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Modelling noise propagation generated by forest operations: a case study in Southern Italy

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Abstract

Noise is defined as an undesired sound that constitutes an unwarranted disturbance potentiality modifying animal behaviour or normal functioning. Forest operations commonly involve the use of equipment and machines that can produce noise and be a potential permanent or temporary disturbance for the wildlife. This study simulates noise propagation in a natural area generated during coppice stand harvesting by direct field noise measurements and the application of a specific GIS model. Two working phases were investigated: felling and yarding operations. Two potential systems were analyzed for the yarding operations: a) yarding by mobile cable yarder and b) skidding by tractor with a three point log grapple. The results are reported in terms of excess noise area for the third-octave bandwidths with the centre in 500 Hz, 1000 Hz and 2000 Hz. Felling by chainsaws presented the largest area where noise exceeds the ambient natural noise, while in the case of yarding, mobile cable yarding operations presented a smaller area of excess noise than skidding by tractor.

Keywords: noise propagation; forest operations; SPreAD-GIS; cable yarding; felling

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1. Introduction

A wide-ranging literature has discussed the ecological effects of anthropogenic noise in natural areas where wildlife shows changes in behaviour and spatial distribution (Barber, Burdett, Reed, Warner, Formichella, Crooks, Theobald & Fristrup, 2011; Kight & Swaddle 2011). In particular, the growth in transport networks (Wiącek, Polak, Kucharczyk, & Bohatkiewicz, 2015) as well as natural resource extraction (Margalida, Moreno-Opo, Arroyo & Arredondo, 2011) and an increment in recreation activities (Taylor & Knight, 2003; Preisler, Ager & Wisdom, 2005) are ascribed as being the main causes of chronic noise exposure within and in proximity to wildlife areas (Barber, Crooks & Fristrup, 2010). As a consequence, there is a strong interest in analysing noise propagation across natural areas by its modelling (Reed, Boggs & Mann, 2012).

Agriculture and forest operations commonly use equipment and heavy machines that can produce potentially harmful noise for operators (Groves & Lyons 1968; Miyakita, Miura & Futatsuka, 1987; Boubaker, Colantoni, Allegrini, Longo, Di Giacinto, Monarca, Cecchini, 2014; Fonseca, Aghazadeh, de Hoop, Ikuma & Al-Qaisi, 2015) as well being a potential source of wildlife disturbance (Potočnik & Poje 2010). Concerning noise propagation as a potential source of wildlife disturbance, the literature has mainly focused on the propagation of the impulsive noise generated by chainsaws, which are well recognized as being one of the most significant noise sources in forest logging even when compared to the noise of a heavy-lift helicopter (Delaney, Grubb, Beier, Pater & Hildegard Reiser, 1999).

Wood harvesting can be defined as a succession of connected and interdependent operations including felling and processing (tree conversion), off-road wood transport (yarding or timber extraction) and on-road wood transport (hauling). Forest operations can be performed at different mechanization level (from semi-mechanized to fully-mechanized) with different carbon footprint (Cosola, Grigolato, Ackerman, Monterotti & Cavalli, 2016) by machinery and equipment working simultaneously. Different machines also mean simultaneous and multiple noise sources with different spectrum and energy noise level.

Wood harvesting can be achieved by different systems according to the site accessibility and terrain characteristics. Yarding is commonly performed with forest machines on trafficable terrain and by cable yarders or air-ships on not trafficable terrain. Anyway the extraction of logs by a ground-based system on steep terrain also depends on the presence of a well-developed skid trail network (Pentek, Poršinsky, Sušnjar, Stankić, Nevećerel & Sporcić, 2008).

In the case of coppice stands, forest cable yarding is still not very common for extracting logs and off-road vehicles are preferred when possible (Cavalli & Grigolato, 2010). This means that for coppice stands on steep terrain the accessibility to the harvesting area is guaranteed by a dense skid trail network that could have a negative impact in terms of erosion (Merino, Edeso, González & Marauri, 1998; Worrell, Bolding & Aust, 2011).

Nevertheless, although the use of a cable yarder in coppice stands has been widely investigated in terms of cost-efficiency (Canga, Fanjul, Sanchez-Garcia, Alonso-Graña & Majada, 2014; Spinelli, Ebone & Gianella, 2014; Schweier, Spinelli, Magagnotti & Becker, 2015; Proto & Zimbalatti, 2015), also in comparison to ground-based extraction, there is still little in terms of its noise propagation when compared to ground-based extraction (Proto, Macrì, Russo & Zimbalatti, 2016).

In this preliminary work noise propagation during a coppice stand harvesting operation on steep terrain is used as a case study. Motor-manual felling by chainsaws and two different types of yarding systems (by cable yarder *versus* by skidding) are surveyed in terms of noise sources and thus analyzed in terms of potential noise propagation. The aim is to determine which operation (felling or yarding) has less potential noise disturbance in the surrounding forest area and then which of the two alternative yarding systems causes less disturbance. The analysis considers as indicator the size of area around the working site where noise propagation from multiple noise sources exceeds the natural ambient sound conditions.

2. Materials and methods

2.1. Case study

The case study was located in a chestnut coppice stand of 5.33 ha in the area of Serra San Bruno in Calabria region. The working operations consisted of motor-manual felling by chainsaw and yarding mainly by a mobile tower yarder (Zimbalatti & Proto, 2009). The ground-based yarding was performed by skidding logs from the stump area to the processing site in proximity to the forest road by a tractor with a three point log grapple.

The study surveyed noise levels of the different machines used in the working site:

- chainsaw for felling and pre-bucking operations in the stand and for bucking logs at the landing site,
- tractor with three point log grapple for ground-based yarding along the skidding trails,
- mobile cable yarder for aerial yarding and excavator for handling logs at the landing site located adjacent to the forest road network.

The mobile cable yarder was the system preferred by the forest company during the study and yarding was only rarely performed by skidding logs. This was favourable for measuring all the machines in the same area during real working conditions.

Tab 1. Machine characteristics identified as noise sources.

Machine	Operation	Manufacturing	Engine	Engine power	Engine displacement
		year	Type	kW	cm^3
Mobile cable yarder with independent engine	Yarding logs	2006	Four stroke (Diesel)	84	2600
4 WD tractor with three point log grapple	Yarding by skidding	2007	Four stroke (Diesel)	66	4000
Excavator (8 t)	Handling logs at landing	2009	Four stroke (Diesel)	43	3800
Chainsaw	Felling and pre-bucking at stand site, bucking at landing	2014	Two-stroke (Petrol)	4.2	70

The measurements were aided by an HD2010 (Delta Ohm®) spectrum analyser integrating a sound level meter with multi-parametric data logging capability and an HD WME microphone able to measure the noise ranging in frequency spectrum from 16 to 18 kHz in the octave bands and one-third octave bands.

For the aims of the work, the noise analysis protocol consisted of independent measurements (3 for each machine) at a distance of approximately 15 metres for the chainsaw, excavator and mobile cable yarder. The protocol differed in the case of skidding operations by the tractor with the three point log grapple as the machine was driving along the skid roads. In this case, the noise measurements were isolated when the machine was running at a distance of 12 to 17 m from the sound level meter. The sound level calibrator HD9101 – Class 1 (Delta Ohm®), producing a signal of 114 dB at the frequency of 1000 Hz, was used for the calibration of the sound level meter before each measurement.

The noise was recorded in equivalent continuous sound level (Leq) for the one octave bands and one-third octave bands frequency spectrum at 1 s interval, in F (Fast) time and Z (Zero) frequency balancing. The equivalent continuous sound level is commonly chosen to describe sound levels varying over time, resulting in a single value that takes into account the total sound energy over the time period of interest.

According to the characteristics of the sound level meter, the recorded noise level ranged in frequency spectrum from 16 Hz to 16 kHz (central frequency) for the octave frequency band and from 16 Hz to 18 kHz (central frequency) for the one-third octave frequency band.

In order to reduce the local ambient condition influence all the samples were taken on flat terrain in the absence of forest cover. Wind speed and direction, temperature and air relative humidity were constantly measured by a portable weather station WatchDog model 550. The specific windscreen-foam microphone cover was used during the sampling. The noise measurements were conducted in June 2015.

The natural ambient noise was also measured with the same protocol as that applied for the noise measurements of the machines by 3 samples of 5 minutes during the day when all the machines were stopped.

In order to separate the worst situation in terms of noise level, the equivalent value of sound and equivalent value by one-third octave frequency bands from the loudest 5-second intervals were isolated. The obtained parameters were then used for computing the noise propagation analysis by a specific GIS model.

2.2. Modelling noise propagation

Noise propagation analysis uses the SPreAD-GIS toolbox, a tool specifically developed by Colorado State University (Reed, Boggs & Mann, 2012) for the ArcGIS toolbox (ESRI®). The SPreAD-GIS toolbox is a freely available GIS application for modelling anthropogenic noise propagation based on the System for the Prediction of Acoustic Detectability (SPreAD) model, which was developed in the 1980s by the U.S. Forest Service and Environmental Protection Agency (EPA).

The SPreAD-GIS toolbox can calculate noise propagation patterns for one-third octave frequency bands (0.125-2 kHz) around a point sound source. The model returns two results for one noise source in the form of continuous surface of noise level: a) predicted pattern of noise propagation around the source (prNOISE) and b) excess noise (exNOISE) propagation representing the difference between the introduced noise and the background or natural environment noise levels.

The SPreAD-GIS toolbox includes six factors to calculate the noise frequency band spatial propagation: a) spherical spreading loss; b) atmospheric absorption loss as a function of air temperature, relative humidity and elevation; c) foliage and ground cover (ground and vegetation) loss; d) downwind and upwind loss, e) decline in sound levels due to the morphology of the terrain; f) excess noise propagation where noise propagated from the source exceeds ambient sound conditions. By combining the results from the single noise sources, the SPreAD-GIS toolbox also allows noise propagation to be predicted for different one-third octave frequency bands from multiple point sources; the tool is thus used to sum the acoustic energy from the different machines working simultaneously and to predict the pattern of noise propagation in terms of excess noise.

Application of the GIS tool considered three scenarios (Tab. 2): Felling, Skidding and Cable yarder. The three scenarios were based on the worst situation for noise propagation in which all the machines are working simultaneously and producing the maximum noise level at the same time.

Tab. 2. Multiple noise sources for each scenario.

Scenario	Simultaneous noise sources			
	Chainsaw	Tractor with three point log grapple	Mobile cable yarder	Excavator
Felling	3	-	-	-
Cable yarder	2	-	1	1
Skidding	2	1	-	1

The Felling scenario simulated the real situation of the complete motor-manual felling operations of the forest stand. In the application of the SPreAD-GIS toolbox the stand areas (5.33 ha) were first subdivided in a grid with cell size of 30 m. The resulting 60 centroids of each cell were assumed as the noise source locations of the chainsaw operators. As in the real condition 3 chainsaw operators were working at the same time at a distance of approximately 30 m from each other, the SPreAD-GIS toolbox was applied to sum the acoustic energy from 3 adjacent centroids. To cover the entire stand area, a total of 20 combinations each one with three different continuous centroids were processed by the SPreAD-GIS toolbox.

The two scenarios concerning the yarding systems were proposed as alternatives: Skidding scenario supposed that all the felled trees were skidded along the existing permanent skid trail network by a tractor with a three point log grapple, the Cable yarder scenario supposed that all the felled trees were extracted by mobile cable yarder.

For the Skidding scenario the skid trails (in total 1650 m) were split into sections of 50 m and the centroids of each section (33) were used as noise sources of a tractor with three point log grapple. The model was applied to sum the acoustic energy from the different machines working simultaneously and to predict the pattern of noise propagation in terms of excess noise from multiple point sources for each of the 33 sections and each one in combination with the simultaneous noise source of 1 excavator and 2 chainsaw operators working at the landing site.

For the Cable yarder scenario, the model was applied to sum the acoustic energy f and to predict the pattern from multiple point sources by considering 3 different locations (within a radius of 50 m in the landing site) of the mobile cable yarders and, as for the Skidding scenario, in combination with the simultaneous noise sources of 1 excavator and 2 chainsaw operators working at the landing site.

The same ambient condition was considered for each scenario: wind direction north-east, wind speed 2.6 km h^{-1}, air temperature 21 °C and relative humidity 67%.

The natural ambient noise was measured with the same protocol applied to the noise measurements of the machines by 3 samples of 5 minutes during the day when all the machines were stopped.

3. Results and discussion

3.1. Noise sources

The maximum noise levels measured during real working condition are shown in Fig. 1. The noise level is shown for the one-third octave band frequencies available for the SPreAD-GIS toolbox and in Z (zero) frequency balancing and equivalent to a 1 s interval.

It is evident that the noise level spectrum from the chainsaw is different from the other machines due to the different type of engine of the chainsaw (two-stroke engine). The equivalent continuous sound level resulted in 89.1 dB for the chainsaw, 87.6 for the tractor with three point log grapple, 82.8 dB for the excavator and 82.4 dB for the mobile crane yarder. The maximum natural ambient noise recorded corresponded to 38.5 dB.

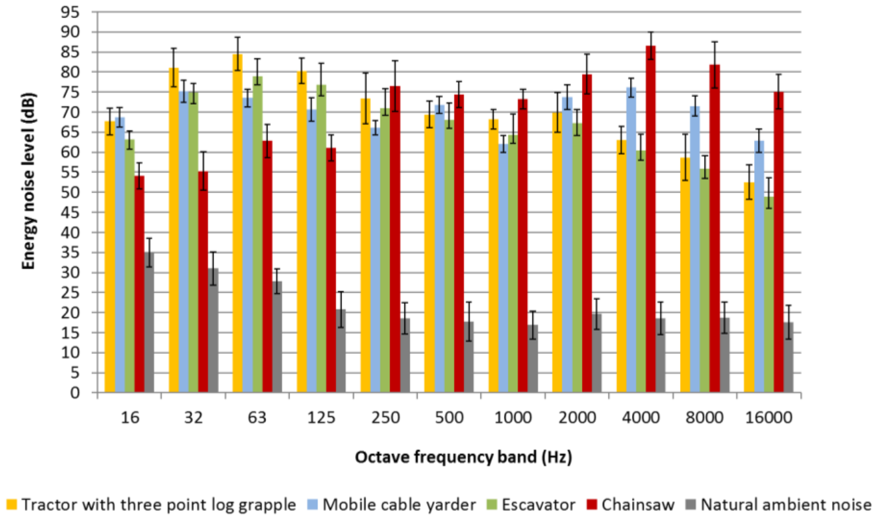

Fig. 1. Noise equivalent energy level for the octave spectrum for the different machines included in the noise propagation model SPreAD-GIS.

3.2. Noise propagation

The resulting excess noise maps in Z (zero) frequency balancing (Fig. 2) for the one-third octave bands of 500 Hz, 1000 Hz and 2000 Hz were analyzed in order to compare the total area exposed to the excess noise in the different scenarios (Felling, Skidding and Cable yarder) at the one-third octave bands of 500 Hz, 1000 Hz and 2000 Hz. The one-third octave bands of 500 Hz, 1000 Hz and 2000 Hz were selected because the strigiform order has the highest hearing sensitivity in these frequency ranges. The strigiform order represents one of the possible protected types of wildlife in the area and the availability of the audiogram (Delaney, Grubb, Beier, Pater & Hildegard Reiser, 1999; Reed, Boggs & Mann, 2012) can be used to highlight the difference between humans and birds in terms of hearing responsiveness.

For each scenario, the resulting average of the excess noise exposed area (ha) is shown (Fig. 2) in terms of interval classes of 5 dB noise level (Fig. 3). The excess noise exposed area with more than 30 dB resulted as less than 2 ha in all scenarios. More specifically, the felling operations presented the largest area of excess noise over 30 dB in the case of 2000 Hz frequency octave band (mean 1.77 ha, standard deviation 0.349 ha). For 2000 Hz, the Skidding scenario showed a marginally larger excess noise area (mean 0.93 ha, standard deviation 0.147 ha) over 30 dB than the Cable yarder scenario (mean 0.84 ha, standard deviation 0.091 ha). In the case of excess noise for the 500 Hz and 1000 Hz frequencies, the felling scenario presented an average exposed area of 0.19 ha (standard deviation of 0.094 ha) and 0.09 ha (st.dev. 0.022 ha).

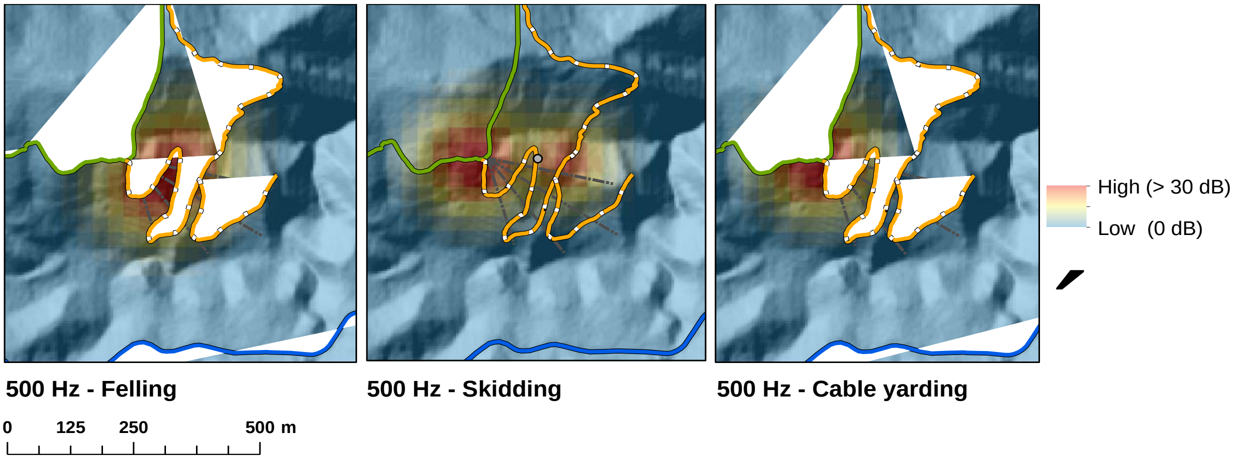

Fig. 1. Examples of summation of excess noise (exNOISE) in dB (in Z frequency balancing) from multiple noise sources: cumulative maximum noise propagation at 500 Hz during felling (sum of 3 chainsaw operators felling trees in the stand), skidding (sum of 1 tractor with three point log grapple skidding whole trees along the skid trail /skid road network, 1 excavator at landing site handling logs and 2 chainsaw operators bucking at landing site) and cable yarding (sum of 1 cable yarder, 1 excavator handling logs and 2 chainsaw operators bucking at landing site).

The excess noise exposed area was relevant in all the scenarios when the excess noise was below 15 dB. The total excess noise (from > 0 dB) exposed area anyway differed between the scenarios: for example, in the case of Felling, for 500 Hz frequency band the total average exposed area resulted as 99.26 ha (st.dev. 3.378 ha), 78.13 ha (st.dev. 1.133 ha) in the case of Cable yarder and 88.53 ha (st.dev. 2.032 ha) in the case of Skidding.

Also in the case of 1000 Hz and 2000 Hz one-third octave band frequencies Felling scenarios presented the largest excess noise exposed area in comparison to Skidding and Cable yarder scenarios. Concerning the difference between the two alternative extraction scenarios, the Cable yarder presented the smaller excess noise exposed area compared to Skidding in the case of both 1000 Hz and 2000 Hz one-third octave band frequencies.

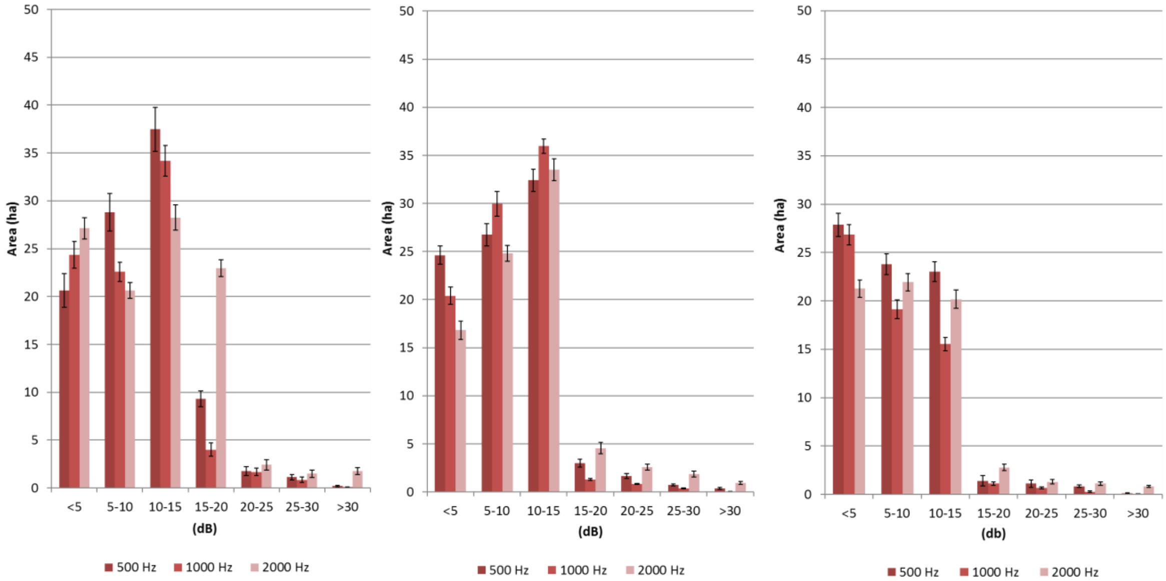

Fig. 2. Excess noise exposed area for (a) Felling, (a) Skidding and (b) Cable yarder scenarios.

By supposing that species of the strigiform order would start to flush when excess noise in the environments exceeds 20 dB (weighted according to the specific audiogram of the strigiform species), the critical area due to the motor-manual felling operation by chainsaw can be estimated at around 9.8 ha; for the extraction operation in the case of skidding the critical area can be estimated as 7.4 ha and 3.7 ha in the case of cable yarder extraction.

4. Conclusions

The study shows the potential of predicting noise exposure generated by forest operation by taking into account specific ambient condition and terrain morphology in terms of frequency bands across specific spatial models.

Although the SPreAD-GIS toolbox results are theoretical information, they were based on empirical noise sources and ambient sound measurements. The results can thus be used to illustrate the possible extent of the area affected by noise from the multiple noise sources active simultaneously in the working site.

The advantage of predicting noise propagation in forest operations can summarized in: 1) supporting the identification of the most environmentally friendly work system in terms of noise propagation by taking into account technical and logistical constraints (for example terrain slope, skidding and forest road network); 2) identifying the area where excess noise level for the different frequency bands can negatively influence the ecological responses of wildlife species (if data are available on wildlife response to noise and on wildlife species audiograms).

The case study highlighted that the excess noise generated by the motor-manual felling covers a larger area than the excess noise generated by the simultaneous multiple noise sources during extraction operations. This confirms that a chainsaw is one of the most critical machines in terms of noise level (Cavalli, Miola & Sartori, 2004; Potočnik & Poje, 2010; Delaney, Grubb, Beier, Pater & Hildegard Reiser, 1999; Kight & Swaddle, 2011) in natural environments. Cable yarder operation presents a reduction in potential disturbed area when compared to skidding by tractor. However, the advantage is not very big as the use of a chainsaw for bucking the tree at the landing site is also a component in both yarding methods.

The success of the spatial model application in GIS environment depends anyway on the availability of the noise frequency spectrum for each noise source in the working site and on the accurate setting of scenarios in terms of noise source locations.

An important limitation of GIS application is that it also needs to be validated with empirical measurements of noise propagation (Barber, Burdett, Reed, Warner, Formichella, Crooks, Theobald & Fristrup, 2011; Reed, Boggs & Mann, 2012) and further field validation in the Mediterranean forest should be a priority for future applications in Southern Italy. The frequency range available in the current version of the SPreAD GIS model (0.125 – 2.0 kHz) can be enough to support prediction of noise propagation in comparison to the spectra of forest machinery sound sources as well as the auditory sensitivity of different animal species.

Anyway the case study highlighted the limit in terms of processing time when multiple point sources and several frequency bands are considered. In fact, complex scenarios including the continuous change of the noise source location, as is typical for forest operations, substantiality increase the processing time for the noise propagation analysis, also requiring an advanced knowledge of GIS analysis and data setting and processing.

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