REPORT

Measurements of underwater noise at floating bridges and ferries

CLIENT

The Norwegian Public Roads Administration

SUBJECT

Underwater acoustics – noise from floating bridges and ferries

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REPORT

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SUMMARY

In a hydroacoustic risk assessment context, acoustic noise has been recorded emanating from the floating Nordhordlands Bridge, from the diesel-electric ferry (Valestrand – Breistein), and from the hydrogen ferries across Bjørnafjorden - E39.

Analysis of the recorded noise shows that the acoustic profiles from the ferries and from the floating bridge are distinctly different. The dominant source of acoustic noise around Nordhordlands bridge is related to boat traffic from ferries and fishing boats, not from traffic on the bridge itself. This causes the bridge to emit a comparatively small amount of noise, which cannot statistically be distinguished from background noise. The ambient noise has a daily average of approximately 100 dB re 1 μPa^2, with a 5 dB variation between day and night.

The noise from the ferry traffic across Bjørnafjorden is mainly related to engine and propulsion sounds, which can be described as broadband noise source with a strength of approximately 173 dB re 1 μPa^2 @1 m. The source can be perceived by marine life at distances up to 14 km and can potentially influence the entire fjord system around Bjørnafjorden. The noise from the Bjørnafjorden ferries is predominantly within the frequency range 50 – 150 Hz, which corresponds to standard ship noise (RANDI 3.1C), showing that this particular model is well suited for further use in acoustic studies of ferry traffic in the region.

In a life cycle perspective, ferry traffic causes a greater acoustic impact than floating bridges, except in the construction/decommissioning phases of the latter, which are characterized by noise from blasting, piling, construction traffic and machinery.

A more detailed study on acoustic noise impact on the vulnerable ecosystems should be carried out, detailing time-varying source terms for both types of infrastructures. Generally, one should require that construction in the coastal zone is complemented by strategies for noise monitoring and mitigating measures, ensuring that marine biological diversity is safeguarded to the greatest extent possible.

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1 Introduction

In 2021/22, a study of the environmental impact of floating utility structures was carried out by NINA [1]. After the study, SVV wanted to carry out measurements and further assessments of these noise conditions with the aim of increasing knowledge about biological environmental impact from floating bridges compared to other transport methods, such as ferry crossings.

Multiconsult and Quiet-Oceans proposed to carry out measurements at the Nordhordlands bridge (position 2 in Figure 1), just north of Bergen, and measurements of the diesel-electric Ro/Ro ferry Ole-Bull (trafficking Valestrand – Breistein in Sørfjorden, position 1 in Figure 1). Finally, it was suggested to characterize the ferry traffic (E39) in the form of the five Hybrid-LNG (Liquid-Natural-Gas) ferries that cross the Bjørnafjorden between Halhjem and Sandvikvåg (position 3 and 4 in Figure 1).

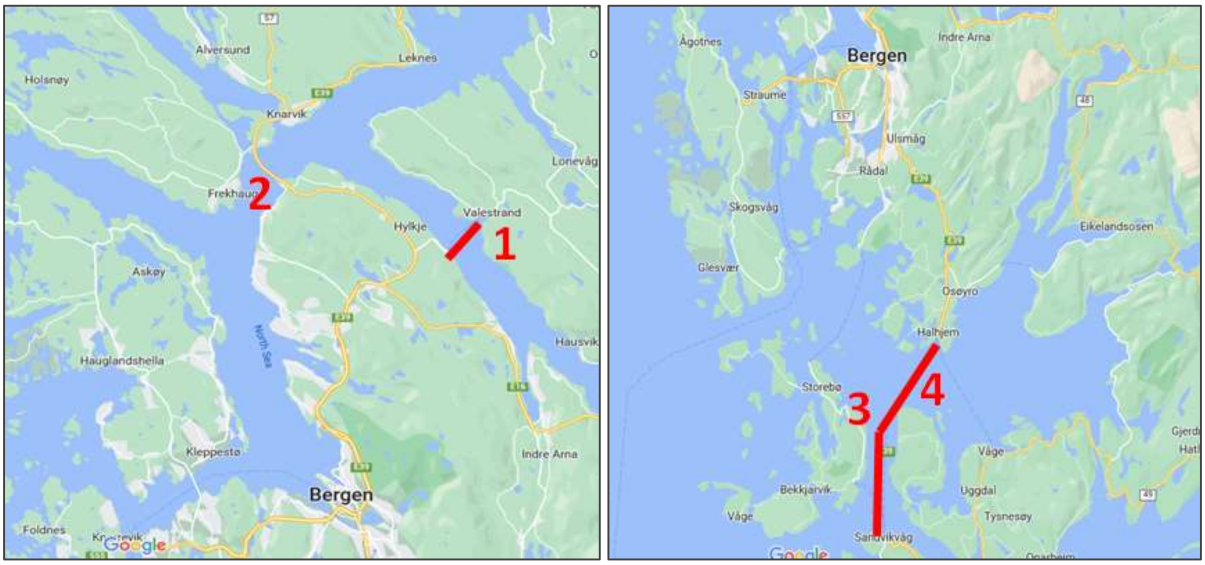

Figure 1. Overview map of the two areas investigated within this assignment. Left panel shows the area close to the Nordhordlands bridge (2) and the Valestrand – Breistein ferry (1). The right panel shows the Bjørnafjorden area where "3" marks the E39-ferries route, and "4" marks the planned ferry-free E39 crossing of Bjørnafjorden. (Figure 5 in Appendix A).

2 Method overview

The measurement program is divided into two parts.

The first part (LEG01) treats recordings from an acoustic measuring rig, deployed for 34 days at the Nordhordlands bridge, together with drifting measurements at the Nordhordlands bridge. In connection with this activity, noise form the ferry Ole Bull in Sørfjorden was recorded. This part of the assignment is detailed in Appendix B, which includes the measurement program, technical instrument descriptions and rigging diagrams.

The second part (LEG02) comprises noise recordings from another set of drifting measurements at the bridge, and another set of drifting measurements a the Bjørnafjorden E39-ferries. A similar hydroacoustic rig, as the one in used for Ole Bull during Leg01, was deployed in Bjørnafjorden. This part is detailed in Appendix C.

Appendix A includes an analysis of all the measurements, a description of the methodology and subsequent interpretations. The interpretations are based on international guidelines for acoustic noise in the sea and highlight individual sources charactering the ferries and the noise from the Nordhordlands bridge. Acoustic risk is discussed for all the risk levels (permanent and temporary damage, changed behaviour and masking of sounds). Noise generated during the construction phase (construction noise) and noise generated under operational conditions are considered. A ranking of the noisiest activities and sound sources has been made, and possible mitigating measures are outlined.

Quiet-Ocean's report (Appendix A) includes a model comparison of underwater noise from floating bridges and ferries where the noise sources are characterized based on measurements. Corresponding noise source characteristics were evaluated during this project.

This report includes a comparison of noise from bridges and ferries, as well as a discussion where measurements and model data are put into a local perspective with respect to fish, birds and marine mammals and implications for local wildlife.

3 Data material

3.1 Valestrand-Breistein

At the Valestrand – Breistein location, an acoustic rig was deployed at a fixed position with one hydrophone placed approximately in the middle of the water column (see Figure 8 in Appendix A). This data comprises 6 passages of the diesel-electric ferry Ole Bull crossing the Sørfjorden. In addition, four drift measurements were carried out with a separate hydrophone lowered from the boat as the ferry crossed the fjord.

3.2 Bjørnafjorden

In Bjørnafjorden, a procedure identical to the procedure at Valestrand-Breistein was carried out. The resulting data comprises 8 passages of the five hybrid LNG ships Flatøy, Færøy, Lysøy, Huftarøy and Samnøy. The drift measurements in Bjørnafjorden were carried out in the same manner as for Ole Bull and ended up with a total of 3 passages.

3.3 Nordhordlandsbrua

At the Nordhordlands bridge, an acoustic measurement rig with 2 hydrophones was deployed for 34 days at the southern end of the bridge (see Figure 11 in Appendix A). In addition, drift measurements were carried out at different pontoons during the two different legs (deployment/LEG01 and recovery/LEG02). This gave a total of 9 drift measurements at the bridge.

The 34-day data sequence from the Nordhordlands bridge provides a data base for a statistical description of noise in the water around the bridge. The hydrophones recorded sounds from both traffic on the bridge and from passages of ships and boats under the bridge.

4 Results

4.1 Ferry

The measurements show that the five hybrid LNG vessels are almost acoustically identical, both in amplitude and in frequency content, and have a broadband source character with a strength of 173 dB re 1 μPa^2@1m (see Figure 17-18 and Table 6-7 in Appendix A). Ole Bull has approximately the same source strength when approaching the harbour at slow speed, but the significantly higher source strength of 196 dB re 1 μPa^2@1m when it is running at high speed out on the fjord (see Figure 19 and Table 8 in Appendix A).

The Bjørnafjord ferries have a dominant signal content with frequencies between 50-150 Hz and agree with a standard model for acoustic ship noise (RANDI 3.1C [2]) for frequencies above 100 Hz. This emphasizes that this model provides a conservative consideration and is suitable as a well-tested parametrization of vessel noise for future work.

The frequency characteristic of Ole Bull is slightly different to that of the five E39 ferries in Bjørnafjorden. The acoustic spectra around Ole Bull shows a high peak at 1 kHz, most likely connected to the electric propulsion. There is a large difference in the lower part of the frequency band (< 100 Hz) when the ferry is going full throttle versus when it is approaching the port area. The spectral difference measured in 1-Hz bands is more than 40 dB re 1 μPa^2/Hz which corresponds to a broadband strength difference of approximately 26 dB re 1 μPa^2. This, in turn, corresponds to an increase in source strength by a factor of approximately 20. This shows that if a meaningful mapping of acoustic risk is to be carried out for ferry traffic, the operational conditions should be correctly defined, and representative operational profiles must be used as a basis for the analysis.

4.2 Floating bridge

From the 34-day data sequence at the Nordhordlands bridge, a statistical overview has been made of how often different noise levels occur and what the daily variation is. In summary, the mean and median values are slightly above 100 dB re 1 μPa^2, with a 5 dB variation between day and night (see Figure 26 in Appendix A). These are normal background levels, compared to other places in Europe, and are mainly attributed to weather conditions (noise from wind and waves), so called ambient noise. The parts of the spectrum elevated with respect to the ambient noise can be traced to noise from ship traffic are confined to the frequency band 80 – 200 Hz, and those originating from traffic on the bridge are located to the frequency band 8 – 30 Hz (see e.g., Figure 29 in Appendix A). Perhaps the most important finding from this measurement is that specific traffic passages cannot be extracted with statistical significance so that it becomes impossible to identify specific sources of the actual traffic on the bridge. Although acoustic traces of individual traffic passages can be identified in the data, they do not differ significantly from the ambient noise from wind, waves, boat traffic and the bridge's own sounds.

For the Nordhordlands bridge (and especially pontoon 3), traffic produces a secondary broadband rattling sound, which is probably due to some loose parts on the bridge. We suspect that it is a loose metal plate that "jumps" when the cars drive over it, creating a broadband noise peak. The magnitude of the rattling sound is around 167 dB re 1 μPa^2, almost as strong as the sound from the ferries, but the rattling sound lasts less than 5 seconds (see Figure 29 in Appendix A).

Sound from several other ferries and fishing boats could be detected and compared to route plans and schedules. The high-speed ferry, Fjordkatt, was identified in the data with a typical source strength of around 145 dB re 1 μPa^2 spread out over frequencies from 50 Hz to 4 kHz.

The other major finding from this measurement is that the energy passages of smaller boats, ferries, and other sea traffic accounts for the bulk part of all sound energy detected in the vicinity of the bridge (see Figures 32-33 in Appendix A). The data indicate that if the bridge structure is made robustly and has no structural/material defects, for example loose metal plates, the acoustic (and mechanical) link between traffic and the produced noise levels in the sea is weak. Hence, traffic on the bridge will produce insignificant direct noise emissions in the sea.

A summary of the source strengths and frequency distributions of the various sources (ferries and the rattling noise at the Nordhordlands bridge) is shown in Figure 2. Above 100 Hz, the noise level from the floating bridge is approximately 20 dB lower than the noise from all types of ferries. For lower frequencies, the noise level is the same, except for Ole Bull with full throttle.

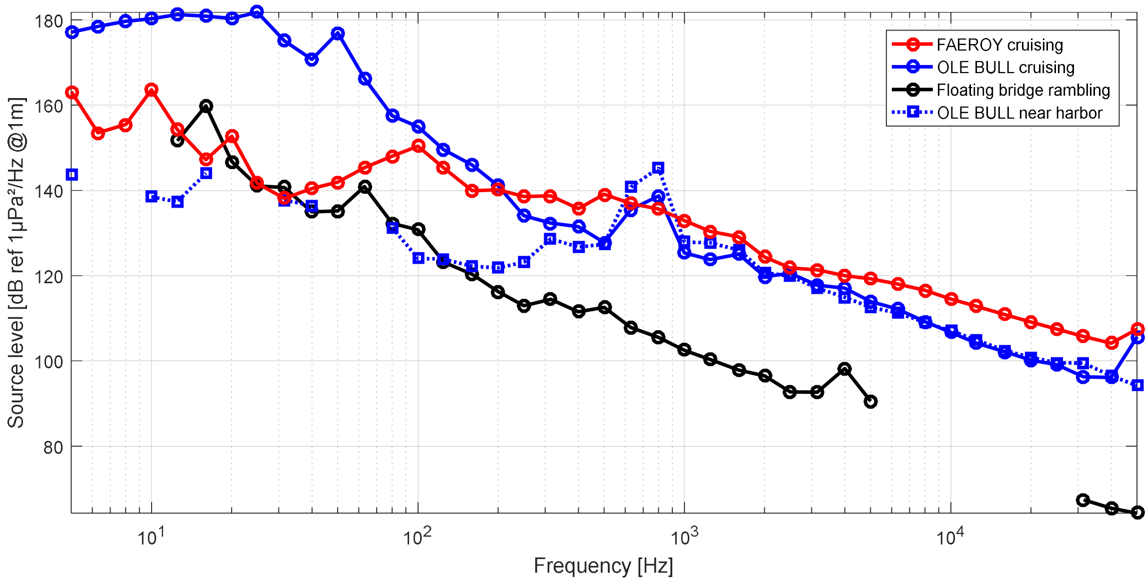

Figure 2. Synthesis of source strength calculations for the various types of ferries that have been measured and characterized within the assignment in relation to the maximum noise source from the Nordhordlands bridge (rattle sound from loose metal plate). (Figure 56 in Appendix A)

4.3 Acoustic environmental impact

Acoustic impact on wildlife is not internationally well established and there are many different standards for how each individual country, region or continent handles the problem. The approach is almost always based on threatened species, for example red-listed species or other conservation measures. An established international risk scale for acoustic impact has been drawn up (see Figure 3). In this case, we use it for acoustics, but it applies to light (electromagnetic fields), sound and vibration both on land and in the sea, and we will probably see many variations of this in future development projects.

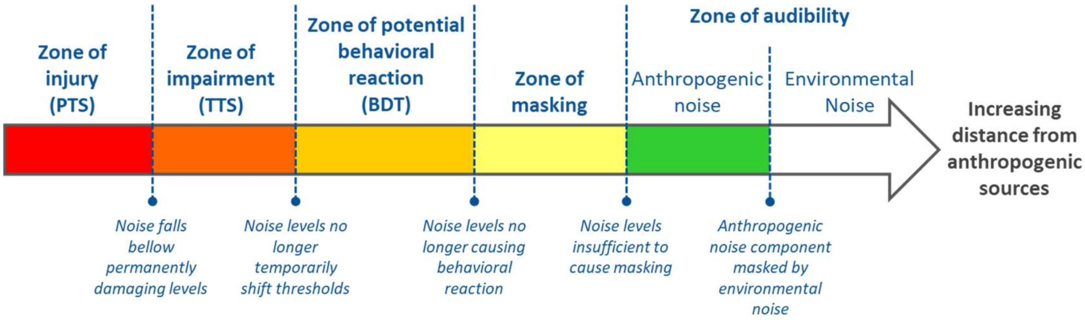

Figure 3. The various risk areas for anthropogenic acoustic environmental impact of wildlife. (Figure 34 in Appendix A).

The assessment for which zone is most important for each specific species depends on the location and type of noise. Most often, the construction phase has the greatest impact (red risk zone with permanent damage) because of impulsive blasting or intense piling. The temporary risk zone can be reached during several phases, but it is often the construction phase that has a dominant effect within this zone. The zones with lower risk, regarding changed behaviour and masking are naturally affected from the construction phase, but here the operational phase begins to play a greater role as this often extends over significantly longer periods. These effects are often underestimated and even if the changes in the environment are small in a human perspective, they can be monumental on scales relevant to organisms that are dependent on an acoustically quiet environment to find food, find a partner or to communicate between individuals.

4.3.1 The constructional phase

The constructional phase is often characterized by loud noises and high energy levels over shorter time periods. It often involves blasting, piling or the installation of secondary structures that generate strong noise. Particularly impulsive noises from piling and blasting can cause damage to hearing organs if the animals are too close to the construction site. For this phase the greatest risk is most likely linked to "temporary loss of habitat" if the noise levels become too high for the organisms in the area to endure. This can be exemplified through the development of offshore wind at Helgoland in the southern North Sea [3], just north of Germany and Holland (see Figure 4). It is shown that the sightings of porpoise are significantly reduced within distances of more than 20 km from the piling site. However, the animals return to the area, after the temporary displacement, within a few weeks or months, depending on the species, location, type, and magnitude of disturbances.

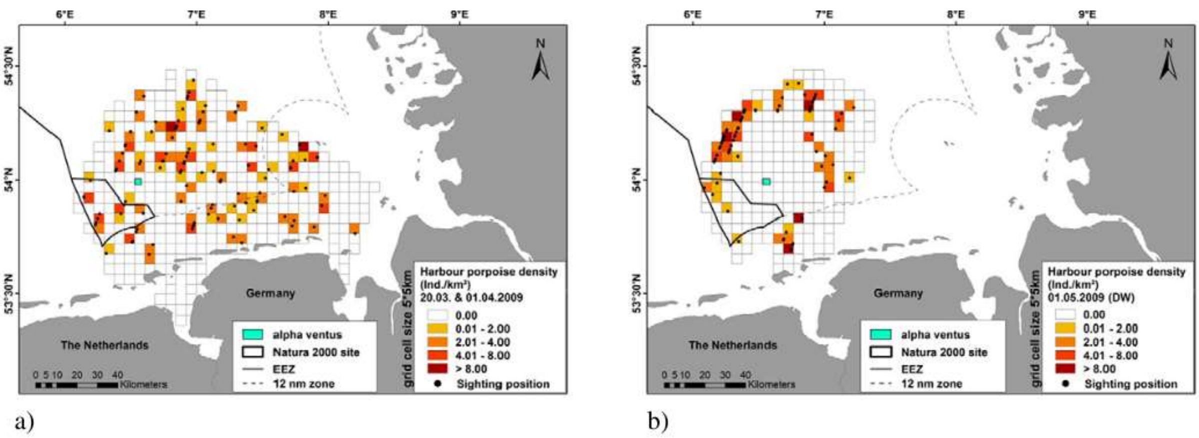

Figure 4. Spatial distribution of porpoise registrations. (a) Pre-piling in March/April 2009 and (b) during pling. Source: [3], Figure 35 in Appendix A.

There are most likely many more risks in the construction phase that have not been observed or have been possible to observe if other effects in the more acute risk-zones dominate. What is certain is that noise during the construction phase should be classified to have a temporary or transient impact. The fundamental question is how long the term "temporary" is in relation to the affected species and the surrounding ecosystem. This will probably vary greatly and might be challenging to quantify.

The construction part of a ferry connection is generally limited to the harbour/quay in a small area close to land. Here, there can be a strong local impact, but in these locations, it is often easier to arrange mitigating measures to reduce the acoustic impact. In addition, the acoustical impact from construction works in urban environments is generally strongly regulated, as they have a major effect on the well-being of people living in or close to the construction site.

4.3.2 The operational phase

The operational phase generally has a lower acoustic impact on the environment and rarely falls into the PTS zone (if this was the case, it would be completely unacceptable from an environmental perspective). In the same way as for the constructional phase, the operational phase can affect the ecosystem over a long period without any acute or directly detectable consequences, since it can be difficult to ascertain small (but significant) changes in the environment that affect a wide range of organisms.

We see from the observations at the Nordhordlands bridge that traffic on floating bridges most likely has little effect on the environment in the immediate area around the bridge itself. The most noticeable noise component attributed to bridge traffic was the intermittent rattling sound from a loose metal plate, which can most likely be easily fixed.

In the measurements from the Nordhordlands bridge, it appears that there are other sources (ferries, fishing boats and other sea traffic) that dominate the noise picture around the bridge. These sources have most likely never been scrutinized or weighed against ecological effects or other indicators, since they have been a natural component many coastal landscapes for a long time.

For the large ferry-line across Bjørnafjorden (E39), the propulsion-type of acoustic broadband noise becomes dominant. This is partly because the ferries are larger than the boats around the Nordhordlands bridge, but they also run more or less continuously around the clock.

Calculations show that marine species (dependent species) can perceive ferry traffic at around 14 km, while typical sounds from a floating bridge may only be perceived a few kilometres from the bridge itself (Figure 5 and 6). For the risk zone 120 – 140 dB, less “behavioural change” or “masking” is expected. This effect is almost negligible for the floating bridge (around 30 m), while it extends approximately half a kilometre from a ferry of the type that traffics Bjørnafjorden, see Figure 5.

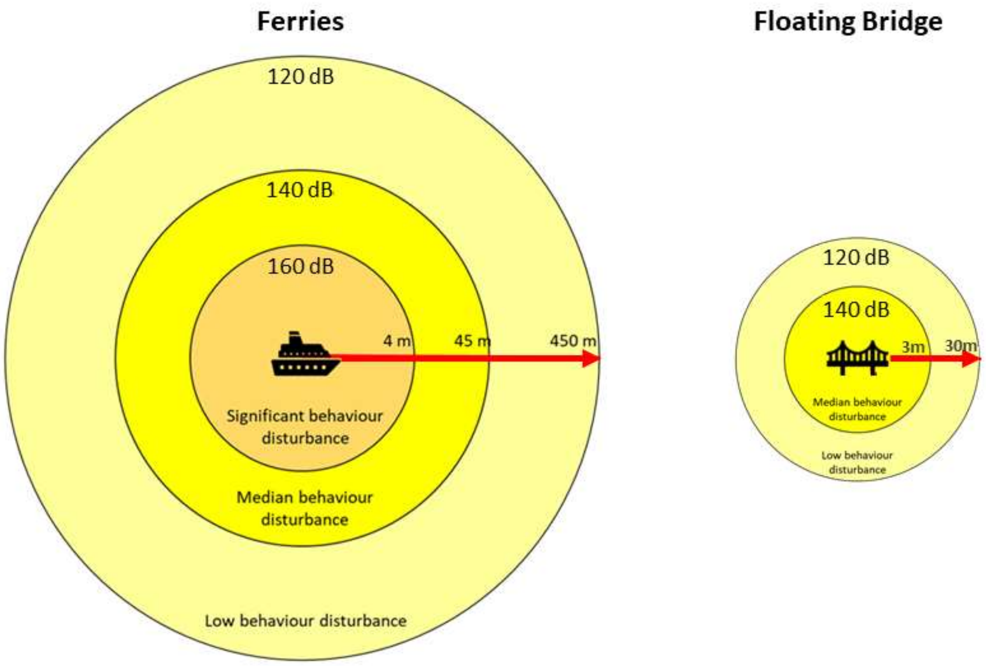

Figure 5. Illustration of the range for risk zones for acoustic noise induced by a ferry (left) and by a floating bridge in the operating phase (right). Note that the distances are logarithmically scaled (adopted from Figure 38 in Appendix A)

This shows that the E39 ferry-connection has an acoustic impact on the entire Bjørnafjorden system, including large parts of Kors- and Lysefjorden in the north to Selbjørnsfjorden and Langenuen in the south. It should be noted that this does not cause direct harmful effects on marine species in the area, but the sound is perceivable if the background noise is low enough.

Figure 6 shows the theoretical boundaries for the extent of audible noise from ferries (left panel) and the bridge (right panel). Mainland, islands, islets, and reefs will shield against the propagation of sound. The real outer boundary will follow the land contour, this applies especially to the ferry connection (right panel).

The operational phase can, in the same way as the constructional phase, cause “habitat loss”. In contrast to the constructional phase, the impact of the operational phase will be present until the bridge/ferry line is taken out of service.

Collisions between ferries and marine mammals, may not be a big problem in the Bjørnafjorden area. But since the speeds of typical ferries were recorded to 14 – 18 knots, a collision between a whale and a ship would nevertheless pose a fatal risk for the animal. In comparison, a floating bridge of the Nordhordlands bridge will only cause a local acoustical impact in a smaller part of Bjørnafjorden, and quite naturally, a bridge will not imply a large collision risk for marine mammals.

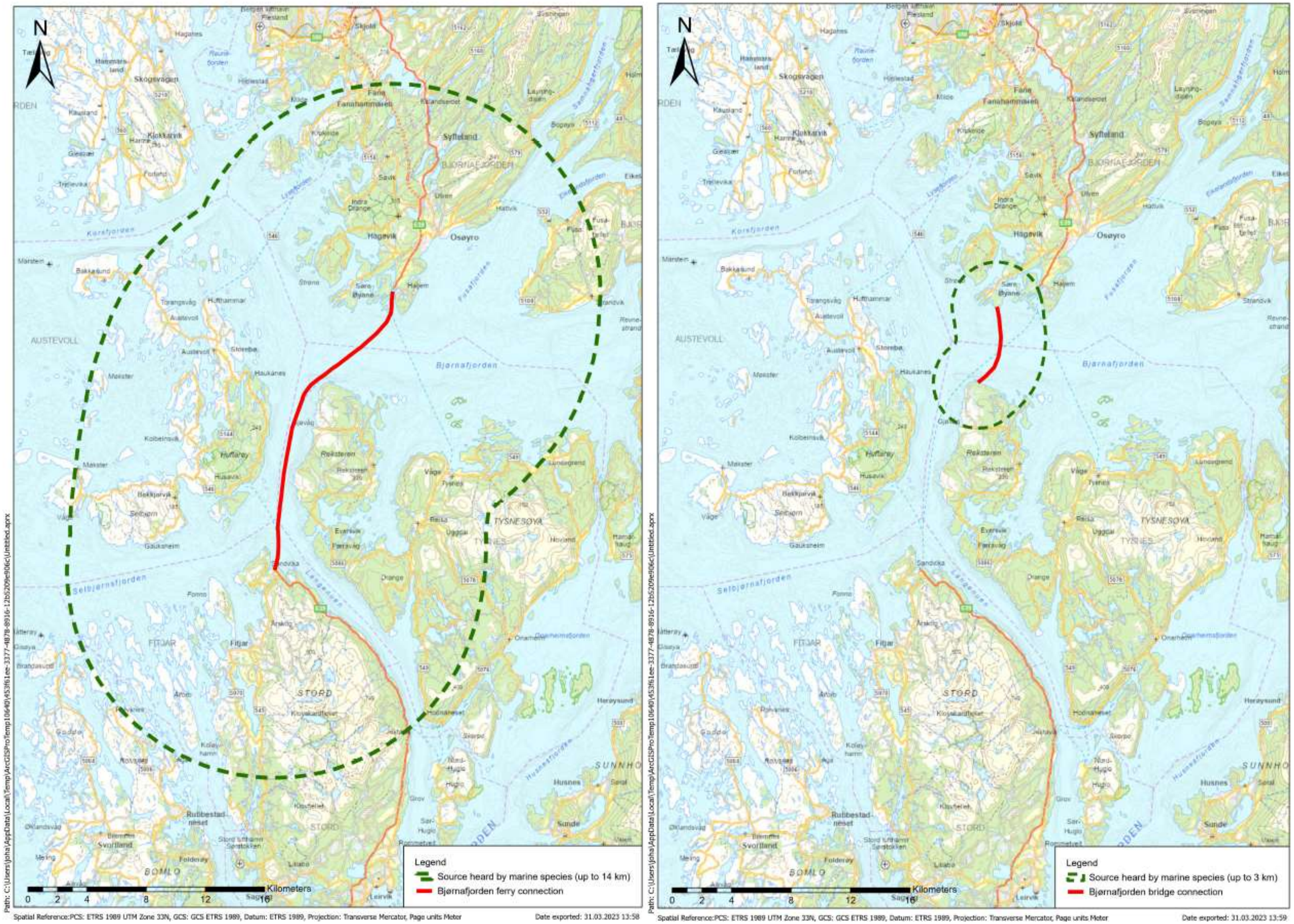

Figure 6. Outer limits for where it is expected that marine animals will perceive noise from ferries (left) and bridge connection (right). Map: Multiconsult.

5 Relevance to local conditions

In the previous chapter, the results from the survey were assessed against general risk and risk distances for floating bridges and ferries in the constructional and operational phases. In this chapter we apply this knowledge to assess whether there are ecological risks for particularly vulnerable species in Bjørnafjorden or whether the noise could have negative effects for other sea-related activities in the area, e.g. the fishing industry or for spawning and nursery grounds.

5.1 Marine species

5.1.1 Fish

Based on information in the Directorate of Fisheries' database and map service Yggdrasil [4] it is assumed that the areas between Os and Fitjar are ecological functional areas for several commercial fish species (see Table 1, Figure 7 and Figure 8). Spawning grounds for cod have also been registered at Bjørnarøyosen in Os municipality and Larnøyosen in Austevoll municipality. The spawning period is from February to April for both areas. In addition, discoveries of red-listed fish species have been registered in the Norwegian Species Data Bank's map solution for folk research (species map [5]): eel (EN), common redfish (EN), turbot (VU) and salmon (NT), where EN= "Endangered", VU= "Vulnerable", NT= "Nearly Threatened" (Near Threatened).

The assessments made by Quiet-Oceans (see Appendix A) regarding fish is considered relevant based on the above.

Table 1. Functional areas and periods for commercial fish species, including times for when fishing takes place (X), in the crossing area for the current ferry connection across Bjørnafjorden (i.e. in Bjørnafjorden and Langenuen). Source: [4].

	Jan	Feb	Mar	April	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Saithe (Sei)	X	X	X	X	X	X	X	X	X	X	X	X
Cod (Torsk)												
Pollock (Lyr)	X	X	X	X	X	X	X	X	X	X	X	X
Ling (Lange)	X	X	X									X
Tusk (Brosme)			X	X	X	X	X	X				
Monkfish (Breiflabb)	X	X	X	X	X	X	X	X	X	X	X	X
Mackerel (Makrill)					X	X	X	X	X			

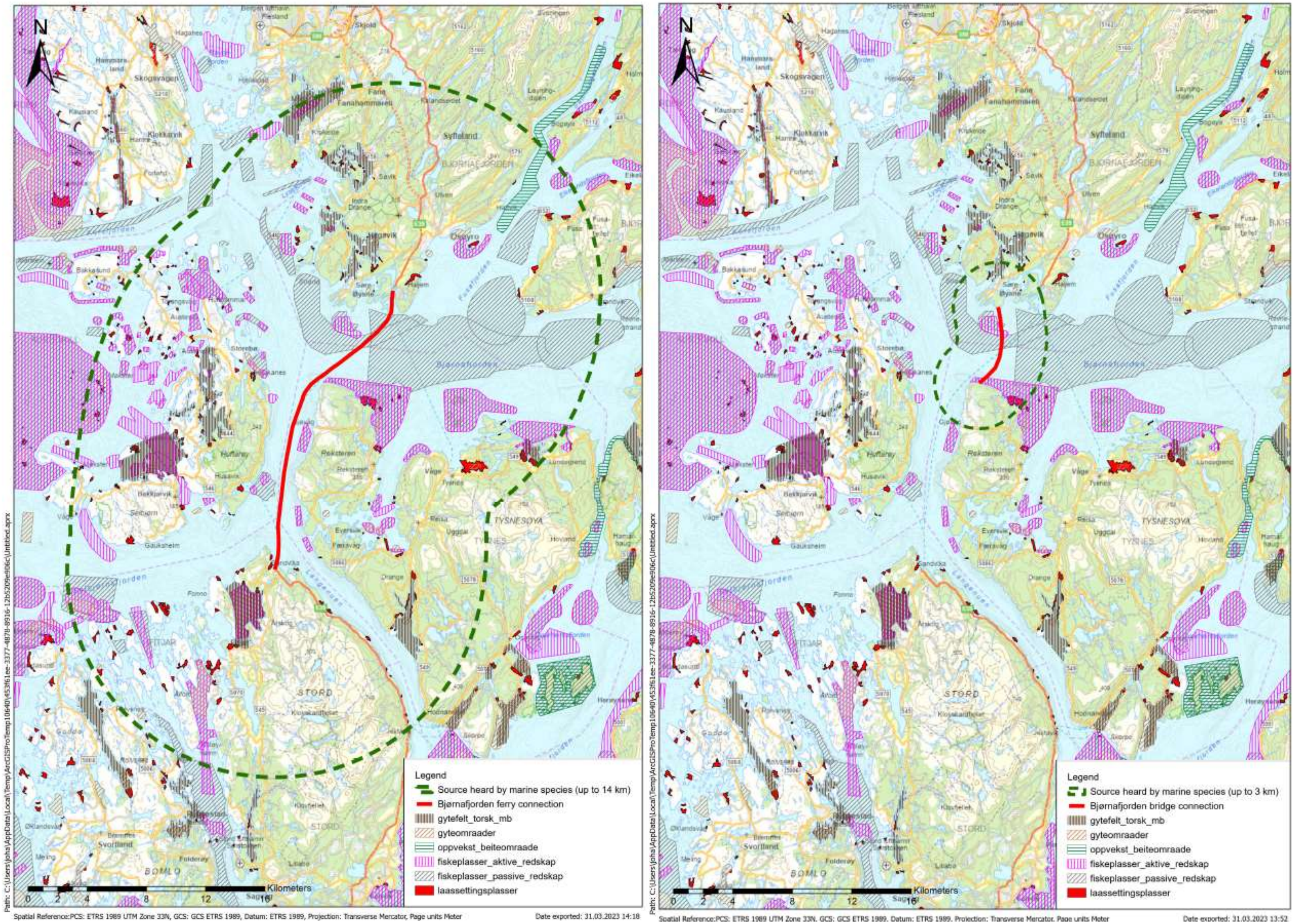

Figure 7. Registered occurrences of commercial fish from website Yggdrasil [4], as well as outer limits for where it is expected that marine animals will perceive noise (i.e. audible noise) from or ferry (left) and bridge connection (right).

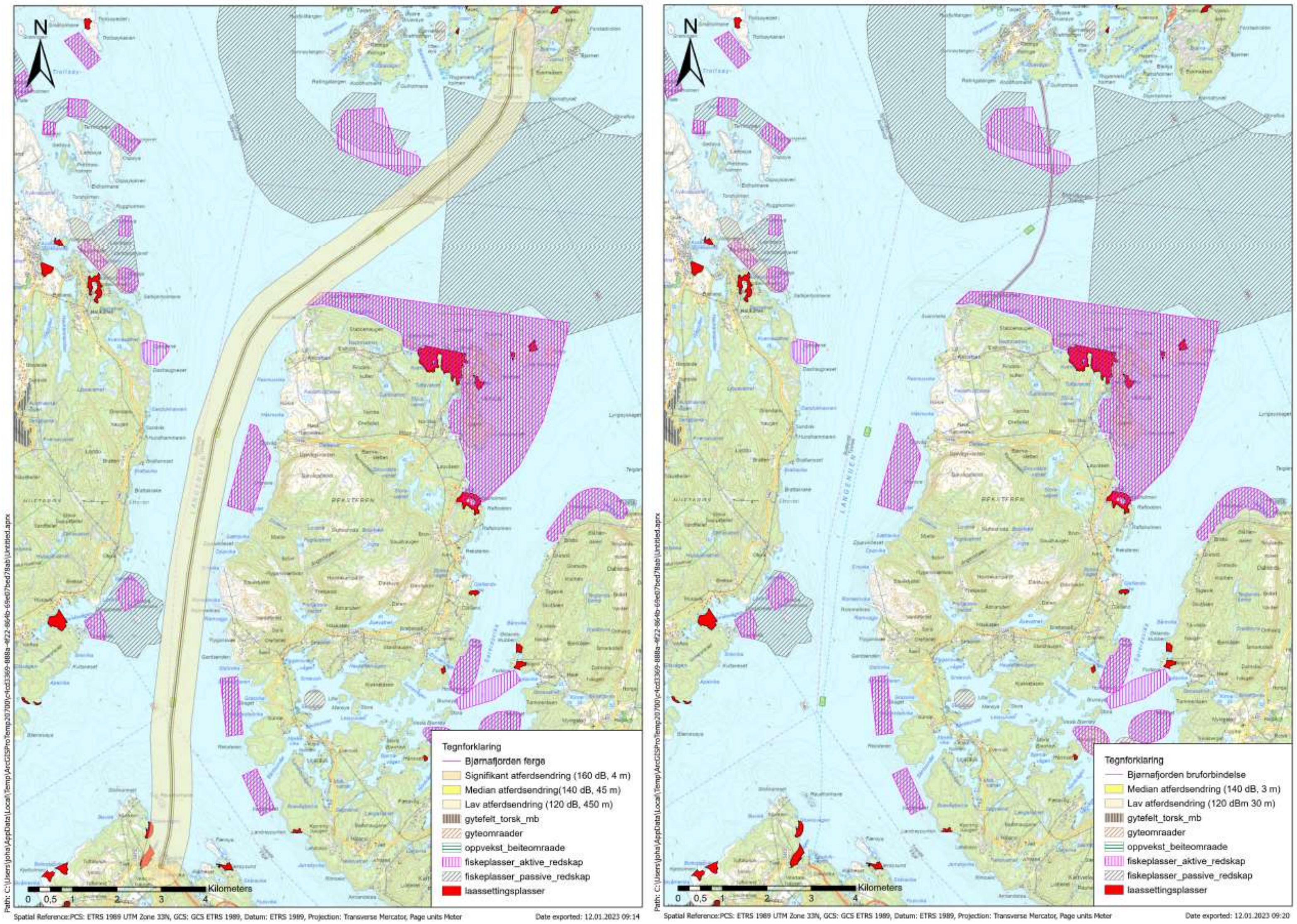

Figure 8. Registered occurrences of commercial fish from Yggdrasil [4], as well as the areas for where it is expected that marine animals will change their behaviour due to noise from ferry (left) and bridge connection (right). Map: Multiconsult.

5.1.2 Marine mammals

As of 11 January 2023, there are several registrations of marine mammals in species maps. Based on the number of registrations, harbour seals and porpoises are considered relatively common in Bjørnafjorden/Langenuen and adjacent fjords. In addition, there are occasional records of killer whales in Bjørnafjorden.

The assessments made by Quiet-Oceans regarding marine mammals (see Appendix A) are considered relevant based on the above.

5.2 Bird

The Bjørnafjorden region is an important ecological functional area for several species of nesting and partly wintering seabirds (Figure 9). When it comes to nesting seabirds, Fluøyane/Lyngøya in Tysnes (7 – 8 km east of the planned stretch of the bridge) is the largest seabird colony in the county, measured in terms of the number of nesting pairs. Here, a wide range of bird species are nesting, such as European herring gull, lesser and great black-backed gull, greylag goose, eider, and tern. The common tern is a rare species in the Bjørnafjorden area today, compared to earlier times, while the arctic tern normally nests further out on the coast. Outside the breeding season, there are also quite a few great cormorants in the fjord, while the European shag has only been observed sporadically. Auks or alcids such as loons, razorbills and black guillemot can also be found in Bjørnafjorden in the winter, while little auk and puffins are less common. Species such as red-throated loon, black-throated loon, common loon, common scoter, velvet scoter and long-tailed duck have also been recorded in the fjord outside the breeding season (these are species that breed in fresh water and overwinter in the sea).

Table 2. Ecological groups of seabirds, as well as normal and assumed maximum depth for foraging.

Pelagic diving species	Pelagic surface-grazing species	Shore-bound diving species	Shore-bound surface grazing species	Feather-related species
Razorbill	Northern Fulmar	Red-throated Loon	Greylag goose	Gray heron
Common Murre	European Storm Petrel	Black-throated Loon	Common Shelduck	Eurasian Oystercatcher
Atlantic Puffin	Leach's Storm Petrel	Common Loon	Mallard duck	Purple Sandpiper
	Northern Gannet	Yellow-billed Loon	Common Gull	Eurasian Curlew
	Great Skua	Red-necked Grebe	European Herring Gull	Ruddy Turnstone
	Parasitic Jaeger	Great Cormorant	Lesser Black-backed Gull	Common Ringed Plover
	Black-legged Kittiwake	European Shag	Great Black-backed Gull	
		Greater Scaup	Common Tern	
		Long-tailed Duck	Arctic Tern	
		Common Eider		
		Common Scoter		
		Velvet Scoter		
		Common Merganser		
		Red-breasted Merganser		
		Black Guillemot		
Typical diving depths for the different bird species.				
Normally < 100 m, but up to 200 m.	< 1 m (sole < 25 m)	Normally < 10 m, but up to 20 - 30 m	< 1 m	0 m

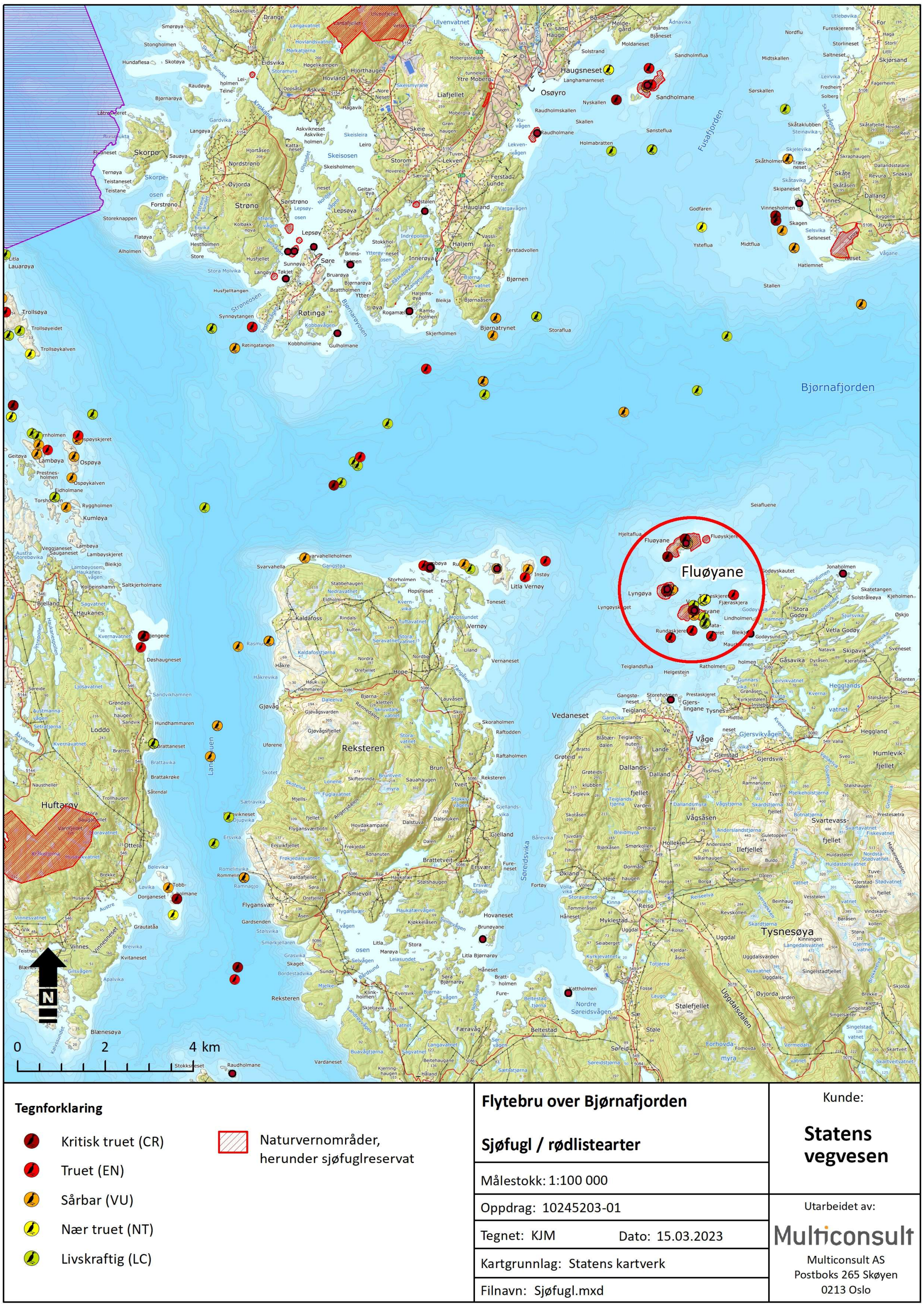

Figure 9. Registered occurrences of seabirds, divided by red list category.

Most species of seabirds have poor underwater vision [1] and recent studies [6, 7] indicates that the hearing of seabirds (in this case cormorants) is better under water. This suggests that hearing probably plays an important role, together with the sense of smell, while vision is subordinate when it comes to catching prey underwater.

Different species of seabirds have different abilities to dive in order to find food (see Table 2). The deeper the seabirds dive, the worse the light conditions become, and it is therefore natural to assume that hearing becomes even more important for catching moving prey, such as fish. This means that pelagic diving species such as razorbill are probably more strongly affected by anthropogenic underwater noise than coastal diving species, which in turn are more affected than grazing species and species associated with beach zones/shallow areas. However, it must be pointed out that this is only a theory, and that this has so far not been conclusively confirmed through scientific studies.

Assuming the results from the trials on cormorants are transferable to other species of seabirds, one can expect that a floating bridge will cause less inconvenience for foraging seabirds in the Bjørnafjord than ferries, as a result of less anthropogenic noise. However, it must be pointed out that the species of nesting seabirds that dominate the area, such as gray gulls, herring gulls and black-backed gulls, will probably be affected to a negligible extent by noise from boats and/or car traffic (these species are often attracted by human activity/boats). A floating bridge is expected to have a stronger positive effect in areas where pelagic or coastal diving species dominate.

6 Conclusions

Measurements of acoustic noise at the Nordhordlands bridge and ferry traffic from modern diesel-electric and hydrogen ferries have been carried out and analysed in a risk context. The analysis shows that there are two widely separated risk profiles for ferries compared to the Nordhordlands bridge. The noise from ferry traffic is spread over time and space and is also generally higher than typical noise from floating bridges, which mainly causes noise during the constructional phase, see Figure 10. One can expect that there may be some impact during the demolition/decommissioning phase of a floating bridge. For the construction/decommissioning phases, it is most likely either construction/piling or demolition/blasting that will result in increased noise. In general, at a construction site the noise levels are always expected to be higher than in the operational phase and can basically be treated as "temporary".

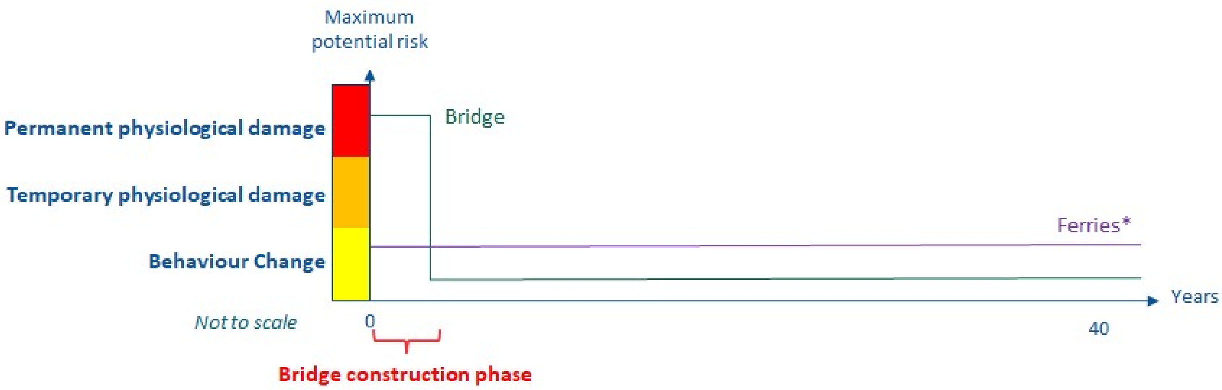

Figure 10. Visual representation of the evolution of potential acoustic risks induced by a floating bridge (construction and commissioning) versus ferries. (Figure 57 in Appendix A).

Ferry noise is mainly related to engine and propeller sounds and is emitted to a varying degree during the entire operational phase. For ferries the construction/decommissioning phases play a minor role in a life cycle perspective. It should be emphasized that a floating bridge has a far greater capacity than a general ferry line. According to SVV, it is estimated that at least 8 ferries of the type in Bjørnafjorden are needed to match the traffic capacity of a bridge connection.

However, it should be emphasized that both types of infrastructure create noise that can mask communication for various fauna in the area and can cause changes in behaviour and, in the long run, perhaps even changes in population and species composition may result.

Table 3 provides an overview of the acoustic risk level for ferries versus floating bridges in the various risk zones. In addition, the contributing effects and activities of this project is listed. A thorough examination of the noise impact in the area should be carried out, considering time-varying source terms for both types of infrastructure, to give a more accurate picture of the sound exposure. In connection with all developments of new infrastructures in a coastal or oceanic zone, it should be required that a good strategy for monitoring and mitigating effects of environmental pollution is established, so that marine biological diversity is safeguarded to a high degree as possible.

Table 3. Overview of the various risk zones for acoustic impact in the various phases of the floating bridge and ferry.

Phase	Construction/Decommissioning phase		The operational phase	
Risk zone	**Bridge**	**Ferry**	**Bridge**	**Ferry**
PTS (Permanent injury or death)	High probability - close to blasting or piling sites	Medium probability – port facilities only	Low probability	Low probability - collision
TTS (Recoverable damage)	High probability within a few km	Low probability – port facilities only	Low probability - within a few m	Medium probability - within a few dozen m
BDT (Changed behavior)	Medium probability – increased construction traffic and activities	Low probability – port facilities only	Low probability - within a few dozen m	Medium/high probability – within a few 100 m
Masking (Changed conditions in the environment)	Medium probability – increased construction traffic?	Medium probability – increased construction traffic?	Low probability – within a few km	Low probability – within approximately 10 km

7 References

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Appendix A. QO-Bridge-Acoustic-Technical-Report

SVV Bridge

Underwater noise impact assessment of floating bridges compared to ferries

Technical report

Multiconsult

Statens vegvesen

Documents identification	
Reference of document	QO.20220427.10.RAP.001.01.A
Stakeholder	Statens Vegvesen
Client	Multiconsult
Reference of contract	

PROJECT	DOC	CHRONO	VER	IND	CLIENT	ACRO	DATE	TYPE	CLASS
QO.20220427.10	RAP	001	01	A	MC	SVV	20.12.2022	PROD	DR

Quiet oceans

Ocean Noise Forecasting Monitoring & Mitigation

Appendix B. QO-Bridge-Mission-Report-LEG01

Acoustic impact study of floating bridges

SEA MISSION REPORT - LEG01

Multiconsult

Statens vegvesen

Identification	
Document reference	QO.20220427.10.CRM.001.01A
Main contractor	Statens vegvesen (SVV)
Customer	Multiconsult
Costumer contact	-

PROJET	DOC	CHRONO	VER	IND	CLIENT	ACRO	DATE	TYPE	CLASS
QO.20220427.10	CRM	001	01	A	MC	SVV Bridge	14.11.2022	PROD	DR

Quiet oceans

Ocean Noise Forecasting Monitoring & Mitigation

Appendix C. QO-Bridge-Mission-Report-LEG02

Acoustic impact study of floating bridges

SEA MISSION REPORT - LEG02

Multiconsult

Statens vegvesen

Identification	
Document reference	QO.20220427.10.CRM.001.02A
Main contractor	Statens vegvesen (SVV)
Customer	Multiconsult
Costumer contact	Tim Fristedt

PROJET	DOC	CHRONO	VER	IND	CLIENT	ACRO	DATE	TYPE	CLASS
QO.20220427.10	CRM	001	02	A	MC	SVV Bridge	20.11.2022	PROD	DR

Quiet oceans

Ocean Noise Forecasting Monitoring & Mitigation

SVV Bridge

Underwater noise impact assessment of floating bridges compared to ferries

Technical report

Multiconsult

Statens vegvesen

Documents identification	
Reference of document	QO.20220427.10.RAP.001.01.A
Stakeholder	Statens Vegvesen
Client	Multiconsult
Reference of contract	

PROJECT	DOC	CHRONO	VER	IND	CLIENT	ACRO	DATE	TYPE	CLASS
QO.20220427.10	RAP	001	01	A	MC	SVV	20.12.2022	PROD	DR

Quiet oceans

Ocean Noise Forecasting Monitoring & Mitigation

Historic of document						
Ver	Ind.	Responsible	Date	Validation	Transmission	Description
01	A	J. Bellanger	19.12.2022	20.12.2022	21.12.2022	Initial version

Citation

J. Bellanger, D. Clorennec, P. Billand, C. Bois (2022), SVV Bridge, Underwater noise impact assessment of floating bridges compared to ferries, number QO.20220427.10.RAP.001.01.A, Quiet-Oceans, Brest, France

Content

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Glossary of technical words

Underwater acoustics is a scientific field of fluid mechanics. It uses its own vocabulary and its own units. A definition of the main terms used is presented in this glossary to facilitate the understanding of the document by the reader.

Active Acoustics
Emission of reference acoustic signals in order to quantify the losses suffered by acoustic waves as they propagate in the marine environment.

AIS
Automated Identification System is a system on board ships that transmits to an observation network their identifications and locations in near real time. Different receiving stations, implemented by government services or private companies, allow to monitor maritime traffic in near real time. The maximum coverage can reach 30 nautical miles from the coast depending on the weather conditions.

CPA
Closest Point of Approach, the minimum distance between a linear trajectory of a vessel and a geographical position.

Decibel
The decibel (dB) is a measure of sound pressure level, a quantity that is the basis for the perception of sound volume. It is a logarithmic scale that describes a multiple of a reference value. When the sound power doubles, the decibel value increases by 3 dB. In underwater acoustics, the reference level of the decibel is 1 µPa (micro-Pascal), a different reference from airborne acoustics. The two scales are therefore not comparable.

Emitted sound pressure
The sound pressure emitted by a source of noise is the amplitude of the signal which would be generated at one meter of this source if this one was a point. This pressure can be expressed in instantaneous value, average value, effective value, or maximum value. It is expressed in dB ref. 1µPa @1m.

Footprint (Ocean Noise Footprint)
The ocean noise footprint is the representation of the noise levels arising from maritime activities that affects a portion of the sea. It includes the description of the noise sources, their distribution, and the propagation of the sound in the ocean environment.

Hydrophone
A hydrophone is a microphone intended for use underwater. It converts a variation of pressure into a variation of electrical voltage to record sound pressure as a function of time.

Mitigation
A noise reduction measure that acts either at the source or at the propagation of sound.

Octave
An octave is the interval between two sounds whose fundamental frequency of one is twice the frequency of the other. A third or tenth of an octave is a fraction of an octave. The American National Standard Institute (ANSI S1.11 2004) defines the centre frequencies and the characteristics of the filters used to distinguish them.

Passive Acoustics
Measurement of the ambient noise without generating noise that can affect the observation of the sound chorus.

Percentile level
A percentile corresponds to the proportion of time and space for which the noise exceeds a given level. This concept is widespread even in everyday life. For example, the average income of the top 10% of income earners or the "income threshold corresponding to the 90th or to the 95th percentile", i.e., the income earned by the poorest individual among the top 10% or top 5% richest individuals. Meanwhile, the 50th percentile corresponds

to the median salary. For underwater noise, the percentile, or exceedance level, is meant to describe the noise level occurring at least.

In the context of underwater noise, it is defined as the level L_N that is exceeded for N percent of the time interval considered. For example, L_1 is the level that is exceeded 1% of the time.

The L_1 is a measure for the maximum level. It is a more robust estimate than taking just the maximum observed level, since the latter may be an outlier caused by a single event, such as rattling of the anchoring system or other types of self-noise. Accordingly, L_{99} and L_{95} are used to describe the minimum level. L_{50} is the median level.

Propagation losses
Acoustics propagation losses correspond to the attenuation of waves caused by the propagation medium as a function of distance from the source.

Quantile
See percentile level.

Received level
The received energy is equal to the square of the received sound pressure signal. It is expressed in dB ref. 1µPa².

Received sound pressure
Received sound pressure is the amplitude of the acoustic signal as it can be measured over the receiving frequency band of a hydrophone at a given distance from any sound source. This pressure can be expressed in instantaneous value, effective value, or maximum value. It is expressed in dB ref. 1µPa.

Sound chorus
The sound chorus represents the diversity of sound sources present in the marine environment. It is composed of three types of sounds: natural sounds (or geophony), biological sounds (or biophony) and human-made sounds (anthropophony).

Sound exposure level
The sound exposure level is the integral of the acoustic energy received on a frequency band of biological sensitivity (frequency band actually perceived by a species) for a given duration. It is expressed in dB ref. 1µPa²s.

Sound frequency
The frequency is the number of oscillations of sound pressure in one second. Low-pitched sounds have a low frequency, high-pitched sounds have a high frequency. The unit of frequency is the Hertz (Hz). As an illustration, the human ear only perceives frequencies between 20 Hz and 20 kHz, although the upper limit generally decreases with age. Underwater species have a different hearing spectrum.

Sound source model
Level of sound pressure or energy emitted by a source at a distance of one meter, described in terms of frequency.

Spectrogram
A spectrogram is the result of an acoustic signal processing that allows the visualization of this signal as a function of time and frequency. This representation of the signal offers interesting possibilities for its analysis.

Tidal range
A change in water height primarily due to the effect of tides. It is expressed in meters and is referenced to chart datum. The hydrographic zero is close to the level of the lowest astronomical seas.

Velocity profile
The celerity describes the speed at which sound waves travel in the marine environment. It is a function of depth, temperature and salinity. Its variability is temporal (depending on seasons, weather events, etc.) and spatial.

Chapter I. Context and objectives of the project

In the context of a possible construction project of a floating bridge in Bjørnafjorden, The Norwegian Public Roads Administration (Statens vegvesen or SVV) has issued a tender for the underwater acoustic effect of floating bridges in operation on biodiversity. Statens vegvesen wishes to study the environmental effect of this type of bridge when commissioned regarding noise effects induced by ferries roads. Multiconsult society, in charge of the project, has requested the expertise of Quiet-Oceans to perform measurements and associated analysis of underwater noise.

To achieve this aim, the main objectives of this study are (Figure 1):

- ✓ To lead underwater noise measurement of:
  - the existing floating bridge in Nordhordlandsbrua area
  - Several ferries sailing on two regular lines: Valestrand – Breistein line and Halhjem – Sandvikvåg line
- ✓ To estimate the source levels of ferries and floating bridge on the basis of the measured acoustic data;
- ✓ To compare the acoustic impacts on marine species (fishes, pinnipeds, porpoises) of a ferry route with the construction and commission of a floating bridge.

In addition, a predictive modelling cartography of noise induced by ferry navigation and floating bridge commission in the study area is proposed in the last part of this report in order to illustrate the footprint of each activity.

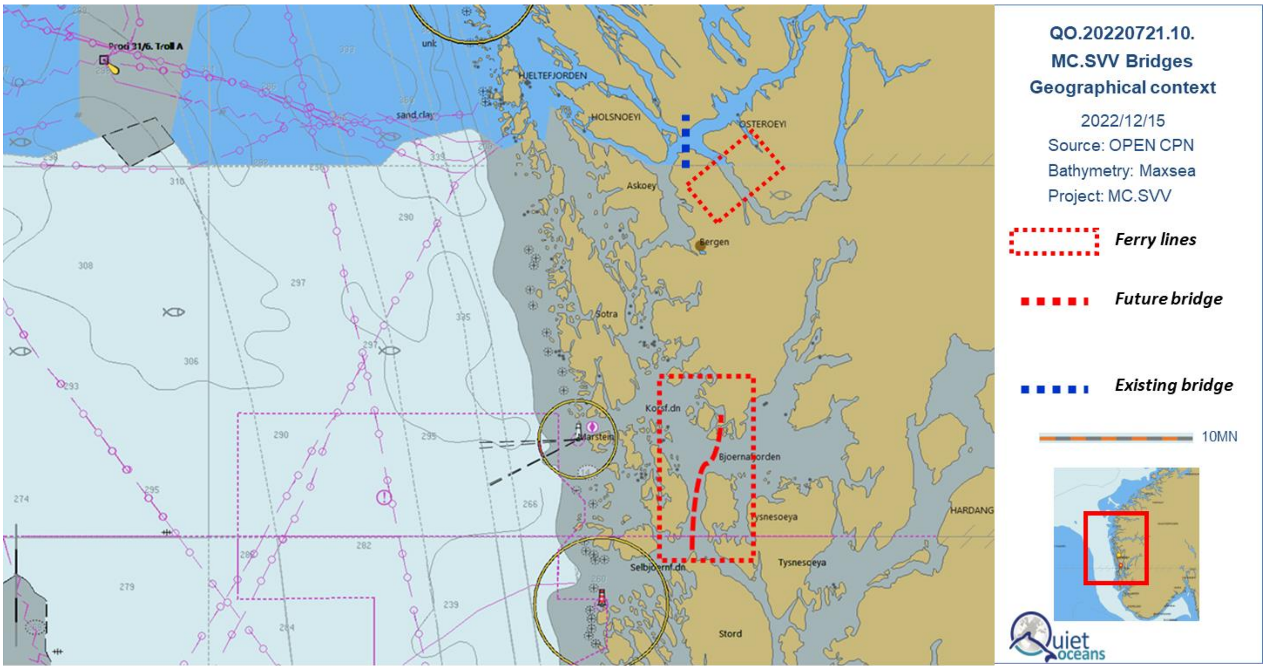


Figure 1: Geographical context of the project.

Chapter II. Introduction

This chapter aims to familiarise the reader with the technical field of underwater acoustics in order to make the reading of this study easier. It refers to specific terms in the field of underwater acoustics. We invite the reader to refer to the glossary available at the beginning of the document.

II.1. The issue of underwater acoustics

The underwater world is anything but silent, and is composed by a chorus of sounds that includes three families of noise: natural noise (waves, seismic crack, ...), biological noise (marine mammals and other marine biodiversity), and anthropogenic noise (human activities, maritime traffic, ...).

These noises are from different nature depending on the place, season, climatic conditions, time of the day, etc. Thus, underwater noise is a physical component to evaluate in a given geographical context, and whose modifications may have consequences on the ecosystem and on some pressure-sensitive marine organisms.

Underwater noise levels are not to be compared with aerial noise levels. Indeed, the reference level is 1 µPa in underwater acoustics and 20 µPa in the air. Moreover, the oceanic environment has a density a thousand times higher than air and therefore, is considered as an incompressible propagation medium. Given this information, any comparison should be avoided. Figure 2 illustrates a scale (amplitude and frequency) of typical sound emitted either by human activities, marine fauna, or environmental conditions.

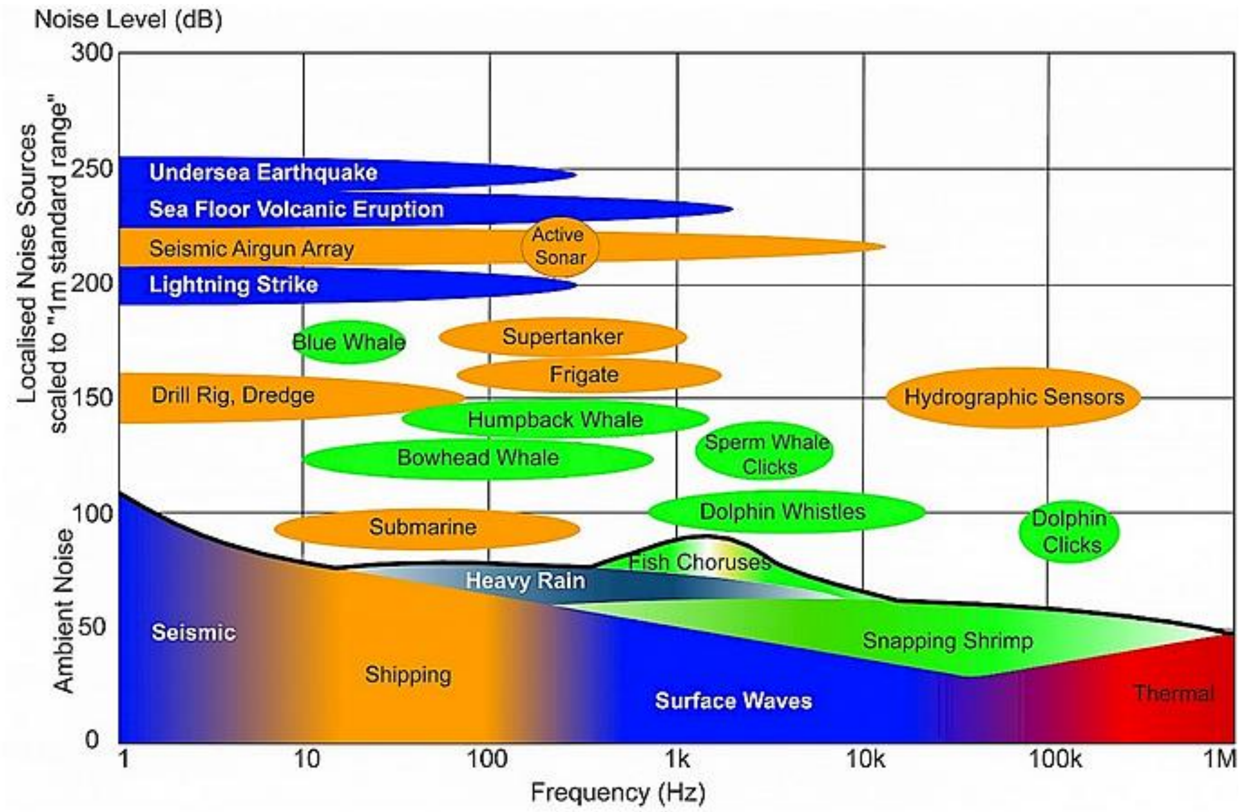


Figure 2: Qualitative scale of levels (emitted at one meter) and frequencies of anthropogenic, biological and natural sound source in the marine environment. (Source: OSPAR).

II.2. About the underwater acoustic chorus

Underwater noise is a real sound chorus where noises of different natures and origins are mixed together:

- ✓ Natural noise or geophony includes noise from the cracking of the Earth, movement of marine sediments, breaking of waves, rainfall, etc.;
- ✓ Biological noise or biophony includes noise of biological origin emitted by marine fauna;
- ✓ Anthropogenic noise, or anthropophony, is the noise of human origin generated by maritime activities.

All these noises interact with each other and dominate each other to form the sound context of a study area (Figure 3).

Figure 4 summarises typical received sound levels in dB ref 1µPa²/Hz based on both their origin (anthropogenic, environmental or biological) and frequency range (Dosits.org, 2016). All sound sources contribute to the ambient noise with a highly variable predominance depending on frequency, environmental conditions, human activities and local context.

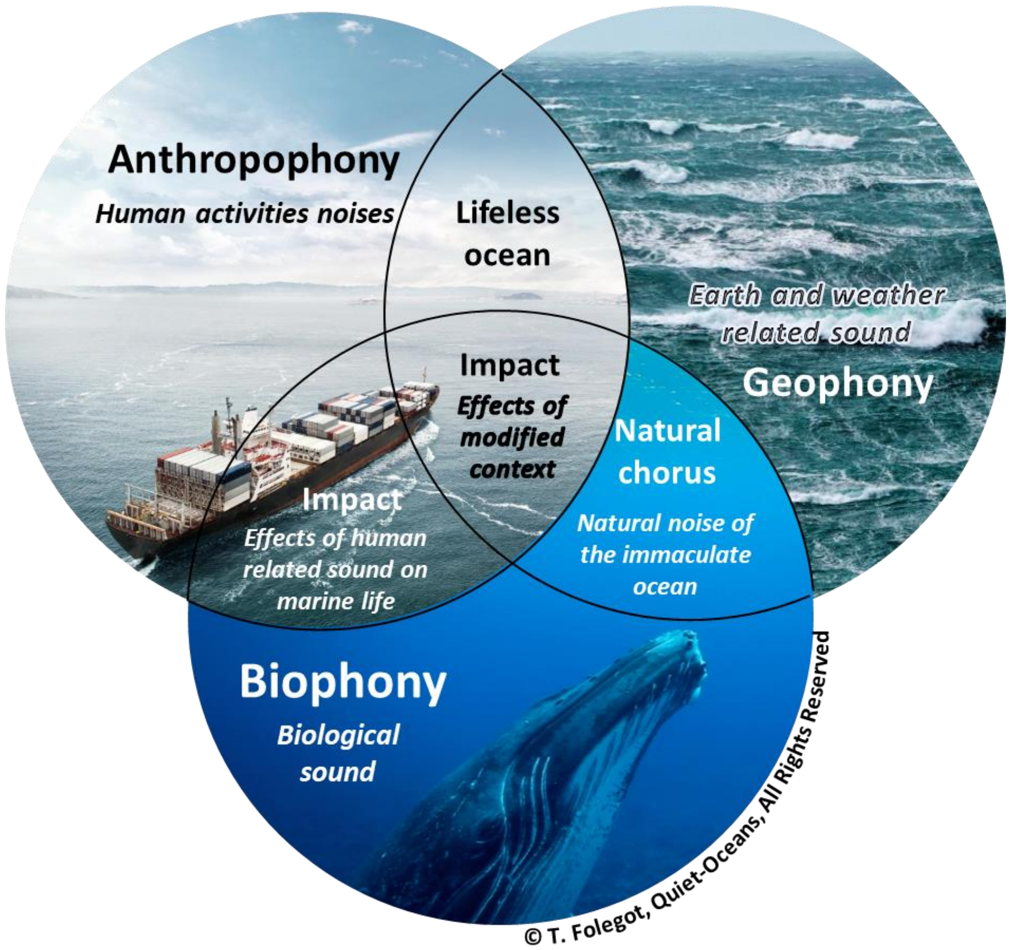


Figure 3: Composition of the underwater acoustic chorus. (Source Quiet-Oceans)

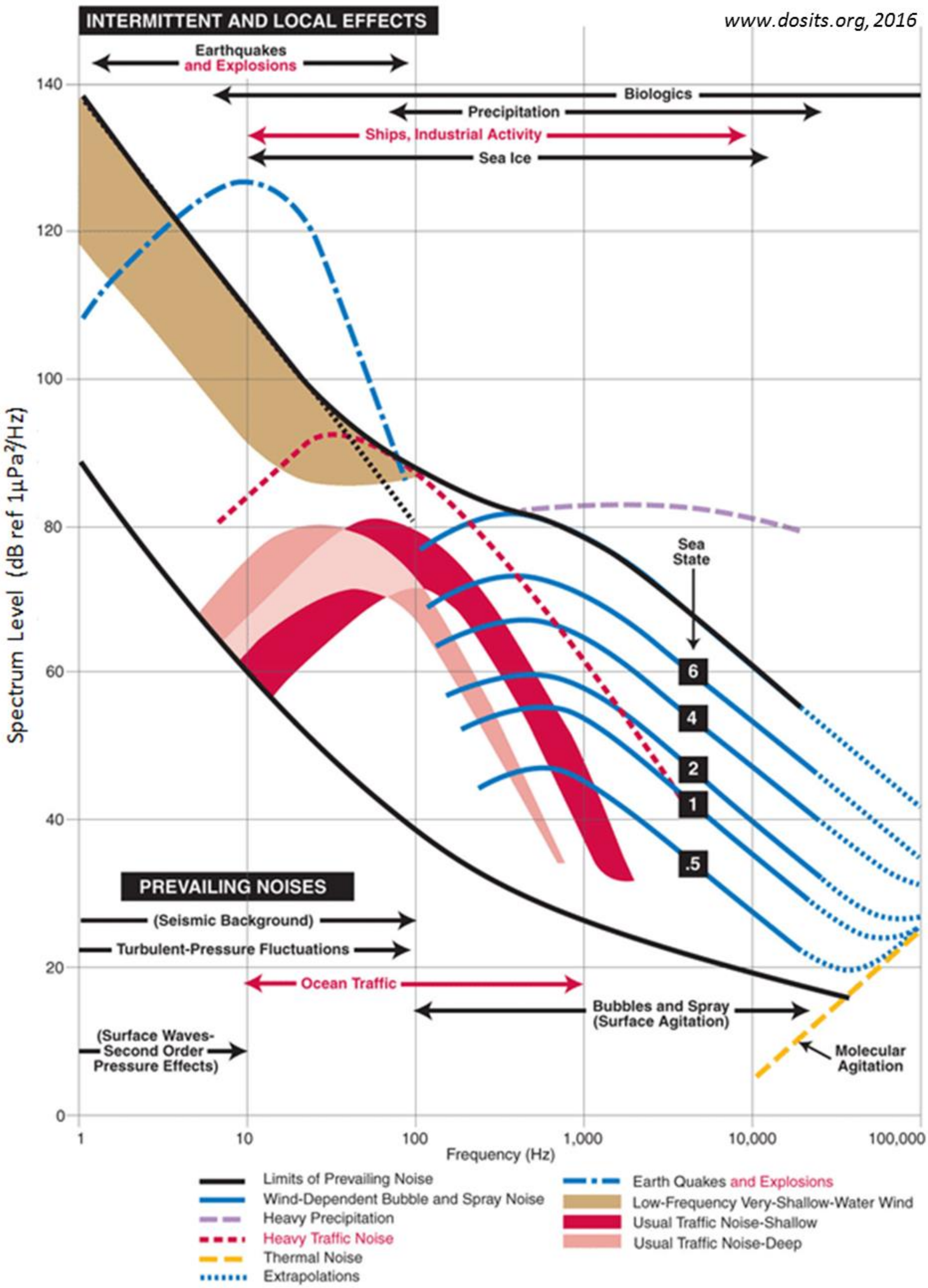


Figure 4: Review of typical noise levels as a function of frequency and nature of the noise source. These values may be dependent on the site, season, and context. Source (Dosits.org, 2016).

Chapter III. Measurement protocol

The acoustic monitoring protocol has been set up in cooperation with both the client and stakeholders.

The operational objectives of measurement concern the deployment of several acoustic recorders in order to characterizs three different acoustic sources, located in three separate areas (Figure 5):

- ✓ Area n°1: Valestrand – Breistein ferry line;
- ✓ Area n°2: Existing floating bridge in Nordhordlandsbrua;
- ✓ Area n°3: Halhjem – Sandvikvåg ferry line.

The area n°4: Bjørnafjorden Is the potential future floating bridge location.

For complementary information about measurements protocol and data, please refer to specific documents:

- ✓ QO.20220427.10.CRM.001.02A.MC.SVV_Bridge_MissionReport_LEG01;
- ✓ QO.20220427.10.CRM.002.01A.MC.SVV_Bridge_MissionReport_LEG02.

Figure 5: Areas of operations.

III.1. Area n°1: Valestrand – Breistein ferry line

This area was chosen because it has a regular line of person and material transport between Valestrand and Breistein cities. The ship using this line is the ferry OLE BULL with a frequency of one rotation every 15 minutes. This reference area was also chosen because of its proximity with Nordhordlandsbrua floating bridge and because it is located in the same perimeter as the study area.

III.1.1. Presentation

The acoustic source to be characterised in area 1 is OLE BULL Ro/Ro vessel (Figure 6). The propulsion of this ship is diesel- electric powered and runs permanently between Valestrand and Breistein harbours.

The expected data is the estimation of source level of this ferry with two types of acoustic measurements (fixed and drifting acquisitions).

Figure 6: OLE BULL ferry.

III.1.2. Deployment protocol

A fixed station attached to a mooring line has been deployed to collect acoustic data of OLE BULL ferry at entrance and departure from Valestrand harbour (Figure 7 and Table 1). A total of 6 recording sessions of OLE BULL passage has been collected.

In addition, a drifting acoustic system has been deployed from a support vessel (MAX tug). The purpose of this measurement was to collect acoustic data of OLE BULL ferry during cruise (Figure 7). At this location, the 330-meters water depth is not favourable for the deployment of a fixed station during a limited measurement period. Therefore, a series of drifting measurements is suitable for the evaluation of the acoustic signal of ships.

The support vessel is drifting and perpendicularly crosses the monitored vessel trajectory. A total of 4 recording sessions of OLE BULL passage has been collected.

The measurement configuration of both types of acquisition systems is shown in Figure 8. All measurement stations have been realised punctually on 22.01.2022 morning.

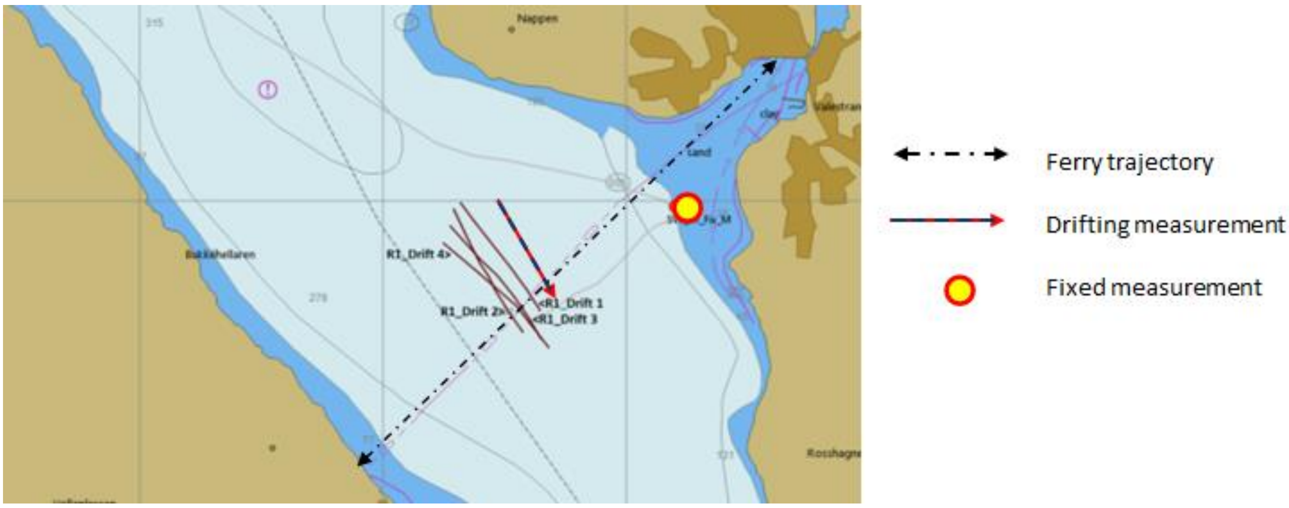


Figure 7: Deployment protocol near Valestrand-Bergen ferry line.

Table 1: Position of fixed station near Valestrand-Bergen ferry line.

Measurement station	Latitude	Longitude	Immersion (m) from bottom	Water depth (m)
Area 1 fixed	60° 29.9945’ N	005° 25.2025’ E	40	95

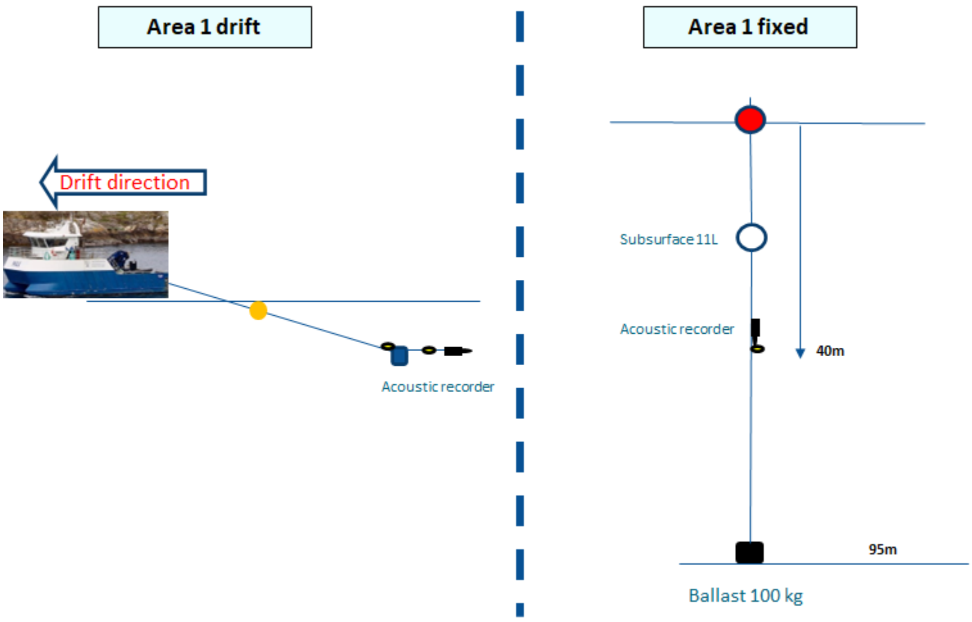


Figure 8: Measurement configuration used near Valestrand-Bergen ferry line (left: drifting measurements and right: fixed station).

III.2. Area n°2: Existing floating bridge in Nordhordlandsbrua

The Nordhordlandsbrua area has been taken as a reference because of the diversity of anthropogenic frequentation of the site, combining a floating bridge and a regular ferry line. The acoustic soundscape is expected to be close to Bjørnafjorden area's.

III.2.1. Presentation

The existing floating bridge in Nordhordlandsbrua (Figure 9) is taken as an acoustic reference in order to anticipate the acoustic effect of the commission of future Bjørnafjorden bridge.

Two objectives of measurement are defined in area n°2:

- ✓ The characterisation of the noise emitted by Nordhordlandsbrua floating bridge while commissioned. Drifting measurement are conducted to analyse the variability of the bridge noise depending of the distance of measurement in a main objective to estimate source level.
- ✓ The analysis of ambient noise sources and fluctuations near Nordhordlandsbrua floating bridge. A fixed station is used for a long-term measurement, allowing to collect the acoustic diversity of the area.

Figure 9: Nordhordlandsbrua floating bridge.

III.2.2. Deployment protocol

To fulfil these objectives, two types of acquisition have been achieved (Figure 11):

- ✓ One fixed long-term acquisition of ambient noise level at 160m from closest pile from 22.09 to 26.10.2022. A total of 34 days of acoustic data has been continuously collected (100% duty cycle). The location of this fixed station is given in Table 2.
- ✓ Several drifting acquisitions of emitted noise by floating bridge during two measurement sessions on 22.09.2022 and on 26.10.2022. A total of 9 recording sessions has been carried out. The geographical context of both sessions is shown in Figure 10.

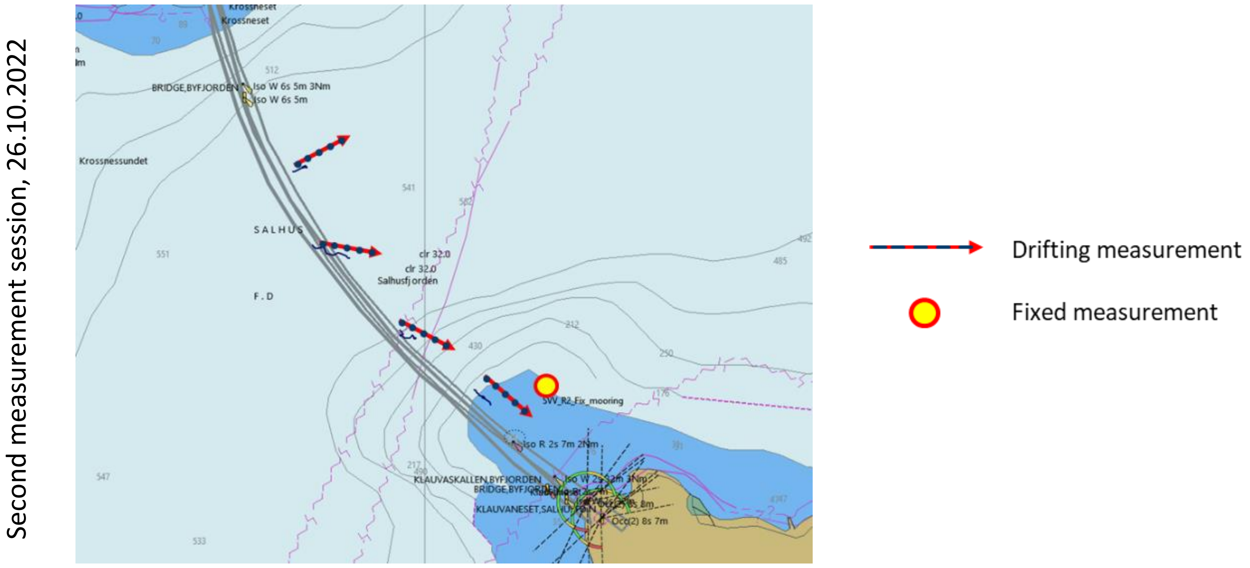


Figure 10: Deployment protocol near Nordhordlandsbrua floating bridge.

Table 2: Position of fixed station near Nordhordlandsbrua floating bridge.

Measurement station	Latitude	Longitude	Immersion (m) from bottom	Water Depth (m)
Area 2 fixed	60° 31.341' N	005° 16.313' E	45	95

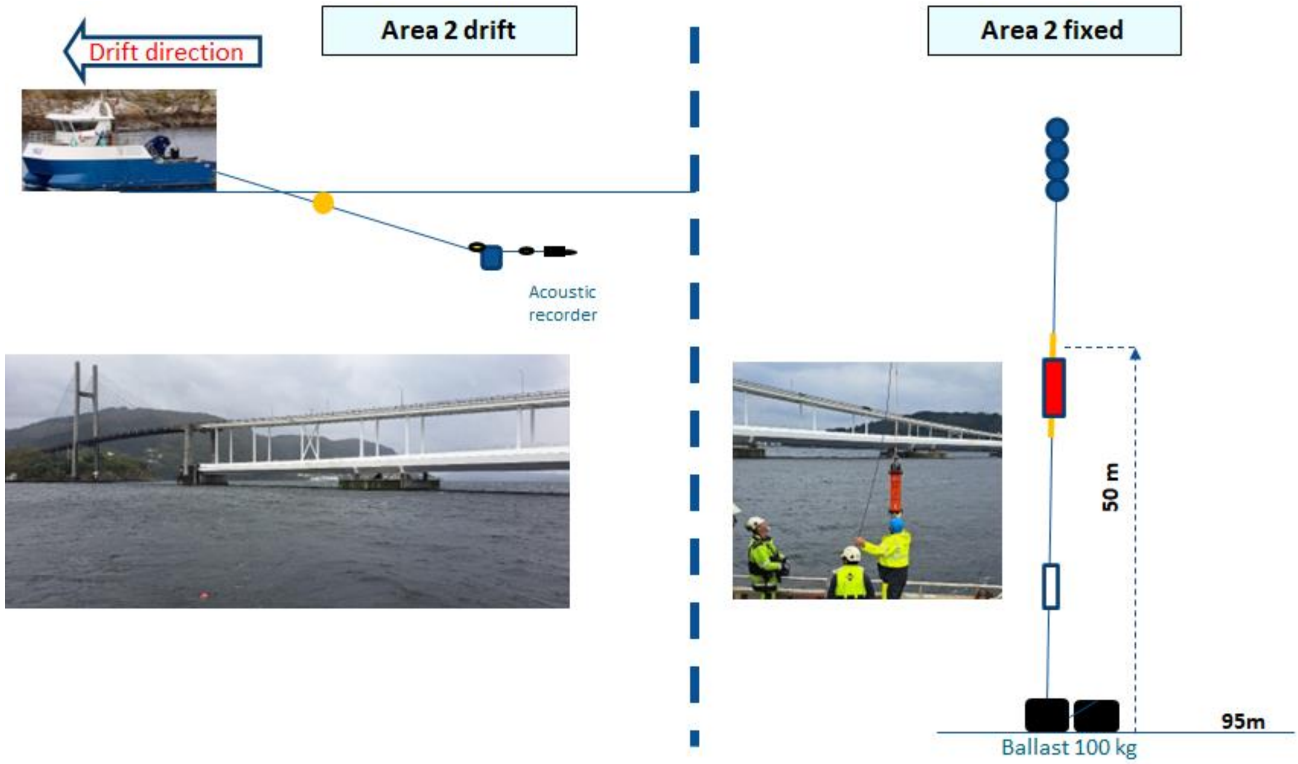


Figure 11: Measurement configuration used near Nordhordlandsbrua floating bridge.

III.3. Area n°3: Halhjem – Sandvikvåg ferry line

The Halhjem – Sandvikvåg ferry line is exploited by five ferries running permanently at a frequency of one rotation every 20 minutes. This area has been studied because of its proximity with the potential future floating bridge in Bjørnafjorden.

III.3.1. Presentation

The acoustic sources to be characterized in area 3 are five sister ship 134-meter-long LNG (liquefied natural gas) ferries (Figure 12):

- ✓ FLATØY
- ✓ FÆRØY
- ✓ LYSØY
- ✓ HUFTARØY
- ✓ SAMNØY

All ferries run permanently between Halhjem and Sandvikvåg harbours. The expected data is the estimation of source level of each ferry with fixed and drifting stations.

Figure 12: FAEROY ferry.

III.3.2. Deployment protocol

A fixed station attached to a mooring line has been deployed to collect acoustic data of ferries close from Halhjem harbour. A total of 8 recording sessions has been collected.

In complement, a drifting station has been deployed from a support vessel (POMPEL tug). The purpose of this measurement is to collect acoustic data of ferries during cruise. The support vessel is carried by current and perpendicularly crosses the monitored vessel trajectory. A total of 3 recording sessions has been collected.

The measurement configuration is the same as used for area n°1 (Figure 8).

The location of fixed station is given in Figure 13 and Table 3.

All measurement stations have been deployed punctually on 26.10.2022 morning.

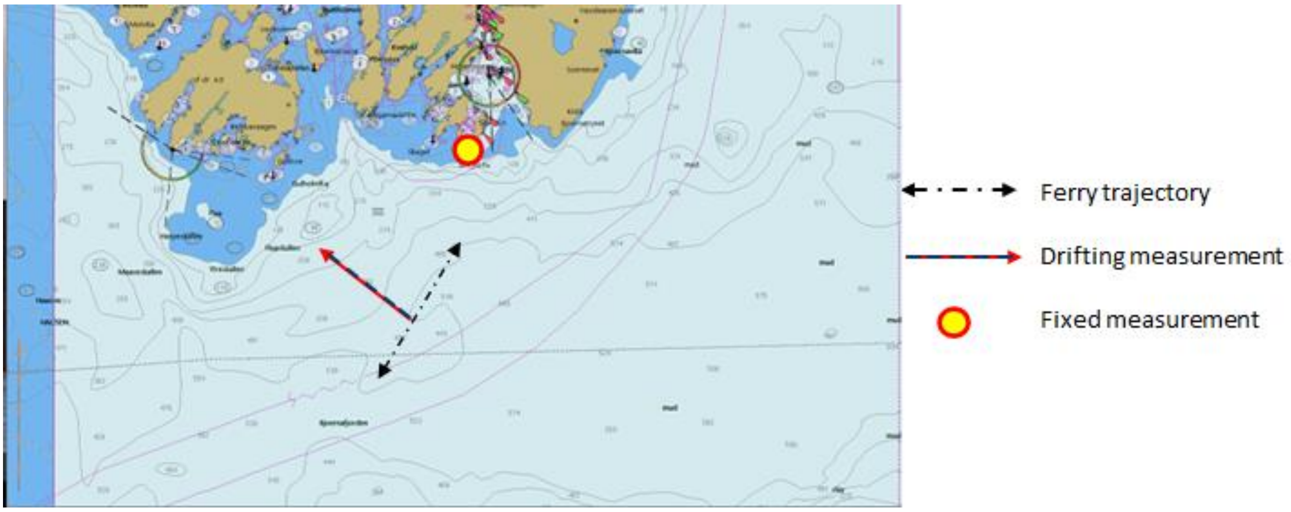


Figure 13: Deployment protocol near Halhjem – Sandvikvåg ferry line.

Table 3: Position of fixed station near Halhjem – Sandvikvåg ferry line.

Measurement station	Latitude	Longitude	Immersion (m) from bottom	Water Depth (m)
Area 3 fixed	60 07.8064 N	005 25.3261 E	28	70

III.4. Acoustic instrumentation specifications

This part of document gives information about the acoustic instrumentation used in this study.

III.4.1. Acoustic recorders used for fixed and drifting acquisitions

The acoustic recorders used for fixed (excepted long-term acquisition) and drifting measurement are stand-alone systems and adapted for acquisition of sound induced by traffic and environment. The first is an IC HF Listen (Figure 14(a)) designed by Oceansonics and the second is a Porpoise-EXT recorder (Figure 14 (b)) designed by Turbulent Research. The technical characteristics of both recorders are detailed in Table 4.

(a) (b)

Figure 14: IC HF Listen recorder(a). Porpoise-EXT recorder (b).

Table 4: Technical characteristics of the icListen recorder

Hydrophone & Recorder	IC Listen	Porpoise
Bandwidth	7Hz-64 kHz	10Hz-48kHz
Sampling Frequency	128 kHz	96 kHz
Acoustic sensitivity	-172.5 dB re: 1V/µPa	-180.1 dB re: 1V/µPa
SPL max **SPL min**	181 dB re: 1V/µPa 73 dB re: 1V/µPa	167 dB re: 1V/µPa – 66 dB re: 1V/µPa
Autonomy	10 hours	50 hours
Dimensions - Weight	267 mm x 45 mm - 0.3 kg	229 mm x 70 mm - 1.2 kg
Operational water depth	200 m	500 m

III.4.2. Acoustic recorder used for long term measurement

The acoustic recorder used for the long-term acquisition in Nordhordlandsbrua area is an ORCA72D recorder designed by Turbulent Research whose characteristics are detailed in Table 5. This recorder is adapted for acquisition of sound induced by traffic and environment. The acquisition is continuous along time (100% duty cycle).

Table 5: Technical characteristics of the ORCA 72 recorder

Hydrophone & Recorder	ORCA 72D	Recorder and mechanical protection frame
Bandwidth	10Hz-48kHz	
Acquisition Channels	1	
Sampling Frequency	96 kHz	
Acoustic sensitivity	-164.8 dB re: 1V/µPa	
Gain	0 dB	
SPL max **SPL min**	167 dB re: 1V/µPa – 66 dB re: 1V/µPa	
Autonomy max	44 days	
Dimensions - Weight	229 mm x 70 mm - 34 kg	

Chapter IV. Noise analysis of ferries

As a reminder, one of the objectives of this study is to estimate the noise emitted by different ferries:

- ✓ From a spectral point of view, by calculating the spectrum of the source level at one meter (by convention) from the vessel;
- ✓ From a broadband (sum of all frequencies contribution) point of view, by estimating the noise level emitted at one meter from the vessel.

In order to determine these two metrics, the measured acoustic data is analysed and then filtered to keep only excess levels considered to be specific to the vessel contribution. An acoustic inversion is then performed to estimate the transmission loss (TL) and in consequence the noise emitted. This analysis is proposed for all the studied vessels (OLE BULL, FLATØY, FÆRØY, LYSØY, HUFTARØY, SAMNØY).

IV.1. Methodology

The data processing methodology for source level estimation of ferry is synthetised in Figure 16.

For each measurement (fixed or drifting) whose objective is to estimate the noise of a vessel:

1. A portion of the signal measured far from the vessel and in the absence of any anthropogenic noise is kept: it will serve as reference ambient noise.
2. For any time, the distance separating the studied vessel from the hydrophone (or from the support vessel for radials in drifting mode) is calculated.
3. A significant instant Ts is considered if (Figure 15):
    a. the distance between the hydrophone and the vessel reaches a minimum;
    b. the received acoustic level reaches a maximum;
    c. both instants are closer than 30s.
4. If a common instant Ts is considered, the acoustic signal is analysed in a total 180 sec temporal window around Ts.

For each Ts significant instant:

5. The exceedance of the measured received noise to the reference ambient noise is calculated for each frequency band fi:

$$\Delta(fi) = measured\ noise\ (fi) - ambiant\ noise\ (fi)$$

6. A filtering is then performed:
    a. The levels in the frequency bands with an exceedance greater than +3dB are retained, as they are considered representative of the noise induced by the inspected source (here vessel source). This step is sufficiently differentiable from the ambient noise;
    b. This ensures that the acoustic inversion will be representative of the exceedances of the vessel to be studied;

7. On the basis of these significant values (in range and frequency), an acoustic inversion is performed to estimate the sound level emitted at one meter (by convention) by the vessel studied:

$$SL\ @1m\ (fi) = measured\ noise\ (fi) + TL\ (fi, di)$$

With TL the indicator of acoustic losses in the propagation medium, calculated for each frequency band fi, at distance di.

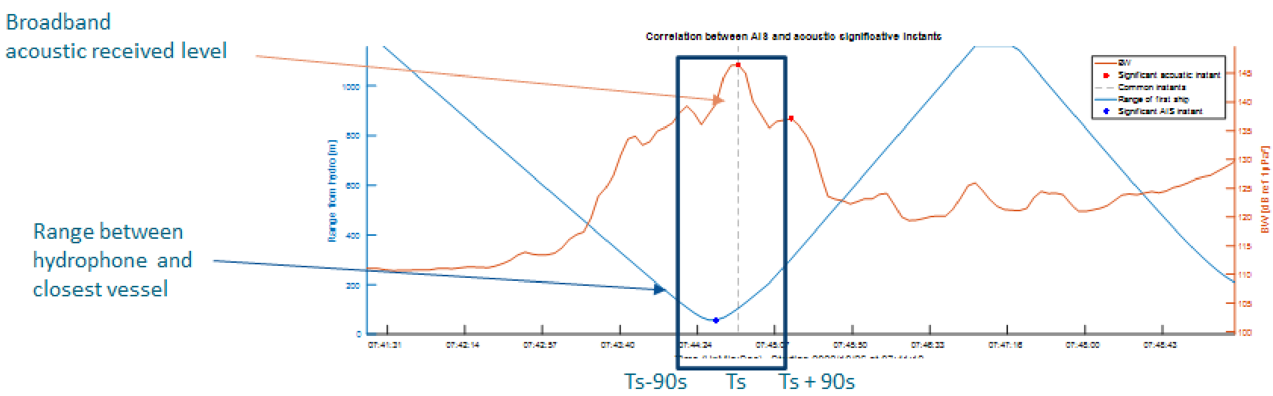


Figure 15: Illustration of significant instant definition.

The acoustic data are processed in the frequency band between 5Hz and 50kHz.

The results are compared with the noise reference provided by the RANDI 3.1C source level model which uses the instantaneous speed, AIS class and length of the vessel (Macgillivray & de Jong, 2021).

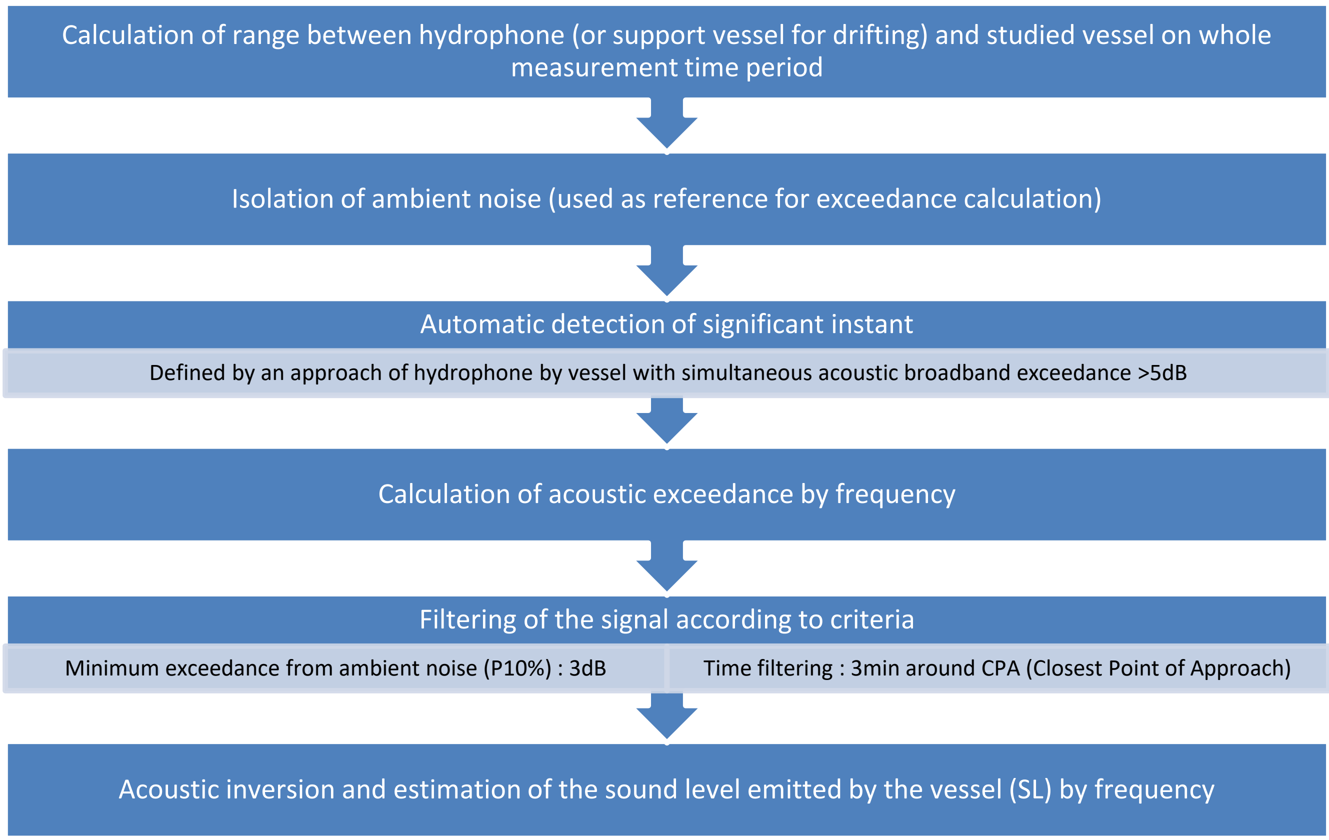


Figure 16: Data processing methodology used for source level estimation of ferries.

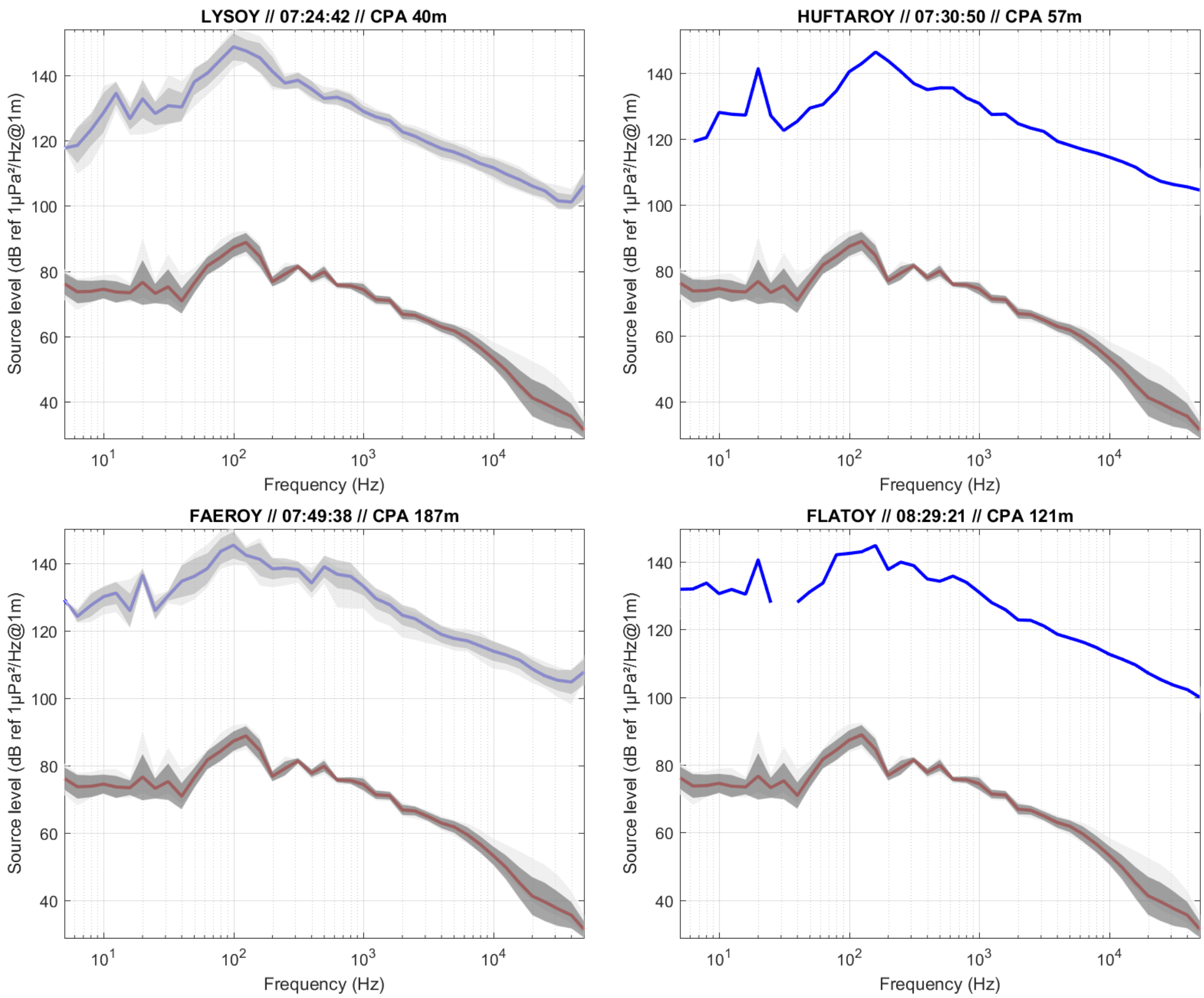
IV.2. Estimation of source levels

IV.2.1. Ferries in area n°3

IV.2.1.a. From fixed acquisition

Applying methodology described in previous parts, the Figure 17 presents the estimation of source levels spectrum for each monitored ferry in area n°3. The source level of vessel is plotted in blue, the ambient noise measurement is plotted in red. A comparison with RANDI 3.1C model is proposed for SAMNOY ferry, in black dotted. The Table 6 presents the broadband estimated values of source level for each ferry, with corresponding CPA (Closest Point of Approach) distance and average speed during measurement, expressed in knots.

After acoustic back-propagation, all five monitored vessels share very close source levels with maximum levels in 80-200Hz frequency band. Despite the varying CPA distances, the medians broadband SPL are grouped near 170dB ref 1µPa²@1m with a standard deviation of ± 1dB. The estimated source profiles share good agreement with RANDI 3.1C model above 100Hz.



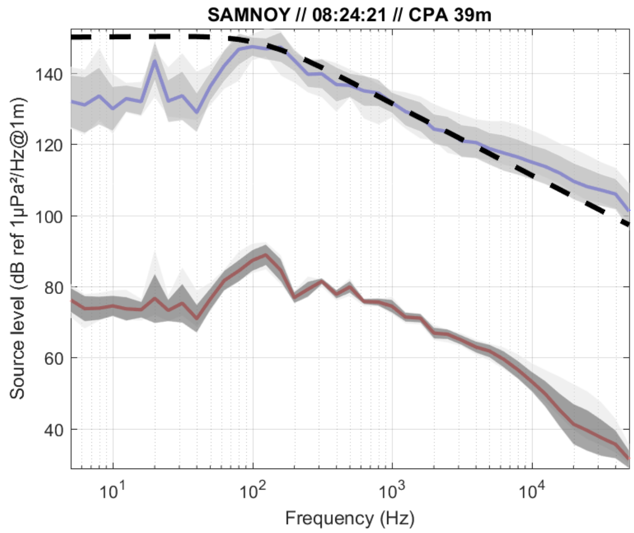


Figure 17: Estimation of source levels for Halhjem – Sandvikvåg ferries with fixed acquisition.

Table 6: Estimation of broadband source levels for Halhjem – Sandvikvåg ferries with fixed acquisition.

Vessel name	CPA (m)	Speed (kn)	Median SPL (dB ref 1µPa² @1m)
LYSØY	40	14.8	170
HUFTARØY	57	14.6	169
FAERØY	187	15.9	169
SAMNØY	39	15.2	171
FLATØY	121	16.2	168

IV.2.1.b. From drifting acquisition

The Figure 18 presents the estimation of source levels for each monitored ferry in area n°3. The source level of vessel is plotted in blue, the ambient noise measurement is plotted in red. A comparison with RANDI 3.1C model is proposed for FEAROY ferry, in black dotted. The Table 7 presents the broadband estimated values of source level for each ferry, with corresponding CPA distance and average speed during measurement, expressed in knots.

The 3 runs (2 for Faerøy ferry + 1 for Flatøy ferry, with same length 134m) share very close estimated source levels with a maximum energy in 50-150 Hz frequency band. Despite the varying CPA distances, the medians broadband SPL are grouped near 173dB ref 1µPa²@1m with a standard deviation of ± 0.5 dB. As seen during fixed acquisition analysis, the estimated profiles share a very good agreement with RANDI model above 100Hz.

Compared to source levels obtained at entrance of the harbour (fixed station), the SPL increasement (+3dB) on cruise is certainly due to the light speed increasement of one knot.

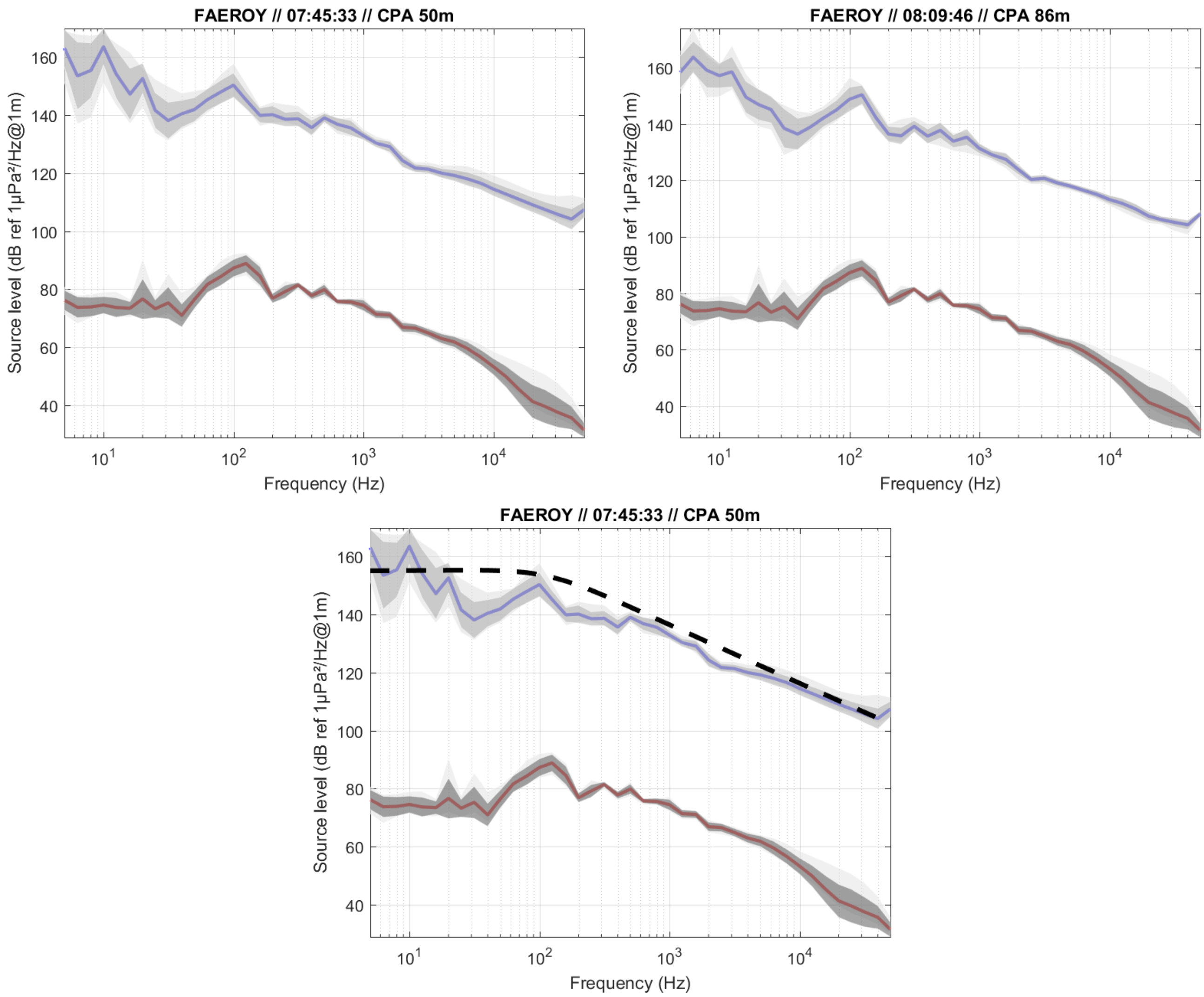


Figure 18: Estimation of source levels for Halhjem – Sandvikvåg ferries with drifting acquisition.

Table 7: Estimation of broadband source levels for Halhjem – Sandvikvåg ferries with drifting acquisition.

Vessel name	CPA (m)	Speed (kn)	Median SPL (dB ref 1µPa² @1m)
FAERØY	50	18.5	173
FAERØY	86	16.4	173
FLATØY	124	16.7	174

IV.2.2. OLE BULL hybrid ferry

Using the same methodology, the estimation of source level of OLE BULL hybrid ferry is processed both for fixed and drifting measurement stations. The results for OLE BULL ferry measured in area n°1 are given in Figure 19.

The left part presents the measured noise, whereas the right part presents the estimation of source levels. The measured noise and estimated source level of OLE BULL vessel are plotted in blue, the ambient noise measurement is plotted in red.

The estimated source profiles are very different depending of the measurement point. The received level profiles are also very different in low frequencies (<100Hz), but share a peak in 1kHz frequency band, probably corresponding to electric propulsion.

The Table 8 presents the broadband estimated source level of OLE BULL ferry both for fixed and drifting acquisition, with corresponding CPA distance and average speed during measurement. The median SPL estimated value is 170 dB ref 1µPa² @1m for fixed measurement (close to harbour) and 196 dB ref 1µPa² @1m for drifting measurement (in cruise). The Figure 20 is a reminder of measurement context for OLE BULL source level estimation.

Looking at the low frequencies received levels difference, the 26dB gap of SPL indicators can be explained by difference of loading of the thermic engine:

- The load of thermic engine is low as the vessel arrives/leaves the harbour;
- The load of thermic engine is higher as the vessel is cruising in the middle of the canal.

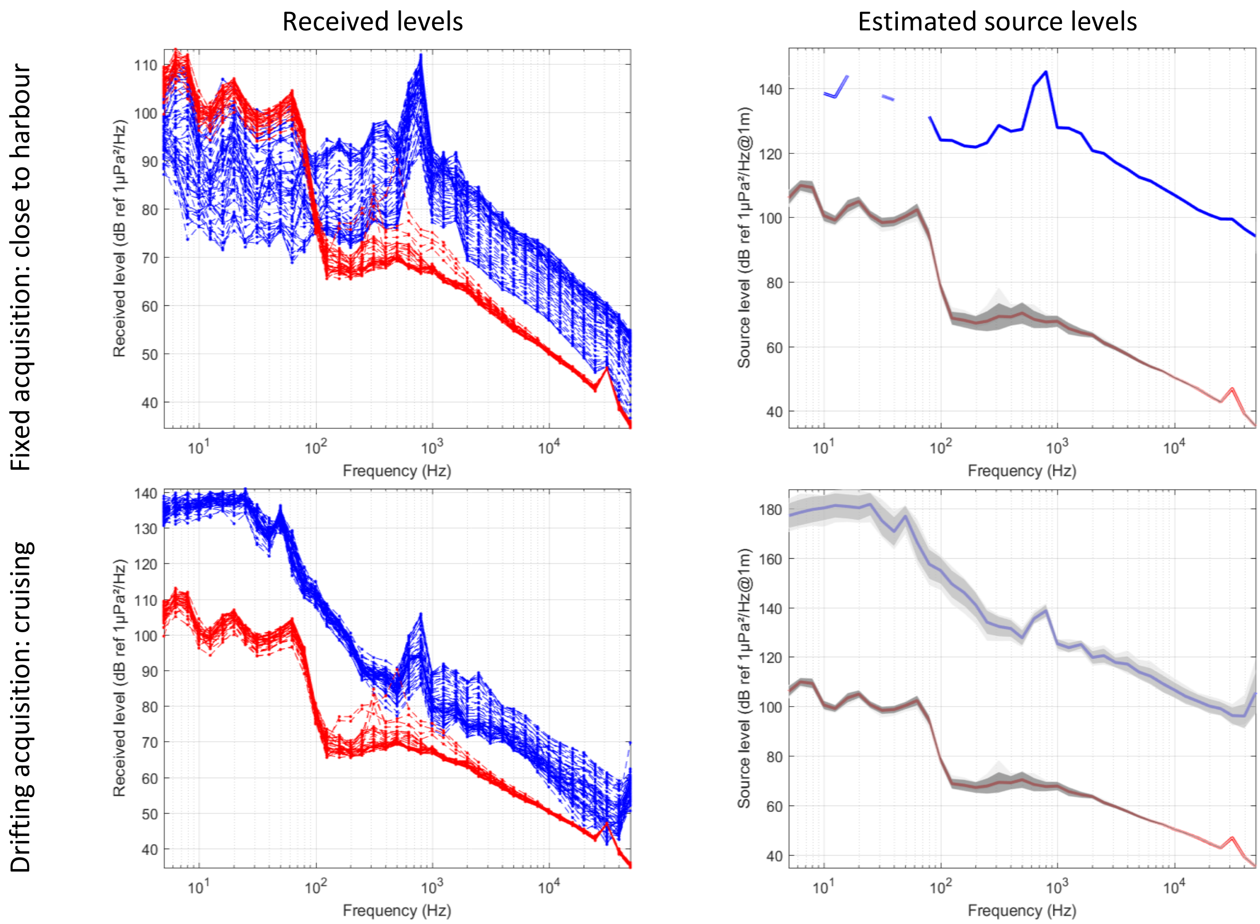


Figure 19: Received levels during OLE BULL ferry acoustic measurement with fixed and drifting stations (left). Estimation of source levels for OLE BULL ferry with fixed and drifting stations (right).

Table 8: Estimation of broadband source levels for OLE BULL ferry.

Method	Vessel location	CPA (m)	Speed (kn)	Median SPL (dB ref 1µPa² @1m)	Loading of thermic engine
Fixed	Near harbour	112	5.1	170	Low
Drift	Cruising	150	7.4	196	High

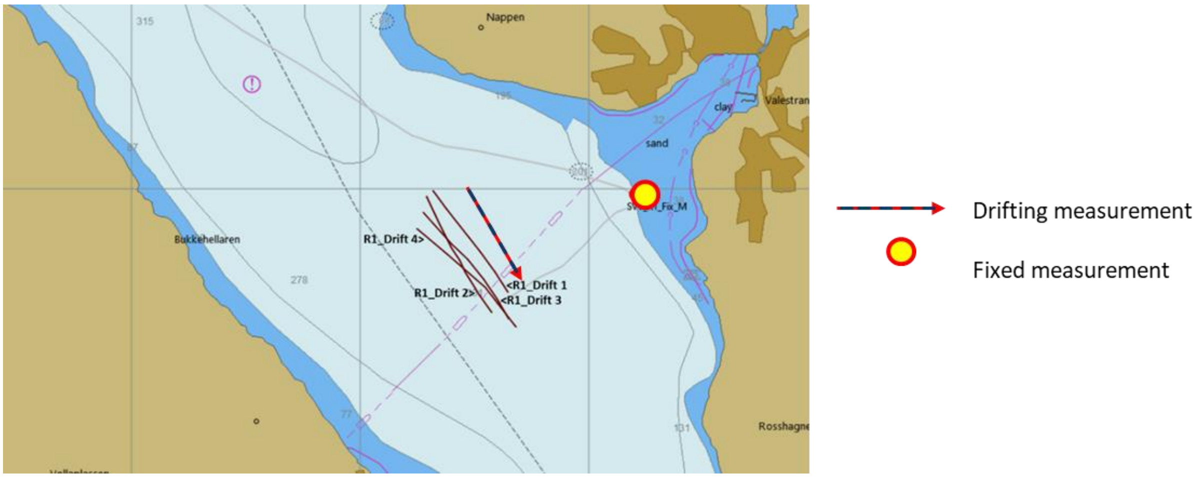


Figure 20: OLE BULL measurement context.

Chapter V. Noise analysis of floating bridge

As a reminder, one if the objective of this study is to estimate the noise emitted by the existing floating bridge in Nordhordlandsbrua area:

- ✓ From a spectral point of view, by calculating the spectrum of the source level at one meter from the bridge;
- ✓ From a broadband point of view, by estimating the noise level emitted at one meter from the bridge.

The measured acoustic data is analysed and then filtered to keep only the noise considered to be specific to the bridge. An acoustic inversion is then performed to estimate the noise emitted by the bridge, for each monitored pile (Figure 21).

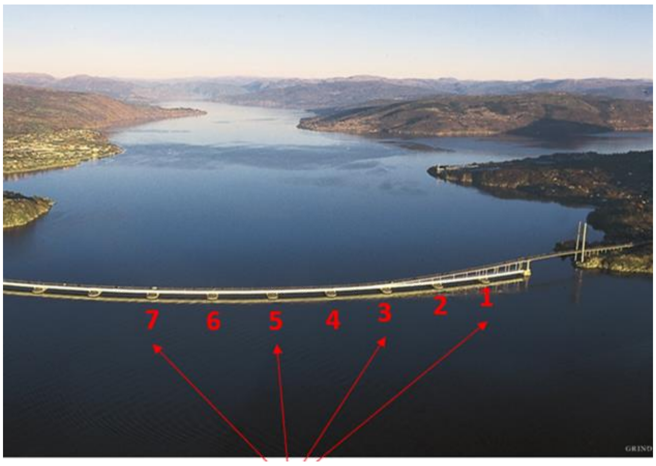


Figure 21: Monitored piles of Nordhordlandsbrua floating bridge.

V.1. Data processing methodology

The data processing methodology for floating bridge level of noise estimation is synthetised in Figure 22.

The data processing protocol is the same as the one used for the ferries. Only a few changes are made:

1. The distance separating the studied bridge pile from the support vessel (and by extension the hydrophone) is calculated.
2. The acoustic signal is then split by pile run. One pile is associated to one drifting radial.

The LEG01 (22.09.2022) data presented higher environmental noise levels than LEG02. Therefore, the analysis has been done on LEG 02 (26.10.2022) data.

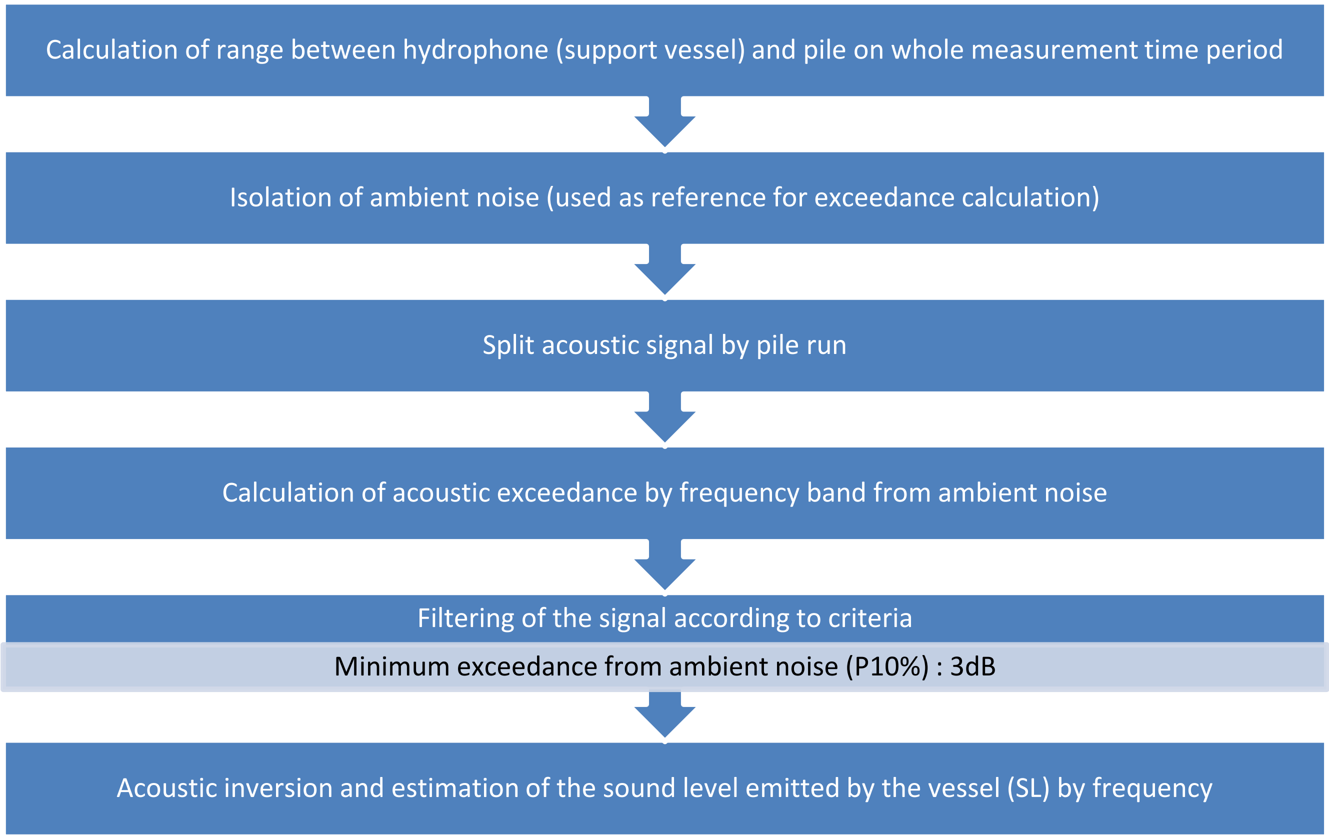


Figure 22: Data processing methodology used for source level estimation of floating bridge.

V.2. Source level of floating bridge

Based on drifting measurements, the Figure 23 presents the spectral distribution of the measured noise of one of the floating bridge piles during drifting measurement. The measured levels are plotted in blue, the ambient noise collected far from the bridge is plotted in red. On all recording sessions, no significative emergence has been detected in comparison with the ambient noise. The bridge cannot be clearly dissociated from ambient noise, independently of the distance between the bridge and the hydrophone.

However, short (5sec) exceedances have been detected on pile 3 during drift acquisition, probably induced by the vibrations of a sheet as the cars pass on the floating bridge. The results of analysis of this phenomenon are visible in Figure 24. The left part presents the spectral distribution of the measured noise during one rambling (10sec time window) at proximity from the pile 3, whereas the right part shows the estimation of the source level of this same rambling, back propagated at one meter of the pile 3.

Both received and estimated source levels show a maximum of energy in 10-15Hz frequency band, and the apparition of several exceedances visible at 50, 300 and 3000Hz, that are typical of mechanical vibrations phenomena.

The median estimated SPL (in frequency band 5Hz-40kHz) of the bridge during rambling is 167 dB ref 1 µPa²@1m.

Drifting measurement did not show significant exceedances of the floating bridge, however, the long-term acquisition (presented in next chapter of the document) highlighted a very low frequency exceedance, not visible here because of the measurement method, which is more sensitive to the noise induced by the current as the hydrophone moves in water.

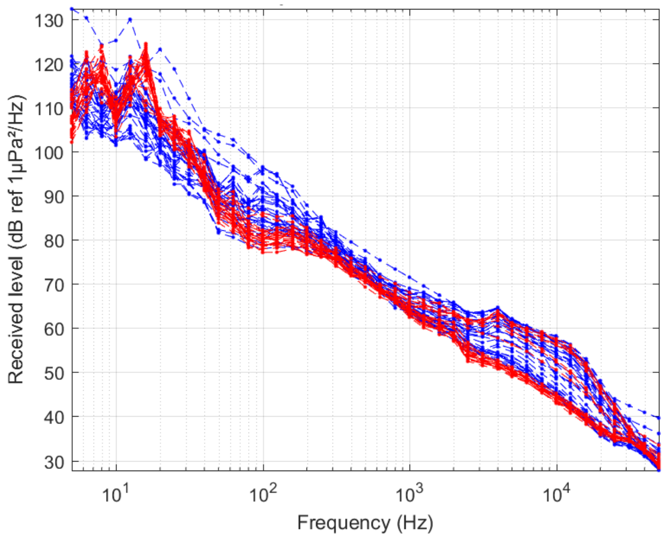


Figure 23: Received levels of noise during drifting acquisition near pile n°5 of floating bridge. Contribution of bridge is not apparent

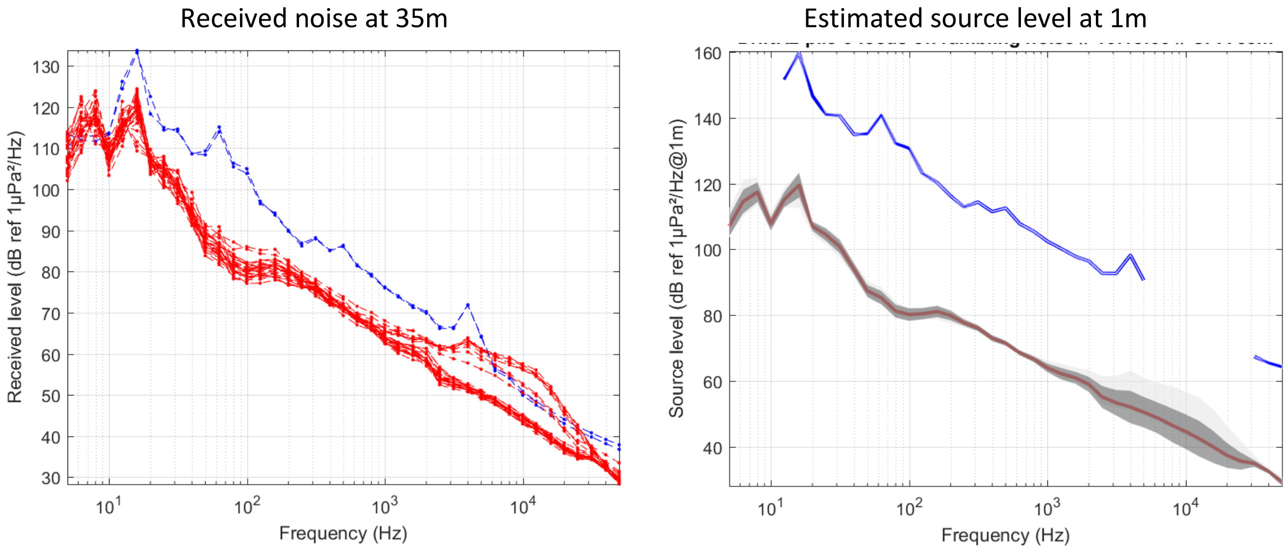


Figure 24: Analysis of intermittent rambling noise (on a 10s-time window) during the drifting acquisition near pile n°3 of floating bridge.

An illustrative spectrogram of rambling phenomenon near pile 3 of the floating bridge is proposed in Figure 25. It is traced between 50Hz and 4kHz in a 10 seconds time window.

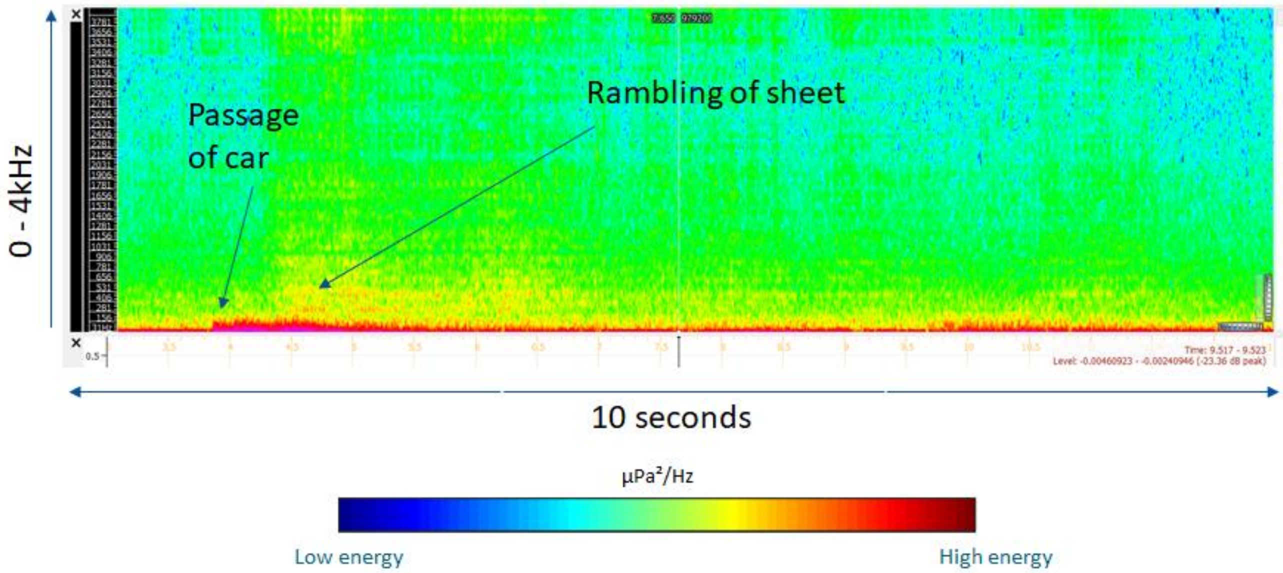


Figure 25: Spectrogram of rambling noise detected near pile n°03 of floating bridge.

Chapter VI. Noise analysis of long-term fixed station near to Nordhordlandsbrua floating bridge

This chapter proposes an analysis of the long-term acoustic data collected between 22.09 and 26.10.2022 at 160 meters from the closest pile of Nordhordlandsbrua existing floating bridge.

VI.1. Analysis

VI.1.1. Statistical analysis of broadband noise

The Figure 26 shows the evolution of broadband sound pressure levels (in frequency range between 5Hz and 40kHz) as a function of time, during the total acquisition period.

The overlayed red curve represents the temporal evolution of permanent noise. Permanent noise levels fluctuate between 80- and 105-dB ref 1µPa² according mainly to a night/day schedule, caused by anthropogenic frequentation of the area (road traffic and navigation). The ambient noise level variation is also strongly correlated with weather conditions, in particular wind speed between 100Hz and 12.5kHz. The agreement between wind speed and environmental noise levels is shown in Figure 27, for 800Hz and 10kHz specific frequencies.

As a mirror of permanent noise, the broadband SPL daily fluctuates from 85 to 125dB ref 1µPa² as the anthropogenic frequentation (road traffic, passage of boat at non immediate proximity) increases. The sound landscape is dominated by short (5 to 15 minutes) and intense anthropogenic exceedances, corresponding to the passages of ships. These make sound levels emerge from 15 to 20dB, inducing sound levels up to 145dB ref 1µPa².

After detection of the passages of these acoustically intense events, i.e. an increase of at least 15dB over the permanent sound level, we note an average of 33 significant events in the measurement area per day.

The navigation frequentation of the area is mainly split between the passages of regular lines of high-speed ferries (Vingtor, Njord, Tyrving, Frøya, Fjordkat…) and fishing vessels.

The Figure 28 traces the specific spectrogram (between 5Hz to 4kHz) of a close passage of Fjordkat ferry near the measurement station on 04.10.2022:

- ✓ During the approach, the sound level increases as the distance separating the vessel from the hydrophone decreases, with the apparition of a line near 100Hz frequency (propulsion noise due to thermic engine);
- ✓ At the minimum distance (CPA, Closest Point Approach), we note a short increase (30s) of the sound level up to 145 dB ref 1µPa², in a frequency band between 50Hz and more than 4kHz with a maximum of energy under 1kHz;
- ✓ The level of noise decreases with the distance as the vessel goes away.

The Table 9 provides the statistical distribution of the broadband noise expressed between 5Hz and 40kHz during the measurement period, with a distinction between night and day time:

- ✓ The median level (50% of the time) is 104.8dB ref 1µPa². In comparison with current levels in Europe, this level of noise is common.
- ✓ The loudest and rarest level (percentile 0%) is 145.5dB ref 1µPa² and is the result of close passages of boats near the hydrophone.
- ✓ The day/night gap is significative for all percentiles of noise, with 6 to 14 dB of exceedance during daytime. This gap is caused by intensive and quasi permanent frequentation of boats in the area.

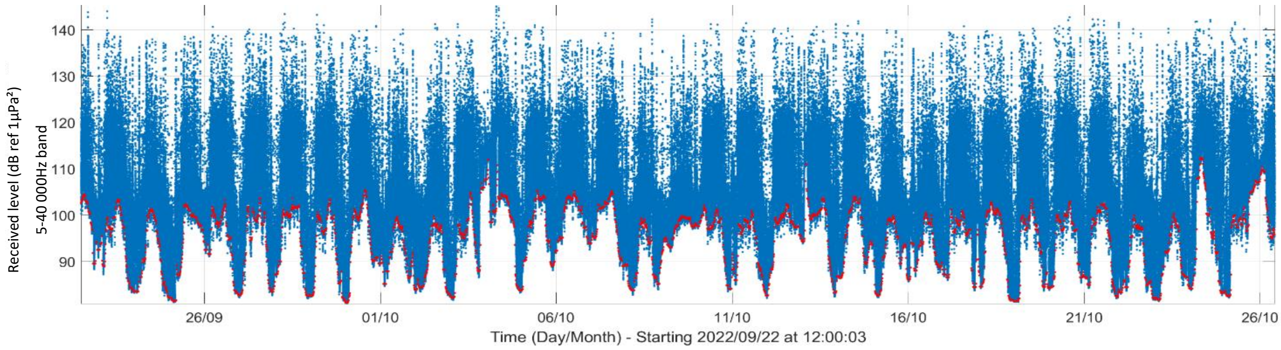


Figure 26: Broadband (5Hz-40kHz) received levels along time measured by fixed station near Nordhordlandsbrua floating bridge, expressed in dB ref 1µPa².

800Hz

10kHz

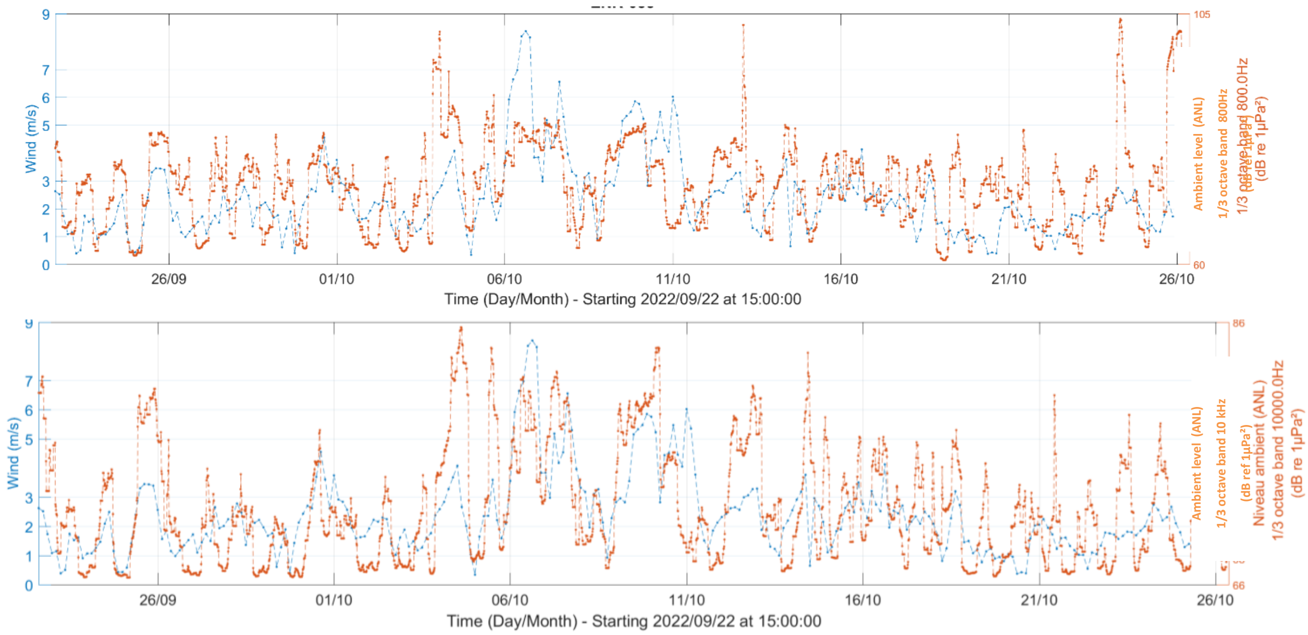


Figure 27: Correlation of permanent noise (in red) at 800Hz and 10kHz frequencies with wind speed (in blue) near Nordhordlandsbrua bridge.

Figure 28: Fjordkat high speed ferry (left.) Victoria fishing vessel (right).

Table 9: Statistics of broadband sound levels (5Hz -40 kHz) measured by fixed station near Nordhordlandsbrua floating bridge expressed in dB ref 1µPa².

		Often reached levels			Median levels			Rare levels		
Percentile	*(%)*	100	99	90	75	50	25	10	1	0
Energy	(dB ref 1µPa²)	80.9	**82.9**	90.6	98.4	**104.8**	110.2	116.8	**128.0**	145.5
Day	(dB ref 1µPa²)	86.3	**94.4**	101.4	104.5	**107.7**	113.4	118.8	**129.8**	145.5
Night	(dB ref 1µPa²)	80.9	**82.3**	87.0	93.2	**100.1**	106.8	113.7	**125.5**	143.9
D/N gap	(dB)	5.4	**12.1**	14.4	11.3	**7.7**	6.6	5.1	**4.2**	1.6

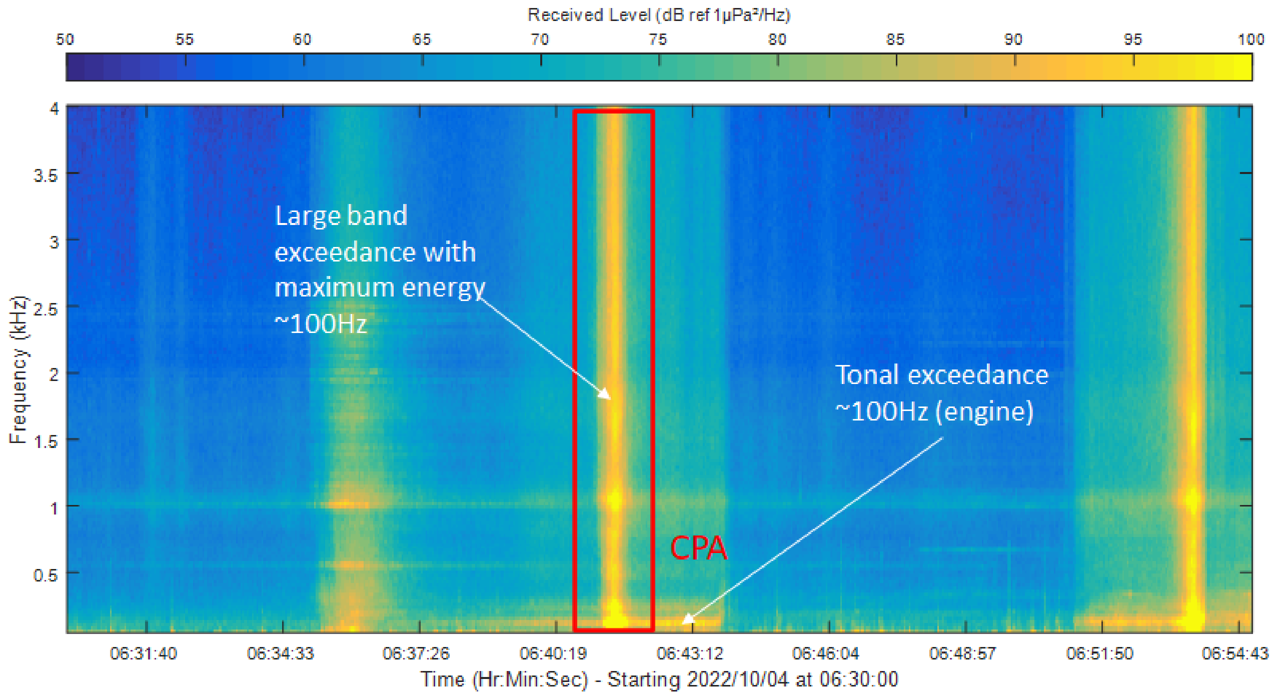


Figure 29: Spectrogram of Fjordkat ferry close passage near the hydrophone during long term measurement, on 2022/10/04.

VI.1.2. Frequency analysis

The Figure 30 gives the spectral distribution of acoustic energy in the area during the measurement period, as a function of percentile (statistical analysis).

The acoustic exceedances caused by navigation and road traffic are clearly visible on percentile range 1% to 50%:

- ✓ The very low frequencies are dominated by road traffic noise in 8-30Hz frequency band;
- ✓ An exceedance in 80-200 Hz frequency band corresponds to propulsion noise of ferries;
- ✓ Above 100Hz, the curves follow RANDI 3.1C model's trend.

The lowest percentiles (greater than 90 %) share a good agreement with Wenz (Wenz, 1962) environmental model (grey dotted curves), depending mainly of meteorological conditions (wind and waves).

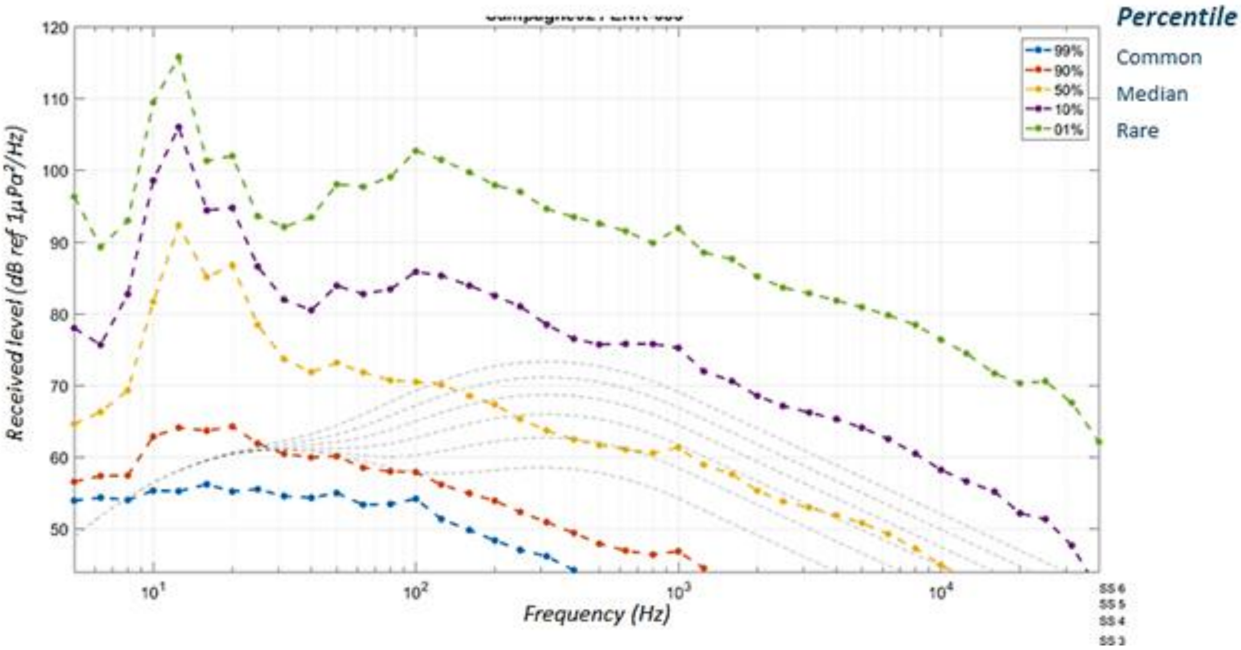


Figure 30: Spectral distribution of acoustic energy measured by fixed station near Nordhordlandsbrua floating bridge expressed in dB ref 1uPa²/Hz for different percentiles.

Focusing on 89-110Hz frequency band which is representative of the propulsion of boats, the Figure 31 shows:

- ✓ On the left side, the polar plot of hourly repartition of noise exceedances in 89-110Hz frequency band. As explained in the previous part, most of the acoustic energy (at least in this band) is concentrated in 4-18h UTC time window.
- ✓ On the right side, the spectrogram of the acoustic energy in 89-110Hz frequency band as a function of UTC hour and day: the regular passages of ferry are visible during working days as they induce redundant exceedances. The 4-18h UTC time window also shows the biggest concentration of energy.

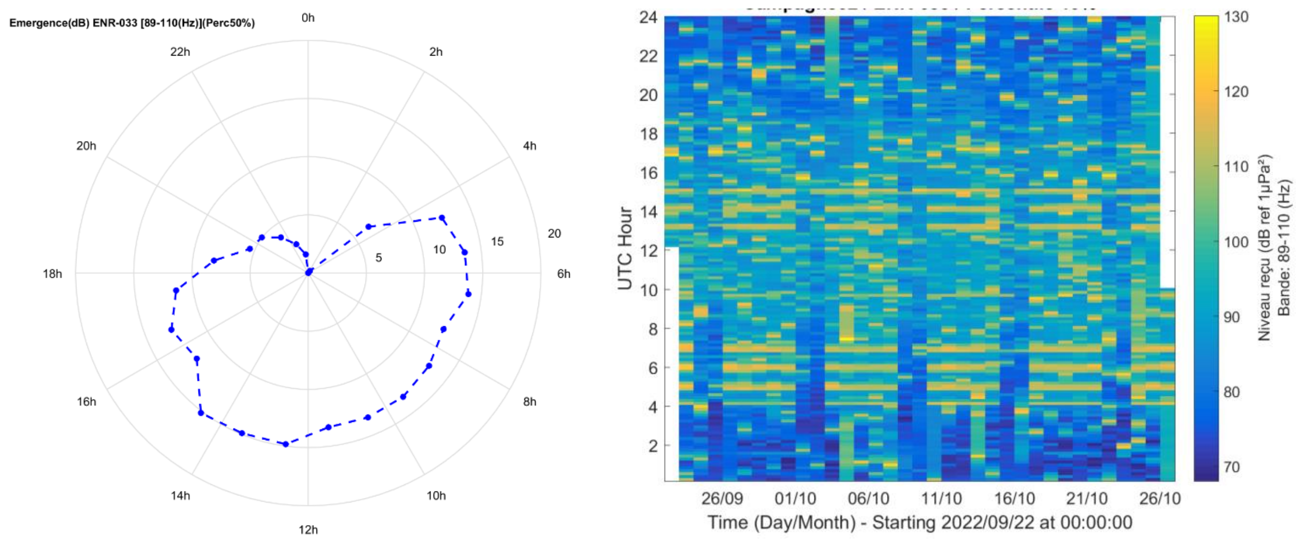


Figure 31: Hourly distribution of exceedances of median acoustic energy in 89-110Hz frequency band measured by fixed station near Nordhordlandsbrua floating bridge (left).

Time (UTC hour vs date) mapping of acoustic energy in 89-110Hz frequency band measured by fixed station near Nordhordlandsbrua floating bridge (right).

VI.2. Cross analysis of bridge noise and boat noise

By performing a spectral analysis, the noise of the floating bridge could be separated from boats 'one. The Figure 32 shows the spectrum (percentile 10%) of all instants found as bridge noise emission (in red) and boats noise emission (in blue).

The bridge noise consists of impulsive (transitory) low frequency noise with a maximum of energy in 10-15Hz frequency band at levels close to 115dB ref 1µPa²/Hz. Passed 20Hz, the acoustic energy rapidly falls out as the frequency increases.

On the other hand, the noise of boats could not be clearly separated from bridge noise, as cars can pass the bridge simultaneously as boats. As for the estimated source profile of the boats in Chapter IV, the spectrum of boats noise shows a maximum of acoustic energy in 100-150Hz frequency band with significant noise present up to 10kHz frequency. The passages of boats carry more total energy than the noise emitted by the floating bridge.

The Figure 33 traces the broadband values (between 5Hz and 40kHz) of acoustic energy of all instants found as bridge noise emission (in red) and boats noise emission (in blue) between Saturday 10/01 and Monday 2022/10/10. The noise emitted by the floating bridge seems to emerge more frequently (more instant founds) but has less energy than the noise emitted by the passage of boats near the hydrophone (approx. 125 vs 145dB ref 1µPa²). This is due to the larger acoustic emission frequency band of boats. Both timeseries share a day/night step effect, with the quasi absence of boats, and really low emission by the bridge (close to ambient noise) during night time. Also, bridges noise tends to drop during the weekend (-5dB), as the road frequentation decreases on non-working period, whereas the frequentation of boats seems quite stable depending on the day of the week.

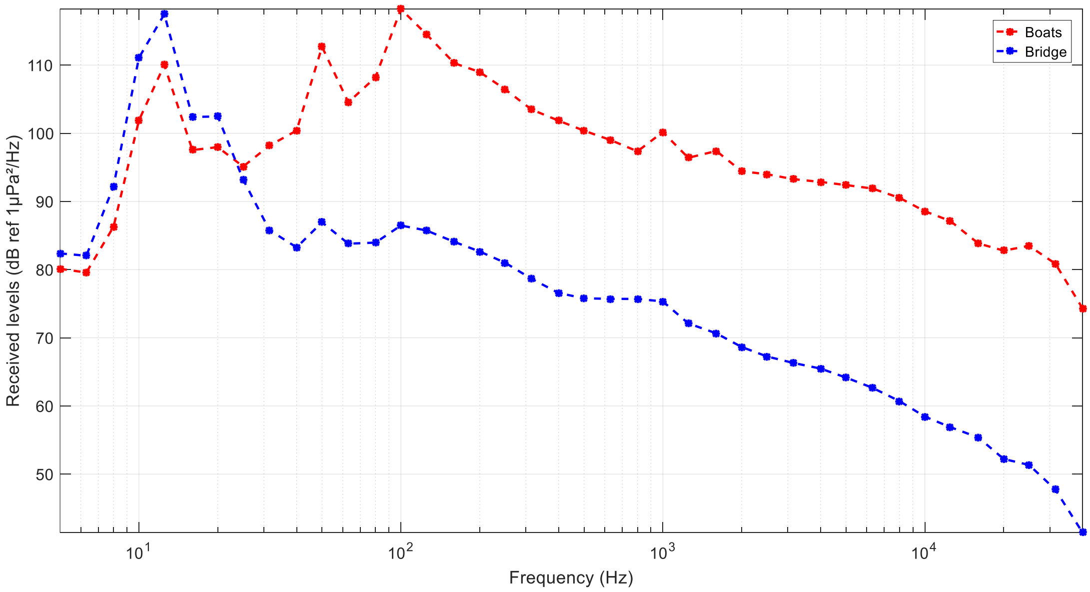


Figure 32: Spectral distribution of the acoustic energy (P10%) received by fixed station near Nordhordlandsbrua floating bridge for anthropogenic classified instants (bridge or boats).

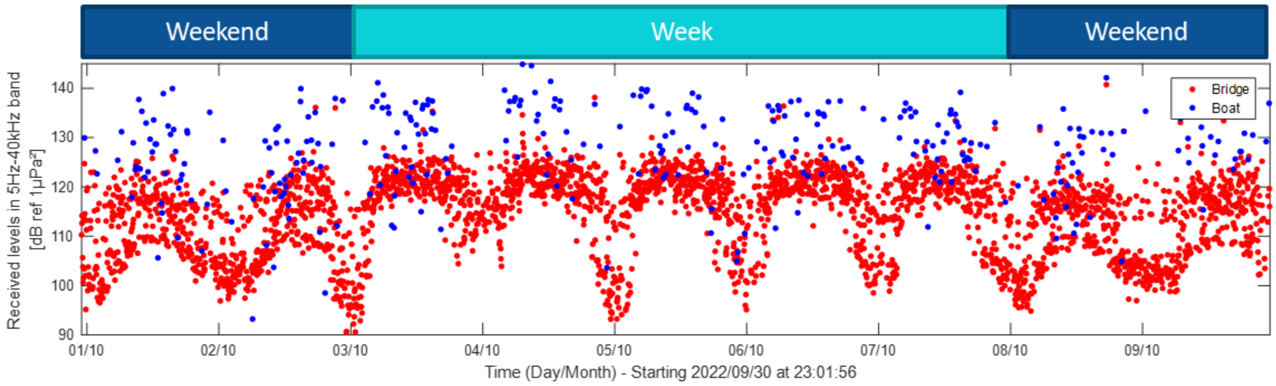


Figure 33: Broadband received levels of acoustic energy received by fixed station near Nordhordlandsbrua floating bridge for anthropogenic classified instants (bridge or boats).

Chapter VII. Comparison of the acoustic impact of a floating bridge and of ferries

Building on the conclusions drawn in the previous chapters, this part of the study aims to define and compare the acoustic risk induced on marine species by the construction and commission of a floating bridge and the exploitation of regular ferry lines.

VII.1. Definition of the acoustic risk

During noise emissions, the potential risks are greater the closer individuals are to one or more noise sources and the more intense the noise exposure. Our methodology provides for a hierarchy of risks on an axis of decreasing noise level, based on the literature and current scientific and technical capabilities to quantify risk distances.

As noise levels decrease, the risk zones change in nature (Dooling RJ, 2013). The transition from one risk zone to another corresponds to the crossing of a biological threshold provided, where appropriate, by research and literature. There is international consensus on risk gradation and threshold values for physiological damage, but the state of scientific knowledge does not yet allow for a decision on thresholds for behavioural changes.

The gradation of effects is shown in Figure 34, and can be decomposed with:

- ✓ A physiological injury zone which corresponds to an area in which noise levels exceed permanent physiological damage (PTS) thresholds, causing irreversible damage;
- ✓ A zone of physiological damage which corresponds to an area in which noise levels are likely to cause temporary physiological damage (TTS) resulting in reversible damage. Cells return to their original state after a period of time away from significant exposure to noise;
- ✓ A behavioural response zone which is an area in which noise levels are likely to cause sufficient annoyance that individuals interrupt their normal activity to flee the area. The consequences are not direct, but cause an increase in individual energy consumption that is all the more critical the younger the individual, an interruption in their hunting or socialising activities, a forced change of habitat. Ultimately, the impacts can be felt at the individual and population level;
- ✓ A masking zone that occurs when the sounds emitted and received by the specimens (essential sounds in their hunting, socialisation, reproduction, or predator avoidance activities) are covered by anthropogenic noise. This type of effect is relevant for continuous sounds or impulse sounds with a high cadence and a long duration.
- ✓ A zone of audibility, a risk-free zone, which corresponds to an area in which anthropogenic, biological and natural noise is perceived by individuals, without causing any particular known effect.

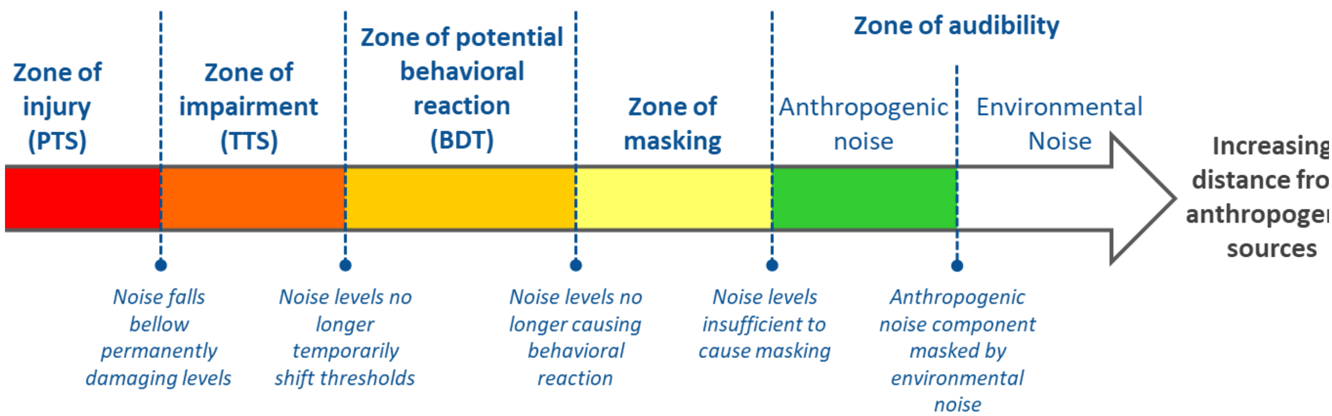


Figure 34: Graduation of biological risks according to the distance to the source(s) of anthropogenic noise.

VII.2. Risk associated to the construction of a floating bridge and ferry port expansion works

VII.2.1. Expected acoustic risks

During the whole construction period of the potential future floating bridge in Bjørnafjorden, two types of noisy activities can be expected:

- The anchorage of floating support units;
- The installation of bridge piles.

The most significant predicted noise impact concerns the installation of bridge piles into the ground, either by pile driving or by drilling.

Even if the work is done on land, the transmission of energy into marine environment is to be expected.

The same underwater noise impact can be generated by ferry port expansion works, for instance the construction or major maintenance of a wharf. Bedrock removal by explosive to ease the navigation of ferries can also cause major underwater noise impact.

In the case of the construction of a floating bridge or port expansion works, depending of the distance of the work and of its acoustic intensity, the potential acoustic risk of pile driving and drilling can cause:

- A masking of communications between marine mammals;
- Behavioural disturbances;
- Impairment;
- Physiological injuries, in worst cases.

VII.2.2. Temporary loss of habitat

Several studies (Brandt et al., 2011; Dähne et al., 2013; Rose, 2019) have exposed significant (approx. 20km of radius) and durable decreases of marine mammals frequentation in the areas exposed to piling (or in general significant acoustic disturbances) highlighting the importance of acoustic risk management during noisy work to protect the marine biodiversity.

An example of change of frequentation of marine mammals (harbour porpoise in this very study) is given in Figure 35 (Dähne et al., 2013). The first offshore wind farm Alpha Ventus in the German North Sea was constructed north east of Borkum Reef Ground approximately 45 km north off the German coast in 2008 and 2009 using percussive piling for the foundations of 12 wind turbines. A significant displacement of the population can be seen during (and after) pile driving.

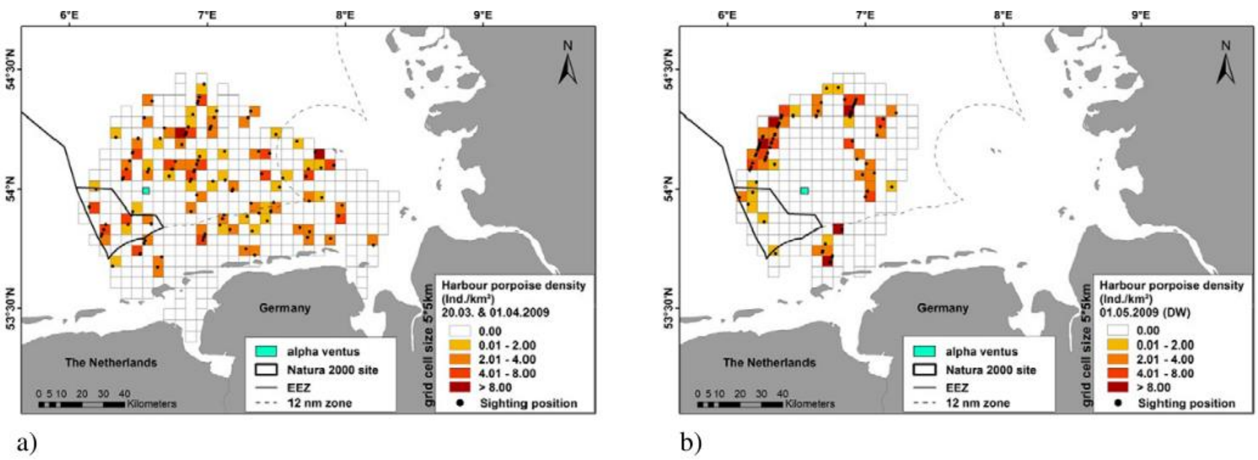


Figure 35: Spatial distribution of harbour porpoise density and sightings. (a) Pre-pile-driving in March/April 2009 and (b) during pile-driving (source: Dähne et al., 2013).

VII.3. Estimated impact during commission

VII.3.1. Auditory capability of species

In order to illustrate the conclusions of estimated acoustic impact on species on Bjørnafjorden area, the M-weighting function of pinnipeds and porpoises (Southall et al., 2019) is given in Figure 36 and is used to define effect on individual species. Also, the audiogram of several fish species (Andersson, 2011) is given in Figure 37.

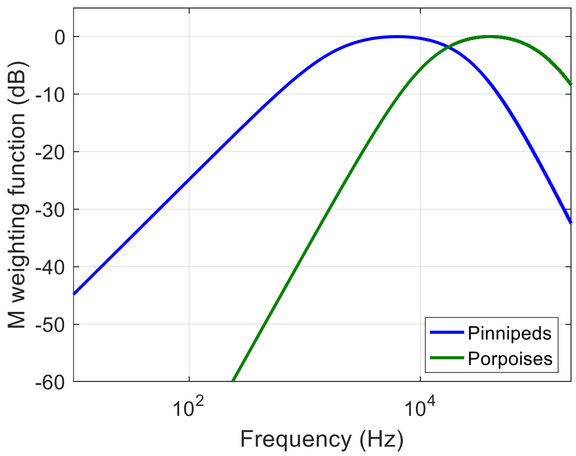


Figure 36: Marine mammals M weighting function based on Southall 2019 and band of emission of bridge (in blue)

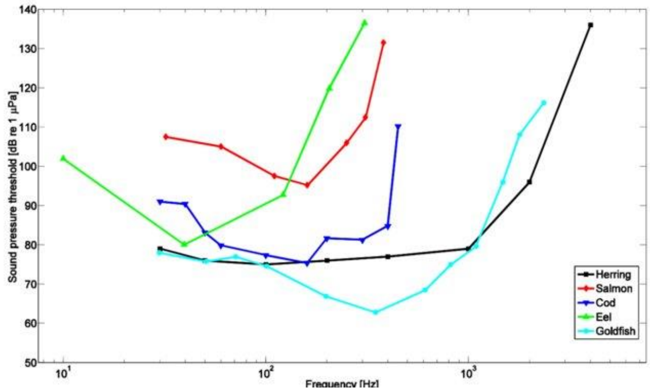


Figure 37: Audiogram of fishes based on Andersson 2011 and band of emission of bridge (in blue).

VII.3.2. Impact caused by ferry traffic

VII.3.2.a. Expected impact due to traffic ferry on individuals

Based on estimation of source levels of ferries (for example Flatøy with 173dB ref 1µPa² @1m), sounds emitted by vessels can be perceived by fish up to 14 km depending of environmental sound levels.

Based on recommendation of (Southall et al., 2007), which is the same for all species, including fish and marine mammals, low, median and significant behaviour disturbance (respectively thresholds 120, 140 and 160dB ref 1µPa) can be expected until 450m, 45m and 4m from ship position.

According to Popper 2014 (Popper et al., 2014) (threshold 158 dB SPL for 12 hours), no injury can be expected on fish population.

An illustration of the range corresponding to each acoustic risk linked to ferry traffic is proposed in Figure 38 page 43.

VII.3.2.b. Risk of habitat loss

When submitted to certain acoustic pressure causing behavioural change, individuals try to adapt to this pressure to continue to use their habitat. If behavioural change strategies prove ineffective, populations may abandon an habitat that has become too degraded (Lusseau D., 2004) (Lusseau & Bejder, 2007).

A study in New Zealand has shown that a frequency of more than one disturbance every 68 minutes leads bottlenose dolphins (*Tursiops truncatus*) to avoid an area (Lusseau D., 2004). Dense maritime traffic can thus cause the loss of habitats for species. These habitat losses can lead to the extinction of species (Lusseau, Slooten, & Currey, 2006).

VII.3.2.c. Risk of collision

Collisions between ships and large cetaceans also represent a very high risk for individuals, especially as collisions are often fatal for them. Although the fatality rate following a collision is difficult to estimate, according to (Jensen & Silber, 2003), death is the outcome of the accident in 68% of cases. According to the International Whaling Commission database on collisions 44% of collisions are fatal (Van Waerebeek & Leaper, 2008).

Outcome of the collision depends on ship's speed. According to (Vanderlaan & Taggart, 2007), the probability of serious injury really starts around 10 knots and death from 12 knots. These probabilities are a function of speed. However, their study indicates a risk at lower speeds. Death is the certain end of a collision from 18 knots (Nichol, Wright, O'Hara, & Ford, 2017). In Bjørnafjorden area, the collected speeds of vessels ranged from 14.5 to 18.5 knots.

Collisions between ships and large cetaceans are the leading cause of unnatural mortality of these species and a major cost for the shipping industry. This issue is a major concern for the shipping industry and the protection of cetaceans. Regulations have been adopted at the international level (MEPC.1/Circ.674 of the International Maritime Organization adopted in 2009; recommendations of the International Whaling Commission) and at the national level (zones where the route and speed of vessels is regulated according to the presence of cetaceans or where special monitoring measures are requested from vessels in France, Canada, the United States, Spain, New Zealand, Panama, Argentina, etc.).

Shall such a measure be adopted in the Bjørnafjorden area, this would lead to a reduction of ferries' speed. That is to say the reduction of the number of vehicles possibly transported by ferry by hour and therefore an increase in time to travel from one side to the other of the Bjørnafjorden because of vessel reduced speed and possible higher waiting time to board ferries. This could lead to the obligation to add ferries on this route to compensate this decrease but therefore increasing underwater noise and collision risks.

VII.3.3. Impact caused by a possible floating bridge commission

The measurements done near Nordhordlandsbrua floating bridge shows that this floating bridge noise is only partly perceivable in a narrow low frequencies band (Figure 36). No significant impact is therefore expected on pinnipeds and porpoises.

Concerning fish (herring, salmon, cod, haddock), present scientific knowledge does not conclude on the hearing of these species in these narrow low frequencies band (Figure 36). Sounds emitted by the floating bridge could be perceived until 1 to 3km depending of ambient noise levels if these species can perceive sounds at these frequencies.

Based on recommendation of Southall 2007, low and median behaviour disturbance (respectively thresholds 120 and 140dB ref 1µPa) can be expected until 30m and 3m from floating support unit.

According to Popper 2014 (threshold 158 dB SPL for 12 hours), no injury can be expected on fish population.

An illustration of the range corresponding to each acoustic risk linked to the floating bridge is proposed in Figure 38.

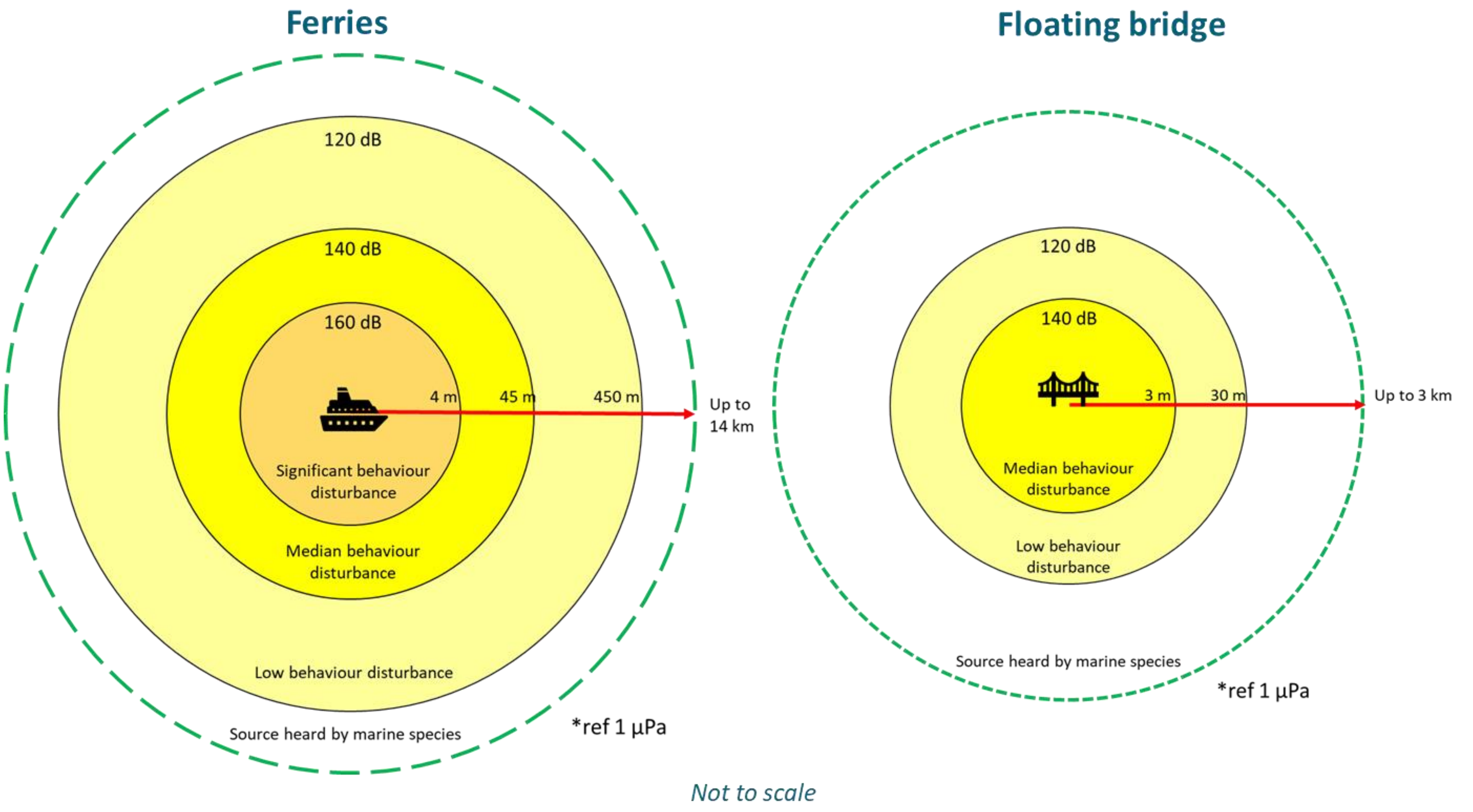


Figure 38: Illustration of acoustic effects induced by ferry (left) and by floating bridge commission (right).

Chapter VIII. Possible mitigation measures

To limit the impact of such workshops, a panel of mitigation solutions can be envisaged and studied trough an acoustic impact assessment study. A quick introduction to mitigation is proposed in this section.

Mitigation management includes:

- ✓ reduction of noise levels perceived by species, that is to say reduction of the acoustic risk;
- ✓ avoidance of the acoustic risk.

VIII.1. Risk reduction

Risk reduction can be achieved through three main levers (Figure 39):

- ✓ Implementing measures to reduce individual noise source levels;
- ✓ Implementing measures to reduce cumulative noise levels;
- ✓ Implementing systems that impede the propagation of noise in the marine environment.

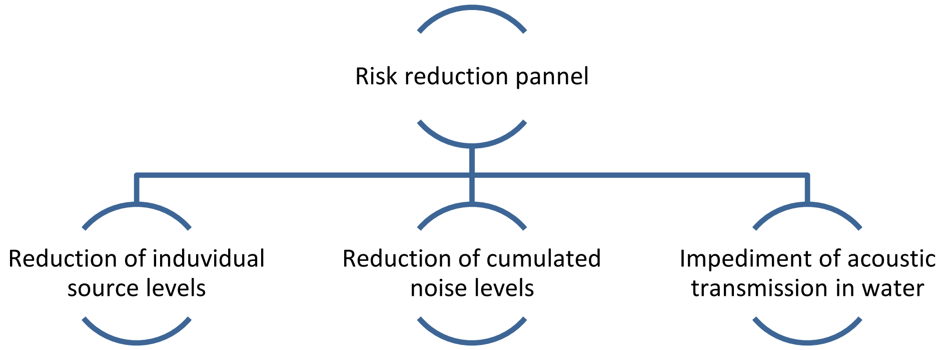


Figure 39: Main levers for acoustic risk reduction.

VIII.1.1. Panel of measures to reduce individual noise source levels of piling

A first approach to reduce the noise (and the risk) induced by pile driving can be to use an alternative technique of construction.

Construction techniques for building offshore foundations as an alternative to pile driving include:

- ✓ Vertical drilling: Vertical drilling techniques are solutions that reduce the noise emitted compared to ramming techniques. Therefore, they are presented here as a reduction measure.
- ✓ Vibro-drilling: The main advantage of vibro-drilling techniques is that it replaces the impact of the hammer on the pile with a less energetic continuous vibration whose maximum sound energy is centred on the vibration frequency. The sound gain can be up to 15dB, but with a larger temporal dispersion (WSDOT, 2005). These techniques are suitable for shallow waters (a few tens of meters), but their use is limited when the bottom is too dense.

If no alternative techniques are suitable, the acoustic optimisation of piling components can be achieved:

- ✓ Either through the various components of a hammer (power, cabinet, etc.);
- ✓ Either at the level of the anvil;
- ✓ Or in the characteristics of the pile.

VIII.1.2. Panel of measures to reduce cumulative noise levels

The multiplicity of noise sources on the site and their duration over time have a direct effect on the cumulative noise levels. There are three ways to manage this accumulation:

- ✓ Management of the overall construction site planning: When possible (favourable weather window, etc.), specific planning of the various workshops can reduce the cumulative noise levels.
- ✓ Management of the timing of impulse noise;
- ✓ Soft start: Cumulative noise levels increase with the duration of exposure. The increase in cumulative sound exposure levels is rapid at the start of operations (first hour), and slower as the operation continues. Managing the timing at the start of operations helps to contain the rapid increase in cumulative noise exposure levels and therefore control the rate of progression of risk areas with levels above the physiological damage thresholds. A theoretical illustration of soft start is given in Figure 40.
- ✓ Noise masking: Intense noise masks lower noise. This is due to the logarithmic nature of noise. Therefore, it may be appropriate, in the proximity of a particularly intense noise source, to simultaneously implement other less noisy techniques in order to mask them in the intense sound field and avoid having to implement them in a later silent period.

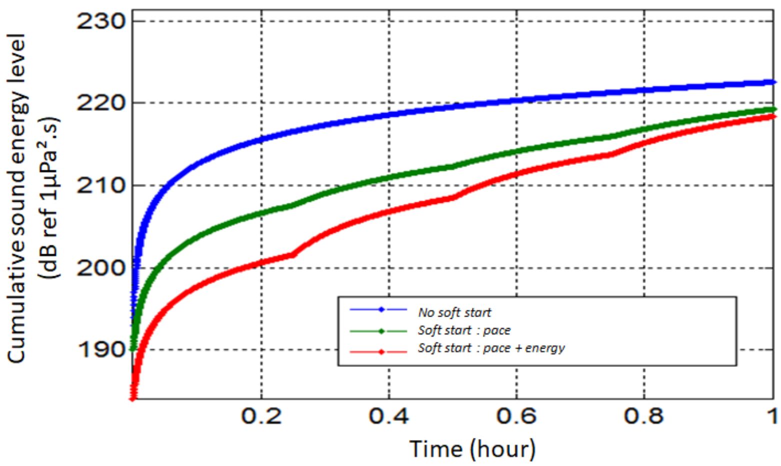


Figure 40: Theoretical comparison of the cumulative noise effects of a soft start of the work during the first hour of the construction site: without soft start (blue), soft increase in the rate (green) and soft increase in the rate and energy of the blows (red).

VIII.1.3. Panel of measures to reduce to impede the acoustic transmission in water

The principle of noise mitigation systems is to locally and physically disturb the oceanic propagation medium in order to increase the sound propagation losses generated by the noise source. In order to disrupt the propagation, the physical mechanisms involved are dispersion, scattering and absorption of sound waves.

Possible techniques are detailed below.

VIII.1.3.a. Bubble curtains

The bubbles create an impedance break in the liquid medium (water), impeding the propagation of acoustic waves. An illustration is given in Figure 41.

Figure 41: Left: Bubble curtain around a pile driver platform in the North Sea.
Right: Bubble curtain implementation test and efficiency assessment for Kystverket in Ålesund. Source: Quiet-Oceans

Sometimes the noise level is so high that a single bubble barrier is not sufficient. In some offshore wind farms, four interlocking bubble curtains have been used (Figure 42).

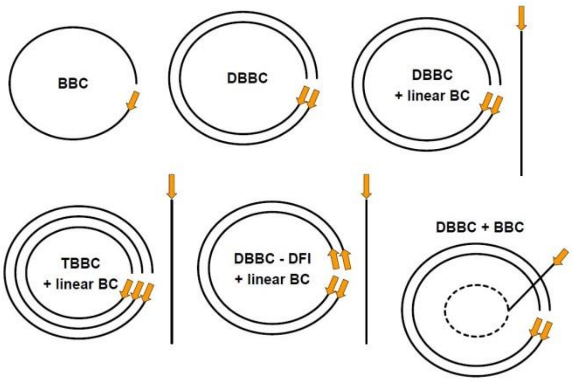


Figure 42: Example of a bubble curtain layout (source: Vattenfall)

The currents also disturb the ascent of the bubbles, sometimes to the point of moving them outside the area to be absorbed. For example, a bubble emitted at a depth of 20 m and subjected to a current of 1 m/s is deviated laterally by 70 m at the surface. The bubble curtains must therefore be placed in such a way as to take account of this drift, which means that the diameter of the curtain is often large, or repeated at several depths (Figure 43).

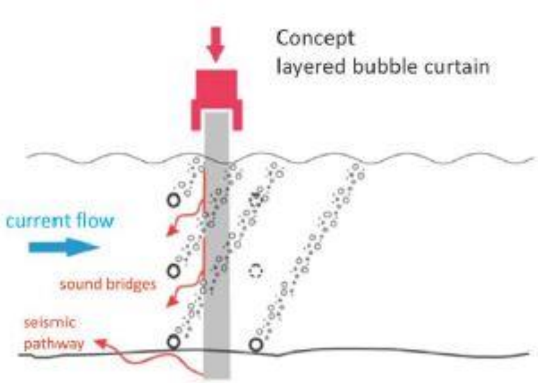


Figure 43: Superimposed bubble curtain system to counteract the effect of the current (Koschinski & Lüdemann, 2013)

Bubble curtain can generally be implemented by depths up to 50m depending on the current speed that could move the bubbles outside of the desired mitigation area. Cost depends on the diameter size of the bubble curtain and can be high if air compressors have to be operated from a boat. Air pollution depends on the air compressor technology (electrical or diesel).

Results from nearly 20 wind farms in Europe have shown (Bellmann, et al., 2015), under optimal conditions of use, a reduction in noise level:

- 10 to 15 dB for a simple bubble curtain;
- 14 to 18 dB for a double bubble curtain;
- 15 to 19 dB for a triple bubble curtain.

VIII.1.3.b. Containment techniques

In order to mitigate the effects of the current, which can totally or partially destructure the bubble curtain and thus alter its performance, bubble containment solutions exist. These systems allow the bubbles to be channelled around the pile. An illustration is given in Figure 44. Several types and providers of such solution exist.

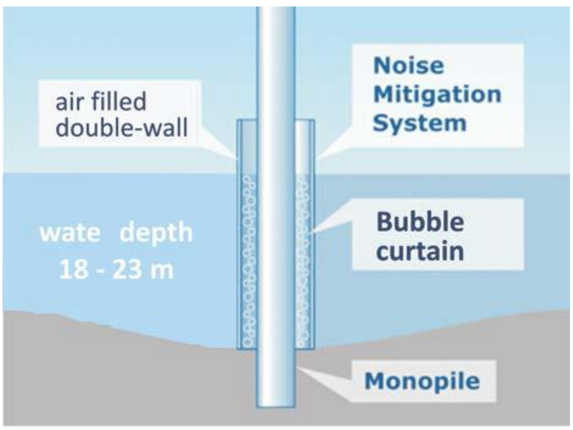
(a)  (b) 

Figure 44: IHC-NMS system. (a) Nozzle arrays of the deployed system (b) Schematic of the operating principle (Source: Koschinski & Lüdemann 2013).

VIII.1.3.c. Acoustic screen

The acoustic screen consists of walls made of synthetic materials, that creates a physical barrier to the sound;

VIII.1.3.d. Hydro-sound damper

The scattering of acoustic waves is achieved by resonance effects of the air contained in the latex spheres leading to a reduction of the energy outside the system. The resonant frequency of the spheres can be adjusted by adjusting the diameter of the spheres, the rigidity of the sphere shell material and the gas pressure in the sphere. An illustration is given in Figure 45.

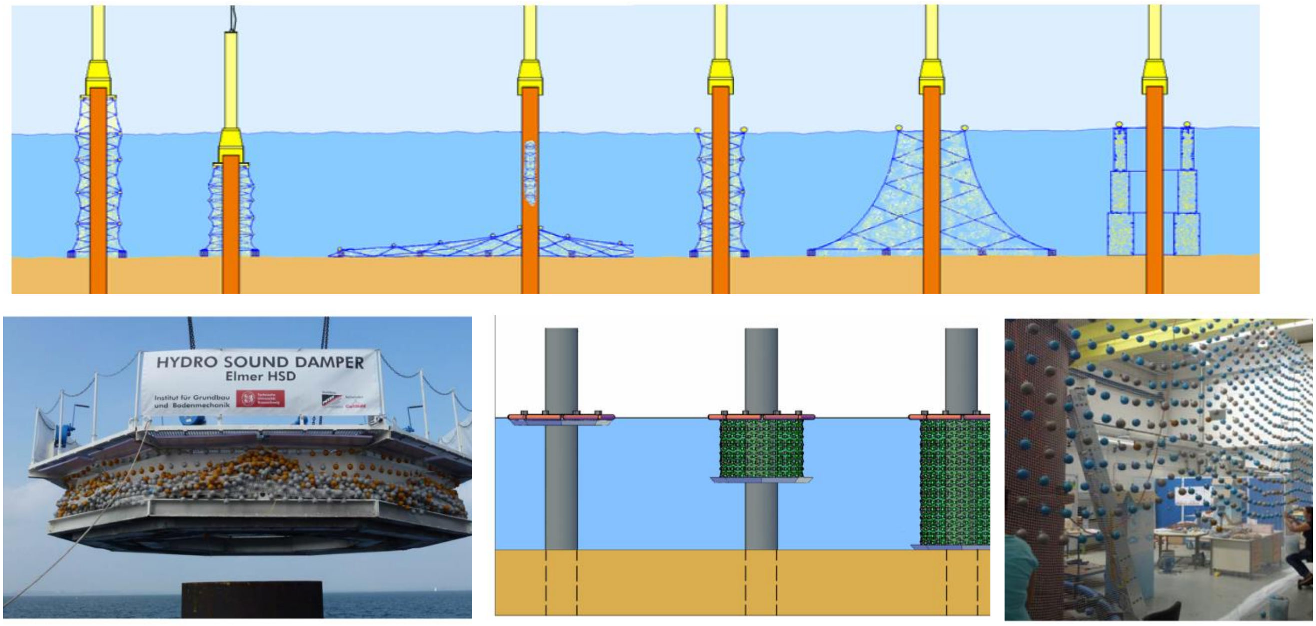


Figure 45: Examples of possible configurations of HSD system (source: Technische Universität Braunschweig / Dr. Elmer.)

VIII.1.3.e. Cofferdam

The oldest method is the cofferdam. Watertight structures are built around the work area and the water is pumped out. The noisy workshop is left dry. The sound waves only propagate through the sediment, depending on its nature.

The installation of a cofferdam is long and complex because the device must be watertight. This may not be compatible with certain works such as pile driving, for which the mobilisation of resources is costly.

The depth also limits the use of cofferdams. Finally, there are environmental issues, depending on the local ecosystem: the construction of the cofferdam creates environmental impacts.

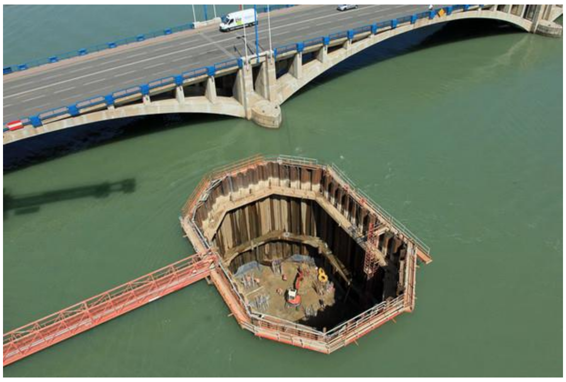


Figure 46: Cofferdam (source: Sytral)

VIII.1.3.f. Acoustic resonator

The US company AdBM has developed a system of ladder-mounted acoustic resonators that are immersed around the driven pile. The performance is said to be good: 37 dB reduction in a small-scale trial during the construction of the Butendiek park in 2014 (Wochner, Lee, McNeese, & Wilson, 2016). To our knowledge, one full scale implementation has been done for the construction of the Borssele offshore wind farm III and IV in Belgium, where it has been associated to a Double Big Bubble Curtain. According to Van Oord, the combination of the acoustic resonator and the Double Big Bubble Curtain resulted in a sound attenuation between 12 and 25 dB (Van Oord, 2022).

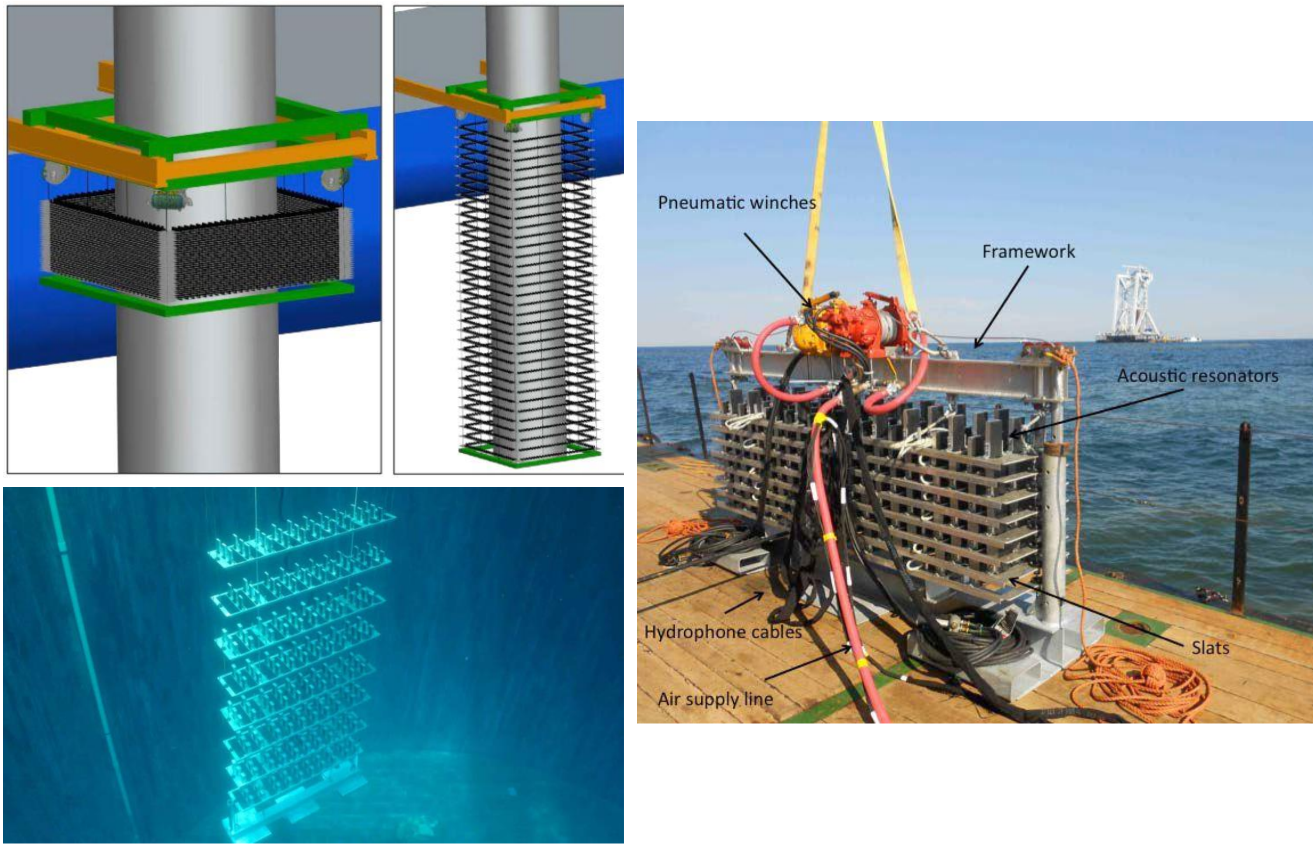


Figure 47: System of acoustic resonators mounted on deployable ladders to frame the pile (source: AdBM)

The Figure 48 proposes an example of comparison of resulting noise reduction obtained with different mitigations configuration, averaged over all applications within the German Exclusive Economic Zone of the North Sea (Bellmann et al., 2020).

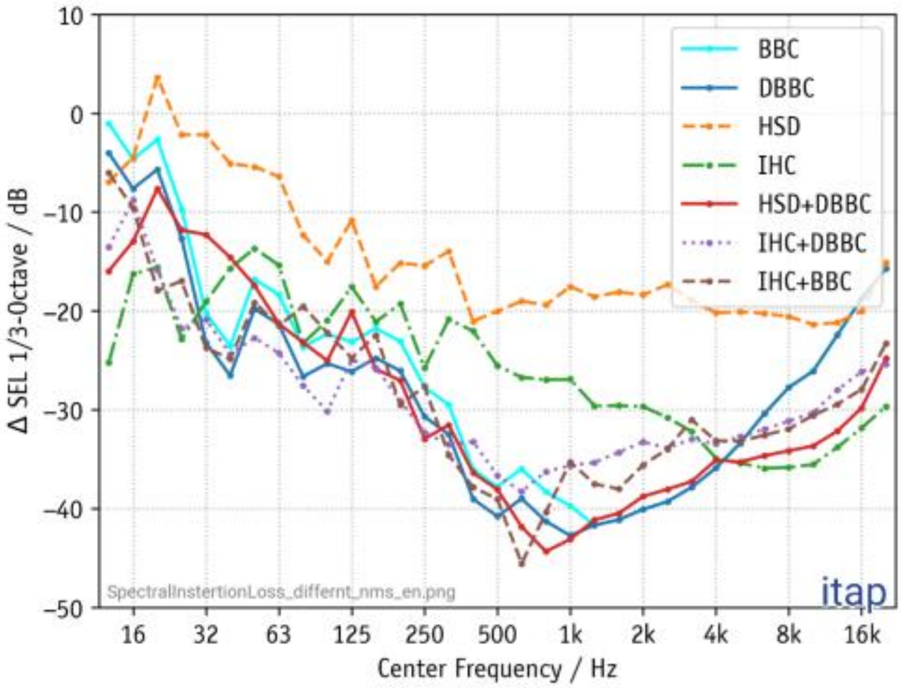


Figure 48: Resulting noise reduction (transmission loss) of the applied Noise Abatement Systems – IHC-Noise Mitigation Screen (NMS8000), Hydro Sound Damper (HSD) and optimized single/double Big Bubble Curtain (BBC/DBBC), averaged over all applications within the German EEZ of the North Sea source: (Bellmann et al., 2020).

VIII.2. Risk avoidance

Risk avoidance can be achieved through three main levers (Figure 39):

- ✓ Implementing measures that temporarily move species away from risk areas;
- ✓ Monitoring the presence or absence of individuals to allow noise production only when no individual is in the acoustic risk area;
- ✓ Monitoring underwater noise levels.

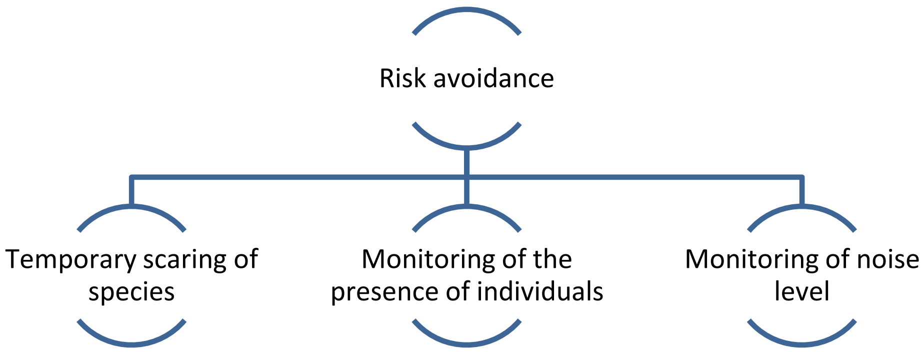


Figure 49: Main levers for acoustic risk avoidance.

VIII.2.1. Panel of measures to temporarily remove species from risk areas

The philosophy behind the removal measures is to ensure that specimens in the physiological risk areas can move away safely before the full power of the noise is emitted.

Three strategies are possible:

- ✓ The "ramp-up" procedure, also used for risk reduction: gradually increasing noise levels in order to scare away potentially present species through increasing noise annoyance. This measure concerns species that are mobile enough to move away from intense noise sources without endangering their survival. The rate of advance of the risk areas can thus be controlled to provide a reasonable escape route for species that can flee offshore or along the coast.
- ✓ Use of proven deterrent devices, which are usually specific to the species like, for instance the sealscarer produced in Norway which is effective on seals and harbour porpoises according to a number of studies.
- ✓ Pavlov procedure: emitting a low-intensity sound signal as an alert to potentially present specimens to generate flight behaviour and/or hearing protection behaviour. This measure is still in the experimental stage and is aimed at marine mammals that have demonstrated their sensitivity to the Pavlov reflex.

Deterrent devices and Pavlov-devices should not be used as a first mitigation measure but only if no other measure is available. The aim is to avoid habituation.

VIII.2.2. Monitoring of the presence of individuals

Monitoring in real-time the presence of marine species in the acoustic risk area allows to avoid the risk. No risk occurs indeed if no individual is present. This strategy is commonly used in some countries like France and Taiwan to avoid risk on marine mammals.

Real-time bioacoustics monitoring systems are deployed to cover the risk area. A monitoring of 20 to 30mn prior to the start of noisy operations is performed. If no individual is detected, works can happen. If individual is detected, monitoring resume in the case they will quickly leave the area. If their presence persists, deterrence devices are implemented.

Once noisy operations have begun, targeted species are expected not to approach the acoustic risk area so close that they are harmed.

Figure 50: SmartPAM real-time bioacoustics buoy in operation during the construction of Saint-Nazaire offshore wind farm. Source: Quiet-Oceans

VIII.2.3. Monitoring of noise levels

The same real-time monitoring system described in the previous section can measure in real-time the noise levels to make sure they do not exceed a limit connected to the acoustic risk for species. The operator of the noisy workshop can, if the technology allows, control the intensity of its workshop according to the noise levels measured in real-time.

Chapter IX. Cartography of noise footprint

A dedicated modelling platform (Quonops Online Services) is used to map the sound footprint of the different noise sources studied in this project. The objective of this chapter is to describe the method and tools used to model noise propagation in the marine environment.

IX.1. Modelling platform

The estimation of sound fields is done by numerical simulation involving the use of models taking into account all the parameters mentioned above (bathymetry, celerity profile, meteorological and oceanic data, noise sources, sedimentology, in situ measurement data, etc.). Quiet-Oceans proposes modelling using parabolic equations (Jensen, Kuperman, Porter, & Schmidt, 2000) (Collins M. D., 1994) (Collins M. , Cederberg, King, & Chin-Bing, 1996) which accurately reflects the propagation of noise in the water column by solving the Helmholtz Equation:

$$\Delta p - \frac{1}{c^2}\frac{\partial^2 p}{\partial t^2} = \delta(t - t_0, r - r_0)$$

$$\rho c^2 = p \quad \rho_0 \frac{\partial \vec{v}}{\partial t} + \vec{\nabla} p = 0$$

$$j 2\pi f \rho_0 \vec{v} + \vec{\nabla} p = 0$$

where p is the acoustic pressure, c is the celerity of sound in water or in sediment, t is the time, t0 is the instant of emission of the acoustic signal, r is the tridimensional position of the observation point, and r0 is the tridimensional position of source, following the punctual source hypothesis.

Sound velocity profiles in water are proportional to water temperature, salinity and pressure (or depth). The main effect of these non-homogeneities in the sound velocity distributions is to bend the propagation radii and create propagation channels. These complex phenomena are, however, predictable by numerical simulation. The modelling of sound propagation will be done by a succession of models in cylindrically interpolated vertical planes.

IX.1.1. Quonops© anthropogenic noise prevision platform

In order to achieve these results, Quiet-Oceans develops and operates Quonops©, an operational system for monitoring and predicting anthropogenic noise at sea (European Union Brevet n° EP2488839, 2009). Like weather forecasting systems, this powerful and patented platform produces an estimate of the spatio-temporal distribution of noise levels generated by all human activities at sea. The maritime activities covered are numerous, including maritime traffic, oil exploration operations, military underwater warfare exercises, construction and offshore fossil fuel extraction operations, offshore wind turbine construction and operation, underwater drilling and blasting, etc. The data produced by Quonops© covers the needs as defined in existing and emerging national and international regulations concerning pollution levels and the preservation of habitats, marine ecosystems and the protection of marine species (Folegot & Clorennec, 2015). It provides new knowledge of noise pollution through the mapping of distributions and allows the acoustic aspects of impact studies to be understood, as well as the planning and mitigation optimisations of maritime industrial activities in their environmental compliance.

IX.1.2. A platform meeting the highest international standards

Within the framework of the European project AQUO (Achieve QUieter Oceans), Quiet-Oceans organised and participated in an international initiative to inter-comparison eight acoustic models used in underwater acoustics, including those implemented in Quonops©. This work consisted of defining several theoretical and realistic propagation test scenarios and evaluating/comparing the results of the different acoustic propagation models from different research institutes. The results, made public in a joint scientific publication (Collin, et al., 2015), demonstrated that the models implemented by Quonops© are among the best of the international state-of-the-art.

IX.1.3. Parameters used in the modelling

The Quonops© modelling platform takes into account most of the data that condition the propagation of noise in the marine environment (Figure 51):

- ✓ Environmental data, i.e., bathymetry, nature of the seabed, water temperature and salinity, tidal range and sea state;
- ✓ Anthropogenic data describing human activities at sea that introduce sound energy into the marine environment;
- ✓ In-situ data where necessary to calibrate the mapping;
- ✓ The results obtained in the form of sound maps faithfully reproduce the specific characteristics of noise propagation and maritime uses at the study site.

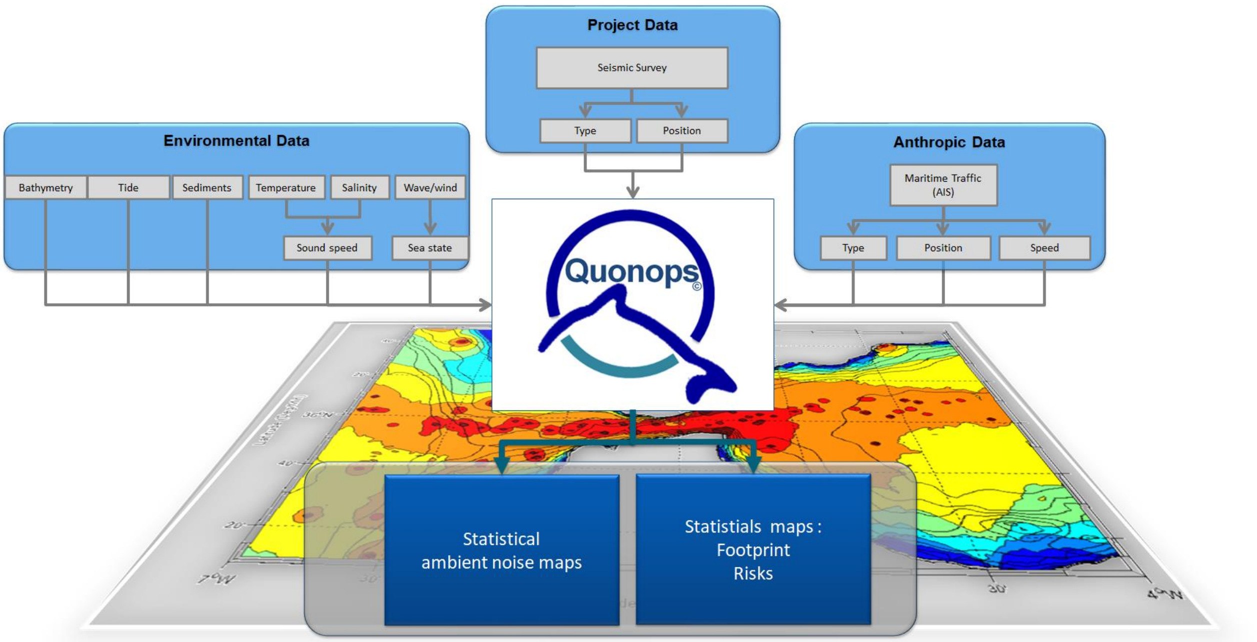


Figure 51: Schematic description of the operational noise prediction platform (Source: Quiet-Oceans).

As part of this project, the Table 10 references data providers and the resolutions for each environmental data type used for acoustic modelling and for sound maps production.

Table 10: Summary of environmental data used for acoustic modelling.

Layer	Source	Spatial resolution		Temporal resolution
Bathymetry	Emodnet	lon 33.9 (m)	lat 49.4 (m)	-
Celerity profile	CMEMS	lon 2117.0 (m)	lat 3088.0 (m)	24 h
Nature of the bottom	SHOM	lon 1325.9 (m)	lat 1852.0 (m)	-
Wave height	CMEMS	lon 2117.0 (m)	lat 3088.0 (m)	1 h
Wind speed	CMEMS	lon 17.0 (km)	lat 27.0 (km)	6h
Tide	COI (SHOM)	Closest harbour		5 min

IX.1.4. Octave estimation

Modelling was carried out at the central frequency f_m of each octave in the emission band of the acoustic sources. To obtain levels in an octave, it is assumed that the energy at the centre frequency is constant in each octave.

Therefore, the level is given by:

$$SPL_1 = SPL_{f_m} + 10.\log_{10}(f_2 - f_1)$$

Where SPL_1 is the acoustic pressure level in the octave between f_1 and f_2 frequencies, as defined by the standards (American National Standards Institute, 2004) and (IEC61260, 1995), and SPL_{f_m} is the modelled sound pressure level at the central frequency f_m.

IX.2. Predictive cartography

IX.2.1. Noise sources

IX.2.1.a. Anthropogenic noise sources to be studied

The main objective of this study is to compare the acoustic impact of ferries navigation with the commission of a potential future bridge in Bjørnafjorden area. In situ measurement permits to characterise the following acoustic sources:

- ✓ FAEROY and sister ship ferries while cruising (IV.2.1. ,Figure 18);
- ✓ OLE BULL hybrid ferry while cruising (IV.2.2. ,Figure 19);
- ✓ Nordhordlandsbrua floating bridge while rambling (0,Figure 24).

Their median processed source levels are used to define custom source level into Quonops© platform. The source levels are defined between 16Hz and 4kHz frequencies.

IX.2.1.b. Wind noise source

The wind data over the period are converted into noise levels for each frequency using the Ainslie conversion formulas (Ainslie, 2010). This noise is added to the noise of the activities studied in the project area. The Figure 52 shows the noise level induced by this environmental component as a function of its speed and frequency.

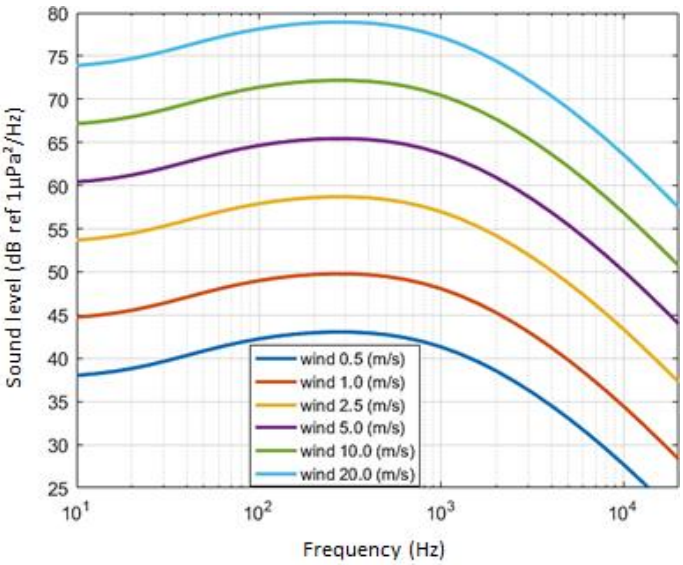


Figure 52: Wind-induced noise level as a function of frequency and speed.

IX.2.2. Mapping study area

The predicted noise will be mapped as a statistic using the percentiles (50th, 25th, 10th and 5th percentiles). The 50th percentile is the median value, which means that the levels shown on the map are reached half the time. The mapping will be done in the area defined by the Table 11.

Table 11: Limits of area used for cartography.

	60° 42’ 00’’ N	
5° 00’ 00’ E		5° 48’ 00’’E
	59° 54’ 00’ N	

IX.2.3. Definition of the scenarios for predictive sound mapping

Six illustrative scenarios are proposed and detailed in the following part. A synthesis of all scenarios is proposed in Table 12.

Table 12: Synthesis of predictive scenarios.

N°	Area	Type of source	Used SL profile	Objective
1	Valestrand – Breistein	Ferry	OLE BULL CRUISING	Acoustic effect of OLE BULL cruise
2	Nordhordlandsbrua	Bridge, central pile only	BRIDGE RAMBLING	Acoustic impact of one pile rambling
3	Nordhordlandsbrua	Bridge, all piles	BRIDGE RAMBLING	Maximum effect theoretically caused by the bridge
4	Nordhordlandsbrua	Ferry	FAEROY CRUISING	Compare effect caused by bridge and ferry navigation
5	Halhjem – Sandvikvåg	Ferry	FAEROY CRUISING	Acoustic effect of ferry cruising
6	Halhjem – Sandvikvåg	Bridge, one fictive pile	BRIDGE RAMBLING	Predictive acoustic effect of one bridge rambling

IX.2.3.a. Area n°1: Valestrand – Breistein ferry line

In order to illustrate the acoustic impact of ferry navigation, the predictive mapping of OLE BULL ferry while cruising on Valestrand – Breistein ferry line is processed, with a modelling date set up to 22.09.2022 (date of measurements). The placing of the source during scenario n°1 is given in Table 13.

Table 13: Definition of source for scenario n°1.

Name of vessel	Latitude (dec. degrees)	Longitude (dec. degrees)	Source profile used in Quonops©
OLE BULL	60.4967	5.4132	OLE BULL CRUISING

IX.2.3.b. Area n°2: Existing floating bridge in Nordhordlandsbrua

To compare the acoustic impact of floating bridge and ferries, three scenarios are proposed in Nordhordlandsbrua area:

- ✓ The first one studies the noise emitted by the rambling of bridge central pile only;
- ✓ Adopting a more conservative approach, the second scenario studies the simultaneous rambling of all 10 bridge piles;
- ✓ The third one studies the noise emitted by the passage of a ferry (FAEROY type) at the same location of the central pile of the bridge.

All scenarios are played on 26.10.2022 (date of measurement). The placing of the sources (piles and FAEROY) is given in Table 14, Table 15 and Table 16.

Table 14: Definition of source for scenario n°2.

Name of source	Latitude (dec. degrees)	Longitude (dec. degrees)	Source profile used in Quonops©
Pile 5	60.5248	5.2636	BRIDGE PILE

Table 15: Definition of source for scenario n°3.

Name of source	Latitude (dec. degrees)	Longitude (dec. degrees)	Source profile used in Quonops©
Pile 1	60.5219	5.2692	BRIDGE PILE
Pile 2	60.5225	5.2676	
Pile 3	60.5232	5.2662	
Pile 4	60.5240	5.2649	
Pile 5	60.5248	5.2636	
Pile 6	60.5256	5.2625	
Pile 7	60.5265	5.2615	
Pile 8	60.5274	5.2606	
Pile 9	60.5283	5.2598	
Pile 10	60.5293	5.2592	

Table 16: Definition of source for scenario n°4.

Name of source	Latitude (dec. degrees)	Longitude (dec. degrees)	Source profile used in Quonops©
FAEROY	60.5248	5.2636	FAEROY CRUISING

IX.2.3.c. Area n°3: Halhjem – Sandvikvåg ferry line

Two scenarios are proposed in Halhjem – Sandvikvåg ferry line:

- ✓ The first one studies the noise emitted by the passage of a ferry (FAEROY type) on Halhjem – Sandvikvåg navigation rail;
- ✓ The second one studies the noise emitted by a fictive bridge pile replacing FAEROY ferry at the same position.

All scenarios are played on 26.10.2022. The placing of the sources (FAEROY and pile) is given in Table 17 and Table 18.

Table 17: Definition of source for scenario n°5.

Name of source	Latitude (dec. degrees)	Longitude (dec. degrees)	Source profile used in Quonops©
FAEROY	60.1091	5.3980	FAEROY CRUISING

Table 18: Definition of source for scenario n°6.

Name of source	Latitude (dec. degrees)	Longitude (dec. degrees)	Source profile used in Quonops©
Pile	60.1091	5.3980	BRIDGE PILE

IX.2.4. Results

All displayed sound broadband (11-5650Hz) exposure levels are expressed in dB ref 1µPa².s and are weighted following fish with swim bladder and no hearing audiogram. The minimum displayed sound level on scale is 108dB ref 1µPa².s (median value measured during long term acquisition +3dB). All produced sound maps can be consulted on Quonops© web platform: http://qos.quiet-oceans.com.

IX.2.4.a. Area n°1: Valestrand – Breistein ferry line

The sound map resulting of scenario n°1 modeling is shown in Figure 53. As expected, a large footprint of OLLE BULL ferry can be seemed as the vessel cruises in the canal. Significant sound increases can be expected in a far range from the ferry with SEL superior to 120dB ref 1µPa².s.

Scenario 1: OLE BULL cruising on Valestrand – Breistein ferry line

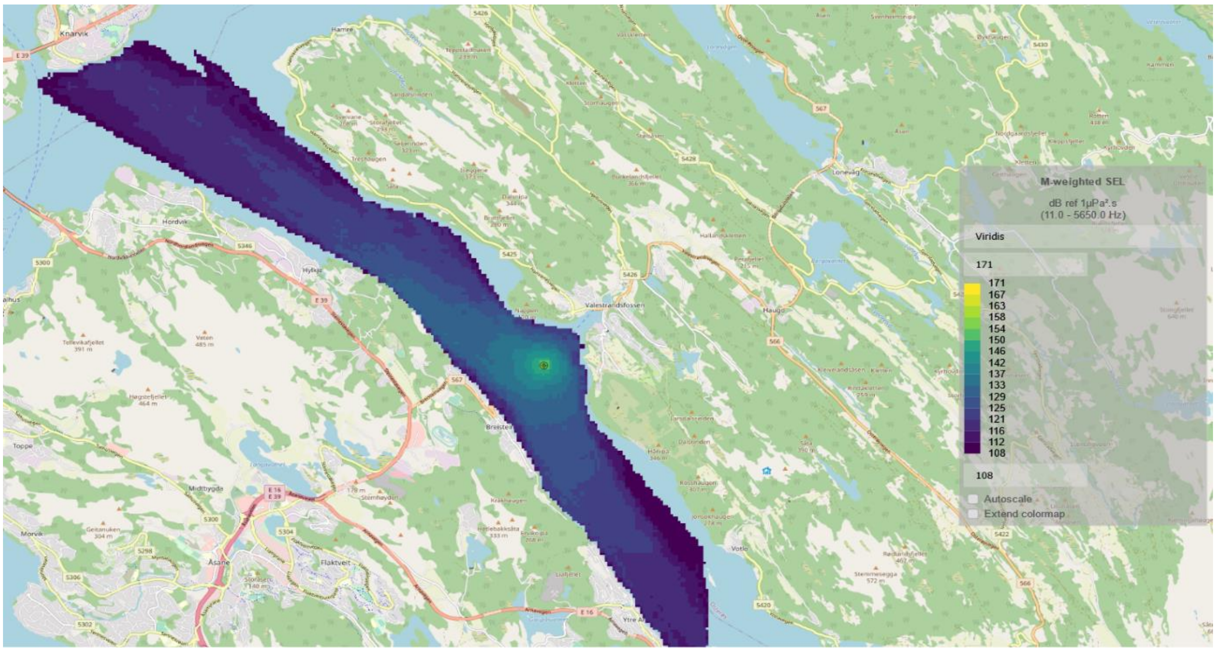


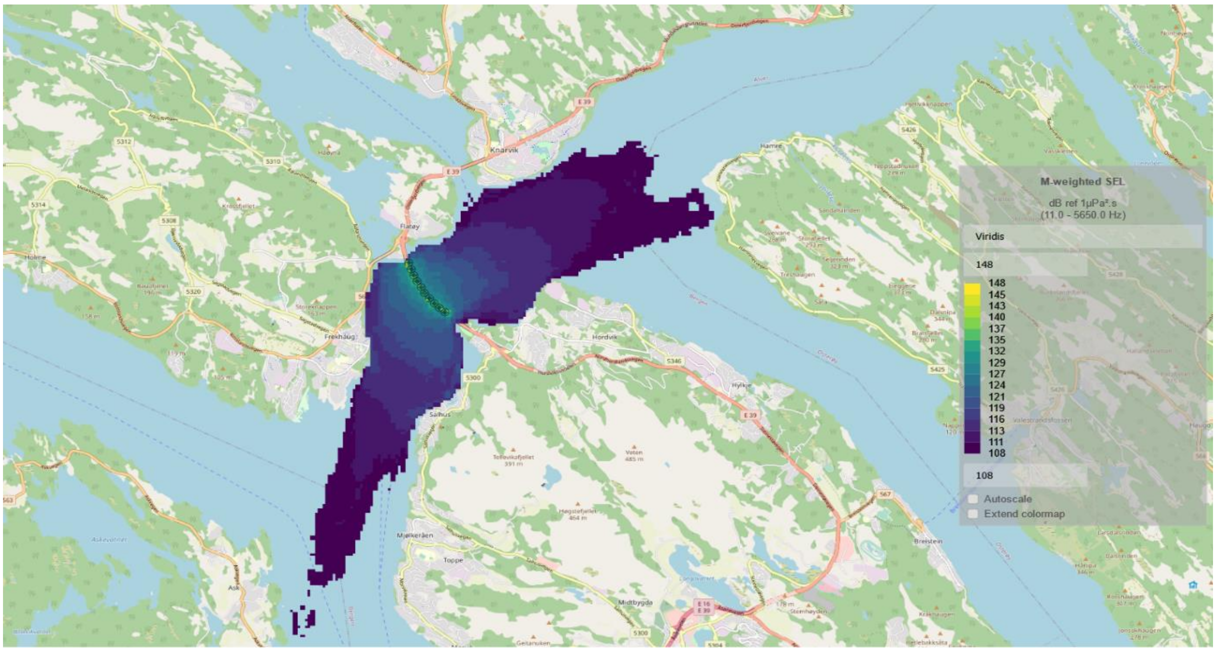
Figure 53: Resulting sound map in Valestrand – Breistein ferry line area.

IX.2.4.b. Area n°2: Nordhordlandsbrua

The sound maps resulting of scenarios n°2, 3 and 4 modelling are shown in Figure 54. The scenario 2 shows a limited exceedance of the bridge central pile in space, with a rapid decrease of noise levels as the distance increases. The sound maps of both scenario 3 and 4 are close. The impact of FAEROY ferry navigation is a least equivalent to the biggest theoretical impact caused by the bridge.

Scenario 2: Ramble of central pile of Nordhordlandsbrua floating bridge

Scenario 3: Simultaneous ramble of all piles of Nordhordlandsbrua floating bridge



Scenario 4: FAEROY cruising in Nordhordlandsbrua area

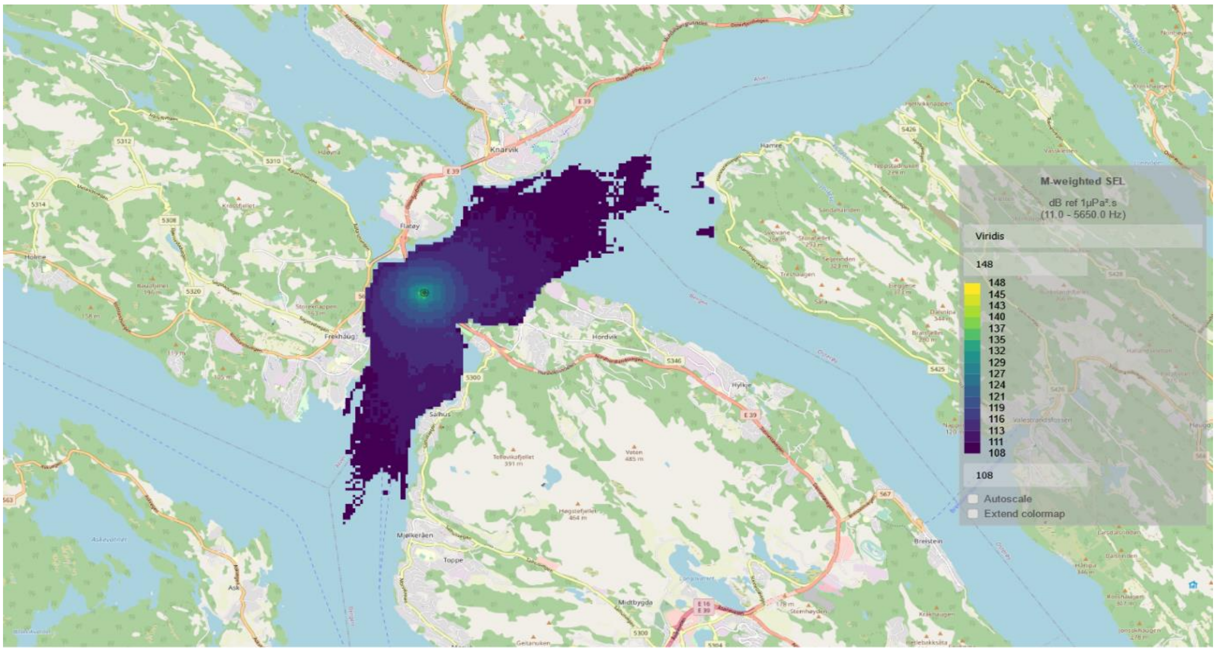


Figure 54: Resulting sound map in Nordhordlandsbrua area.

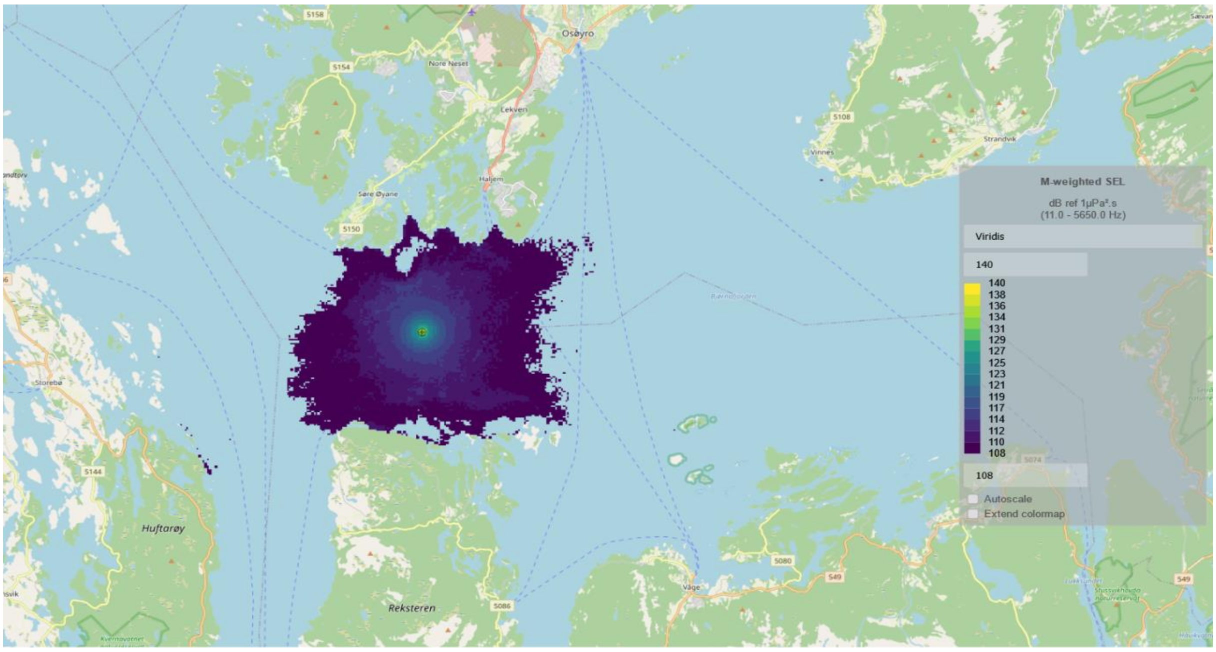
IX.2.4.c. Area n°3: Halhjem – Sandvikvåg ferry line

The sound maps resulting of scenarios n°5 and 6 modelling are shown in Figure 55. As shown in previous parts of the study, the noise induced by the rambling of the pile causes a significantly closer area of impact than the navigation of FAEROY ferry.

However, the limit of this approach is that no time integration of the acoustic energy emitted by the source is taken into account. With a complementary estimation of the area frequentation both by ferries on water and of cars on the future bridge, a more accurate comparison could be processed to integrate the emitted sound pressure along time.

Moreover, this scenario compares one ferry and one rambling pile while several ferries and several piles are expected to take place simultaneously.

Scenario 5: FAEROY cruising on Halhjem – Sandvikvåg ferry line



Scenario 6: Ramble of fictive bridge pile on Halhjem – Sandvikvåg ferry line

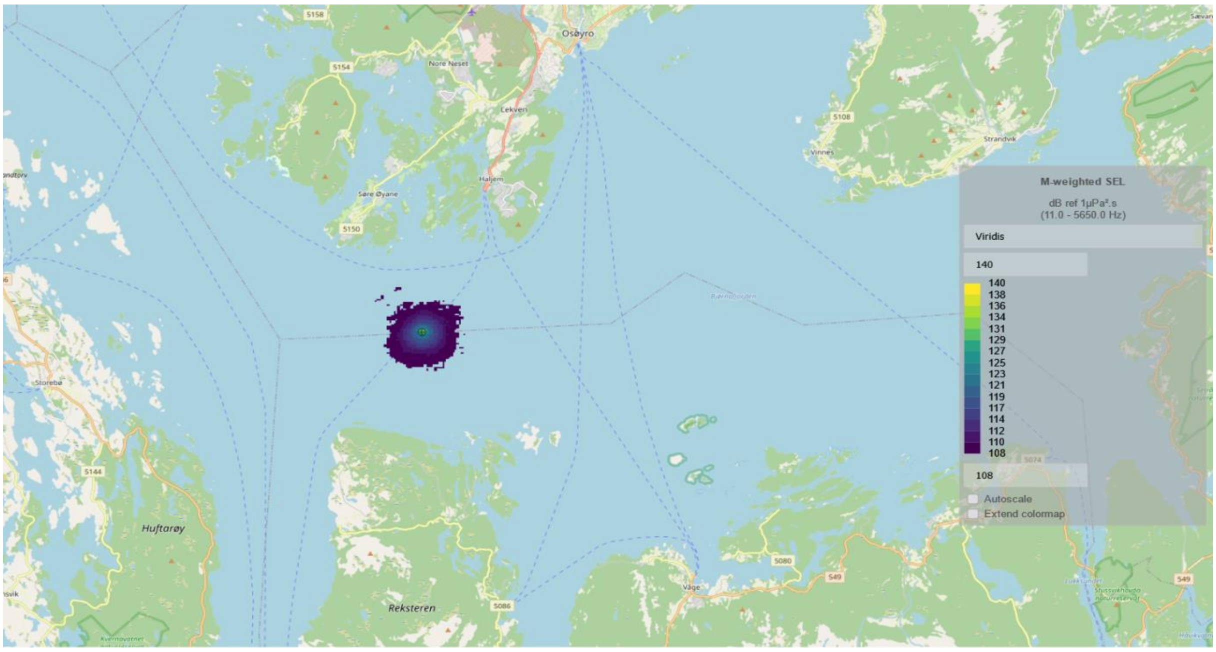


Figure 55: Resulting sound map in Halhjem – Sandvikvåg ferry line area.

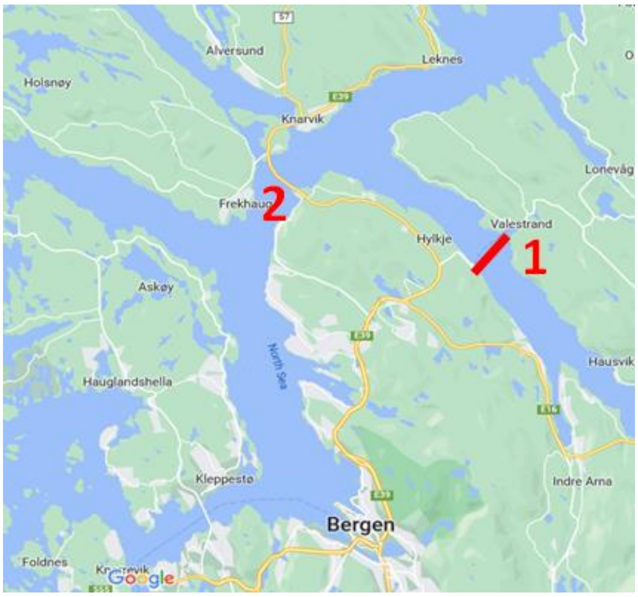
Chapter X. Conclusion

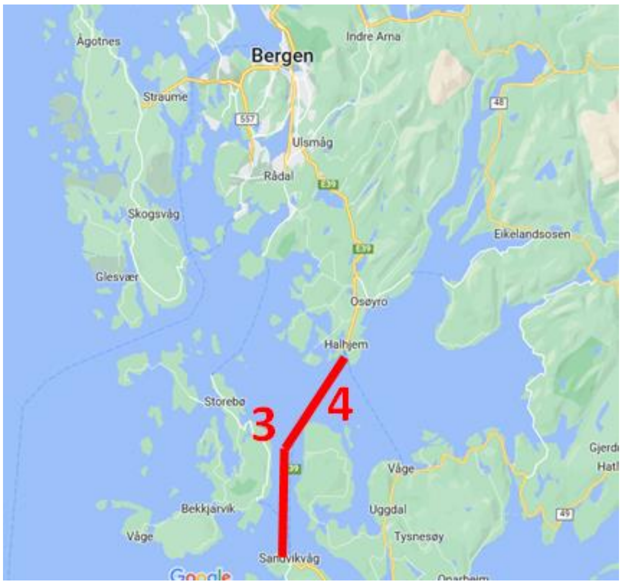
In the context of a possible construction project of a floating bridge in Bjørnafjorden, The Norwegian Public Roads Administration (Statens Vegvesen or SVV) has issued a tender for the underwater acoustic impact of floating bridges in operation on biodiversity.

Quiet oceans has been requested to compare the acoustic impact induced by ferries navigation and a floating bridge commission.

Two sessions of passive acoustic measurement have been carried on 22.09 and 26.10.2022 in order to characterise the sound level emitted by:

- ✓ OLE BULL hybrid ferry in– Breistein-Valestrand (area 1);
- ✓ Five identical ferries (FLATØY, FÆRØY, LYSØY, HUFTARØY, SAMNØY sister ships) in Halhjem-Sandvikvåg (area 3);
- ✓ A floating bridge in Nordhordlandsbrua (area 2);
- ✓ All noise sources during a long time period between 09/09 and 2022/10/26 in Nordhordlandsbrua (area 2).





X.1. Analysis of noise emitted by ferries and of floating bridge

X.1.1. Estimation of source levels

The Figure 56 shows the overlay of source levels estimation of both OLE BULL hybrid ferry at cruise and entrance of harbour, FAEROY ferry at cruise and the existing floating bridge intermittent rambling phenomenon. The Table 19 provides the respective estimation of broadband source levels.

- ✓ The source levels estimated of OLE BULL ferry vary between 170 and 196 dB ref 1µPa²@1m, depending of the propulsion mode with a maximum of energy close to 20Hz.
- ✓ The source levels estimated for the ferries in area 3 are close to 170dB ref 1µPa²@1m while arriving at harbour and 173dB ref 1µPa² @1m while cruising with a maximum of energy in 80-200Hz frequency band. The estimated profiles also share a good agreement with the generic model RANDI 3.1C values, and present a very low standard deviation between vessels: the values are given with a high confidence level.

✓ Concerning the floating bridge, no significant exceedance has been detected during the drifting measurement, excepted isolated rambling noises with source levels estimated of 167dB ref 1µPa²@1m.

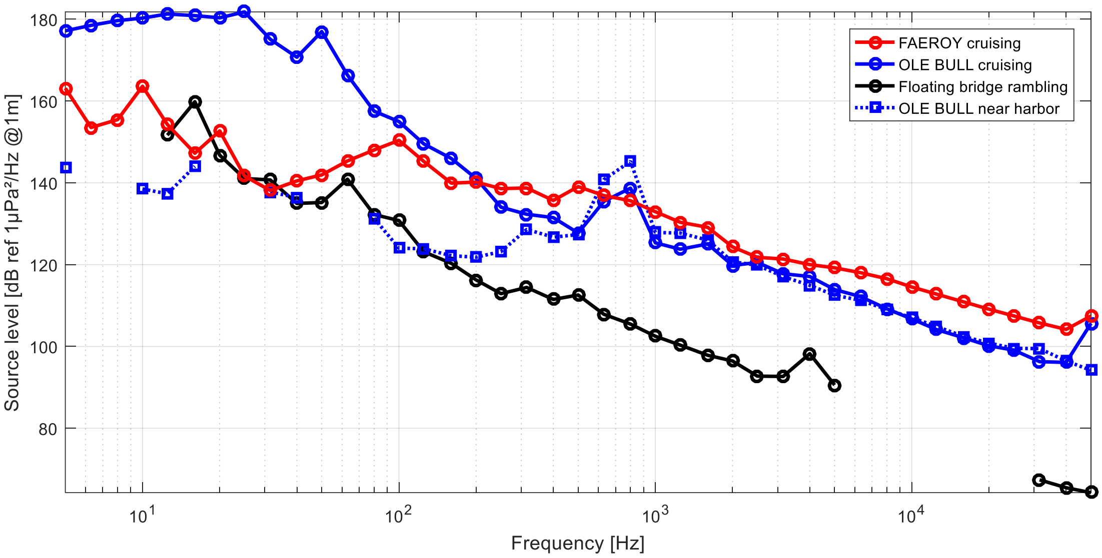


Figure 56: Synthesis of source levels estimations for ferries and floating bridge.

Table 19: Synthesis of broadband source levels estimations for ferries and floating bridge.

Source	Broadband source level [dB ref 1µPa²@1m]
OLE BULL (cruising)	196
OLE BULL (near from harbour)	170
FAEROY (cruising)	173
Bridge (intermittent)	167

X.1.2. Analysis of long-term acquisition in Nordhordlandsbrua area

In contrast with the drifting acquisitions, the long-term acquisition done at a distance of 160m of the nearest pile of Nordhordlandsbrua floating bridge highlighted a very low frequency road traffic noise in a narrow 8-30Hz frequency band, up to 50% of the time.

The median sound level during the measurement period is 105dB ref 1µPa², which is a common median value of existing noise. Also, the long-time acquisition shown a regular and intense passenger and fishing traffic, with a mean of 33 significative acoustic exceedances (at least 15dB) by day. These anthropogenic exceedances raise the ambient noise to absolute levels up to 145 dB ref 1µPa².

The classification of the noise emitted by the bridge and the boats shows more frequent occurrence of anthropogenic emergences due to bridge (road traffic) than due to boats. On the other hand, the increases of sound levels induced by the passage of boats are 20 dB higher than those caused by the bridge (received levels of 145 vs 125dB ref 1µPa²).

Finally, the analysis shows a reduction in noise emissions from the bridge (-5dB) on weekends.

X.2. Potential impact of floating bridge versus ferries

X.2.1. Synthesis

The Figure 57 proposes a graphic comparison of the acoustic risk evolution of bridge during construction phase and commissioning, with the acoustic risk linked to continuous ferries navigation.

- ✓ Depending of the distance of the work and of its acoustic intensity, the potential acoustic risk of pile driving and drilling during the construction of a floating bridge can cause:
  - A masking of communications between marine mammals;
  - Behavioural disturbances;
  - Physiological injuries, in worst cases.

  The expected risk is significant and has to be anticipated and controlled.

  Though, after the construction is done, the previous parts of this study shown a limited acoustic effect induced by the commission of the bridge, with only light and median behaviour change to be expected.

- ✓ The same risks apply for possible ferry port expansion works.

- ✓ In contrast to the bridge, ferries exploitation induces a constant acoustic effect along time, which is proportional to the amount of cruising ferries. Median to significant behavioural changes can be expected. After the achievement of the bridge construction, the risk linked to ferries would be significantly higher than the risk induced by the commission of a floating bridge. Also, this analysis does not take the potential future underwater works done to improve ferry terminals in account.

  In addition, a risk of collision between ferries and large cetaceans exists, depending on the presence of such species in the area of ferry operations.

Chapter VIII also proposes a comparison of predictive noise emitted sound maps, both by ferries and a floating bridge in the studied area. The modelling confirmed the more restricted acoustic footprint of the floating bridge commission compared to the ferry navigation. However, the limit of this approach is that no time integration of the acoustic energy emitted by the source is taken into account. A more refined comparison could be processed to integrate the emitted sound pressure along time, with a complementary estimation of the area frequentation both by ferries on water and by cars users on the future bridge.

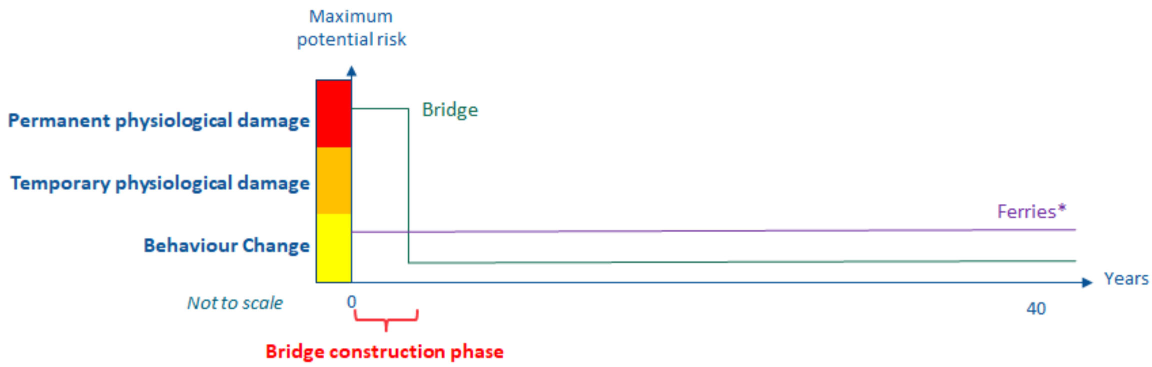


Figure 57: Visual representation of the evolution of acoustic risks induced by a floating bridge (construction and commission) versus ferries.

X.2.2. Recommendations in case of the construction of the floating bridge

Several studies (Brandt et al., 2011; Dähne et al., 2013; Rose, 2019) have exposed significant (approx. 20km of radius) and durable decreases of marine mammals frequentation in the areas exposed to piling (or in general significant acoustic disturbances) highlighting the importance of acoustic risk management during noisy work to protect the marine biodiversity.

In order to limit the acoustic impact on marine mammals during the potential construction phase of the bridge, we recommend:

- To carry an acoustic impact assessment study of the project;
- To set up monitoring and mitigation measures, according to the results of impact assessment study.

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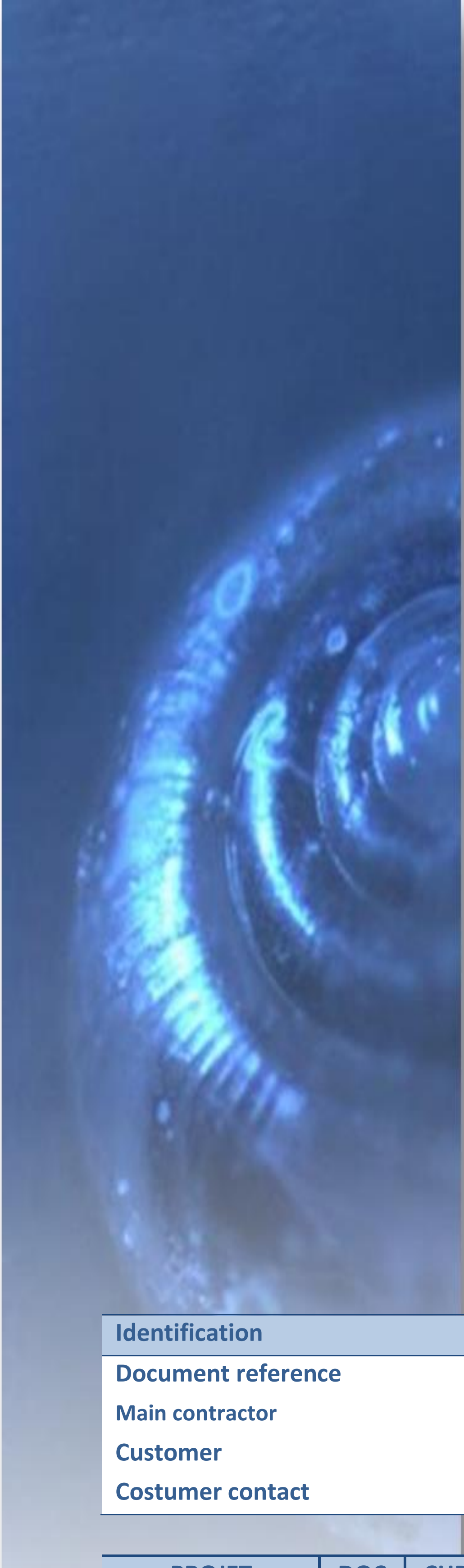

Acoustic impact study of floating bridges

SEA MISSION REPORT - LEG01

Multiconsult

Statens vegvesen

Identification	
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Quiet oceans

Ocean Noise Forecasting Monitoring & Mitigation

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Chapter I. Context and objectives

I.1. Context of the study

In the context of a possible construction project of a floating bridge in Bjørnafjorden, SVV has issued a tender for the underwater acoustic impact of floating bridges in operation on biodiversity. SVV wishes to study the environmental impact of this type of bridge when commissioned versus ferries. Multiconsult, in charge of the project, has requested the expertise of Quiet-Oceans to perform measurements and associated analysis of underwater noise.

I.2. Scope of work

The work in the framework of this project has been divided in three phases:

- Drafting of the monitoring program and detailed protocol, including the selection of the most suitable equipment and positions that enable to gather pertinent data, and an operational protocol to ensure that measurement is made right;
- Perform in situ measurements (2 sessions) in September 2022 and October 2022 in cooperation with Multiconsult including:
  - The measurement of underwater noise generated by an existing floating bridge (Nordhordlandsbrua);
  - The measurement of a ferry as a comparison in two areas (Valestrand – Breistein line and Halhjem – Sandvikvåg line).
- Analysis and comparison of underwater acoustic sounds produced by field measurements.

I.3. Document overview

This document is a report of the first mission named LEG01.

The operational objectives of the LEG01 are to:

- Prepare the instrumentation to deploy,
- Deploy the fixed mooring and the drifting mooring near the line Valestrand-Breistein during four passages of ferry to record the underwater noise radiated by few ferries in navigation,
- Deploy one long term fixed mooring to monitor the underwater noise radiated by the existing floating bridge Nordhordlandsbrua during 1 month,
- Deploy a drifting mooring to monitor the underwater noise radiated by the existing floating bridge Nordhordlandsbrua along it,

This report describes:

- The defined protocol,
- The equipment and its preparation,
- The operational operations.

I.4. Protocol

The monitoring protocol of the LEG01 was defined in concertation with Multiconsult team. The underwater noise monitoring considers two areas presented in the Figure 1 for the LEG01.

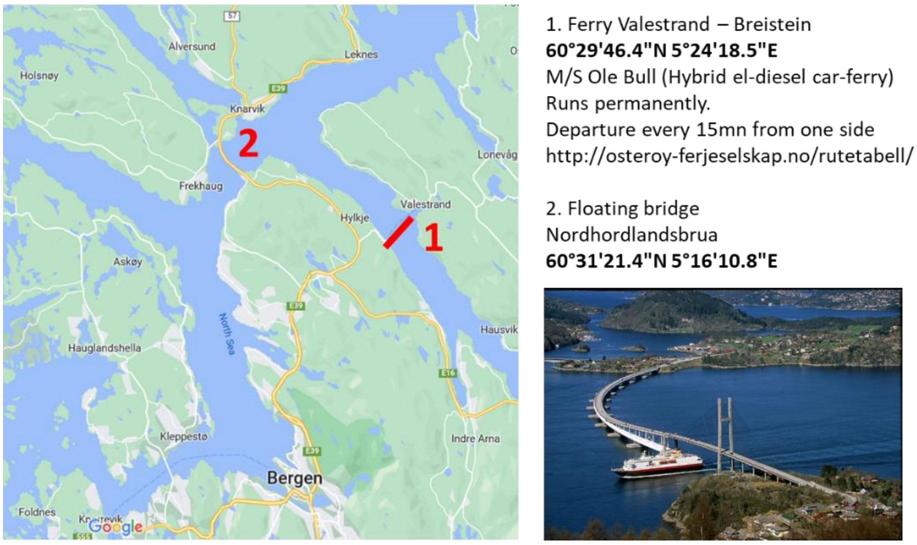


Figure 1: Overview of the area project – LEG01

I.4.1. Area 1: Ferry Valestrand-Breistein

The Figure 2 presents the area and the position point of the drifting mooring (start of drift) and the fixed mooring.

The Table 1 resumes the information and outlines the requirements for the measurements in the area 1.

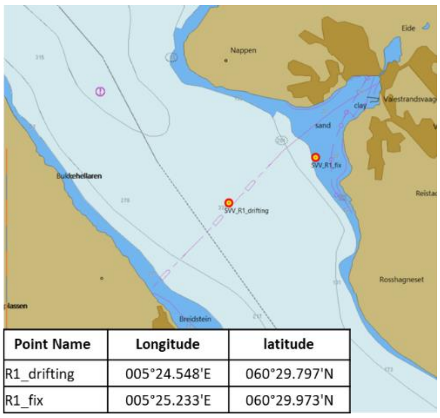


Figure 2: Location of the 2 acoustics mooring lines on area 1

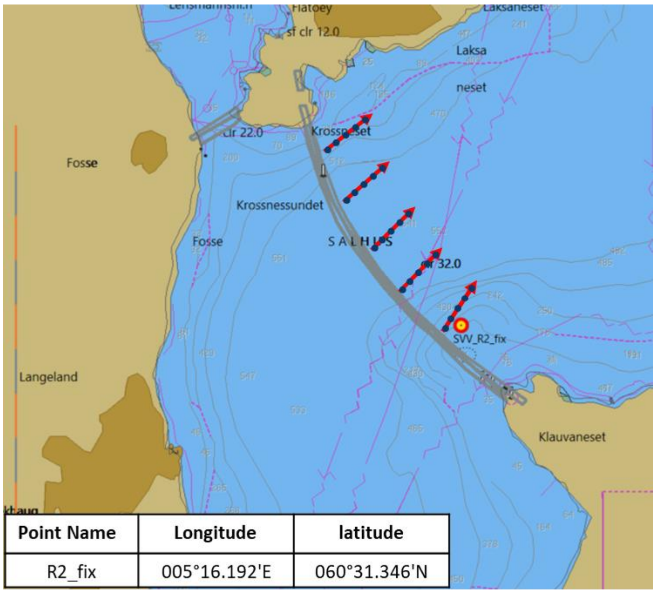
Table 1: Measurement information and requirements on area 1

Area	Name	Point name	Water depth	Hydrophone immersion	Duration	Status
1	Ferry Valestrand – Breistein	R1_fix	~100m	40 to 50m	2 h	Static
		R1_drifting	variable (330 m)	10 to 25m	2 h	Drifting

I.4.2. Area 2: Floating bridge Nordhordlandsbrua

The Figure 3 presents the area 2 and the position point of the drifting mooring (start of drift) and the fix mooring.

The Table 2 resumes the information and outlines the requirements for the measurements in the area 1.



Point Name	Longitude	latitude
R2_fix	005°16.192'E	060°31.346'N

Figure 3: Location of the 2 acoustics mooring lines on area 2

Table 2: Measurement information and requirements on area 2

Area	Name	Point name	Water depth	hydrophone immersion	Duration	Status
2	Nordhordlandsbrua bridge	R2_fix	100m	50m	30 days	Static
		R2_drifting	variable	10 to 25m	5 h	Drifting

I.5. Support Vessel

The vessel used for the deployment of the acoustic moorings is a tug named "MAX" (Figure 4) of the Valen Marina company. Vessel speed was 7 knots maximum. The duration of the mission at sea was planned for 8 hours.

Figure 4: Support vessel used for the project

Chapter II. Instrumentation and mooring preparation

This chapter present all acoustic equipment, its associated settings for the project and the design of the mooring lines deployed.

II.1. Assignment of recorders to moorings

Table 3 resume the assignment of recorders and pressure sensors to moorings during the LEG01.

Table 3: Assignment of recorders to moorings

Point Name	Acoustic RECORDER (Type / Reference)					Pressure sensor ref.
R1_fix	-	*IC Listen SCW1985*	-	*Porpoise ENR-062*	-	*17321*
R1_drifting	*IC Listen SCW1983*	-	*Porpoise ENR-029*	-	-	*15345* *17273*
R2_fix	-	-	-	-	*ORCA 72D ENR-033*	-
R2_drifting	*IC Listen SCW1983*	-	*Porpoise ENR-029*	-	-	*15345* *17273*

II.2. Presentation of the acoustic recorders for R1-Fix, R1-Drifting and R2-Drifting

The acoustic recorders used for the acoustic measurement on R1_Fix, R1_Drifting and R2_Drifting are stand-alone systems, the first is an IC HF Listen (Figure 6) designed by Oceansonics, the technical characteristics of the recorder are detailed in Table 2 and the second is a Porpoise-EXT recorder (Figure 7) designed by Turbulent Research whose characteristics are detailed in Table 3.

The settings adopted for the LEG 01 are presented in the mooring sheet in Appendix 1.

Table 4: Technical characteristics of the icListen recorder

Hydrophone & Recorder	IC Listen
Bandwidth	7Hz-200kHz
Sampling Frequency	Up to 512 kHz
Acoustic sensitivity	-171.5 dB re: 1V/µPa
SPL max / SPL min	181 dB re: 1V/µPa - 73 dB re: 1V/µPa
Autonomy	10 hours
Dimensions - Weight	267 mm x 45 mm - 0.3 kg
Operational water depth	200 m

Figure 5: IC HF Listen recorder

Table 5: Technical characteristics of the PORPOISE recorder

Hydrophone & Recorder	Porpoise
Bandwidth	10Hz-192kHz
Sampling Frequency	384 kHz
Acoustic sensitivity	-164.8 dB re: 1V/µPa
Gain option	**0**-15-30-45 dB
SPL max / SPL min	167 dB re: 1V/µPa - 66 dB re: 1V/µPa
Autonomy	50 hours
Dimensions - Weight	229 mm x 70 mm - 1.2 kg
Operational water depth	500 m

Figure 6: Porpoise-EXT recorder

II.3. Presentation of the acoustic recorders for R2-Fix

The acoustic recorders used for the acoustic measurement on R2_Fix is an ORCA72D recorder (Figure 7) designed by Turbulent Research whose characteristics are detailed in Table 6.

The settings adopted for the LEG 01 are presented in the mooring sheet in Appendix 1.

Table 6: Technical characteristics of the ORCA 72 recorder

Hydrophone & Recorder	ORCA 72D
Bandwidth	10Hz-192kHz
Acquisition Channels	5
Sampling Frequency	384 kHz
Acoustic sensitivity	-180 dB re: 1V/µPa
Gain option	**0**-15-30-45 dB
SPL max / SPL min	167 dB re: 1V/µPa - 66 dB re: 1V/µPa
Autonomy	44 days
Dimensions - Weight	229 mm x 70 mm - 34 kg

Figure 7: ORCA72D recorder in its mechanical protection frame

II.4. Preparation of the recorder

The ORCA72 was shipped from Brest and received a few days before the arrival of the Quiet-Oceans team.

Before deployment, the following preparation task was realized on 21 September 2022 on the recorders:

- Battery charging, Test and UTC time synchronisation setting of the IC Listen recorder,
- Battery replacement, test and UTC time synchronisation of the porpoise recorder,
- Mechanical integration of the recorder in its mechanical protection frame (Figure 7), connection the hydrophone, UTC time synchronisation setting, programming and functional testing.

II.5. Preparation of the moorings

The drifting mooring was prepared by Quiet-Oceans and presented Figure 8.

For each fixed mooring the final configuration was designed (Figure 9) and realized by Multiconsult with the collaboration of Quiet-Oceans team on 21 September 2022.

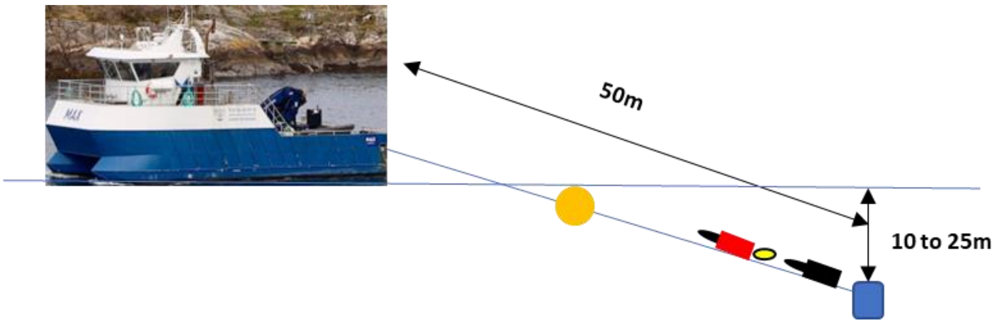


Figure 8: Design of the drifting mooring line

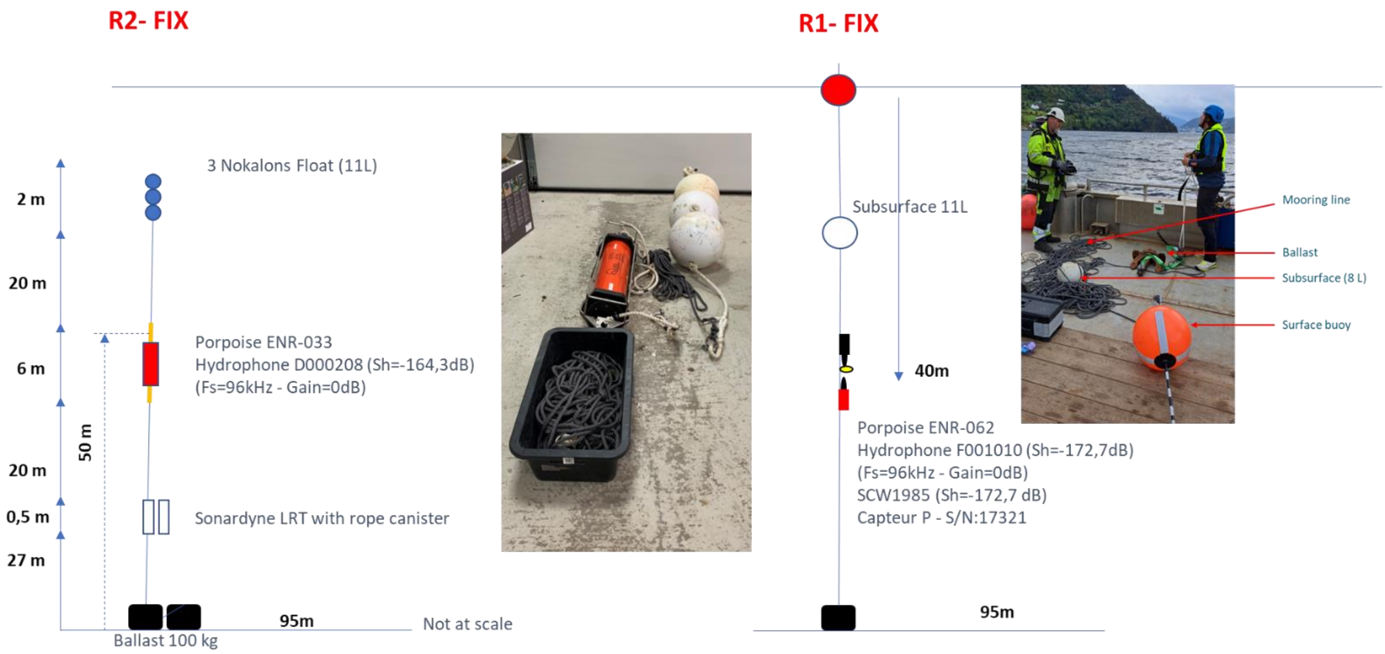


Figure 9: Design of the 2 fix mooring lines

Chapter III. Sea operations

III.1. Boarding

Personnel of Multiconsult and Quiet-Oceans embarked on the support vessel "MAX" on 22 September 2022 at 06h10 UTC.

III.2. Preparation

The end of the deck preparation of all moorings was finalised onboard during 1 hour.

III.3. Navigation

The position of the vessel is recorded from a portable GPS device presented in the Table 7.

The acquisition is made at the start of the mission. The position of each mooring line is recorded with this GPS device as well as the latitudes and longitudes of the navigation at every second.

Table 7: GPS for navigation

Characteristics	Value
Brand	GARMIN
Model	GPS 78
Precision	±5 m
Measurement rate	1 Hz

The navigation and the maritime traffic on site are monitored and recorded from a portable AIS receiver.

III.4. Measurement in area 1

The acoustic measurements in area 1 (Ferry Valestrand-Breistein) to evaluate the underwater noise of the ferry took two hours and included the following operations:

- the deployment of a short-term fixed mooring placed at more than 100m from the navigation rail,
- 4 ferry passages in drift mode with a repositioning of the support vessel between two passages.

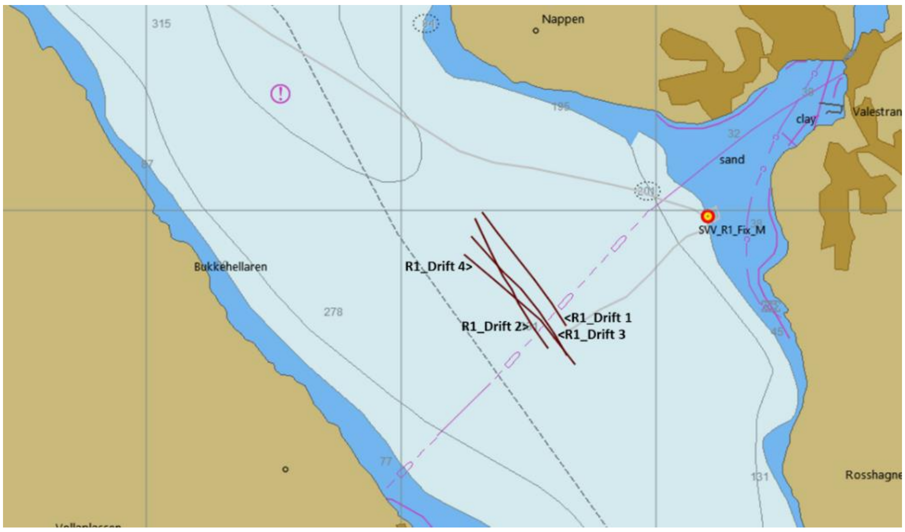


Figure 10: Measurement in area 1

III.4.1. Fixed mooring

The deployment operations were conducted on 22 September 2022 at the beginning of the mission (see Appendix B). The fixed mooring named R1_Fix has been deployed at the position presented in Table 8.

The completed mooring sheet is presented in Appendix A.

Table 8: Acoustic recorders location in area 1

Point	Mooring Time (UTC)	Recovery Time (UTC)	Water depth (m)	Distance of hydrophone / Sea bottom (m)	Latitude	Longitude
R1_Fix	08h34	10h24	95	55	60° 29.9945 N	005°25.2025 W

Figure 11: Deployment of the R1_Fix mooring

III.4.2. Drifting mooring

Four drifting measurements were conducted after the deployment of R1_Fix. Each drift is described in Figure 10. The Figure 12 illustrates the deployment with a passage of one ferry.

Figure 12: Drifting mooring deployed during a passage of ferry

III.1. Measurement in area 2

The acoustic measurements in area 2 (Ferry Valestrand-Breistein) to monitor the underwater noise radiated by an existing floating bridge took two hours and included the following operations:

- the deployment of a long-term (1 month) fixed mooring placed at more than 100m from the navigation rail,
- transect in drift mode pushed by the marine current on site with a repositioning of the support vessel between two transects along the bridge to cover its length.

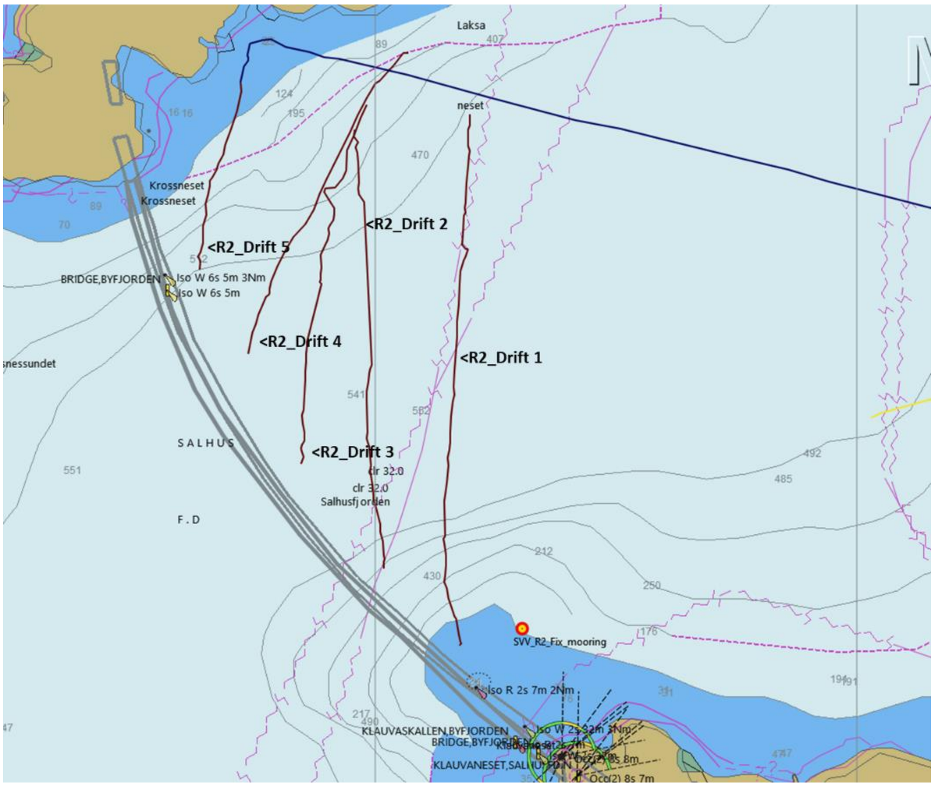


Figure 13: Measurements on area 2

III.1.1. Fixed mooring

The deployment operations were conducted on 22 September 2022 after the transit from area 2 (Figure 2). The fixed mooring named R2_Fix has been deployed at the position presented in the Table 9.

The completed mooring sheet is presented in Appendix A.

Table 9: Acoustic recorders location in area 2

Point	Mooring Time (UTC)	Recovery Time (UTC)	Water depth (m)	Distance of hydrophone / Sea bottom (m)	Latitude	Longitude
R2_Fix	11h43	-	95	50	60° 31,341’N	005° 16,313’E

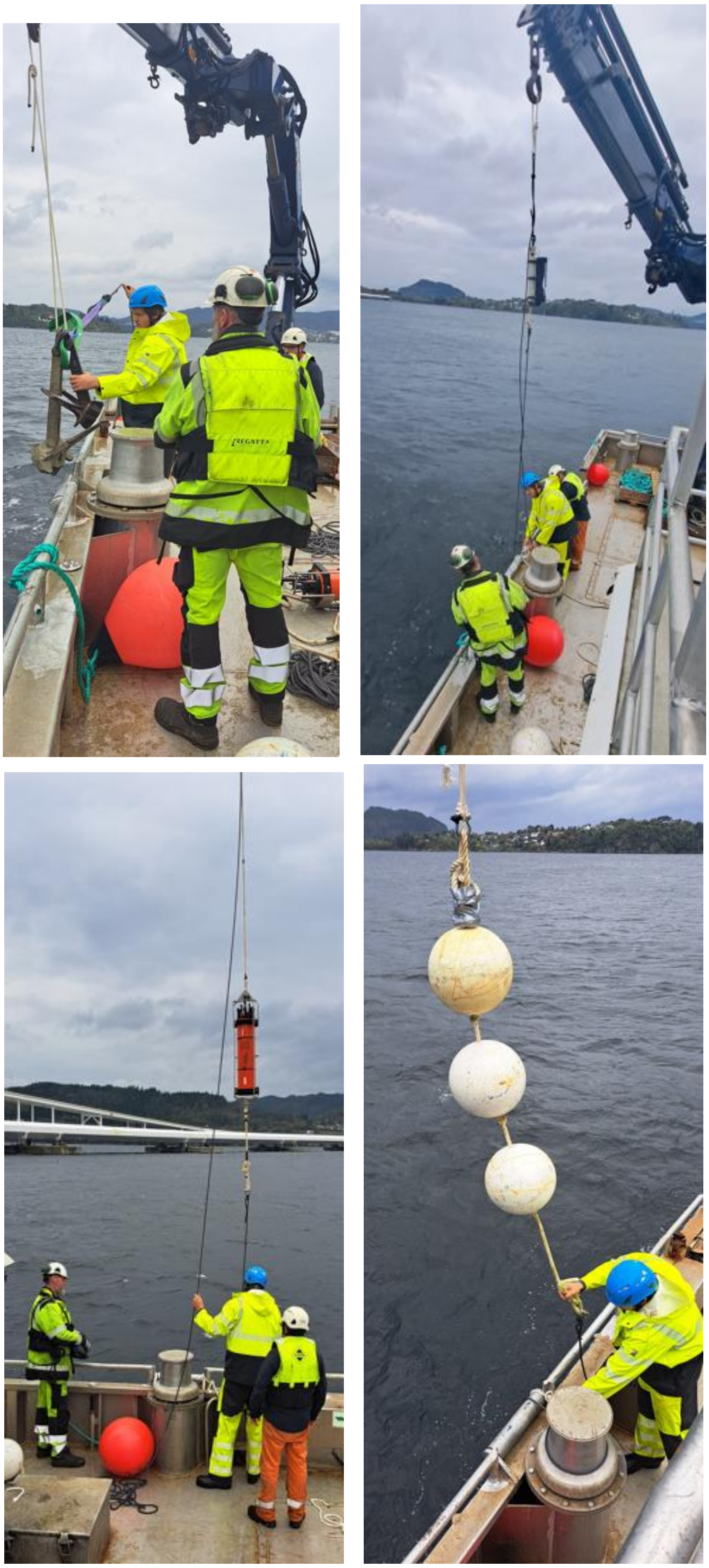


Figure 14: Deployment of the R2_Fix mooring

III.1.2. Drifting mooring

Five drifting measurements were conducted after the deployment of R1_Fix. Each drift is described in Figure 13. The Figure 15 and Figure 16 illustrates the deployment and the drifting mooring configuration.

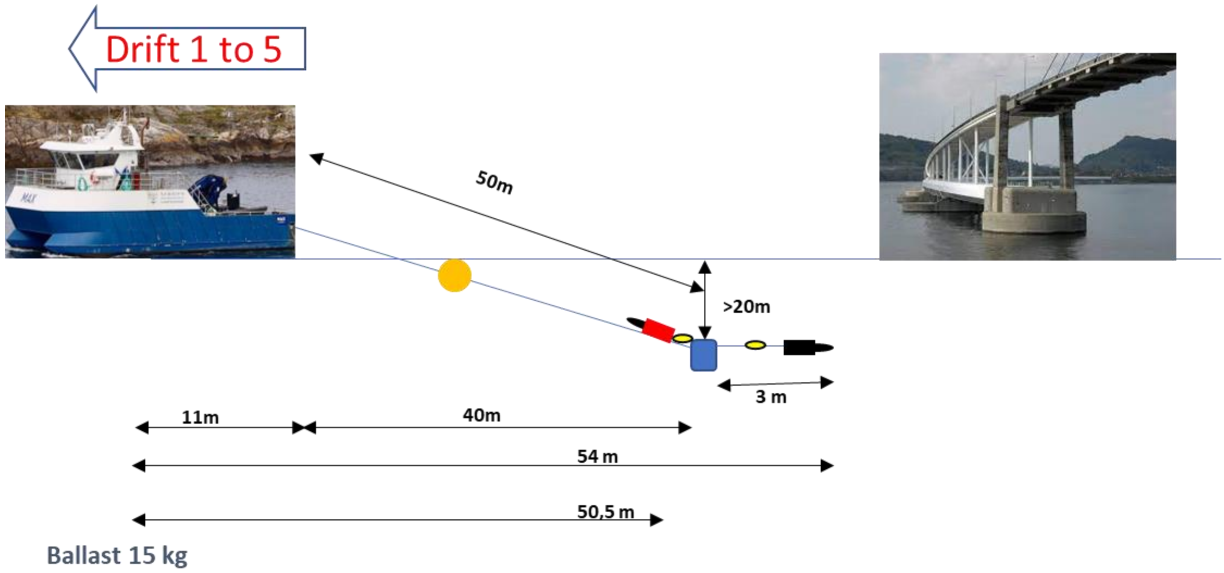


Figure 15: Drifting mooring configuration in Area 2

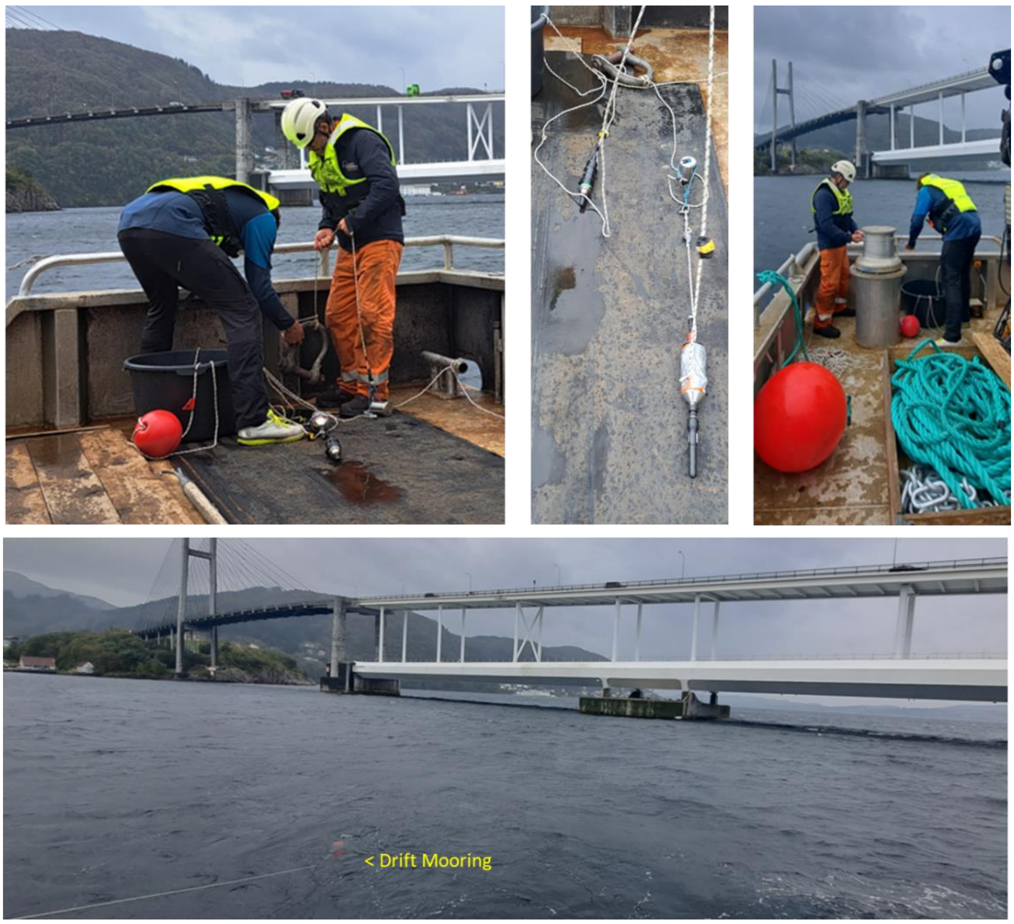


Figure 16: Drifting mooring deployment in Area 2

III.2. Logbook

The logbook of the operational mission is presented in Appendix 2.

III.3. Review of recorded data

Table 10 summarises the information related to the data files extracted from the used recorder.

Table 10: Review of the acoustic data recovered from the measurement campaign

Mooring point	Information related to the recorded data files	Observation/Comments
SCW1985	Recorded File Number: 25 Total size (WAV format): 2.68 (Go) Sampling Frequency (Hz): 128000 Number of days: 1 Start date: 22/09/2022 08:25:00 End Date: 22/09/2022 10:25:00	Valid dataset
SCW1983	Recorded File Number: 38 Total size (WAV format): 3.92 (Go) Sampling Frequency (Hz): 128000 Number of days: 1 Start date: 22/09/2022 09:15:00 End Date: 22/09/2022 13:40:00	Valid dataset
ENR-062	Recorded File Number: 26 Total size (WAV format): 6.96 (Go) Sampling Frequency (Hz): 96000 Number of days: 1 Start date: 22/09/2022 07:10:52 End Date: 22/09/2022 15:24:36	Incomplete but present dataset valid
ENR-029	Recorded File Number: 18 Total size (WAV format): 7.24(Go) Sampling Frequency (Hz): 96000 Number of days: 1 Start date: 22/09/2022 07:26:23 End Date: 22/09/2022 15:04:41	Valid dataset

Chapter IV. List of Appendixes

This chapter lists the appendixes

Appendix A: Mooring Sheet

Appendix B: Logbook

Appendix A: Mooring Sheet

<table>
<tr><th colspan="2">Mooring Reference</th><th colspan="2">R1_Fix</th></tr>
<tr><th colspan="2">Equipment</th><th colspan="2">S/N</th></tr>
<tr><td rowspan="2">Acoustic Recorder</td><td>Recorder</td><td>SCW1985</td><td>ENR062</td></tr>
<tr><td>Hydrophone</td><td>-</td><td>F001010</td></tr>
<tr><th colspan="4">Acquisition Parameters</th></tr>
<tr><td colspan="2">Acoustic recorder</td><td colspan="2"></td></tr>
<tr><td colspan="2">Sensitivity hydrophone</td><td>-169.8 dB re 1V/µPa</td><td>-169.8 dB re 1V/µPa</td></tr>
<tr><td colspan="2">Selected Gain</td><td>0 dB</td><td>☐0 dB ☒15 dB</td></tr>
<tr><td colspan="2">Sampling Frequency</td><td>128000 Hz</td><td>96000 Hz</td></tr>
<tr><td colspan="2">Acquisition mode</td><td colspan="2">Continuous acquisition</td></tr>
</table>

<table>
<tr><th colspan="5">Mooring Position</th></tr>
<tr><td>Source</td><td>Date</td><td>Hour (UTC)</td><td>Latitude (Deg Min)</td><td>Longitude (Deg Min)</td></tr>
<tr><td>QO GPS</td><td>22/10/2022</td><td>08:34</td><td>60° 29.9945 N</td><td>005°25.2025 W</td></tr>
</table>

<table>
<tr><td rowspan="2">Water depth at the mooring point</td><th>Date-Time</th><th>Depth (m)</th></tr>
<tr><td>22/02/2022- 08:30</td><td>95</td></tr>
</table>

Instrument	Depth position on deck (m / sea bottom)
Hydrophone position	45 m from the sea bottom

Notes

Mooring: 08:34
Recovery: 10:24

Operator Name	Date and signature
P. Billand	22/10/2022 

<table>
<tr><th colspan="2">Mooring Reference</th><th colspan="3">R2_Fix</th></tr>
<tr><th colspan="2">Equipment</th><th colspan="3">S/N</th></tr>
<tr><td rowspan="2">Acoustic Recorder</td><td>Recorder</td><td colspan="3">ENR-033</td></tr>
<tr><td>Hydrophone</td><td colspan="3">F001010</td></tr>
<tr><th colspan="5">Acquisition Parameters</th></tr>
<tr><td colspan="2">Acoustic recorder</td><td colspan="3"></td></tr>
<tr><td colspan="2">Sensitivity hydrophone</td><td colspan="3">dB re 1V/µPa</td></tr>
<tr><td colspan="2">Selected Gain</td><td colspan="3">☒0 dB ☐15 dB</td></tr>
<tr><td colspan="2">Sampling Frequency</td><td colspan="3">96000 Hz</td></tr>
<tr><td colspan="2">Acquisition mode</td><td colspan="3">Continuous acquisition</td></tr>
<tr><td colspan="5">Mooring Position</td></tr>
<tr><td colspan="5"></td></tr>
<tr><td>Source</td><td>Date</td><td>Hour (UTC)</td><td>Latitude (Deg Min)</td><td>Longitude (Deg Min)</td></tr>
<tr><td>QO GPS</td><td>22/10/2022</td><td>11:43</td><td>60° 31,341’N</td><td>005° 16,313’E</td></tr>
<tr><td colspan="3" rowspan="2">Water depth at the mooring point</td><td>Date-Time</td><td>Depth (m)</td></tr>
<tr><td>22/02/2022- 11:42</td><td>95</td></tr>
<tr><td>Instrument</td><td colspan="4">Depth position on deck (m / sea bottom)</td></tr>
<tr><td>Hydrophone position</td><td colspan="4">50 m from the sea bottom</td></tr>
<tr><td colspan="5">Notes</td></tr>
<tr><td colspan="5">Subsurface mooring with acoustic releaser equipped with a rope canister</td></tr>
<tr><td colspan="2">Operator Name</td><td colspan="3">Date and signature</td></tr>
<tr><td colspan="2">P. Billand</td><td colspan="3">22/10/2022
</td></tr>
</table>

Appendix B: Loogbook

Date	Time (UTC)	Event	Measurement phasis	Equipment	Point	Lat	Lon
22/09/2022	06:10	Arrival on the support vessel and preparation					
22/09/2022	07:35	Start of fuel supply					
22/09/2022	07:55	End of fuel supply and Departure					
22/09/2022	08:24	Arrival on R1 area					
22/09/2022	08:30	Begin mooring R1_fix	R1_Fix	Hydrophone F001010 (Sh=-172,7dB) (Fs=96kHz - Gain=0dB) SCW1985 (Sh=-172,7 dB) Capteur P - S/N:17321	R1_Fix	60° 30.0085' N	005° 25.2311' E
22/09/2022	08:34	End mooring R1_Fix	R1_Fix		R1_Fix	**60° 29.9945' N**	**005° 25.2025' E**
22/09/2022	09:20	Deployment R1_Drift_01	R1_Drift_01	On the direct Line Ballast 2 kg: Porpoise ENR-029 Hydrophone D000209 (Sh=-166,5dB) (Fs=96kHz - Gain=0dB) SCW1983 (-172,2 dB) Capteur P - S/N:15345	R1_Drift_01 begin	60° 29.7225' N	005° 24.7407' E
22/09/2022	09:25	Recovery R1_Drift_01	R1_Drift_01		R1_Drift_01 end	60° 30.0255' N	005° 24.2482' E
22/09/2022	09:35	Deployment R1_Drift_02	R1_Drift_02	Ballast 2 kg Porpoise ENR-029 in the direct mooring line (Fs=96kHz - Gain=0dB) Hydrophone D000209 (Sh=-166,5dB Capteur P - S/N:15345 ---- SCW1983 (-172,7 dB) connected E19mafter ballast Capteur P - S/N:17273	R1_Drift_02 begin	60° 29.735' N	005° 24.576' E
22/09/2022	09:40	Recovery R1_Drift_02	R1_Drift_02		R1_Drift_02 end	60° 29.9763' N	005° 24.2989' E
22/09/2022	09:50	Deployment R1_Drift_03	R1_Drift_03		R1_Drift_03 begin	60° 29.701' N	005° 24.669' E
22/09/2022	09:52	Closest Point with Ferry	R1_Drift_03		R1_Drift_03 CPA	60° 29.8012' N	005° 24.5488' E
22/09/2022	09:56	Recovery R1_Drift_03	R1_Drift_03		R1_Drift_03 end	60° 29.9485' N	005° 24.2803' E
22/09/2022	10:05	Deployment R1_Drift_04	R1_Drift_04		R1_Drift_04 begin	60° 31.336' N	005° 24.671' E
22/09/2022	10:06	Closest Point with Ferry	R1_Drift_04		R1_Drift_04 CPA	60° 29.7845' N	005° 24.5548' E
22/09/2022	10:11	Recovery R1_Drift_04	R1_Drift_04		R1_Drift_04 end	60° 29.9464' N	005° 24.1660' E
22/09/2022	10:24	Recovery R1_Fix	R1_Fix	Porpoise ENR-062 (Fs=96kHz - Gain=0dB) Hydrophone F001010 (Sh=-172,7dB) SCW1985 (-172,7) Capteur P - S/N:17321	R1_Fix	60° 49.992' N	005° 42.001' E
22/09/2022	11:21	Begin mooring R2_fix	R2_Fix	ENR-033 (Fs=96kHz - Gain=0dB - CHAN2)	R2_Fix	60° 31.336' N	005° 16.291' E
22/09/2022	11:26	Recorder mooring R2_fix in water 95m	R2_Fix	Hydrophone D000208 (Sh=-164,5 db)	R2_Fix	60° 31.334' N	005° 16.300' E
22/09/2022	11:43	End mooring R2_fix (Ballast touches the seabed) - Water depth 95m	R2_Fix	Synchro UTC OK	R2_Fix		
22/09/2022	11:45	Interrogation of the acoustic realeaser unit by MultiConsult - Distance 65m	R2_Fix	Recording lightening OK	R2_Fix	60° 31.341' N	005° 16.313' E
22/09/2022	12:06	Deployment R2_Drift_01	R2_Drift_01	Ballast 15 kg Porpoise ENR-029 in the direct mooring line (Fs=96kHz - Gain=0dB) Hydrophone D000209 (Sh=-166,5dB Capteur P - S/N:15345 ---- SCW1983 (Sh=-172,2 dB) connected 3m after ballast Capteur P - S/N:17273	R2_Drift_01 begin	60° 31.317' N	005° 16.177' E
22/09/2022	12:21	Recovery R2_Drift_01	R2_Drift_01		R2_Drift_01 end	60° 31.835' N	005° 16.192' E
22/09/2022	12:32	Deployment R2_Drift_02	R2_Drift_02		R2_Drift_02 begin	60° 31.391' N	005° 16.017' E
22/09/2022	12:32	Passage of two boats : 1 ferry at 1.5km (Lifjord IMO: 9521710 / MMSI: 257518000) and 1 MultiConsult	R2_Drift_02				
22/09/2022	12:44	Recovery R2_Drift_02	R2_Drift_02		R2_Drift_02 end	60° 31.841' N	005° 15.955' E
22/09/2022	12:55	Deployment R2_Drift_03	R2_Drift_03		R2_Drift_03 begin	60° 31.491' N	005° 15.848' E
22/09/2022	13:06	Recovery R2_Drift_03	R2_Drift_03		R2_Drift_03 end	60° 31.878' N	005° 15.993' E
22/09/2022	13:16	Deployment R2_Drift_04	R2_Drift_04		R2_Drift_04 begin	60° 31.586' N	005° 15.724' E
22/09/2022	13:26	Recovery R2_Drift_04	R2_Drift_04		R2_Drift_04 end	60° 31.895' N	005° 16.012' E
22/09/2022	13:34	Deployment R2_Drift_05	R2_Drift_05		R2_Drift_05 begin	60° 31.693' N	005° 15.631' E
22/09/2022	13:35	Passage of a boat (and following minutes) Heimtun 2 (257306500 NO LFFB)	R2_Drift_05				
22/09/2022	13:39	Recovery R2_Drift_05	R2_Drift_05		R2_Drift_05 end	60° 31.872' N	005° 15.719' E
22/09/2022	13:43	Transit back to port					
22/09/2022	13:54	Arrival to port					

Acoustic impact study of floating bridges

SEA MISSION REPORT - LEG02

Identification	
Document reference	QO.20220427.10.CRM.001.02A
Main contractor	Statens vegvesen (SVV)
Customer	Multiconsult
Costumer contact	Tim Fristedt

PROJET	DOC	CHRONO	VER	IND	CLIENT	ACRO	DATE	TYPE	CLASS
QO.20220427.10	CRM	001	02	A	MC	SVV Bridge	20.11.2022	PROD	DR

Document history

Version	Ind.	Author	Validation	Date	Released	Description
01	**A**	BLD	CBS	20.11.2022	01.12.2022	Initial version

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Chapter I. Context and objectives

I.1. Context of the study

In the context of a possible construction project of a floating bridge in Bjørnafjorden, SVV has issued a tender for the underwater acoustic impact of floating bridges in operation on biodiversity. SVV wishes to study the environmental impact of this type of bridge when commissioned versus ferries. Multiconsult, in charge of the project, has requested the expertise of Quiet-Oceans to perform measurements and associated analysis of underwater noise.

I.2. Scope of work

The work in the framework of this project has been divided in three phases:

- Drafting of the monitoring program and detailed protocol, including the selection of the most suitable equipment and positions that enable to gather pertinent data, and an operational protocol to ensure that measurement is made right;
- Perform in situ measurements (2 sessions) in September 2022 and October 2022 in cooperation with Multiconsult including:
    - The measurement of underwater noise generated by an existing floating bridge (Nordhordlandsbrua);
    - The measurement of a ferry as a comparison in two areas (Valestrand – Breistein line and Halhjem – Sandvikvåg line).
- Analysis and comparison of underwater acoustic sounds produced by field measurements.

I.3. Document overview

This document is a report of the first mission named LEG02.

The operational objectives of the LEG02 are to:

- Prepare the instrumentation to deploy,
- Deploy the drifting mooring and a fix mooring near the line Halhjem – Sandvikvåg during few passages of ferry to record the underwater noise radiated by few ferries in navigation,
- Recovery one long term fixed mooring to monitor the underwater noise radiated by the existing floating bridge Nordhordlandsbrua during 1 month,
- Deploy a drifting mooring to monitor the underwater noise radiated by the existing floating bridge Nordhordlandsbrua along it,

This report describes:

- The defined protocol,
- The equipment and its preparation,
- The operational operations.

I.4. Protocol

The monitoring protocol of the LEG02 was defined in concertation with Multiconsult team. The underwater noise monitoring considers two areas presented in the Figure 1 for the LEG02.

Area 2. Floating bridge
Nordhordlandsbrua
60°31'21.4"N 5°16'10.8"E

Area 3. Ferry Halhjem - Sandvikvåg
5 ferries : FLATØY, FÆRØY, LYSØY, HUFTARØY, SAMNØY (Hybrid LNG)
Run permanently.

Figure 1: Overview of the area project – LEG02

I.4.1. Area 3: Ferry Halhjem – Sandvikvåg

The Figure 2 presents the area and the position point of the drifting mooring (start of drift) and the fixed mooring.

The Table 1 resumes the information and outlines the requirements for the measurements in the area 3.

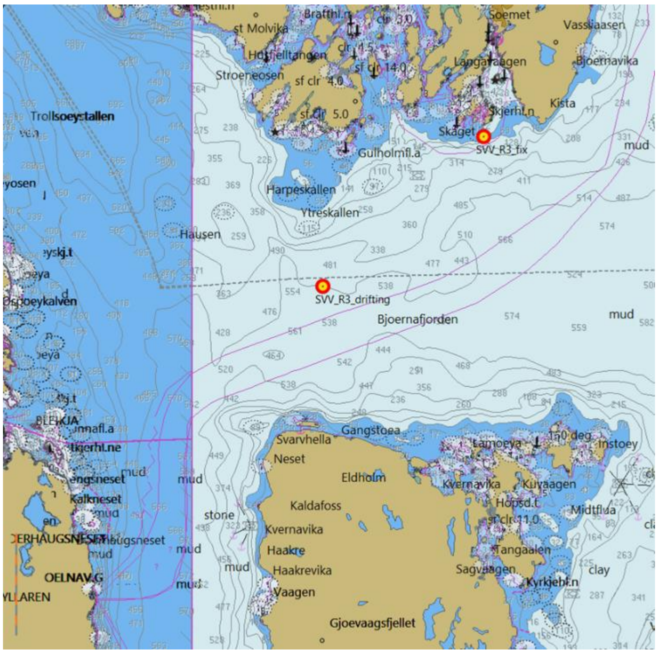

Figure 2: Location of the 2 acoustics mooring lines on area 3

Table 1: Measurement information and requirements on area 3

Area	Name	Point name	Water depth	Hydrophone immersion	Duration	Status
1	Ferry Valestrand – Breistein	R3_fix	~80m	30 to 40m	2 h	Static
		R3_drifting	variable (350 m)	10 to 25m	2 h	Drifting

I.4.2. Area 2: Floating bridge Nordhordlandsbrua

The Figure 3 presents the area 2 and the position point of the drifting mooring (start of drift) and the fix mooring.

The Table 2 resumes the information and outlines the requirements for the measurements in the area 2.

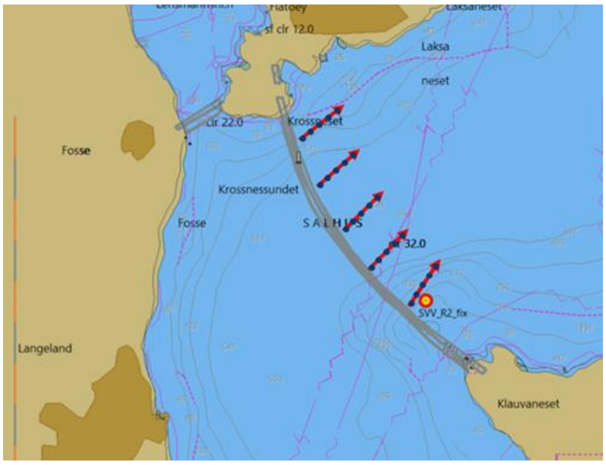

Figure 3: Location of the 2 acoustics mooring lines on area 2

Table 2: Measurement information and requirements on area 2

Area	Name	Point name	Water depth	hydrophone immersion	Duration	Status
2	Nordhordlandsbrua bridge	R2_fix	100m	50m	30 days	Static
		R2_drifting	variable	25 to 30m	1 h	Drifting

I.5. Support Vessel

The vessel used for the deployment of the acoustic moorings is a tug named "POMPEL" (Figure 4) of the Valen Marina company. Vessel speed was 28 knots maximum. The duration of the mission at sea was planned for 6 hours.

Figure 4: Support vessel used for the project

Chapter II. Instrumentation and mooring preparation

This chapter present all acoustic equipment, its associated settings for the project and the design of the mooring lines deployed.

II.1. Assignment of recorders to moorings

Table 3 resume the assignment of recorders and pressure sensors to moorings during the LEG02.

Table 3: Assignment of recorders to moorings

Point Name	Acoustic RECORDER (Type / Reference)					Pressure sensor ref.
R3_fix	-	*IC Listen SCW1983*	-	*Porpoise ENR-029*	-	*17361*
R3_drifting	*IC Listen SCW1985*	-	-	-	-	*17292*
R2_fix	-	-	-	-	*ORCA 72D ENR-033*	-
R2_drifting	*IC Listen SCW1985*	-	-	-	-	*17361* *17292*

II.2. Presentation of the acoustic recorders for R3-Fix, R3-Drifting and R2-Drifting

The acoustic recorders used for the acoustic measurement on R3_Fix, R3_Drifting and R2_Drifting are stand-alone systems, the first is an IC HF Listen (Figure 6) designed by Oceansonics, the technical characteristics of the recorder are detailed in Table 2 and the second is a Porpoise-EXT recorder (Figure 7) designed by Turbulent Research whose characteristics are detailed in Table 3.

The settings adopted for the LEG 02 are presented in the mooring sheet in Appendix 1.

Table 4: Technical characteristics of the icListen recorder

Hydrophone & Recorder	IC Listen
Bandwidth	7Hz-64 kHz
Sampling Frequency	128 kHz
Acoustic sensitivity	-172.5 dB re: 1V/µPa
SPL max / SPL min	181 dB re: 1V/µPa - 73 dB re: 1V/µPa
Autonomy	10 hours
Dimensions - Weight	267 mm x 45 mm - 0.3 kg
Operational water depth	200 m

Figure 5: IC HF Listen recorder

Table 5: Technical characteristics of the PORPOISE recorder

Hydrophone & Recorder	Porpoise
Bandwidth	10Hz-48kHz
Sampling Frequency	96 kHz
Acoustic sensitivity	-180.1 dB re: 1V/µPa
Gain option	0-**15**-30-45 dB
SPL max / SPL min	167 dB re: 1V/µPa - 66 dB re: 1V/µPa
Autonomy	50 hours
Dimensions - Weight	229 mm x 70 mm - 1.2 kg
Operational water depth	500 m

Figure 6: Porpoise-EXT recorder

II.3. Presentation of the acoustic recorders for R2-Fix

The acoustic recorders used for the acoustic measurement on R2_Fix is an ORCA72D recorder (Figure 7) designed by Turbulent Research whose characteristics are detailed in Table 6.

The settings adopted for the LEG 02 are presented in the mooring sheet in Appendix 1.

Table 6: Technical characteristics of the ORCA 72 recorder

Hydrophone & Recorder	ORCA 72D
Bandwidth	10Hz-48kHz
Acquisition Channels	5
Sampling Frequency	96000 kHz
Acoustic sensitivity	-164.8 dB re: 1V/µPa
Gain option	**0**-15-30-45 dB
SPL max / SPL min	167 dB re: 1V/µPa - 66 dB re: 1V/µPa
Autonomy	44 days
Dimensions - Weight	229 mm x 70 mm - 34 kg

Figure 7: ORCA72D recorder in its mechanical protection frame

II.4. Preparation of the moorings

The drifting mooring was prepared by Quiet-Oceans and presented Figure 8.

The final configuration of R3 _Fix was designed and realized by Multiconsult with the collaboration of Quiet-Oceans team.

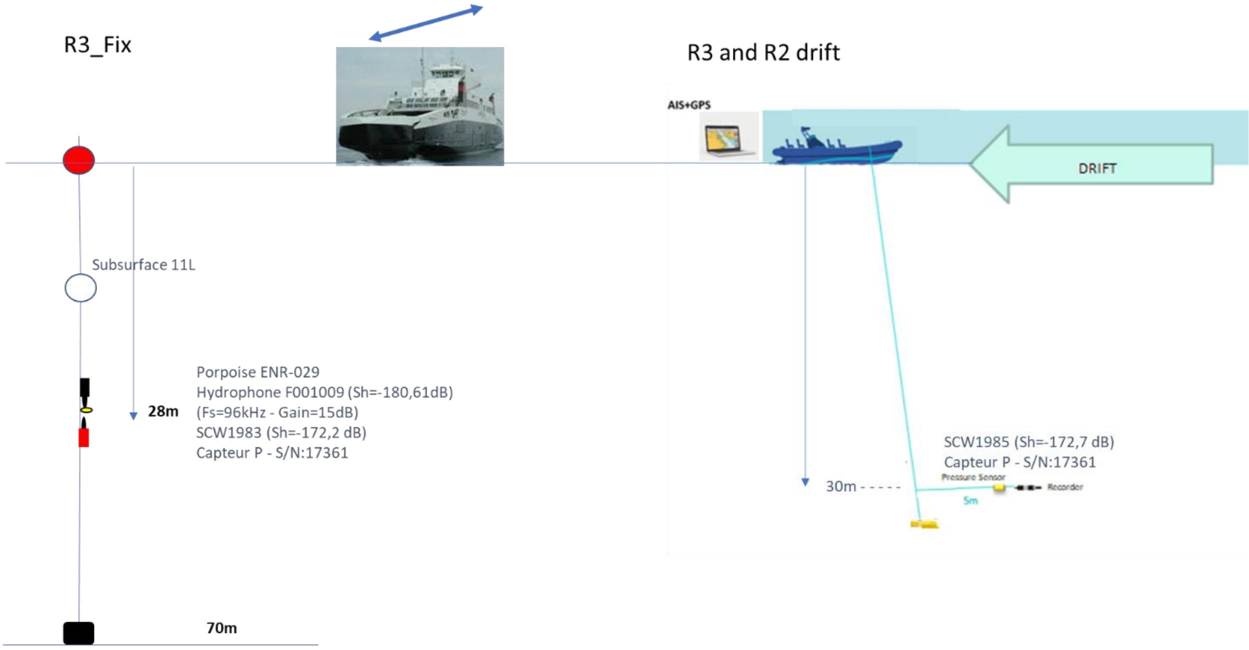

Figure 8: Design of the drifting mooring line and R3-Fix mooring line

Chapter III. Sea operations

III.1. Boarding

Personnel of Multiconsult and Quiet-Oceans embarked on the support vessel "POMPEL" on 26th October 2022 at 05h30 UTC.

III.2. Preparation

The end of the deck preparation of all moorings was finalised onboard during 30 minutes.

III.3. Navigation

The position of the vessel is recorded from a portable GPS device presented in the Table 7.

The acquisition is made at the start of the mission. The position of each mooring line is recorded with this GPS device as well as the latitudes and longitudes of the navigation at every second.

Table 7: GPS for navigation

Characteristics	Value	
Brand	GARMIN	
Model	GPS 78	
Precision	±5 m	
Measurement rate	1 Hz	

The navigation and the maritime traffic on site are monitored and recorded from a portable AIS receiver.

III.4. Measurement in area 3

The acoustic measurements in area 3 (Ferry Halhjem – Sandvikvåg) to evaluate the underwater noise of the ferry took one hour and included the following operations:

- the deployment and recovery of a short-term fixed mooring placed at more than 200m from the navigation rail,
- 7 ferry passages in 2 drifting phasis with one repositioning of the support vessel.

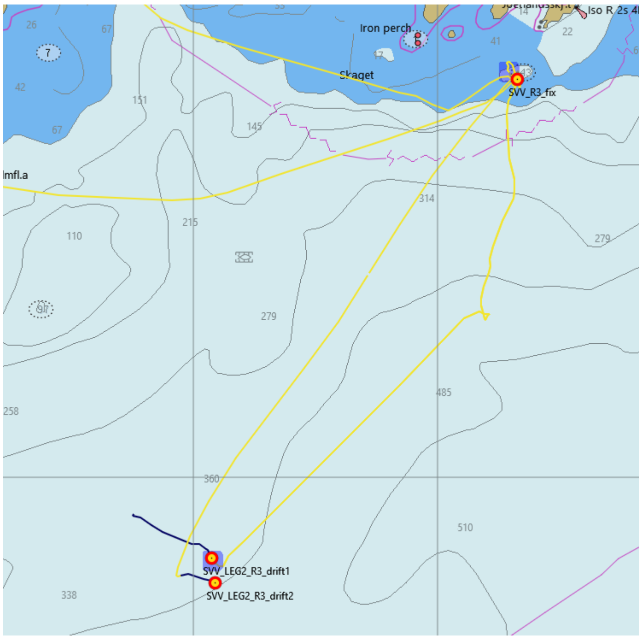

Figure 9: Measurement in area 3

III.4.1. Fixed mooring

The deployment operations were conducted on 26tOctober 2022 at the beginning of the mission (see Appendix B). The fixed mooring named R3_Fix has been deployed at the position presented in Table 8.

The completed mooring sheet is presented in Appendix A.

Table 8: Acoustic recorders location in area 3

Point	Mooring Time (UTC)	Recovery Time (UTC)	Water depth (m)	Distance of hydrophone / Sea bottom (m)	Latitude	Longitude
R3_Fix	07h34	08h40	70	42	60° 29.9945 N	005°25.2025 W

III.4.2. Drifting mooring

Four drifting measurements were conducted after the deployment of R3_Fix. Each drift is described in Figure 9. The Figure 10 illustrates the deployment with a passage of one ferry.

Figure 10: Drifting mooring deployed during a passage of ferry

III.1. Measurement in area 2

The acoustic measurements in area 2 to monitor the underwater noise radiated by an existing floating bridge took one hour and included the following operations:

- Four transect in drift mode pushed by the marine current on site with a repositioning of the support vessel between two transects along the bridge to cover its length,
- The recovery of a long-term (1 month) fixed mooring placed at more than 100m from the navigation rail.

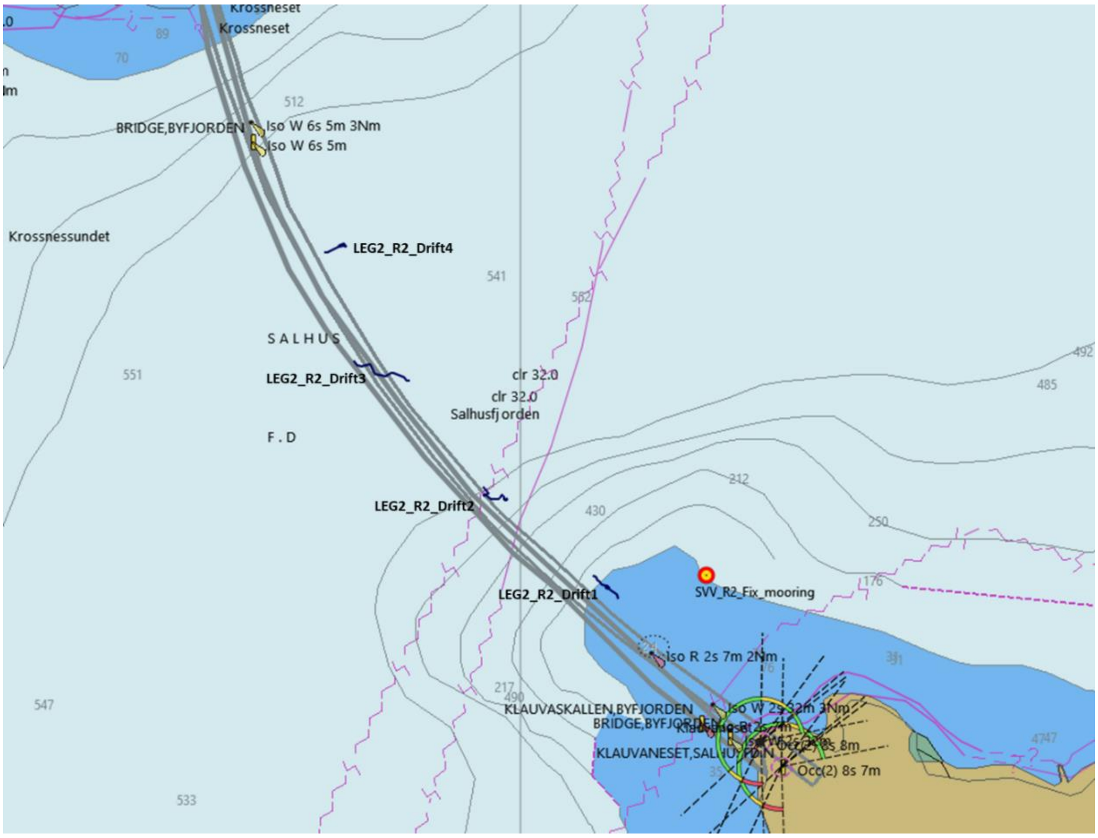

Figure 11: Measurements on area 2

III.1.1. Drifting mooring

Four drifting measurements were conducted after the check of presence of the mooring R2_Fix (by sonardyne unit surface). Each drift is described in Figure 11.

III.1.2. Fixed mooring

The recovery operation was conducted on 26 October 2022 after the drifting measurements. The fixed mooring named R2_Fix has been deployed and recovered at the position presented in the Table 9.

The completed mooring sheet is presented in Appendix A.

Table 9: Acoustic recorders location in area 2

Point	Mooring Date/Time (UTC)	Recovery Date/Time (UTC)	Water depth (m)	Distance of hydrophone / Sea bottom (m)	Latitude	Longitude
R2_Fix	22.09.22/11h43	26.10.22/10h40	95	50	60° 31,341’N	005° 16,313’E

III.2. Logbook

The logbook of the operational mission is presented in Appendix 2.

III.3. Review of recorded data

Table 10 summarises the information related to the data files extracted from the used recorder.

Table 10: Review of the acoustic data recovered from the measurement campaign

Mooring point	Information related to the recorded data files	Observation/Comments
SCW1985	Recorded File Number: 29 Total size (WAV format): 3.11 (Go) Sampling Frequency (Hz): 128000 Number of days: 1 Start date: 26/10/2022 07:15:00 End Date: 26/10/2022 10:40:00	Valid dataset
SCW1983	Recorded File Number: 25 Total size (WAV format): 2.68 (Go) Sampling Frequency (Hz): 128000 Number of days: 1 Start date: 26/10/2022 06:55:00 End Date: 26/10/2022 08:55:00	Valid dataset
ENR-029	Recorded File Number: 10 Total size (WAV format): 4.66(Go) Sampling Frequency (Hz): 96000 Number of days: 1 Start date: 26/10/2022 06:44:09 End Date: 26/10/2022 11:02:11	Valid dataset
ENR-033	Recorded File Number: 535 Total size (WAV format): 144.57 (Go) Sampling Frequency (Hz): 96000 Number of days: 34 Start date: 21/09/2022 08:12:59 End Date: 26/10/2022 12:51:51	Valid dataset

Chapter IV. List of Appendixes

This chapter lists the appendixes

Appendix A: Mooring Sheet

Appendix B: Logbook

Appendix A: Mooring Sheet

<table>
<tr><th colspan="2">Mooring Reference</th><th colspan="2">R3_Fix</th></tr>
<tr><th colspan="2">Equipment</th><th colspan="2">S/N</th></tr>
<tr><td rowspan="2">Acoustic Recorder</td><td>Recorder</td><td>SCW1983</td><td>ENR062</td></tr>
<tr><td>Hydrophone</td><td>-</td><td>F001009</td></tr>
<tr><td colspan="4">Acquisition Parameters</td></tr>
<tr><td colspan="2">Acoustic recorder</td><td colspan="2"></td></tr>
<tr><td colspan="2">Sensitivity hydrophone</td><td>-172.2 dB re 1V/µPa</td><td>-180.1 dB re 1V/µPa</td></tr>
<tr><td colspan="2">Selected Gain</td><td>0 dB</td><td>☐0 dB ☒15 dB</td></tr>
<tr><td colspan="2">Sampling Frequency</td><td>128000 Hz</td><td>96000 Hz</td></tr>
<tr><td colspan="2">Acquisition mode</td><td colspan="2">Continuous acquisition</td></tr>
</table>

<table>
<tr><td colspan="5">Mooring Position</td></tr>
<tr><td colspan="5"></td></tr>
<tr><td>Source</td><td>Date</td><td>Hour (UTC)</td><td>Latitude (Deg Min)</td><td>Longitude (Deg Min)</td></tr>
<tr><td>QO GPS</td><td>26/10/2022</td><td>07:14</td><td>60° 07.7997' N</td><td>005° 25.3352' E</td></tr>
</table>

<table>
<tr><td rowspan="2">Water depth at the mooring point</td><td>Date-Time</td><td>Depth (m)</td></tr>
<tr><td>26/10/2022- 07:16</td><td>70</td></tr>
</table>

Instrument	Depth position on deck (m / sea bottom)
Hydrophone position	42 m from the sea bottom

Notes

Mooring: 07:14
Recovery: 08:37

Operator Name	Date and signature
T.Lebrun	26/10/2022

<table>
<tr><th colspan="2">Mooring Reference</th><th colspan="3">R2_Fix</th></tr>
<tr><th colspan="2">Equipment</th><th colspan="3">S/N</th></tr>
<tr><td rowspan="2">Acoustic Recorder</td><td>Recorder</td><td colspan="3">ENR-033</td></tr>
<tr><td>Hydrophone</td><td colspan="3">D000208</td></tr>
<tr><th colspan="5">Acquisition Parameters</th></tr>
<tr><td colspan="2">Acoustic recorder</td><td colspan="3"></td></tr>
<tr><td colspan="2">Sensitivity hydrophone</td><td colspan="3">-164.5 dB re 1V/µPa</td></tr>
<tr><td colspan="2">Selected Gain</td><td colspan="3">☒0 dB ☐15 dB</td></tr>
<tr><td colspan="2">Sampling Frequency</td><td colspan="3">96000 Hz</td></tr>
<tr><td colspan="2">Acquisition mode</td><td colspan="3">Continuous acquisition</td></tr>
<tr><td colspan="5">Mooring Position</td></tr>
<tr><td colspan="5">Recovery</td></tr>
<tr><td>Source</td><td>Date</td><td>Hour (UTC)</td><td>Latitude (Deg Min)</td><td>Longitude (Deg Min)</td></tr>
<tr><td>QO GPS</td><td>26/10/2022</td><td>10:40</td><td>60° 31.341’N</td><td>005° 16.313’E</td></tr>
<tr><td colspan="3" rowspan="2">Water depth at the mooring point</td><td>Date-Time</td><td>Depth (m)</td></tr>
<tr><td>22/10/2022- 11:42</td><td>95</td></tr>
<tr><th colspan="2">Instrument</th><th colspan="3">Depth position on deck (m / sea bottom)</th></tr>
<tr><td colspan="2">Hydrophone position</td><td colspan="3">50 m from the sea bottom</td></tr>
<tr><td colspan="5">Notes</td></tr>
<tr><td colspan="5">Subsurface mooring with acoustic releaser equipped with a rope canister
Mooring: 22/09/2022 @11:43
Recovery: 26/10/2022 @10:40</td></tr>
<tr><th colspan="2">Operator Name</th><th colspan="3">Date and signature</th></tr>
<tr><td colspan="2">T.Lebrun</td><td colspan="3">26/10/2022
</td></tr>
</table>

Appendix B: Loogbook

Date	Time (UTC)	Event	Measurement phasis	Equipment	Point	Lon	Lat
25/10/2026	08:50:00	Departure from Brest					
25/10/2026	17:30:00	Arrival in Bergen					
26/10/2026	03:21:00	Time synchronisation IC LISTEN 1983		IC LISTEN 1983 (ENR-027)			
26/10/2026	03:23:00	Start acquisition IC LISTEN 1983		IC LISTEN 1983 (ENR-027)			
26/10/2026	03:26:00	Time synchronisation IC LISTEN 1985		IC LISTEN 1985 (ENR-028)			
26/10/2026	03:28:00	Start acquisition IC LISTEN 1985		IC LISTEN 1985 (ENR-028)			
26/10/2026	03:40:00	Time synchronisation Porpoise		ENR-029			
26/10/2026	03:43:00	Start acquisition Porpoise		ENR-029			
26/10/2026	04:40:00	Departure from htel					
26/10/2026	05:30:00	Arrival at harbour Bildøy Marina AS (60.343070446301176, 5.111976018645885) Loading of equipment on support vessel POMPEL					
26/10/2026	06:00:00	Leaving harbour. Transit to Bjoernafjorden					
26/10/2026		Setup of navigation equipment : - AIS station - GPS - PC					
26/10/2026		Recorders check onboard		ENR-O27 / ENR-028 / ENR-029			
26/10/2026	06:50:00	Arrival on R3_fix area	R3_fix	ENR-029 (PORPOISE TR-12-1R0-88) : Fs : 96 KSPS Gain : 15 dB Filter : None + Hydrophone M36-900 SN-F001009 (SH : -180,61 dB @100 Hz) ------ ENR-027 (ICHF LISTEN SCW1983) Fs : 128 KSPS SH : -172,2 dB ------ P° Sensor : U-17361 (Interval : 5s) ------ Synchro UTC OK Recording lightening OK	R3_fix	5.421918	60.129986
26/10/2026		Rigging of R3_fix mooring : - Mooring depth : 70 m - Recorders depth : 28 m - Recorders : ENR-029 + ENR-027 + Pressure sensor 17361	R3_fix		R3_fix		
26/10/2026	07:09:00	Start deployment R3_fix	R3_fix		R3_fix	5.422253	60.12999
26/10/2026	07:14:00	End deployment R3_fix	R3_fix		R3_fix	5.422102	60.130106
26/10/2026		Rigging of R2_drift mooring : - Recorder depth : 30 m / Paravane depth : 33 m	R3_drift	ENR-028 (ICHF LISTEN SCW1985) Fs : 128 KSPS SH : -172,7 dB ------ P° Sensor : U-17292 (Interval : 5s) ------ Synchro UTC OK Recording lightening OK ------ Paravane fitted on the line	R3_drift		
26/10/2026	07:25:52	Deployment of R3_drift_test	R3_drift_test		R3_drift_test_begin	5.419963	60.122062
26/10/2026	07:30:00	Passage of Ferry 150 m	R3_drift_test		R3_drift_test		
26/10/2026	07:31:50	Recovery of R3_drift_test	R3_drift_test		R3_drift_test_end	5.420187	60.122237
26/10/2026		Relocate to the middle of the fjord, between the two ferry tracks (incoming / outcoming)					
26/10/2026	07:43:15	Deployment of R3_drift_01	R3_drift_01		R3_drift_01_begin	5.401779	60.113678
26/10/2026	07:43:55	Sensor at the bottom (30 m)	R3_drift_01		R3_drift_01	5.401612	60.113738
26/10/2026	07:45:25	Passage of Ferry < 100 m	R3_drift_01		R3_drift_01	5.401387	60.113785
26/10/2026		Drifting mooring straight behind the boat	R3_drift_01		R3_drift_01		
26/10/2026	07:46:00	POMPEL motors for 5 sec	R3_drift_01		R3_drift_01	5.401318	60.113827
26/10/2026		Shuttle 200/300 m	R3_drift_01		R3_drift_01		
26/10/2026	07:48:45	Passage of Ferry < 200/300 m	R3_drift_01		R3_drift_01	5.401118	60.114051
26/10/2026	08:02:00	Mooring pulled up to ~15m and back down	R3_drift_01		R3_drift_01	5.398717	60.114647
26/10/2026	08:06:00	Passage of Ferry ~500 m	R3_drift_01		R3_drift_01	5.397853	60.114859
26/10/2026	08:09:25	Passage of Ferry ~100 m	R3_drift_01		R3_drift_01	5.397269	60.115045
26/10/2026	08:18:12	Recovery of R3_drift_01	R3_drift_01		R3_drift_01_end	5.395869	60.11545
26/10/2026		Relocate to the middle of the ferry channel					
26/10/2026	08:20:53	Deployment of R3_drift_02	R3_drift_02		R3_drift_02_begin	5.401393	60.113162
26/10/2026	08:24:35	Passage of Ferry ~130 m	R3_drift_02		R3_drift_02	5.400862	60.113202
26/10/2026	08:28:45	Passage of Ferry ~200 m	R3_drift_02		R3_drift_02	5.400045	60.113384
26/10/2026	08:32:11	Recovery of R3_drift_02	R3_drift_02		R3_drift_02_end	5.399099	60.113362
26/10/2026		Transit to R3_fix					
26/10/2026	08:36:40	Arrival on R3_fix area	R3_fix		R3_fix	5.421988	60.130362
26/10/2026	08:37:00	Start recovery of R3_fix	R3_fix		R3_fix	5.421721	60.130178
26/10/2026	08:38:00	Recorders out of water	R3_fix		R3_fix	5.421963	60.130168
26/10/2026	08:40:00	End recovery R3_fix	R3_fix		R3_fix	5.422008	60.130165
26/10/2026		Transit to BYFJORDEN Bridge					
26/10/2026	09:57:00	Arrival on R2_fix area	R2_fix		R2_fix	5.271877	60.521741
26/10/2026	10:00:00	Ping of R2_fix acoustic release : presence OK	R2_fix		R2_fix	5.271603	60.522278
26/10/2026		Transit to pile 01					
26/10/2026	10:01:46	Deployment R2_drift_01 (Pile 01)	R2_drift_01		R2_drift_01_begin	5.269276	60.521954
26/10/2026	10:08:07	Recovery of R2_drift_01	R2_drift_01		R2_drift_01_end	5.268599	60.522258
26/10/2026		Transit to pile 03		ENR-028 (ICHF LISTEN SCW1985) Fs : 128 KSPS SH : -172,7 dB ------ P° Sensor (recorder) : U-17292 (Interval : 5s) P° Sensor (paravane) : U-17361 (Interval : 5s) ------ Synchro UTC OK Recording lightening OK ------ [illegible]			
26/10/2026	10:10:59	Deployment R2_drift_02 (adding of a pressure sensor on the paravane) (Pile 03)	R2_drift_02		R2_drift_02_begin	5.266274	60.523287
26/10/2026	10:16:50	Recovery R2_drift_02	R2_drift_02		R2_drift_02_end	5.265618	60.523449
26/10/2026		Transit to pile 05					
26/10/2026	10:18:51	Deployment R2_drift_03 (Pile 05)	R2_drift_03		R2_drift_03_begin	5.263676	60.524844
26/10/2026	10:25:00	Recovery R2_drift_03	R2_drift_03		R2_drift_03_end	5.262123	60.525115
26/10/2026		Transit to pile 07					
26/10/2026	10:27:18	Deployment R2_drift_04 (Pile 07)	R2_drift_04		R2_drift_04_begin	5.261739	60.526618
26/10/2026	10:33:00	Recovery R2_drift_04	R2_drift_04		R2_drift_04_end	5.261369	60.526533
26/10/2026		Transit to R2_fix					
26/10/2026	10:40:00	Start recovery of R2_fix	R2_fix	ENR-033 (Fs=96kHz - Gain=0dB - CHAN2) Hydrophone D000208 (Sh=-164,5 db)	R2_fix	5.271695	60.522241
26/10/2026	10:49:00	End recovery R2_fix	R2_fix		R2_fix	5.271497	60.522291
26/10/2026		Transit to harbour Bildøy Marina AS					