Investigation of Underwater Noise Pollution in European Rivers Due to Urban Traffic: Case Study of the River Spree, Berlin

William L. Wu, James A. Campbell, Franz Hölker, Paul S. Kemp,
and Paul R. White

Contents

OPEN ACCESS with major support from JASCO APPLIED SCIENCES

W. L. Wu (✉) · P. R. White
Institute of Sound and Vibration Research, University of Southampton, Southampton, UK
e-mail: William.Wu@soton.ac.uk; P.R.White@soton.ac.uk

J. A. Campbell · F. Hölker
Community and Ecosystem Ecology, Leibniz Institute of Freshwater Ecology and Inland Fisheries (IGB), Berlin, Germany
e-mail: james.campbell@igb-berlin.de; hoelker@igb-berlin.de

P. S. Kemp
International Centre for Ecohydraulics Research, Boldrewood Innovation Campus, University of Southampton, Southampton, UK
e-mail: P.Kemp@soton.ac.uk

A. N. Popper et al. (eds.), *The Effects of Noise on Aquatic Life IV*,
https://doi.org/10.1007/978-3-031-94229-7_227-1

Abstract

Urban rivers are often lined and crossed by dense transport infrastructure, including road bridges, heavy and light rail, tunnels, and intensive tourist and commercial vessel traffic. These sources inject substantial acoustic energy into shallow, laterally confined waveguides, yet riverine underwater noise has received far less attention than marine shipping noise. This chapter presents a case study from the River Spree in Berlin, Germany, where a 7 km transect was surveyed to characterize underwater noise associated with road traffic on bridges, urban and regional rail on bridges, metro traffic in tunnels beneath the river, and sightseeing vessels. Measurements were made with a calibrated spherical hydrophone at 2.8–3.6 m depth (mean 3.1 m). Event-level broadband sound pressure levels (SPL) reached approximately 152 dB re 1 μPa for cars on bridges, 161 and 166 dB re 1 μPa for regional and S-Bahn trains, 174 dB re 1 μPa for U-Bahn traffic in tunnels, and up to 181 dB re 1 μPa for nearby vessel passages. Spectrograms revealed distinct source-specific signatures, including a pronounced shallow-water low-frequency cutoff for vessel noise. The results illustrate that land-based transport can be a major contributor to urban river soundscapes and highlight the need for river-appropriate propagation models, long-term monitoring, and integration of underwater noise into river corridor planning and ecosystem restoration.

Keywords

Urban rivers · Underwater noise · Environmental impact · Vessel noise · Underwater acoustics · Bioacoustics · Noise mapping

Introduction

Anthropogenic underwater noise is widely recognized as an environmental pressure in marine systems, with substantial literature on shipping, seismic exploration, pile driving, and offshore construction. In contrast, riverine and canal environments, especially those embedded within major cities, remain comparatively under-characterized, despite their close coupling to transport infrastructure and high levels of daily human activity. Many urban rivers are crossed by multiple road and rail bridges, underlain by tunnels, and used intensively by commercial and tourist vessels, creating a dense and spatially heterogeneous set of noise sources within shallow, laterally confined channels. These settings also present distinctive propagation conditions, where depth, banks, and bed materials can reshape spectra and constrain low-frequency transmission over short ranges. As a result, both the intensity and spatial footprint of anthropogenic noise may be difficult to anticipate using intuition or models derived from deeper-water environments.

Existing studies demonstrate that anthropogenic sound can strongly structure river and estuarine soundscapes. Monitoring in the Hudson River has shown that bridge traffic and vessel activity impose clear temporal patterns linked to human behavior (Martin and Popper 2016). In the Swan-Canning River system, vessel traffic, bridge noise, and construction contribute prominently alongside biotic sounds (Marley et al. 2016). Surveys along the Yangtze River further suggest that elevated underwater noise may coincide with habitats used by sensitive taxa, including freshwater cetaceans and fish (Wang et al. 2021). In parallel, engineering-focused work has shown that cross-river infrastructure can radiate low-frequency energy into the water column via structure-sediment coupling, including road and metro tunnels (Song et al. 2020, 2024) and underwater traffic-tunnel settings where signals correlate with vehicle flow (Reeder et al. 2020). Reviews of sound exposure assessments for fish highlight the fact that such structure-borne sources remain underrepresented in routine evaluations (Zang et al. 2023).

Together, this literature implies that urban river noise arises from a combination of waterborne and structure-borne sources, yet systematic measurements in European rivers remain limited and are often not linked to infrastructure context or shallow-water propagation constraints. This chapter therefore presents a case study from the River Spree in Berlin. It characterizes representative underwater acoustic signatures from road traffic on bridges, rail traffic on bridges, rail traffic in tunnels beneath the river and sightseeing vessels; illustrates how shallow-water waveguide effects (including low-frequency cutoff) shape received spectra; and discusses implications for future measurement strategies, impact assessment, and the development of river-appropriate modeling and noise mapping tools.

Study Area and Measurement Overview

River Reach and Transect Design

Measurements were conducted along an approximately 7 km reach of the River Spree in Berlin, extending from central city sections with dense traffic to more suburban portions of the corridor. A single longitudinal sampling transect was established, along which discrete measurement points were occupied sequentially. Figure 1 summarizes the transect and measurement design, with the color coding of points indicating near-bridge, between-bridge, tunnel-related, and dedicated vessel-noise locations. Red dots along the transect denote close-range bridge measurements, typically arranged at −100 m, −50 m, 0 m, directly under the bridge, +50 m and +100 m relative to the bridge centerline, with 50 m spacing between near-bridge locations. These sampling points were used to characterize source signatures and short-range decay patterns for individual bridges with different traffic mixes, including cars, S-Bahn and U-Bahn traffic, and regional rail. Blue dots represent longer-range transect measurements spaced at least 250 m apart between bridges. These provide a coarse description of how overall sound levels vary along the corridor and how far bridge- and vessel-related energy remains detectable away from the most

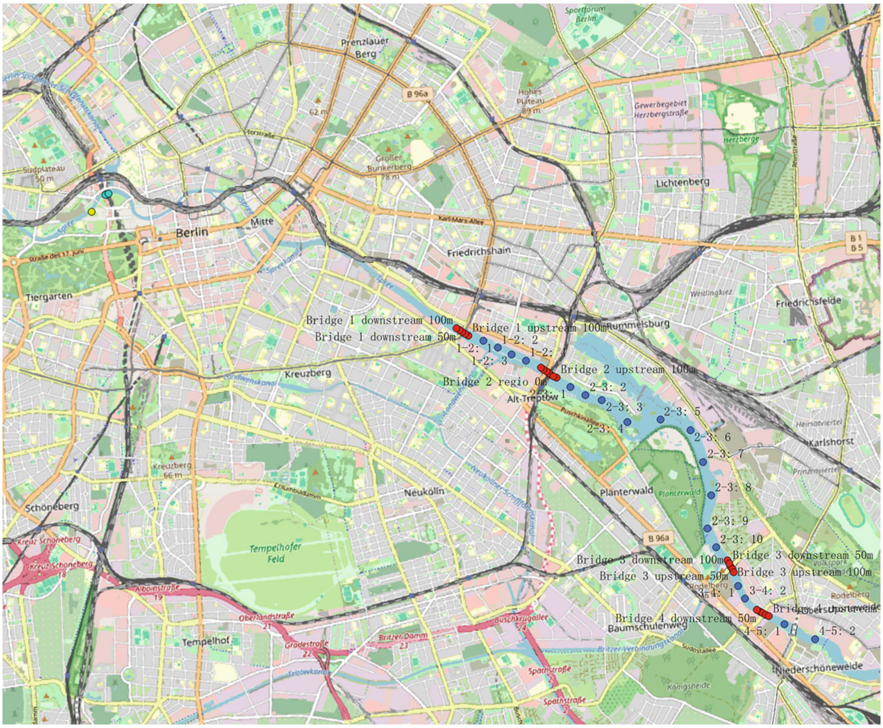

Fig. 1 Map of the River Spree transect showing measurement locations, basemap. (© OpenStreetMap contributors (ODbL)). Red dots: near-bridge measurements (50 m spacing). Blue dots: between-bridge transect points (≥250 m spacing). Cyan dots: tunnel-related measurement points near Berlin Central Station. Yellow dot: dedicated vessel-noise measurement site

intense sources. The transect crosses four bridges with different structural forms and traffic combinations, including road-only bridges, mixed road-urban rail crossings, and bridges carrying regional rail. Cyan dots near Berlin Hauptbahnhof (top left of map) denote locations above tunnels where both road traffic and U-Bahn trains pass beneath the river. These locations were used to characterize tunnel-borne noise. The yellow dot nearby marks the site where dedicated vessel-pass measurements were obtained near a river bend with intensive tourist boat traffic.

Water depth was measured at each location. Across all sites, depth ranged from 2.8 m to 3.6 m, with a mean of 3.1 m. This shallow-water regime is important for interpreting propagation and the observed low-frequency cutoff.

Instrumentation and Deployment

Acoustic data were acquired using a Brüel and Kjær Type 8105 spherical hydrophone with a nominal receiving sensitivity of −205 dB re 1 V/μPa, connected to a

RESON EC6081 mk2 preamplifier and recorded with a ZOOM H6 digital recorder at a sampling frequency of 44.1 kHz. Signals were stored as uncompressed WAV files. Real-time monitoring via headphones was used throughout the survey to adjust gain settings to avoid clipping while maintaining adequate dynamic range.

During pontoon-based measurements along the transect, the hydrophone was suspended approximately 1 m below the water surface. The cable was routed down the pontoon ladder and decoupled using a sponge and cable ties to reduce mechanical coupling and flow-induced motion. A small weight of about 100 g was attached to stabilize depth and limit cable strumming. Gain settings were typically 40 dB at the preamplifier with an additional zoom gain of -14 dB on the recorder, except at the dedicated vessel-noise site where the pre-amp gain was reduced to 20 dB to accommodate higher expected levels at close range.

For tunnel measurements near Hauptbahnhof and dedicated boat recordings, similar deployment geometries were used: the hydrophone was maintained at roughly 1 m depth and 1 m from the bank using a rigid pole, again with mechanical isolation between pole and cable. Throughout the survey, notes were taken on visible and audible sources, including type of vehicle, direction, and apparent speed, as well as potential artifacts such as chain noise from nearby moorings.

Source Categories

Four major source categories were identifiable in the recordings and are the focus of this chapter: road traffic on bridges, rail traffic on bridges, rail traffic in tunnels beneath the river, and sightseeing vessels. The following sections describe the spectrogram characteristics of each category, with emphasis on event-level root-mean-square (rms) SPL, frequency content, and qualitative propagation behavior.

Source-Specific Observations and Spectrogram Descriptions

Road Traffic on Bridges

Figure 2 shows the spectrogram (up to 5 kHz) of a 60 s recording obtained directly beneath Bridge 4, Stubenrauchbrücken, which carries road traffic. Individual vehicle passages appear as short, approximately 1 s broadband events extending up to about 2.5 kHz, with clearly identifiable low-frequency components below 100 Hz. The highest measured event-level SPL (all event-level SPLs in this chapter are given as rms levels) in this sequence was approximately 152 dB re 1 μPa. Each event corresponds primarily to tire-road interactions and structural responses as vehicles pass over bridge piers and deck joints. Because the hydrophone was located between piers, it was not possible to attribute individual events to specific piers; instead, the sequence represents repeated excitation as vehicles traverse multiple pier bays.

Given typical urban speed limits and bridge length, one vehicle is likely to take several seconds to traverse the bridge. It is therefore reasonable to interpret each

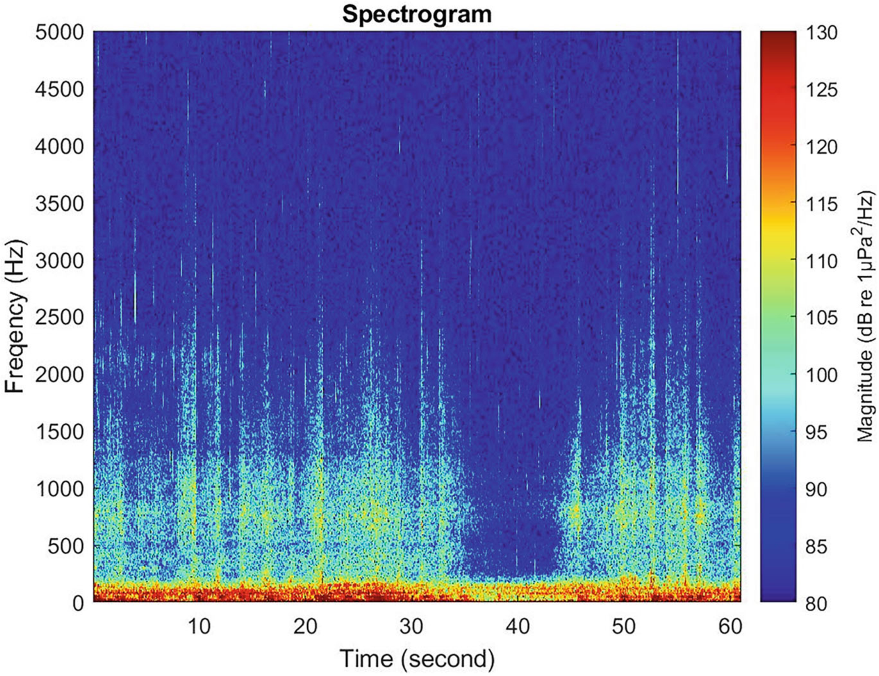

Fig. 2 Spectrogram of 60 s recording beneath Bridge 4 (road traffic only). Short (~1 s) broadband events correspond to individual vehicle passages, with energy up to ≈2.5 kHz and dominant low-frequency components below ≈100 Hz. Maximum event-level SPL ≈152 dB re 1 µPa

roughly 1 s event as a vehicle crossing a structurally significant discontinuity, such as an expansion joint or pier support, which maximizes structure-water coupling. With appropriate traffic count data, cumulative exposure metrics such as hourly equivalent continuous levels could be estimated by combining event-level sound levels and occurrence rates, though this is not pursued here.

Rail Traffic on Bridges

Urban Rail on Mixed Road-Rail Bridge

Figure 3 presents a 60 s spectrogram from directly beneath Bridge 1, Oberbaumbrücke, which carries both U-Bahn (underground commuter trains) and road traffic. As in Fig. 2, car passages appear as short, broadband events. Superimposed on these is a longer-duration, predominantly low-frequency event associated with a U-Bahn train. The U-Bahn passage extends over several tens of seconds and is characterized by elevated energy below about 1 kHz. The maximum event-level SPL during this recording was approximately 155 dB re 1 µPa. During fieldwork, U-Bahn noise was audible underwater before the train reached the bridge span, suggesting that vibration propagated along tracks and supporting structures and coupled into the river via the

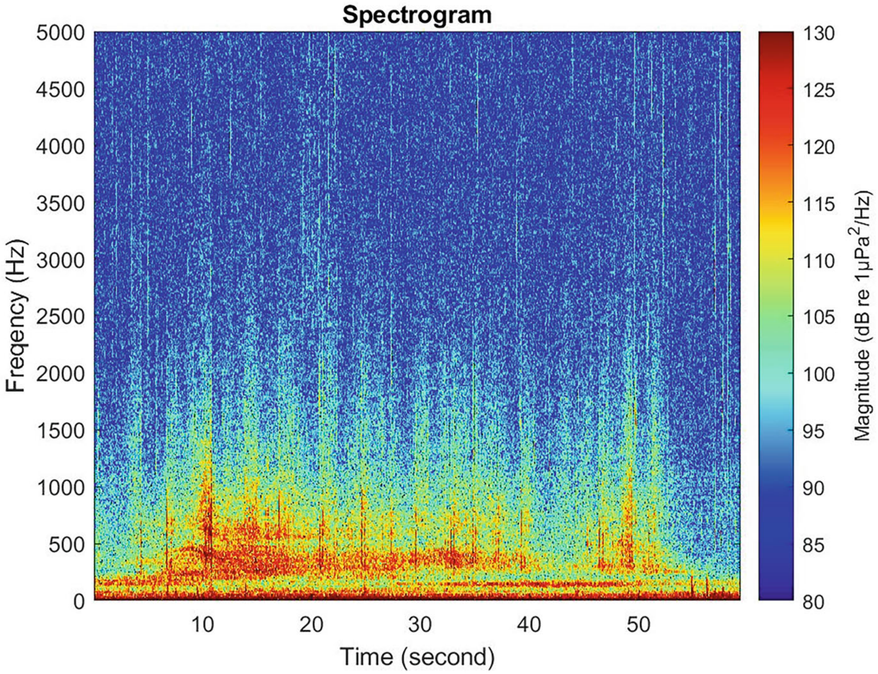

Fig. 3 Spectrogram of 60 s recording beneath Bridge 1 (mixed U-Bahn and road traffic). Short broadband events correspond to car passages, while a longer, low-frequency band (<1 kHz) represents a U-Bahn train. Maximum SPL ≈155 dB re 1 μPa

piers ahead of the train's physical crossing. This is consistent with tunnel and bridge studies reporting that vibration can travel along rails and structures beyond the immediate vehicle location before radiating into water (Song et al. 2024).

Comparison of S-Bahn and Regional Rail on a Tied-Arch Bridge

Figure 4 presents a 75 s spectrogram recorded beneath Bridge 2 (Parkwegbrücke, a tied-arch structure carrying regional rail traffic), containing an S-Bahn (surface commuter trains) passage between 0 and 20 s followed by a regional train (DB Regio) passage between about 50 and 75 s. The acoustic signatures differ from Fig. 3, reflecting both differences in vehicle type and structural form, as Parkwegbrücke does not have intermediate piers standing directly in the river. Both events are broadband with dominant low-frequency components, but the S-Bahn passage produced a higher maximum SPL of approximately 166 dB re 1 μPa, compared to about 161 dB re 1 μPa for the regional train. Several factors may contribute to this difference. Local commuter trains such as the S-Bahn typically operate with high service frequency and frequent acceleration and braking, which may increase dynamic wheel-rail interaction forces. In contrast, regional trains are often optimized for smoother, higher-speed intercity travel, potentially associated with stricter track maintenance standards. Differences in train mass, bogie

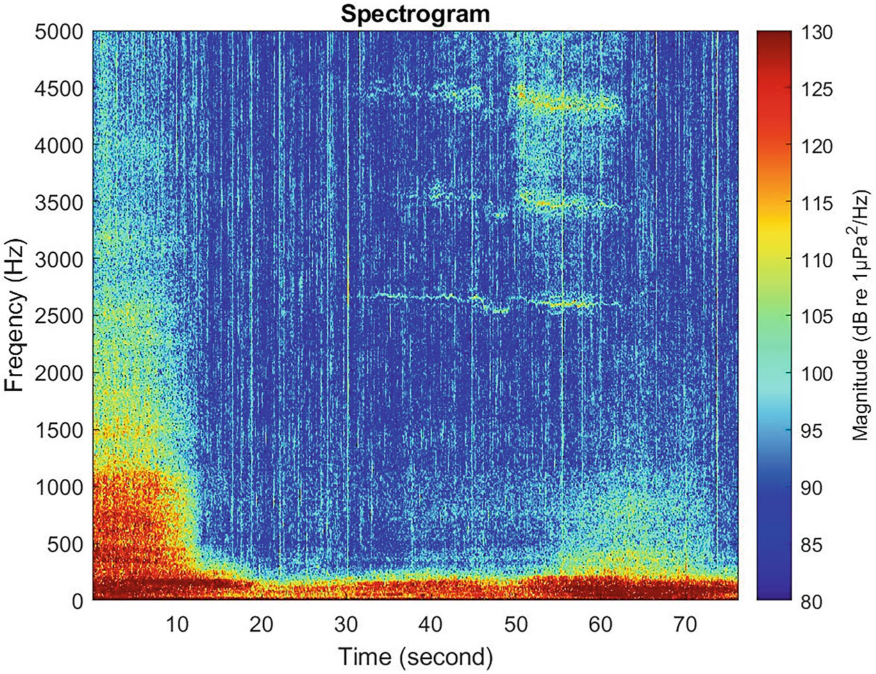

Fig. 4 Spectrogram of 75 s recording beneath Bridge 2 with an S-Bahn passage (at 0–20 s) and a regional train passage (at ≈50–75 s). The S-Bahn event produces a higher maximum SPL (≈166 dB re 1 μPa) than the regional train (≈161 dB re 1 μPa). Narrowband features at ≈2.5, 3.5, and 4.5 kHz may reflect non-acoustic interference

(wheel frame) design, and wheel condition could also play a role. At present, these explanations remain hypotheses; systematic joint measurements of structural vibration and underwater sound would be required to test them.

In Fig. 5, narrowband tonal features are also visible near 2.5, 3.5, and 4.5 kHz. Given the frequencies involved and their persistence across other broadband events at different sampling sites, these components may be related to electromagnetic interference or electronic systems rather than direct acoustic radiation in water. Signs warning of high-voltage cables underground were observed at some sampling sites. The use of piezoelectric hydrophones means that such interference cannot be completely excluded and should be considered during interpretation.

Rail Traffic in Tunnels Beneath the River

Figure 5 illustrates a 350 s spectrogram recorded above the U55 metro line near Berlin Hauptbahnhof, where the tunnel passes under the river. Three U-Bahn passages are visible. Compared with bridge-borne trains, several differences are apparent. Individual events last around 15 s, shorter than many bridge passages,

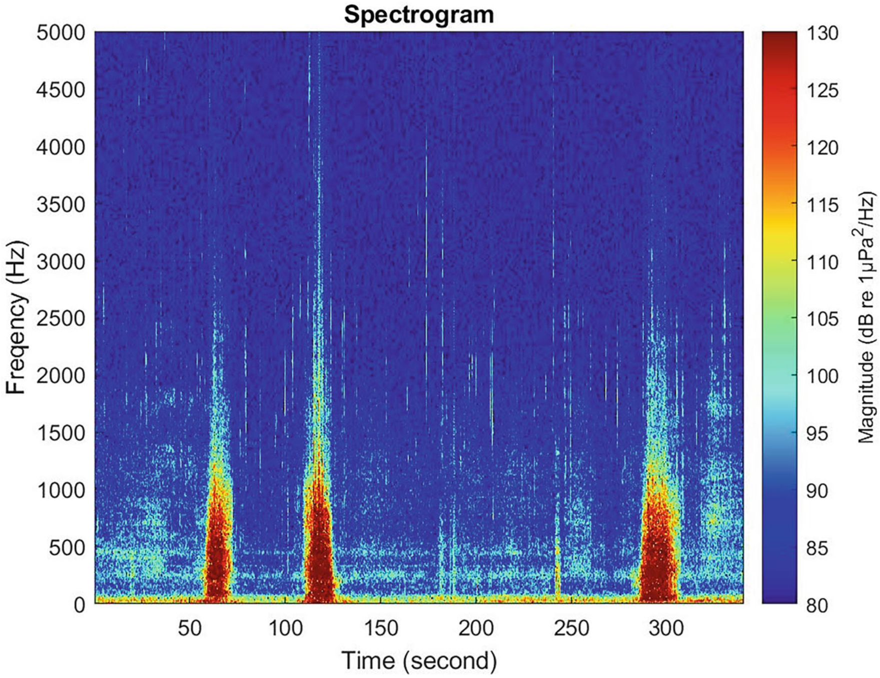

Fig. 5 Spectrogram of 350 s recording above the U55 line. Three U-Bahn passages (at 60 s, 110 s, and 280 s, respectively) are visible, each with ≈15 s duration and strong energy below 1 kHz. Maximum SPL ≈174 dB re 1 μPa

which may reflect a more compact structural coupling region associated with the tunnel segment nearest the river. The strongest event reached approximately 174 dB re 1 μPa, higher than any bridge-related train event observed in this campaign. All three passages exhibit similar spectral shapes, with energy concentrated below 1 kHz. These observations are consistent with tunnel studies that show strong, low-frequency radiation into overlying water, driven by vehicle-induced vibration of tunnel linings and surrounding sediments (Song et al. 2020, 2024). The combination of high event-level SPL and relatively short duration suggests that tunnel sections directly beneath rivers can constitute acoustic hotspots, even where surface activity appears quiet.

Vessel Traffic Along the River

Figure 6 shows a 39.5 m sightseeing vessel (Phantasia) passing the dedicated measurement location (hydrophone at 1 m depth and 1 m from the bank), with closest approach of approximately 11 m. The maximum received level at closest approach was approximately 172 dB re 1 μPa. The signature contains broadband propeller-related cavitation energy and tonal components associated with machinery

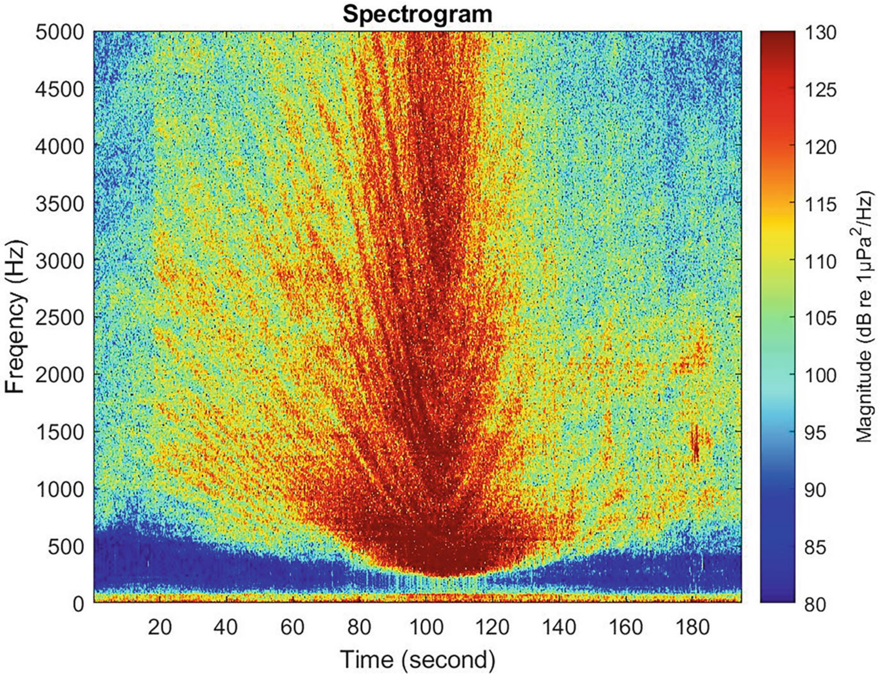

Fig. 6 Spectrogram of a 39.5 m sightseeing vessel (Phantasia) passing at ≈11 m closest approach. Broadband cavitation noise and engine-related components are visible. Maximum SPL ≈172 dB re 1 μPa. A pronounced low-frequency cutoff is evident below ≈125 Hz, with strong attenuation up to ≈500 Hz in this ≈3 m-deep waveguide

and hull vibration. A clear interference pattern consistent with Lloyd's mirror is evident, reflecting superposition of direct and surface-reflected paths as range changes.

A pronounced shallow-water low-frequency cutoff is visible, with little stable energy below 125 Hz despite expectations of strong low-frequency output from propeller and engine sources. This is consistent with modal limitations in a shallow river waveguide: energy below cutoff is largely evanescent and decays rapidly with range, while additional losses from boundary and sediment interaction can extend significant attenuation into bands above the formal cutoff. The relative reduction in energy up to 500 Hz further suggests that, in this confined geometry, frequencies with wavelengths comparable to the water depth can experience high propagation loss. The increase in level at 20 s corresponds to a change in vessel-receiver geometry as the boat emerges from a bend and a more direct propagation path becomes available.

Figure 7 depicts a 5-min spectrogram containing three sightseeing vessel passages at the same measurement location. Maximum received levels were approximately 177, 181, and 175 dB re 1 μPa for the three events, respectively. All passages exhibit strong energy below 1 kHz, despite shallow-water filtering, with recognizable cavitation and engine-related components.

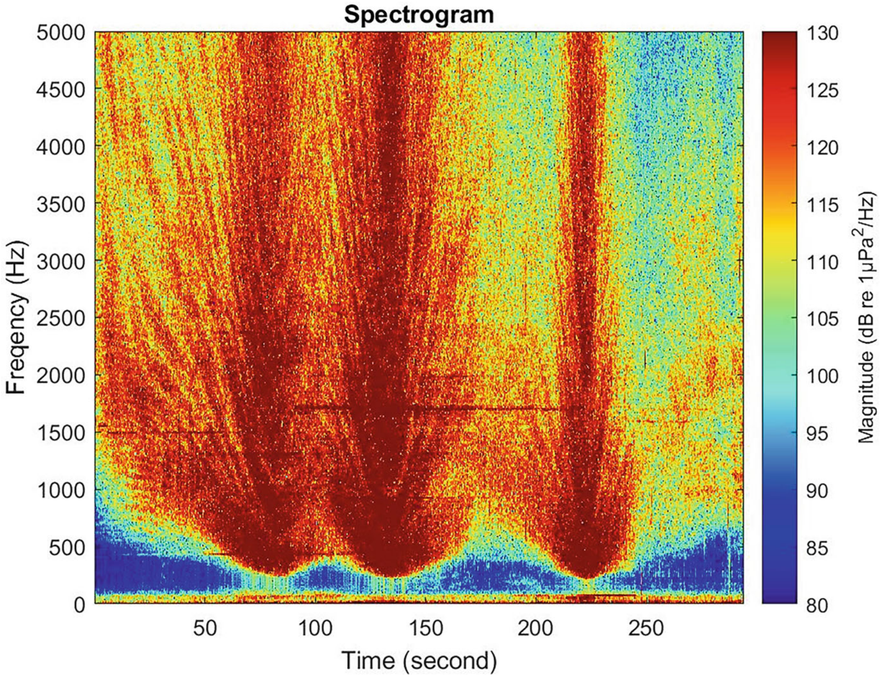

Fig. 7 Spectrogram of three sightseeing vessels passing within 5 min at the dedicated measurement site. Maximum received levels are ≈177, 181, and 175 dB re 1 μPa. Energy is concentrated below ≈1 kHz, with repeated high-level events over a short interval

From a soundscape perspective, the sequence in Fig. 7 illustrates that multiple high-level events can occur within a short time frame at popular tourist reaches. Even with shallow-water cutoff, the sub-1 kHz band, which overlaps the hearing range of many fish species, is repeatedly and strongly excited. The detailed temporal and spectral structure of such sequences will vary by site and season, but the example makes clear that vessel noise may be a major contributor to cumulative noise exposure in urban rivers, alongside land-based transport.

Discussion

Ubiquity of Transport-Related Underwater Noise in Urban Rivers

This River Spree case study indicates that land-based transport infrastructure and vessel traffic can together generate substantial underwater noise in a typical European urban river. Event-level SPLs in the 150–180 dB re 1 μPa range were observed for individual passes of cars, trains, and boats at close to moderate ranges, and short transect samples rarely fell below 140 dB re 1 μPa. Given the prevalence of rivers that are crossed and paralleled by dense rail and road networks in major cities, similar soundscape conditions are likely elsewhere. Yet underwater noise from bridges, tunnels, and local boat traffic is seldom treated as an explicit environmental variable in impact assessment, river corridor planning, or restoration, where attention typically focuses on physical barriers, flow, and water quality.

The results here support calls in the broader literature to treat underwater noise as an environmental variable in freshwater and estuarine systems, analogous to how acoustic metrics are used to characterize marine soundscapes and assess impacts on cetaceans and fishes (Martin and Popper 2016; Marley et al. 2016; Wang et al. 2021; Zang et al. 2023).

Shallow-Water Propagation and Low-Frequency Cutoff

The vessel spectra and shallow depths emphasize shallow-water waveguide physics. For a depth of around 3.1 m, the lowest-mode cutoff is on the order of 100–150 Hz; below this, energy becomes evanescent and attenuates rapidly, with additional losses from bottom interaction. Thus, even if a source radiates strong low-frequency energy, the received spectrum at modest ranges may be depleted below cutoff. Comparable behavior has been reported in the Hudson River, where monitoring suggested limited reliable information below 75 Hz at 5 m depth (Martin and Popper 2016).

This has practical implications for monitoring and assessment: criteria or expectations derived from deeper-water settings may not transfer directly to shallow rivers without accounting for cutoff and frequency-dependent loss. The observed attenuation up to 500 Hz further suggests that, in narrow shallow channels, even frequencies above cutoff can experience substantial propagation loss due to boundary and sediment effects.

Structural Versus Water-Column Sources

Bridge-borne and tunnel-borne rail events highlight that structure-borne sources can rival, or exceed, classic water-column sources such as vessel propellers. The maximum event-level SPL in this campaign (174 dB re 1 μPa) was associated with a U-Bahn passage in a tunnel beneath the river, rather than a vessel. High levels were also observed for bridge-borne rail traffic. These findings align with engineering studies showing that vibration in tunnels and bridges can radiate efficiently into water, particularly at low frequencies (Song et al. 2020, 2024; Reeder et al. 2020). In many urban rivers, traffic over and under the river follows predictable schedules, implying that structure-borne noise may be a frequent, and sometimes quasi-continuous, component of the soundscape. Mitigation options should therefore consider structural and operational measures (e.g., vibration isolation, track design and maintenance, and scheduling) alongside vessel-focused measures such as speed management, propeller condition and routing.

Potential Ecological Implications

Although no biological measurements were conducted, the observed levels and frequency content overlap with hearing ranges of many freshwater fishes and invertebrates. Hearing-specialist groups (including many otophysans) often show greatest sensitivity below 1 kHz, and many riverine species rely on acoustic and hydrodynamic cues for orientation, communication, and predator-prey interactions. Repeated high-level noise in these bands may plausibly contribute to masking, behavioral avoidance, or physiological stress. Evidence from large river systems indicates that elevated underwater noise can coincide with habitats used by sensitive taxa, reinforcing that noise can act as an additional pressure in already impacted freshwater ecosystems (Wang et al. 2021). In urban settings, bridges, tunnels, and rail corridors may function as "acoustic bottlenecks," producing reaches where underwater noise is systematically higher than adjacent habitat; whether these bottlenecks alter movement or habitat use for migratory species remains a key research question.

From a management perspective, these findings support incorporating underwater noise into river corridor planning and restoration. New bridges and tunnels should consider underwater noise prediction where rivers function as ecological corridors or support protected species, and existing tunnel/bridge modeling frameworks provide starting points but require adaptation to river geometry and substrate conditions. Restoration and green-infrastructure schemes could treat acoustic conditions as a design variable, for example through structural isolation of crossings, spatial separation of sensitive habitats from dominant sources, and operational measures where feasible (e.g., vessel speed management in high-traffic reaches). Finally, many relevant data streams already exist (rail timetables, traffic counts, vessel tracking where available, hydrological records); coupled with targeted acoustic measurements, these can support data-driven assessments and, ultimately, river noise mapping for cumulative exposure evaluation and mitigation prioritization.

Toward Three-Dimensional Propagation Modeling and River Noise Mapping

The complexity of propagation in shallow, engineered rivers implies that three-dimensional, range-dependent models will be required to predict underwater sound fields with sufficient fidelity for planning and ecological assessment. Insights from tunnel and bridge studies show that multi-physics models combining structural dynamics, sediment response, and acoustics can reproduce measured levels for specific projects (Song et al. 2020, 2024). Extending such models to longer river reaches and multiple source types will require careful abstraction and validation. A pragmatic approach is to develop detailed models for a small number of representative crossings to characterize their frequency-dependent source behavior, to couple these descriptions to simpler shallow-water models that account for depth and boundary changes along a reach, and to drive these models with operational data such as traffic intensity, vessel statistics, and water level. Such a framework would allow the construction of city-scale river noise maps that can be updated as operations and infrastructure evolve. Further refinement will depend on validation against longer-term measurements and, where possible, particle motion data, but the River Spree results already show that these tools are needed if underwater noise is to be considered alongside more traditional river management variables.

Conclusions

This chapter has presented a case study of underwater noise in the River Spree, Berlin, documenting acoustic signatures from road and rail traffic on bridges, rail in tunnels beneath the river, and sightseeing vessels. Event-level SPL values reached about 152 dB re 1 μPa for road vehicles, 161–166 dB for bridge-borne trains, up to 174 dB for U-Bahn in tunnels, and up to 181 dB for nearby sightseeing vessels. The observations highlight the pervasiveness of transport-related underwater noise in a typical European urban river reach, the strong influence of shallow-water propagation and low-frequency cutoff on received spectra, the significance of structure-borne noise from bridges and tunnels alongside classic vessel noise, and the need to integrate underwater noise into river corridor planning, conservation, and restoration.

While the study is exploratory and event-focused rather than long-term, it illustrates that underwater sound from land-based transport should not be neglected in assessments of freshwater ecosystems. Future work should combine extended monitoring, biological observations, and three-dimensional modeling to quantify ecological risks and support the design of quieter, more ecologically compatible urban river corridors.

Competing Interest Declaration The author(s) has no competing interests to declare that are relevant to the content of this manuscript.

References

Marley SA, Erbe C, Salgado Kent CP (2016) Underwater sound in an urban estuarine river: sound sources, soundscape contribution, and temporal variability. Acoust Aust 44:171–186

Martin SB, Popper AN (2016) Short- and long-term monitoring of underwater sound levels in the Hudson River (New York, USA). J Acoust Soc Am 139(4):1886–1897

Reeder DB, Joseph JE, Rago TA (2020) Underwater sound generated by motor vehicle traffic in an underwater tunnel. J Acoust Soc Am 148:EL215–EL220

Song X, Zhang X, Xiong W, Guo Z, Wang B (2020) Experimental and numerical study on underwater noise radiation from an underwater tunnel. Environ Pollut 267:115536

Song X, Yin L, Xiong W, Wu H, Cai CS, Li X (2024) Underwater noise prediction and control of a cross-river subway tunnel: an experimental and numerical study. Int J Environ Sci Technol 21: 4045–4062

Wang Z-T, Duan P-X, Akamatsu T, Chen Y-W, An X, Yuan J, Lei P-Y, Li J, Zhou L, Liu M-C, Yang Y-N, Fan F, Wang K-X, Wang D (2021) Riverside underwater noise pollution threaten porpoises and fish along the middle and lower reaches of the Yangtze River, China. Ecotoxicol Environ Saf 226:112860

Zang X, Carlson TJ, Martinez JJ, Lu J, Deng ZD (2023) Towards assessing the impact of anthropogenic sound on fishes: gaps, perspectives, and a case study of a large floating bridge. Fish Res 265:106747