




Article

# Noise Assessment of Small Vessels for Action Planning in Canal Cities

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Received: 6 February 2019; Accepted: 3 March 2019; Published: 5 March 2019



**Abstract:** After the European Environmental Noise Directive prescribed noise maps and action plans, wide scientific literature and a consistent number of mitigation strategies emerged for road, railway, airport, and industrial noise. Unfortunately, very little attention has been paid to the noise produced by ports in their surroundings, even though there could be many areas affected by it. At present, more attention seems to be paid to noise produced underwater, mostly for military and security reasons and for its interference with wildlife, rather than airborne noise and its influence on human health. In the framework of a project aiming to shed more light on a topic so far under-investigated, this paper presents an acoustical characterization of different small vessels at various speeds that move around on a daily basis in every type of port, produced by means of short- and long-term measurements. The new information acquired was used to produce a map of noise generated by vessels moving in Livorno's canals, which branch off in a densely inhabited area. The simulations were validated using long-term measurement. The number of citizens exposed was also estimated and used to calculate the number of highly annoyed people according to the recent curve for road traffic noise proposed by Guski et al. In order to prevent citizen exposure to noise and possible complaints about small boats, different scenarios and possible future situations such as various vessel speeds, limited flow, restricted areas for some categories, or new residential areas were studied.

**Keywords:** port noise; harbor noise; noise emission; noise mapping; noise mitigation; small vessel noise; noise exposure; noise action plan; noise annoyance; urban planning

## 1. Introduction

When not properly assessed, prolonged exposure to noise can be the cause of many issues for human health, such as sleep disorders [1], learning impairment [2–4], hypertension [5,6], cardiovascular and respiratory diseases [7–11], and annoyance [12–14]. Political and scientific attention on the subject grew in 2002 when the European Directive 2002/49/EC (END) [15] obliged the member states to produce noise maps and action plans every five years in order to prevent these health problems [16]. The maps should include mainly noise produced by road, railway, airport, and industrial sources. As a consequence, in the last decade the member states and the scientific community have expended much in the way of effort and resources to study and propose high-level mitigation strategies for the main sources of noise: road traffic [17,18], railway traffic [19,20], airport operations [21,22], and industrial activities [23,24]. Even noise produced by wind turbines has seen an increase in the number of studies on its mitigation, given its highly annoying features [25–27]. The recent END revision [28]

reported how noise pollution still represents a major health issue even after the mitigation strategies introduced in the last years, thus stimulating the scientific community into studying the subject and the environmental agencies into proposing mitigation actions where needed.

In contrast with the flourishing literature and number of mitigation actions for the aforementioned noise sources, very little attention has been paid to addressing noise produced by ports in their surroundings. Most of the scientific studies about noise generated from vessels concern onboard noise [29–31] or interference with animal life [32–34] and oceanic ambient noise [35,36], since, currently, noise produced underwater is more studied than airborne noise [37–40]. Overall underwater ship-radiated noise is the sum of propulsion noise, propeller noise, auxiliary noise, and hydrodynamic noise [41], with eventual tonal components caused by the propeller and associated cavitation noise [42]. However, the noise generated by ships affects a wider range of receivers than animals, workers, or passengers, including, in fact, inhabitants living in coastal area near ports or canals, especially where ship traffic is intense or where loading/unloading operations frequently occur. Therefore, port noise shares some features with road, railway, or industrial noise but, differently from these sources, specific instruments to characterize, assess, and control this noise are missing [43]. The acoustic impact of ports has gained more attention in recent years at a technical and pre-normative level as a consequence of several European projects like HADA [44], Eco.Port [45], NoMEPorts [46], SIMPYC [47], EcoPorts [48], MESP [49], and SILENV [50]. All these projects tried to define guidelines in order to characterize the noise made by ports on an END basis.

All studies agree about the complexity of airborne noise produced by big ships, where a multitude of different sources contribute to the overall noise emission [51]. Internal structure-borne sources, such as engines, propagate outside through hull vibrations that cause acoustic re-emission. Probably the most impactful source is the funnel, which emits aerodynamic noise from a consistent height, followed by heating, ventilation, and air-conditioning systems. Some ships are also equipped with noisy machinery such as cranes or winches used when the ship is moored. The complexity of noise generated by ships increases when treating port activities of a ship as four different operating conditions, each characterized by different noise emission: in motion, maneuvering, moored, and loading/unloading. It has been shown that if not properly managed, and if no mitigation measures are implemented to prevent long-term exposure [52], environmental noise from nearby ports has the potential to be a significant public health concern. An example is the case of the city of Dublin [53], where self-reported impacts of noise exposure through qualitative interviews of residents in the immediate vicinity of the port reported sleep disturbance and annoyance associated with over-exposure. The results were comparable with those reported by World Health Organization (WHO) [54] for direct sleep disturbance and the secondary impacts in terms of fatigue, reduced productivity, anger, and lack of motivation and focus.

In order to avoid public disturbance by correctly assessing port noise, in the very latest years some authors presented several different measurement methods [55–58]. Unfortunately, these works concerned only noise produced by moored ships and thus did not consider moving ships of any size, except for a preliminary study in Venice [59,60].

This study looks at the modern urban reality of canal cities, where noise impact is not only due to the usual sources such as road or railway traffic but is also produced by boats passing through canals or rivers. Although roads are the most widespread noise source, as well as the most studied so far, in some situations, boats could represent a major source of disturbance for citizens. This could originate for touristic reasons in arts cities or for economic reasons in coastal towns, but also in view of the recent trend in urban planning of recovering dockland. In fact, the development of a touristic city seldom implies the re-use of old areas or historic areas that can become new residential areas. Without proper management, citizens could therefore go to live in pleasant environments from the landscape point of view, while underestimating the soundscape.

The first part of the present paper reports the characterization of noise emitted by different categories of small vessels by means of specific pass-by measurements. The new information was used to simulate a map of noise produced by small vessels moving in the canals in the city center of

Livorno and analyze citizen noise exposure. The simulations were validated by comparing the results with a one-month-long measurement. Further simulations were performed for alternative scenarios with respect to the present one in order to prevent noise impact at receivers in different hypothetical conditions that could result from port expansion. Different vessel speeds, different flow, restricted areas for some categories, and the presence of new residential areas were the different conditions studied in order to avoid bad placements of living environments, causing disturbance to citizens. The curve developed by Guski et al. [13] for road traffic noise was used to calculate disturbance to citizens and thus compare the different scenarios.

## 2. Materials and Methods

### 2.1. Measurements

The first set of noise measurements for characterization of small vessels was performed on 20 June 2018, 19 September 2018, and 4 October 2018 at the entrance of the civil port of Livorno, “Porto Mediceo”, so called because it was originally built in the 14th century by the Medici family. Due to the depth and entrance width, the speed limit is fixed to 5 knots and only small vessels such as motorboats, sailing boats, rigid-hulled inflatable boats, fishing boats, and fireboats are allowed in the area. From this access, only motorboats and sailing boats can enter the canals that branch off into the densely inhabited city center, a situation similar to those in many other cities sited along a river or the coast where people can be disturbed by ship noise. The only other, and most impactful, noise source in the city center area is road traffic.

A second campaign of noise measurements was performed on 24 October 2018 at the very entrance of the whole port of Livorno in order to acquire boat transits at different speeds. A specific long-term measurement for the validation of the noise modelling was performed from 29 May 2018 to 22 June 2018 using the terrace of Francesco de Medici’s palace facing the access to the “Porto Mediceo” as the measurement site. The satellite map of the area and the measurement positions are reported in Figure 1.

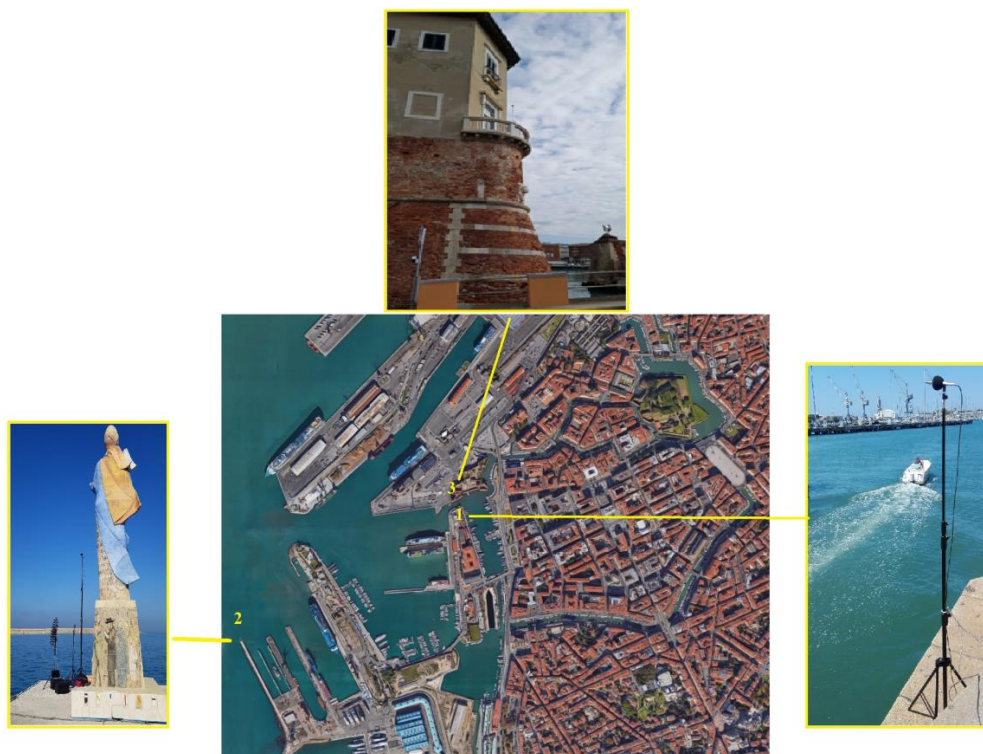


Figure 1. Satellite map of the area and localization of the measurement positions.

The time history of the noise level was acquired every 100 ms using class I instrumentation according to IEC 61672-1 [61]. Microphones equipped with a 90 mm windscreen were placed far from obstacles in free field conditions and pointing towards the direction of the sources at 1.5 m from the ground, except for Point 3, which was placed on a 12 m high terrace. Data affected by rainfall were discarded, as well as those with wind speeds exceeding 5 m/s. All small vessels passing during measurements at Points 1 and 2 were photographed in order to collect their type and their speed was measured.

## 2.2. Data Analysis

The present work mainly consisted of two different phases: a first phase aiming to characterize the noise emission of passing small vessels, and a second one assessing the consequent noise exposure in the present real scenario or in alternative future scenarios by means of noise simulations.

From the time history of the three noise measurements performed at Point 1,  $L_{Aeq}$  and the linear spectrum of each passage of a small vessel was extracted, marking 10 dB(A) around their peak. In this way a database was created, with each row containing, for each pass-by, the measured  $L_{Aeq}$ , speed, time of the measurement, passage duration, type of vessel obtained from the photos, and noise spectrum. A preliminary analysis showed that the available data would allow the acoustical characterization of two different categories from the point of view of their noise produced, which was loosely related to the size of the vessel.

Thus, the consequent analysis was performed separately for Category 1 vessels (Cat1), which include small motorboats, sailing boats, and rigid-hulled inflatable boats, and for Category 2 (Cat2) vessels, i.e., small and mid-sized fishing boats, fireboats, and public security boats. Given the mandatory low speed for boats at the entrance of "Porto Mediceo", measurements at Position 2 were performed in order to expand the database to higher speeds.

The background noise was variable during all the measurement sessions due to other port operations and ferry embarking procedures; thus, normalized values of  $L_{Aeq}$  and the spectrum for each transit were calculated by energetically subtracting the corresponding residual level ( $L_{90}$ ). The average of  $L_{Aeq}$ s and 1/3 octave band spectra was calculated for each combination of categories and low, medium, and high speed. As reported later in the text, the speed division was performed based on experimental data: low speed ranges from 6.4 to 9.4 km/h (3.4–4.9 kn) for Cat1 and 8.8 to 9.1 km/h (4.7–4.9 kn) for Cat2, medium speeds are 9.5–14.3 km/h (5.0–7.7 kn) for Cat1 and 9.2–10.7 km/h (5.0–5.7 kn) for Cat2, and high speeds are 14.4–19.2 km/h (7.8–10.4 kn) for Cat1 and 10.8–13.3 km/h (5.8–7.2 kn) for Cat2. Medium speed is the most common, which is why it was used for the current scenario.

Considering a geometrical distance of 7.5 m from the measurement point to the source, the average total sound power level ( $L_{W/m}$ ) and the 1/3 octave band sound power spectrum were calculated for each category and speed by using the Expert Industry Toolbox of SoundPLAN vers. 8.0, which enables the estimation of a source emission from measurements. The 1/3 octave band spectrum and  $L_{W/m}$  of both Cat1 and Cat2 at medium speed were used as input in the validation phase of the acoustic model, and using the real corresponding boat traffic flows, a preliminary noise simulation was produced at the receiver point of the measurement performed at Point 3. For the purpose of obtaining acoustic maps, routes were modeled as lines and boats were implemented as linear sources with usage times calculated from the average event duration and flow in day, evening, and night periods. The flow information known in the measurement points and in some control points at the port exit, i.e., where the flow is maximum, was decreased inside the channels following a decay proportional to the distance from the maximum points. This measure wants to limit the effect of the flow reduction due to the boats that interrupt their transit in the channels to park, since along all the channels there are parking lots with a constant density.

After the validation, noise maps of the central canals of Livorno were obtained for the following scenarios:

- Scenario 1 (present): Cat1 can access “Porto Mediceo” and the canals, while Cat2 boats can only access “Porto Mediceo”. Speed is medium;
- Scenario 2: Cat2 can access the canals, too;
- Scenario 3: Cat1 can access “Porto Mediceo” and the canals, while Cat2 can only access “Porto Mediceo”. Speed is high;
- Scenario 4: Cat1 can access “Porto Mediceo” and the canals, while Cat2 can only access “Porto Mediceo”. Speed is low;
- Scenario 5: similar to Scenario 1, with a new residential area in the south part of the port area in Figure 1. This hypothesis is based on the municipality expansion plan.

For all the scenarios, noise contours maps were produced using  $L_D$ ,  $L_E$ ,  $L_N$ , and  $L_{DEN}$  metrics, with day (06:00–20:00), evening (20:00–22:00), and night (22:00–06:00) periods evaluated according to the END. Façade noise maps were then used to evaluate the inhabitants’ exposure to noise in the different conditions studied. The parameters and setting used in SoundPLAN for simulations are reported in Table 1. In order to assess the number of people exposed to noise, façade noise maps were also calculated for the same time periods by using the VBEB method [62] for assigning noise levels to buildings and inhabitants living in them.

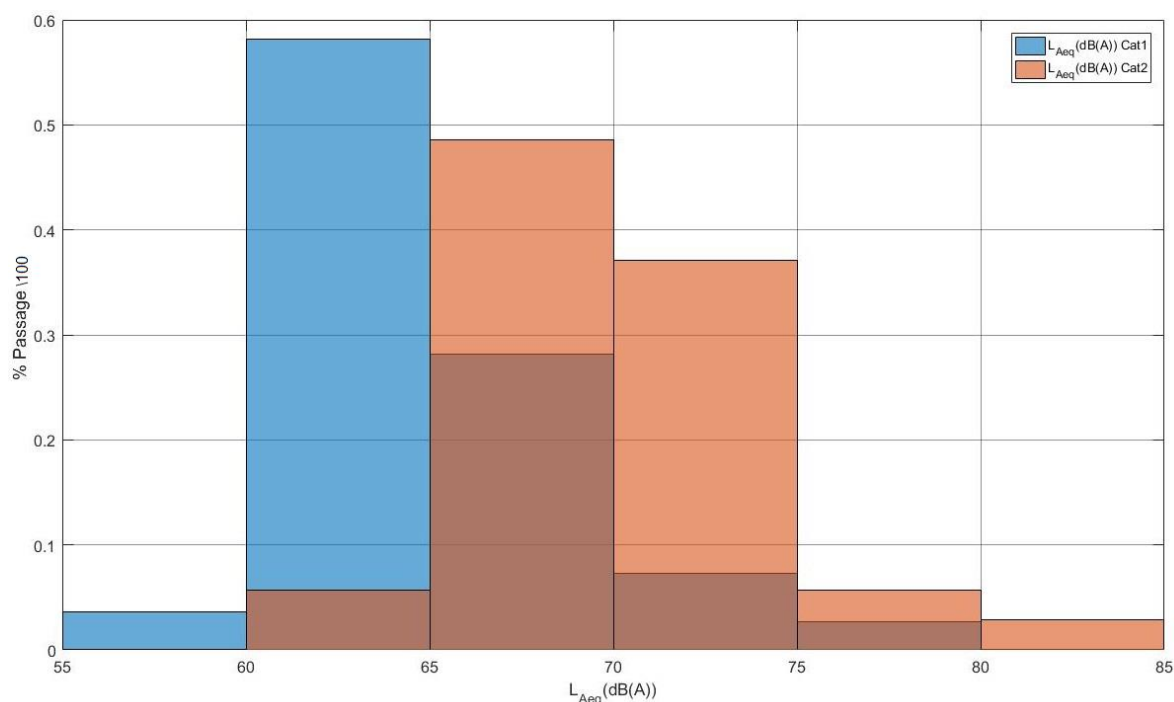
**Table 1.** Parameters and settings used in the noise simulations.

Calculation Parameters	
Number of reflections	1
Maximum distance of reflections from the receivers	200 m
Maximum distance of reflections from the sources	50 m
Research radius	500 m
Weighting	A
Tolerated error	0.1 dB
Environmental Data	
Atmospheric pressure	1013.25 mbar
Moisture	70%
Temperature	10 °C
% fixed favorable/homogeneous	pFav (6–20 h) [%] = 50.0; pFav (20–22 h) [%] = 70.0; pFav (22–6 h) [%] = 100.0;
Map	
H measurements 1, 2	1.5 m
H measurement 3	12 m
Metrics used	$L_D$ , $L_E$ , $L_N$ , $L_{DEN}$
Grid spacing	10 m
Height from ground	4 m

### 3. Results

#### 3.1. Acoustic Characterization of Small Vessels

The first part of the acoustical characterization of small vessel pass-by events consisted of identifying different categories from the point of view of noise emission during the pass-by. As reported previously, the measurements performed at Point 1 allowed us to distinguish two categories using both noise data and pictures taken at every transit. Category 1 (Cat1) includes small motorboats, sailing boats, and rigid-hulled inflatable boats, while Category 2 (Cat2) includes small and mid-sized fishing boats, fireboats, and public security boats. The distribution of noise levels for all the measured transits at Point 1 is reported in Figure 2. No distinction for different speeds is considered in this histogram; thus, part of the distribution wideness is due to speed differences.



**Figure 2.** Histogram of noise produced by two categories of small vessel pass-by events at a 7.5 m distance.

As described in Section 2.2, background noise was energetically subtracted in order to normalize noise values measured in different conditions; then, by using SoundPLAN Expert Industry Toolbox, the average total sound power level ( $L_{W/m}$ ) and the 1/3 octave band sound power spectrum were calculated for both categories. With the available data, the consequent analyses were performed separately for the low-, medium-, and high-speed classes.

The sound power levels and 1/3 octave band sound power spectra of Cat1 vessels for the low-, medium-, and high-speed classes are reported in Figure 3, together with their uncertainties. For Cat1, low speeds are 6.4–9.4 km/h (3.4–4.9 kn), medium speeds are 9.5–14.3 km/h (5.0–7.7 kn), and high speeds are 14.4–19.2 km/h (7.8–10.4 kn).

Sound power levels and 1/3 octave band sound power spectra of Cat2 vessels for low-, medium-, and high-speed classes are reported in Figure 4, together with their uncertainties. For Cat2, low speeds are 8.8–9.1 km/h (4.7–4.9 kn), medium speeds are 9.2–10.7 km/h (5.0–5.7 kn), and high speeds are 10.8–13.3 km/h (5.8–7.2 kn).

In Table 2 a summary of all the speed categories and the average sound power levels with their statistical uncertainty is reported.

**Table 2.** Summary of the obtained  $L_{W/m}$  and 1/3 octave band sound power spectra for different category and speeds of small vessels.

Category	Speed Category	Speed (km/h)	Speed (kn)	$L_{W/m}$ (dB(A))
Cat1	Low	6.4–9.4	3.4–4.9	76.3 ± 2.4
Cat1	Medium	9.5–14.3	5.0–7.7	77.4 ± 3.4
Cat1	High	14.4–19.2	7.8–10.4	88.8 ± 4.3
Cat2	Low	8.8–9.1	4.7–4.9	81.2 ± 2.9
Cat2	Medium	9.2–10.7	5.0–5.7	83.5 ± 6.7
Cat2	High	10.8–13.3	5.8–7.2	84.9 ± 3.4

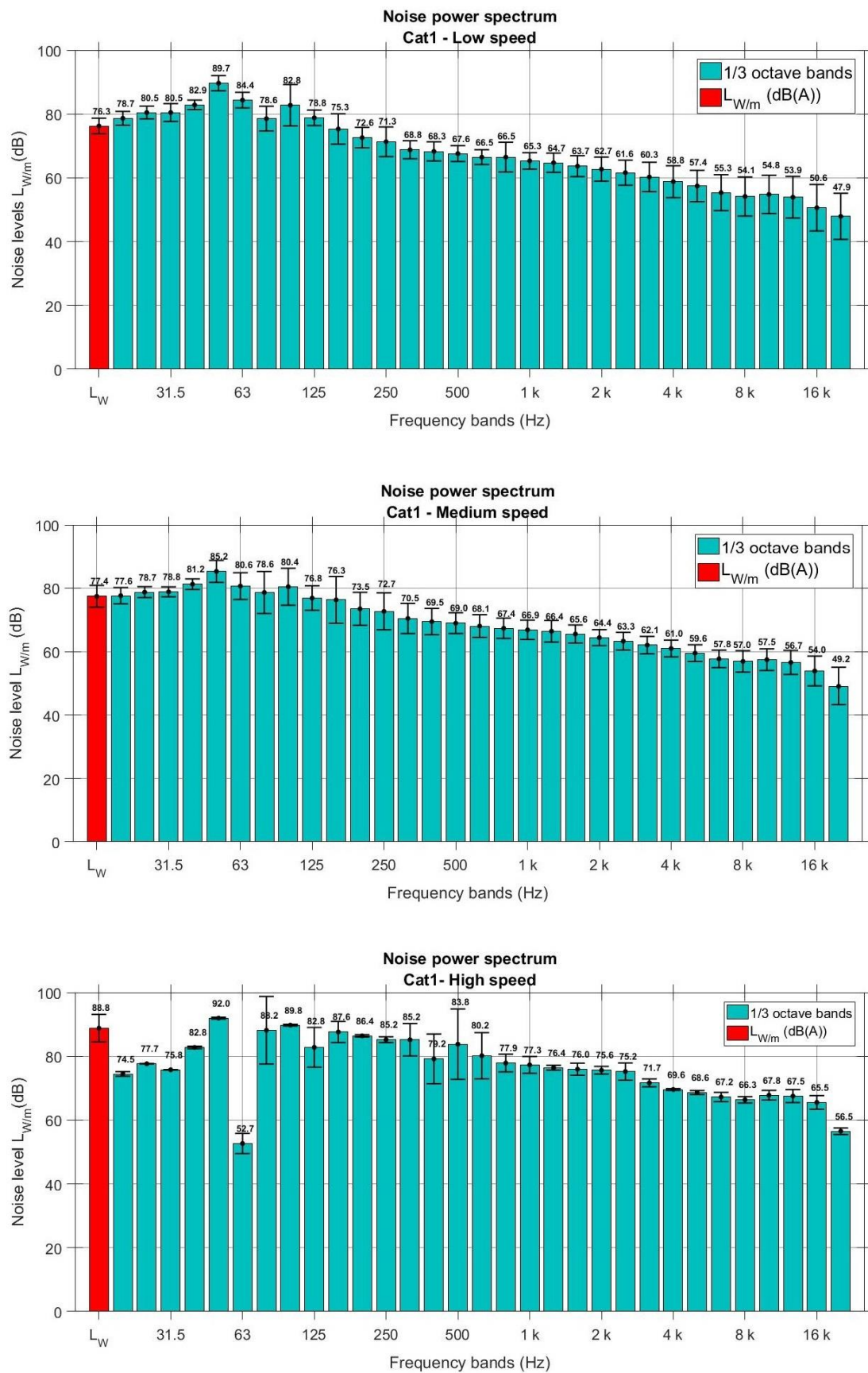
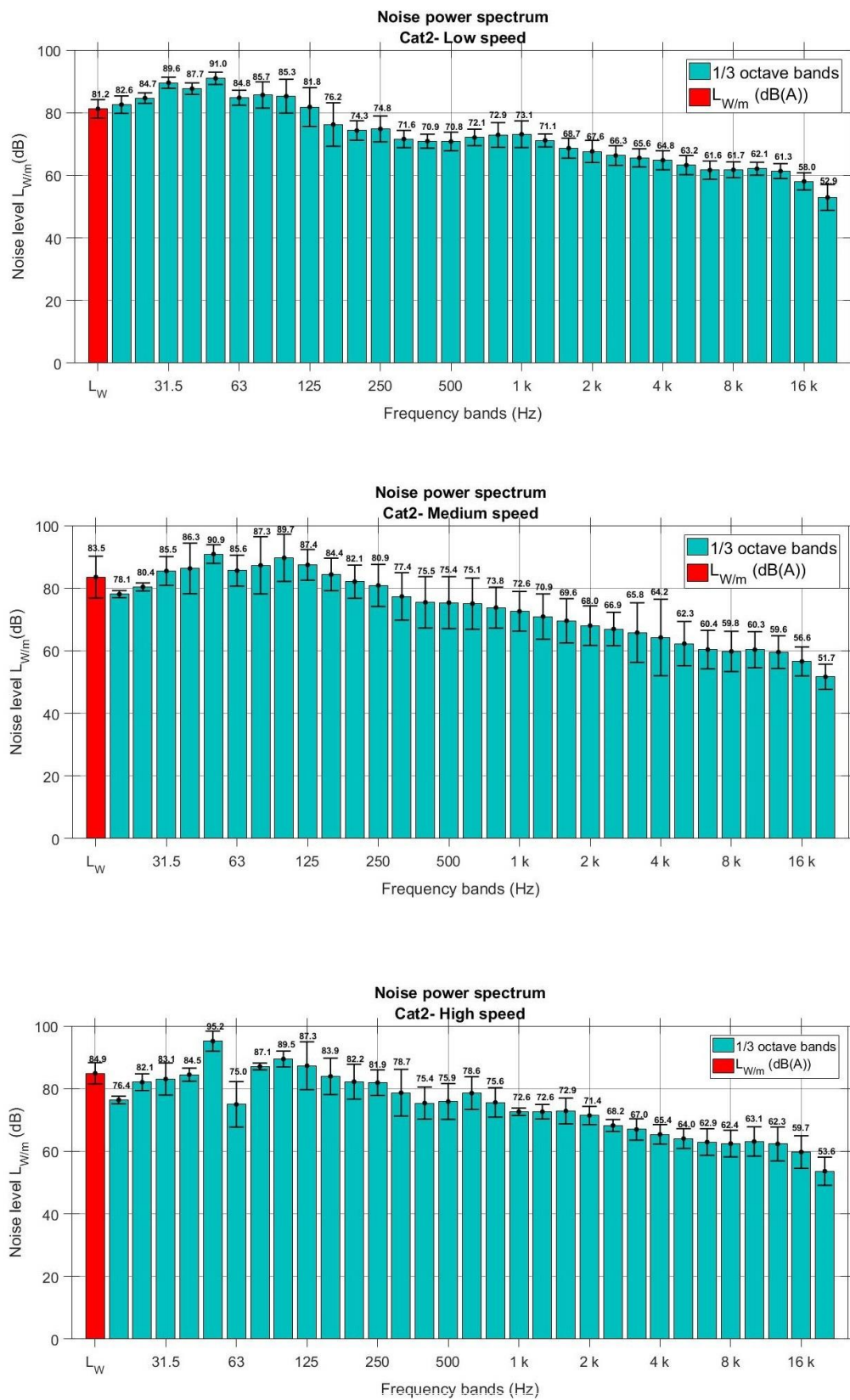


Figure 3.  $L_{W/m}$  and 1/3 octave band sound power spectra of Cat1 vessels for low-, medium-, and high-speed classes together with uncertainties.



**Figure 4.**  $L_{W/m}$  and 1/3 octave band sound power spectra of Cat2 vessels for low-, medium-, and high-speed classes together with uncertainties.



### 3.2. Noise Maps and Citizens Exposed to Noise in the Present Situation

With the newly acquired 1/3 octave band sound power spectra of the two small vessels categories and with the settings previously reported in Table 1, the noise contour maps and façade noise maps were produced for Scenario 1, the present situation. According to the END, the  $L_D$ ,  $L_E$ ,  $L_N$ , and  $L_{DEN}$  metrics were used with day (06:00–20:00), evening (20:00–22:00), and night (22:00–06:00) periods. The annual average number of sailing vessels in the area was provided by the Port Authority.

The noise contours maps for Scenario 1, where speed is medium and Cat1 can access “Porto Mediceo” and the canals, while Cat2 can only access “Porto Mediceo”, are reported in Figure 5 for  $L_{DEN}$  and in Figure 6 for  $L_N$ .

For Scenario 1, the present situation, the histograms of citizens exposed to noise levels above 40 dB(A) of  $L_{DEN}$  or  $L_N$  are reported in Figure 7, as obtained from the façade noise maps.

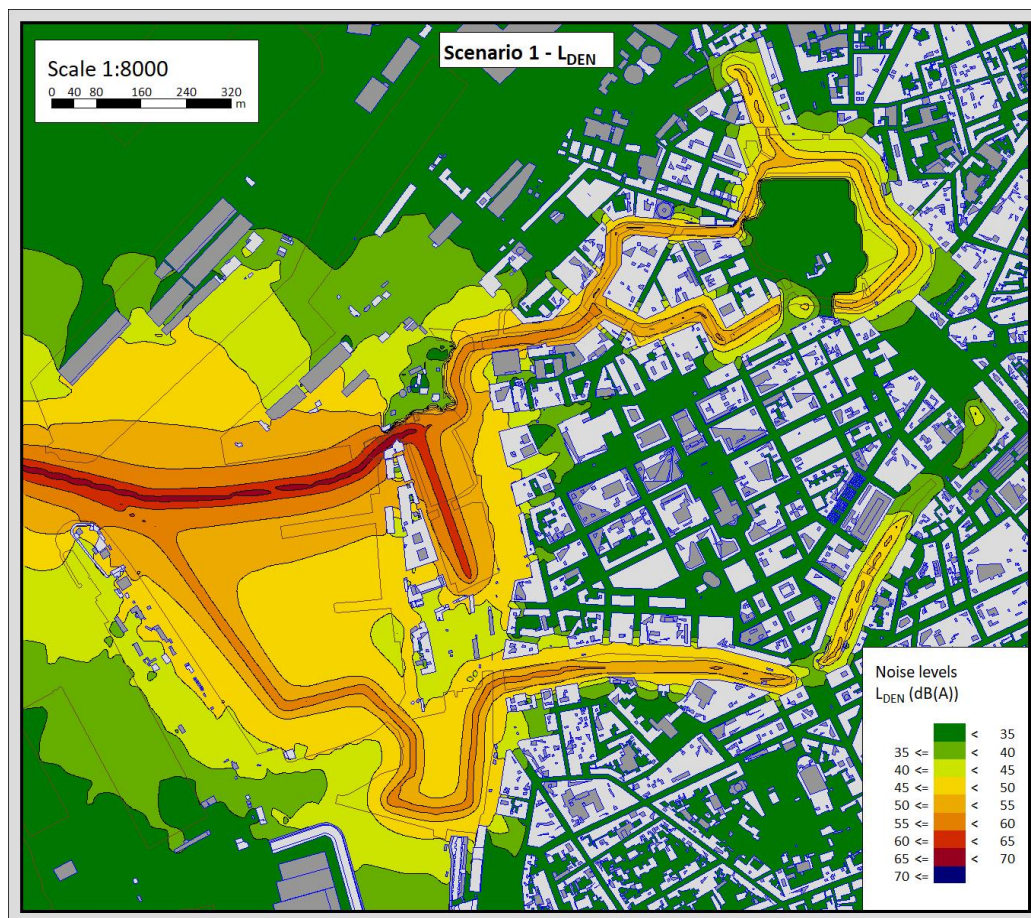


Figure 5.  $L_{DEN}$  noise contours map for Scenario 1 (present).

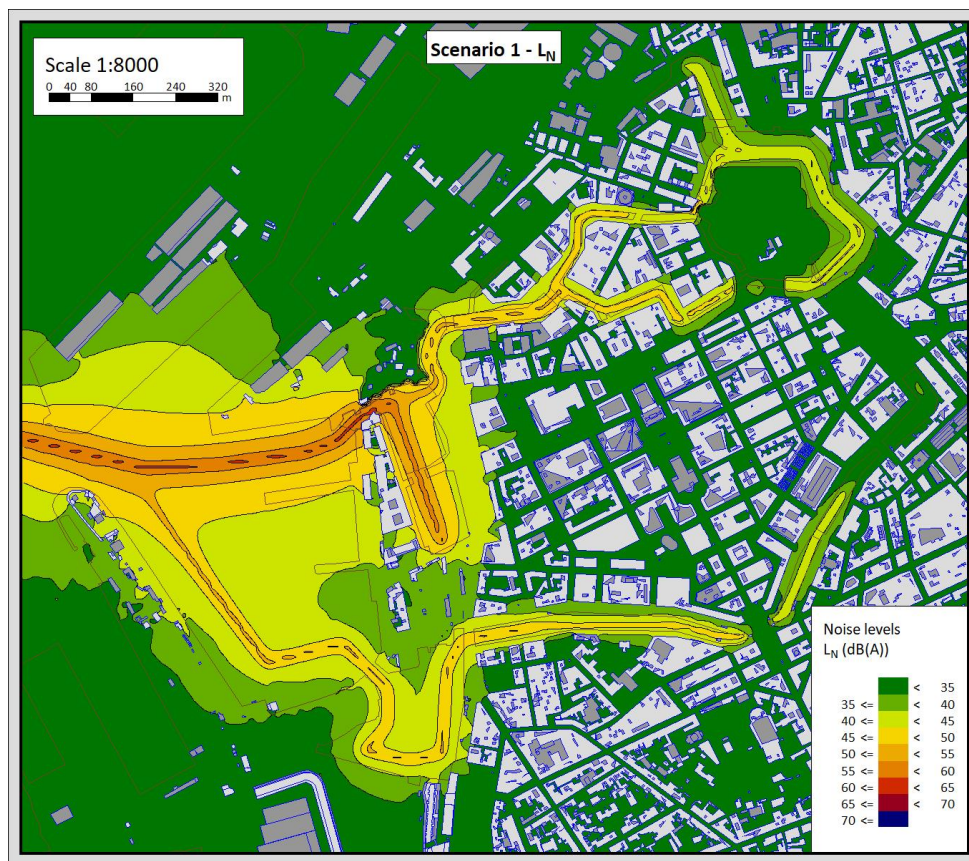


Figure 6.  $L_N$  noise contours map for Scenario 1 (present).

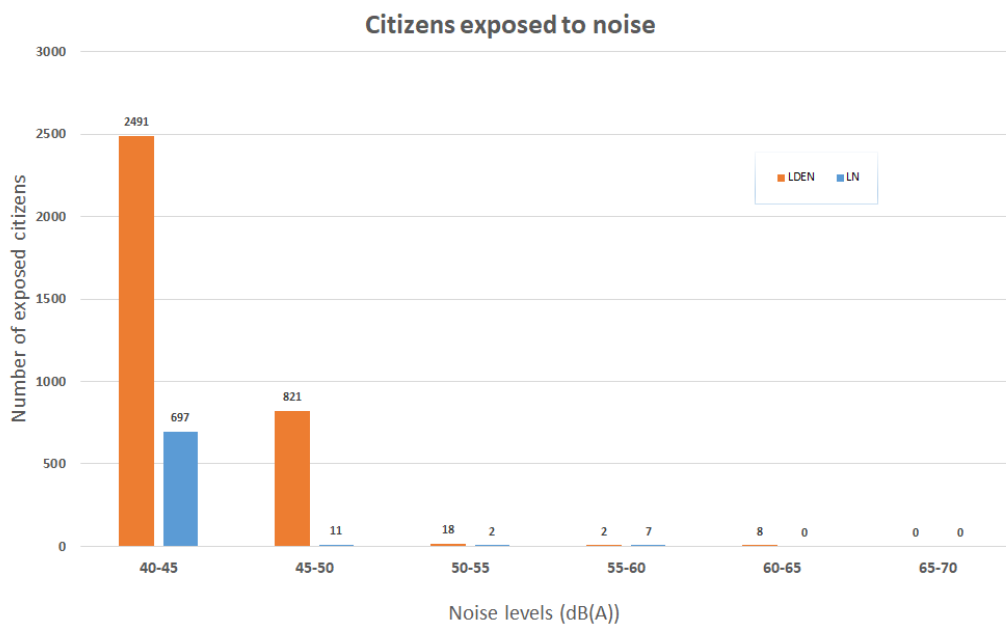


Figure 7. Number of citizens exposed to noise levels above 40 dB(A) of  $L_{DEN}$  or  $L_N$  in Scenario 1.

#### 4. Discussions

To the best of the authors’ knowledge, the present study is the first one that aims to characterize the noise produced by small vessels moving in ordinary conditions, not in laboratory or in special operative conditions, but in a real case scenario by means of pass-by sound measurements. Through the types of boats and the number of their transits measured over several days at two different positions in

the port of Livorno, it was possible to estimate the sound power level and the sound power spectrum of two categories of vessels at three different speeds.

Thus, small motorboats, sailing boats, and rigid-hulled inflatable boats had similar results from an acoustic point of view, but differed from small and mid-sized fishing boats, fireboats, and public security boats.

In the histogram of the noise produced by the vessels reported in Figure 2, the standard deviation around the average of each of the two categories is mainly due to the different transit speeds of the vehicles. The speed was considered in the subsequent analyses and calculations but, as shown by the uncertainty values associated with the sound power level for different categories and speeds shown in Table 2, there should be some other factors that enlarge the distribution around the average in the histograms.

A first factor is related to the measurement, where the geometric source–microphone distance was not fixed but ranged from a minimum of 5 m to a maximum of 10 m depending on where the boat passes in the canal. Normally, boats pass in the center of the canal, which is 7.5 m from the microphone, but, assuming a Gaussian distribution, this difference in distance translates into (−2.5; +3.5) dB of oscillation in the measured noise. A second factor is linked to the engines of the boats, which obviously could be different within boats of the same category, but information about which and how many engines each boat had was not available.

An area of intersection between the two categories emerged in Figure 2: a sign that Cat1 vessels with higher speed, closer to the microphone or with more numerous or more powerful engines than average can produce a noise similar to slow Cat2 vessels. However, the spectral analysis reported in Figures 3 and 4 shows different shapes; therefore, the categories are different from a spectral point of view, especially at low frequencies.

It is interesting to note, and it would be worthy of further specific studies, that for both categories a big reduction in noise at 63 Hz occurs when the speeds are higher.

Clearly, further developments such as the expansion of the possible types or speed ranges of vessels are required, since this is a first study. Also, knowledge on the type and number of engines aboard each boat could be an improvement of paramount importance, since the engine is the main mechanism of noise emission for boats; this is unlike other sources such as cars, where many mechanisms contribute to the overall noise generation, and already at medium–low speeds, the tire/road interaction becomes predominant. However, the information on the sound power obtained can be used already in port situations similar to the studied one, or can be integrated with specific studies on site.

The noise maps produced with the data obtained by measurements were validated with the one-month-long measurement performed at Position 3. The resulting difference between the simulated and measured values was lower than 2 dB, according to Table 5 of the ISO 9613-2:1996 [63].

The number of exposed citizens reported in Figure 6 showed that the acoustic impact produced by small vessels in the present situation is quite low. Assuming that the response of people to the source studied is similar to the response to road traffic noise, it is possible to use the recent dose–effect relationship given by Guski et al. [13] to estimate the percentage of highly annoyed people to noise (%HA). According to this curve, the half value of the 40–45 dB(A)  $L_{DEN}$  interval corresponds to 8.3%HA, 8.1% in the 45–50 dB(A)  $L_{DEN}$  interval, 9.6% in the 50–55 dB(A) interval, 12.8% in the 55–60 dB(A) interval, 17.8% in the 60–65 dB(A) interval, and 24.4% in the 65–70 dB(A) interval. The exposure estimated for Scenario 1 led to a total number of 280 highly annoyed estimated citizens, which is consistent with the fact that no complaints from the population have been reported.

In order to prevent situations in which citizens complain about noise produced by small boats, different scenarios and possible future situations were studied.

In Scenario 2, the authors hypothesize that fishing boat and public security boat hubs are moved in an inner area inside the city, and, therefore, Cat2 can also access the northern canals with the same flow. The resulting numbers of citizens exposed to noise levels above 40 dB(A)  $L_{DEN}$  or  $L_N$  are reported in Figure 8.

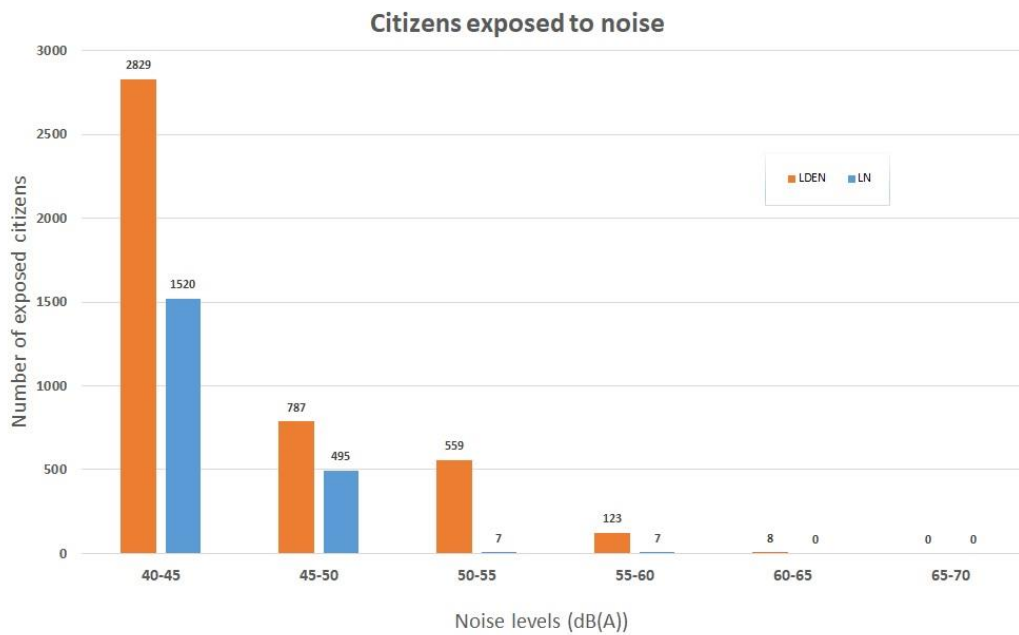


Figure 8. Number of citizens exposed to noise levels above 40 dB(A) L<sub>DEN</sub> or L<sub>N</sub> in Scenario 2.

In Scenario 3, the authors hypothesize the same access situation as in Scenario 1, but with the speed category increased to “high” for both categories. The resulting numbers of citizens exposed to noise levels higher than 40 dB(A) L<sub>DEN</sub> or L<sub>N</sub> are reported in Figure 9.

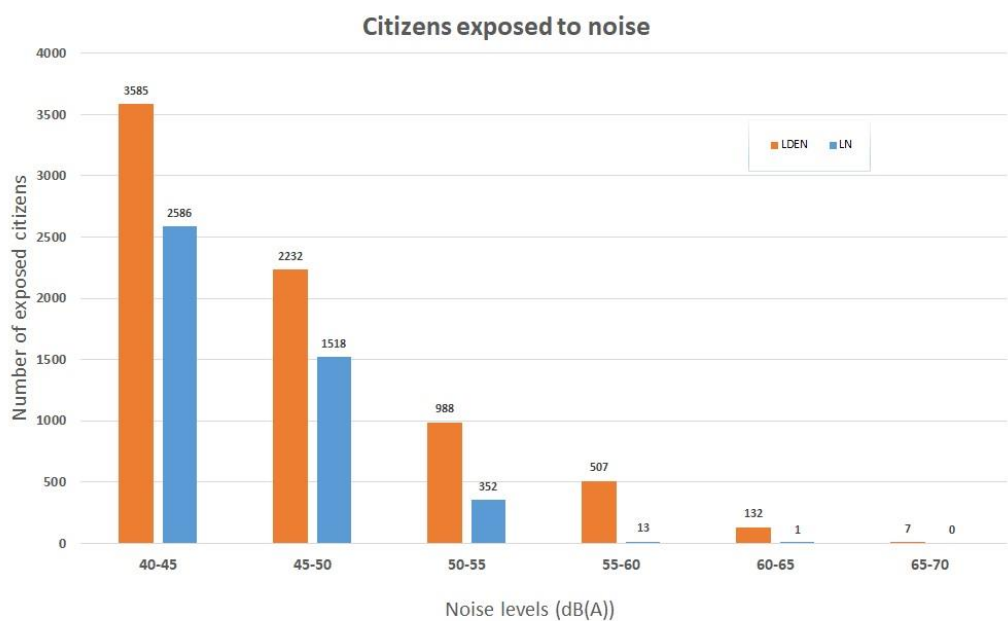


Figure 9. Number of citizens exposed to noise levels above 40 dB(A) L<sub>DEN</sub> or L<sub>N</sub> in Scenario 3.

Scenario 4 is similar to Scenario 3, but the speed category is set to “low” for both categories. The resulting numbers of citizens exposed to noise levels above 40 dB(A) L<sub>DEN</sub> or L<sub>N</sub> are reported in Figure 10.

A future municipality expansion plan involves the construction of a new residential area in the southern part of the port area. Given the role of urban planning in managing and reducing residential exposure to port noise highlighted by Bing and Popp [64], the corresponding Scenario 5 was studied.

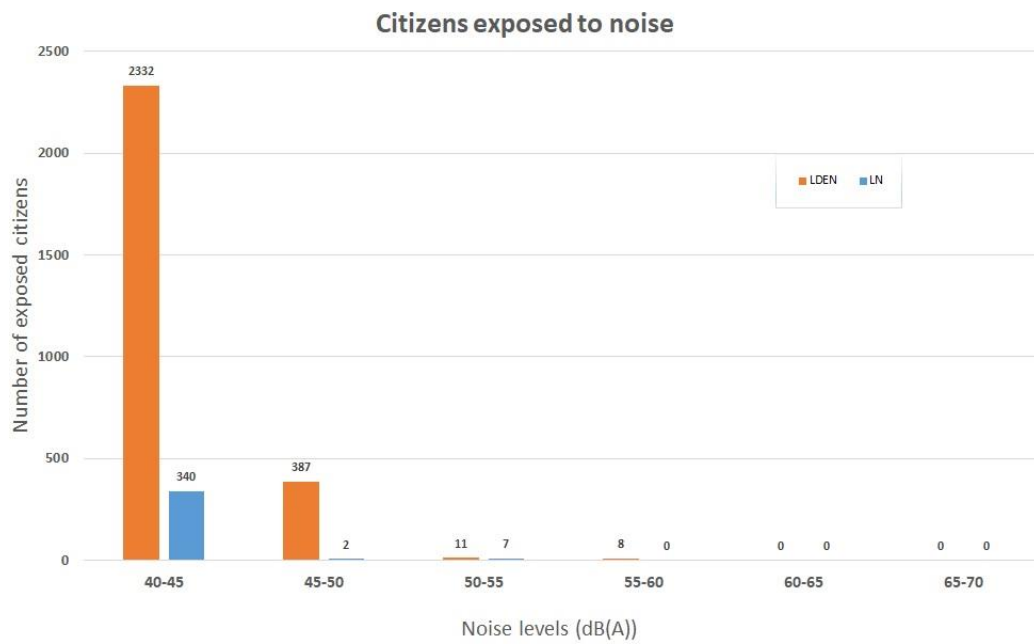


Figure 10. Number of citizens exposed to noise levels above 40 dB(A) L<sub>DEN</sub> or L<sub>N</sub> in Scenario 4.

The noise contours maps of the Scenario 5 area, which differs from that of Scenario 1, is reported in Figure 11 for L<sub>DEN</sub>, while the numbers of citizens exposed to noise levels above 40 dB(A) L<sub>DEN</sub> or L<sub>N</sub> in Scenario 5 are reported in Figure 12.

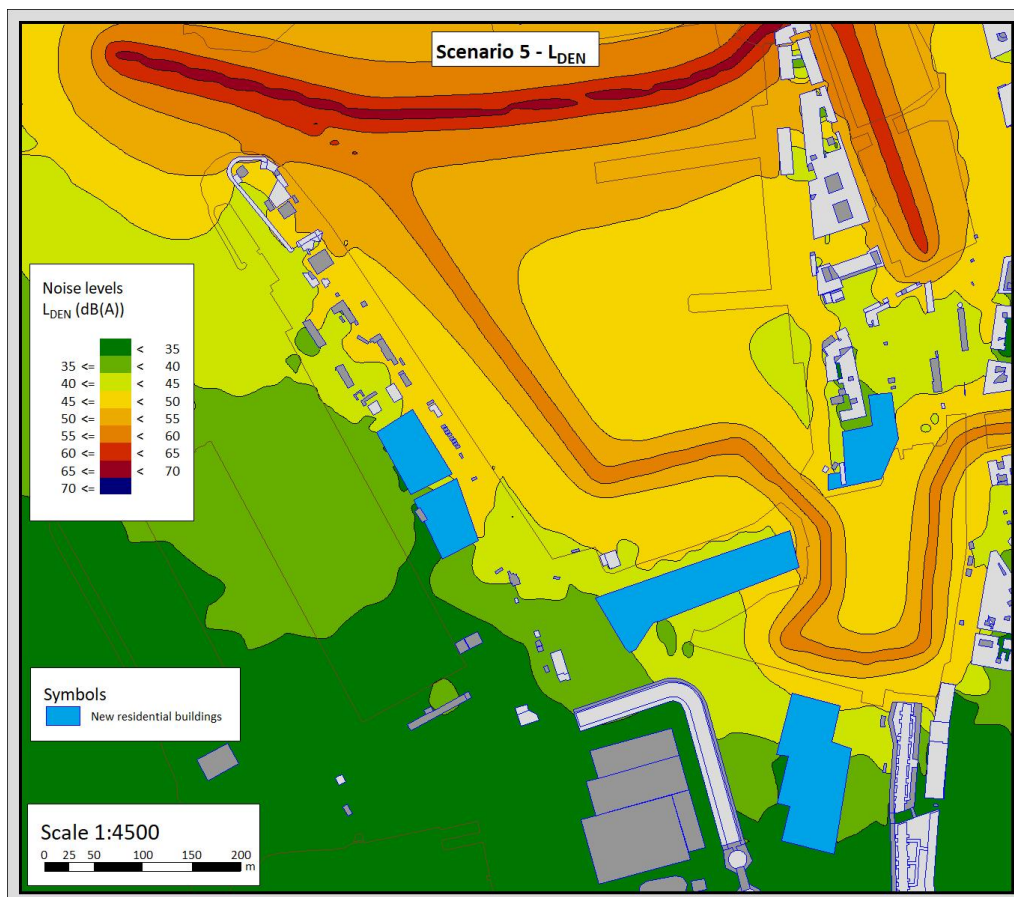
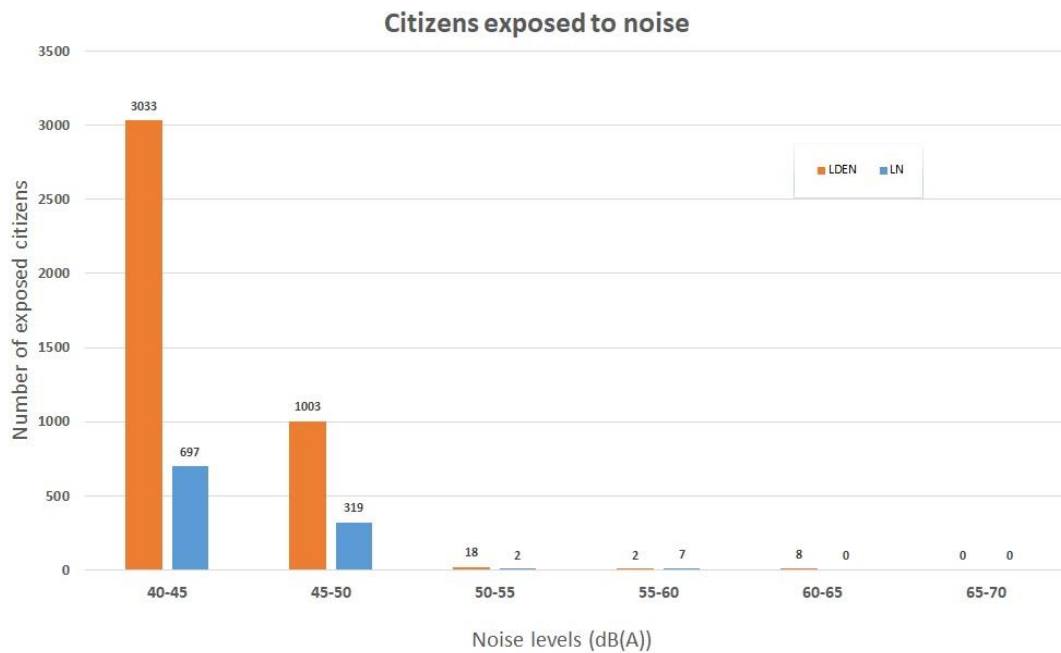


Figure 11. L<sub>DEN</sub> noise contour map for the southern area of the port in Scenario 5.



**Figure 12.** Number of citizens exposed to noise levels above 40 dB(A) L<sub>DEN</sub> or L<sub>N</sub> in Scenario 5.

A comparison of the results obtained in the different scenarios is reported in Table 3, where the number of citizens exposed to each 5 dB(A) interval of both L<sub>DEN</sub> ( $\Delta N_{L_{DEN}}$ ) and L<sub>N</sub> ( $\Delta N_{L_N}$ ) is calculated as a difference with respect to Scenario 1. Furthermore, the last column reports the percentage difference with respect to Scenario 1 of the total number of citizens ( $\Delta N_{HA}$ ) highly annoyed by noise emitted by small vessels according to the dose–effect relationship developed by Guski et al. [13] for road traffic noise.

The comparison aligns with our expectations: Allowing Cat2 vessels to access the northern canals (Scenario 2) would lead to an increase in the number of people exposed to lower noise levels and a sensible increase in night exposure, given the mainly nocturnal movement of fishing boats. Scenario 2 leads to an increase of +14.43% in  $\Delta N_{HA}$ . Allowing a higher speed in the canals (Scenario 3) will drastically increase the population exposed, inducing an increase of +108.41% in  $\Delta N_{HA}$ . On the contrary, a reduction of the speed would reduce the number of exposed citizens but not by the same quantity as for the high-speed setting; in fact, the corresponding reduction in  $\Delta N_{HA}$  is −18.63%, which is still a viable solution for mitigation. Adding a new residential area (Scenario 5) will obviously lead to an increase in the number of citizens exposed, with a consequent +21.73% increase in  $\Delta N_{HA}$ , confirming that this kind of urban modification should be properly assessed prior to construction in order to avoid future complaints by citizens.



## 5. Conclusions

To date, the scientific community and control bodies have paid little or no attention to noise produced by ports in their surroundings. Nevertheless, the local realities in which vessels in transit can be a source of disturbance are various: from canal cities, to cities built around rivers, to the modern urban use of docklands. For all these situations, a wrong noise assessment could cause a problem to citizens with consequent complaints being made. Until now, most noise studies have assessed the impact of noise from traffic sources or industrial sources, while, to the best of the authors' knowledge, the present study is the first of noise produced by the transit of small boats in ordinary transit conditions that also evaluates their impact on a real case scenario, aimed at characterizing the consequent disturbance of the citizens.

Noise emissions of two different categories of small vessels were characterized by means of short- and long-term pass-by measurements. The analysis showed that small motorboats, sailing boats, and rigid-hulled inflatable boats can be included in the same acoustical category, while small and medium sized fishing boats, fireboats, and public security boats are a different category. Their sound power level and 1/3 octave band sound power spectra were reported for three different speed ranges.

Consequently, a map of noise produced by small vessels moving in the canals in the city center of Livorno was computed for the present situation and the noise exposure of citizens was estimated. The simulations were validated by comparison with a one-month-long measurement. Then, further simulations were performed, each one hypothesizing an alternative scenario where speed, flow, and restricted areas for some categories were changed, or the presence of new residential area was simulated.

The mitigation or deterioration brought about by the different hypotheses with respect to the present scenario were studied by evaluating citizen disturbance in all the studied scenarios according to the recent Guski et al. [13] curve, assuming that the road noise curve maintains its form for noise produced by boats. In this way, it was demonstrated that the present situation does not lead to concern, but if the conditions of speed and flow or residential areas change, it is very likely that complaints from citizens will arise.

The study carried out herein represents a preliminary work in a wider context of port acoustic impact assessment. Surely, by measuring more vessels' transits at different speeds and with the possibility of a larger fleet, as well as a proper dose–effect relationship for annoyance related to boat noise, the present research would be greatly enriched. Moreover, possible future developments will involve the use of acoustic cameras with beamforming techniques to better determine the emission points of the sources.

The results obtained in this study can be used in contexts similar to the studied one in order to evaluate the acoustic impact of moving small vessels, a noise source underestimated until now. Moreover, the studied scenarios could be considered in the urban planning of the residential areas in the vicinity of ports or canals, where correct management of the territories would lead to the prevention of excessive noise impact and disturbance of citizens.

**Author Contributions:** Conceptualization, L.F.; Data curation, M.B., L.F., P.G. and M.N.; Formal analysis, M.B., P.G. and M.N.; Funding acquisition, F.F. and G.L.; Investigation, M.B., L.F. and M.N.; Methodology, L.F.; Project administration, L.F., F.F. and G.L.; Supervision, L.F., F.F. and G.L.; Validation, M.B., P.G. and M.N.; Writing—original draft, L.F.; Writing—review and editing, M.B., F.F., P.G., M.N. and G.L.

**Funding:** This research received no external funding.

**Acknowledgments:** The authors wish to thank Sandra Hill and Alessandro Del Pizzo for providing linguistic help and for their proofreading of the article. The authors also thank the Port Authority of Livorno for providing the needed data.

**Conflicts of Interest:** The authors declare no conflict of interest.



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