613 tended to under-estimate the sound levels when the distance from the jet-boat exceeded 60 metres. This was probably due to terrain effects.

The findings show the potential environmental impact of jet boating noise on the surrounding soundscape and ecosystems. The elevated noise levels generated by jet boating activities have the potential to disturb wildlife, including potentially endangered bird species in some areas. This emphasises the need to extend this initial investigation to assess the specific effects of noise on wildlife behaviour, breeding patterns, and overall ecological dynamics and the importance of implementing noise reduction strategies, such as utilizing quieter engine technologies or enforcing speed limits in sensitive areas.

The methodology trialled in this study provides a basis for determining levels of anthropogenic noise in National Parks directly from the operation of jet boats. Based on the predicted noise levels found we recommend expediting a full program to encompass the range of commercial jet boats sizes operating in the various NZ national parks with a view to exploring the environmental and financial costs of controlling the daily number of boat operation trips allowed. The study's findings will contribute to the development of noise regulations and management guidelines for jet boating activities.

5. References

1 Muir, J. The Grand Canyon of the Colorado. Century Magazine, In Badè W.F (Ed) 1918. *Steep Trails*. Houghton Mifflin. Boston, USA.

2 Harrison, R.T., Clark, R.N., Stankey, G.H. 1980. Predicting Impact of Noise on Recreationists. U.S. Forest Service, Equipment Development Centre.

3 Baker, C.S.; MacGibbon, J. 1991: Responses of sperm whales (Physeter macrocephalus) to commercial whale watching boats off the coast of Kaikoura. Report to the Department of Conservation, Wellington, New Zealand (unpublished). 57 p.

4 Gordon, J.; Leaper, R.; Hartley, F.G.; Chappell, O. 1992: Effects of whale-watching vessels on the surface and underwater acoustic behaviour of sperm whales off Kaikoura, New Zealand. Science & Research Series 52. Department of Conservation, Wellington, New Zealand. 64 p.

5 Richter, C.F.; Dawson, S.M.; Slooten, E. 2003: Sperm whale watching off Kaikoura, New Zealand: effects of current activities on surfacing and vocalisation patterns. Science for Conservation 219. Department of Conservation, Wellington. New Zealand. 78 p.

6 Barr, K. 1997: The impacts of marine tourism on the behaviour and movement patterns of dusky dolphins (Lagenorynchus obscurus) at Kaikoura, New Zealand. Unpublished MSc thesis, University of Otago, Dunedin, New Zealand. 87 p.

7 Würsig, B.; Duprey, N.; Weir, J. 2007: Dusky dolphins (Lagenorhynchus obscurus) in New Zealand waters: present knowledge and research goals. DOC Research and Development Series 270. Department of Conservation, Wellington, New Zealand. 28 p.

8 Markowitz, T.M.; Markowitz, W.J.; Lundquist, D.J.; Du Fresne, S.; Würsig, B. 2009: Dusky dolphin interactions with tourism off Kaikoura: an ecological multi-platform synthesis. Pp. 64–85 in Markowitz, T.M.; Du Fresne, S.; Würsig, B. (Eds): Tourism effects on dusky dolphins at Kaikoura, New Zealand. Kaikoura Dusky Dolphin Tourism Research Project, Christchurch, New Zealand.

9 Lusseau, D. 2002: The effects of tourism activities on bottlenose dolphins (Tursiops spp.) in Fiordland, New Zealand. Unpublished PhD thesis, University of Otago, Dunedin, New Zealand. 244 p.

10 Lusseau, D. 2006: The short-term behavioral reactions of bottlenose dolphins to interactions with boats in Doubtful Sound, New Zealand. Marine Mammal Science 22(4): 802–818.

11 Constantine, R.; Baker, S.C. 1997: Monitoring commercial swim-with-dolphin operations in the Bay of Islands. Science for Conservation 56. Department of Conservation, Wellington, New Zealand. 34 p.

12 Walls, G. 1999: Visitor impacts on freshwater avifauna in New Zealand. Conservation Advisory Science Notes 240. Department of Conservation, Wellington, New Zealand. 69 p.

13 Montgomery, P.J. 1991: The effects of water based recreational disturbance on water birds at Lake Rotoiti, Rotorua. Department of Conservation Technical Series 14. Department of Conservation, Rotorua, New Zealand. 30 p.

14 Hartley, B.; Medway, D.G. 2001: Rotokare bird and habitat survey. Report for the Taranaki region of the Ornithological Society of New Zealand (unpublished). 26 p.

15 Bright, A.; Reynolds, G.R.; Innes, J.; Waas, J.R. 2003: Effects of motorised boat passes on the time budgets of New Zealand dabchick Poliocephalus rufopectus. Wildlife Research 30: 237–244.

16 Environment Court, Decision No:C299/99: In the matter of the Resource Management Act 1991 and in the matter of two appeals pursuant to section 120 of the Act. G.R and E.E.;Kemp and E.A. Billoud. And Queenstown Lakes District Council.

17 Hannah, L. 2007. Wind and temperature effects on sound propagation. J. New Zealand Acoustics, NZ Acoustical Society.

18 N. T. Office. "NZ 8m Digital Elevation Model (2012)." https://data.linz.govt.nz/layer/51768-nz-8m-digital-elevation-model-2012/ (accessed. 2023).