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Action A8.2 Deliverable – Review on the acoustic signatures created by different vessels in the Archipelago Sea

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BIODIVERSEA
for marine nature

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Summary

Sub-Action A8.2 in the Life-IP Biodiversea project aims at identifying environmental pressures on marine environment caused by anthropogenic activities, such as underwater noise emitted by different types of vessels sailing in the Finnish coastal areas. In particular, the Finnish Archipelago Sea, characterized by high hydrological connectivity and biodiversity, is a sea area with various islands, straits, and a variety of seaways. The present report identified the most common vessel types in the Archipelago Sea and reviewed the current state of knowledge on acoustic signatures of commercial ships and recreational vessels. The sea area is mainly trafficked by ferries, Roll-on Roll-off passenger ships and general cargo ships, while motorboats with an outboard engine is by far the most common recreational vessel type. The source levels of larger ships reach up to 195 decibels (dB) re 1 µPa at 1m distance and is the most intense at relatively low frequencies (≤125 Hz). The source levels of sound pressure from various smaller vessels are generally much lower but with higher variability and uncertainty in relation to type of engine, size, and speed of the boat. Readily applicable national mitigation measures on underwater noise reduction include regional speed limits and so-called no-go zones, where movement of vessels can be restricted or completely prohibited. However, the effects of speed limits on acoustic emissions vary highly, especially for smaller vessels. Therefore, further research is required to identify the most cost-effective mitigation measures that equally protect marine species from excessive underwater noise.

Contents

1. Background

The United Nations and European Union have set targets to protect at least 30% of the land and sea for nature by 2030 (EC, 2020; UN, 2022), and the national LIFE-IP Biodiversea project aims to fulfil this goal for marine areas in Finland. The Archipelago Sea, in Southwestern Finland, is a useful pilot area for such project, since it consists of thousands of islands, straits and inlets (Miettunen et al., 2020). The shallow sea area has a mean depth of 19 metres and a relatively short water age due to high hydrological connectivity. The coast on the Finnish mainland side of the Archipelago Sea is under relatively heavy maritime traffic from commercial ships, as well as ferries and leisure boats.

The aim of this report is to identify the most common vessel types sailing in the Archipelago Sea and review the current state of knowledge on acoustic signatures (i.e. the acoustic characteristics of sound emissions from a source) of various commercial and recreational vessels that commonly sail in the area. Further, the applicability of potential operational mitigation measures to reduce underwater noise emissions spatially and temporally are discussed.

2. Maritime traffic in the Archipelago Sea

Commercial shipping traffic close to the mainland of Finland within the Archipelago Sea is mainly to and from two larger commercial ports – ports of Turku and Naantali – both among the fifteen largest ports in Finland in terms of volume of annually transported goods (Satamaliitto, 2024). Both ports receive more than 1500 port calls by ships annually (Port of Naantali, 2022; Port of Turku, 2024). Vast majority of ship traffic to and from Port of Turku is Roll-on Roll-off passenger (ROPAX) ships including some general cargo vessels, whereas Port of Naantali is one of the largest cargo ports in Finland hosting mainly general and bulk cargo ships (Tables 1 and 2, appendices) (Logistiikan maailma, 2024). In addition to cargo and ROPAX ships, the Turku shipyard has a strong history of constructing some of the largest cruise vessels in the world (Yle, 2023; Meyerturku, 2024).

In addition, the Archipelago Sea consists of numerous marinas and smaller lanes for ferries and recreational boats (Väylävirasto, 2024) (Figure 1). In general, the number of registered recreational boats and estimated number of days of usage per boat during boating season have increased from 2016 to 2024 in Finland (Traficom, 2024). Ferries and recreational vessels utilise these seaways particularly in the summer, and the number of all registered boats can be obtained from the national boat register, containing information on all recreational vessels of length ≥5,5 meters, or power above 15kW (or 20 horsepower) (administrated by the Finnish Transport and Communications Agency, Traficom). Figure 2 shows the number of first-time registered boats per year from 2018 to 2024 in Southwestern Finland. Even though first-time boat registrations have decreased over the last few years, the annual numbers remain relatively high. Figure 3 depicts the total number of registered boats per vessel type as of 1 January 2024 in Southwestern Finland. In addition, the national boat registry also provides an overview of the types and technical details of registered vessels. Figure 4 shows the distribution of registered vessels (in Southwestern Finland) according to boat type, engine power and mounting. The most common boat type is motorboat with an outboard gasoline engine.

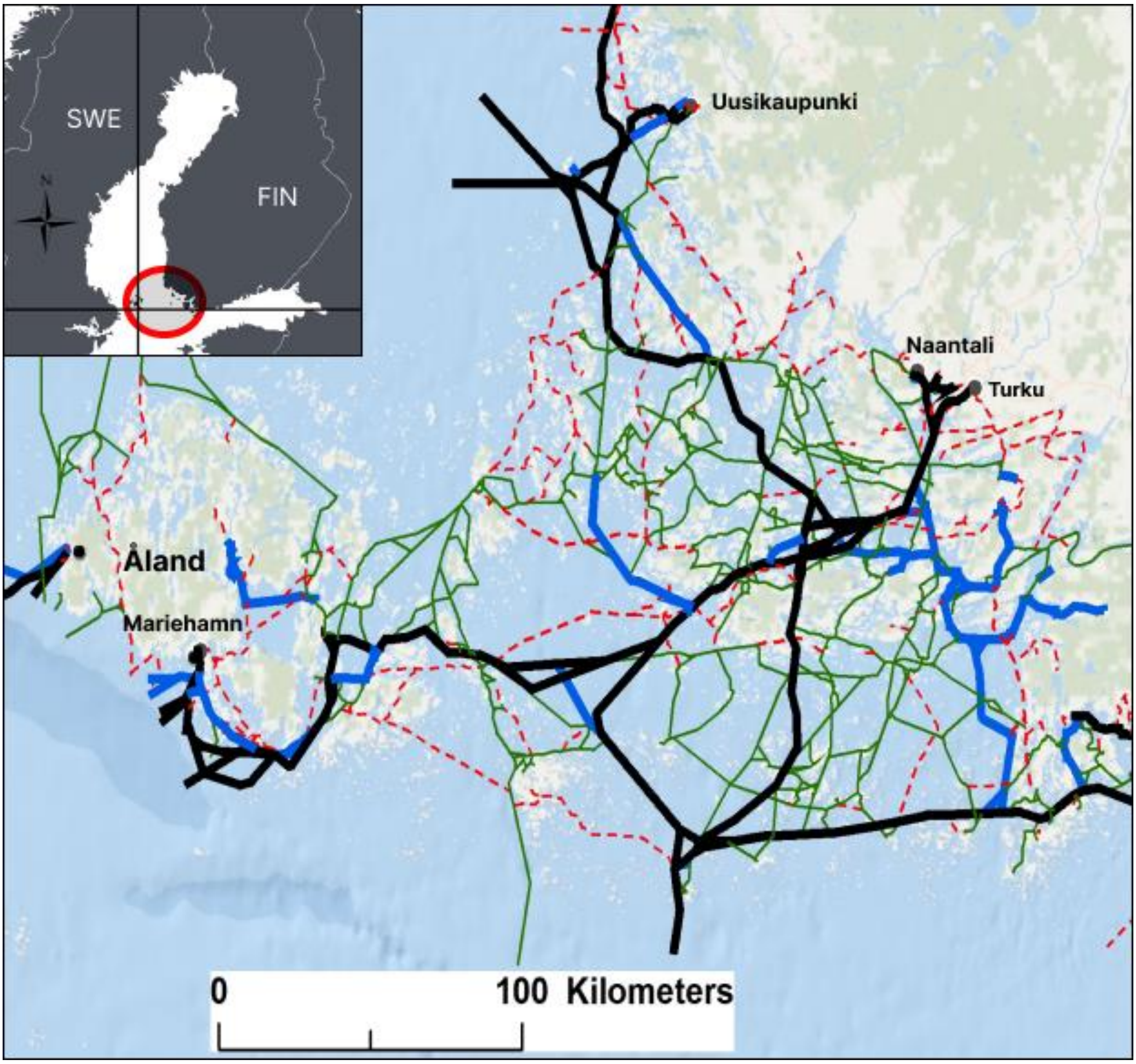

Figure 1. Map of the Archipelago Sea, Southwestern Finland (ArcGIS map source: Finnish Maritime Spatial Planning). The bolded black and blue lines represent class 1 and 2 shipping lanes for commercial ships, respectively. Green lines represent lines for ferries and the dashed red lines represent additional boating lanes. Mariehamn, Naantali, Turku and Uusikaupunki represent some of the major ports in the area.

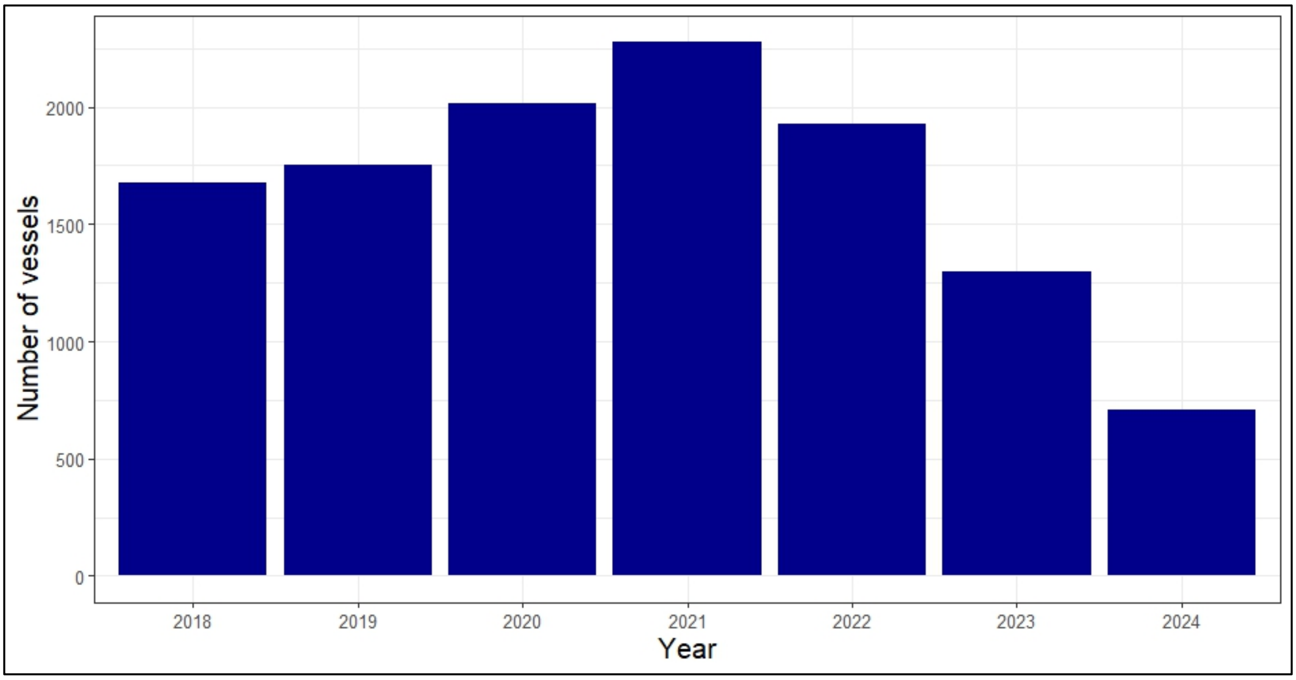

Figure 2. Number of first-time registered small vessels (<25m) per year in Southwestern Finland (regions Varsinais-Suomi and Uusimaa together) as of 1.7.2024. Source: Traficom.

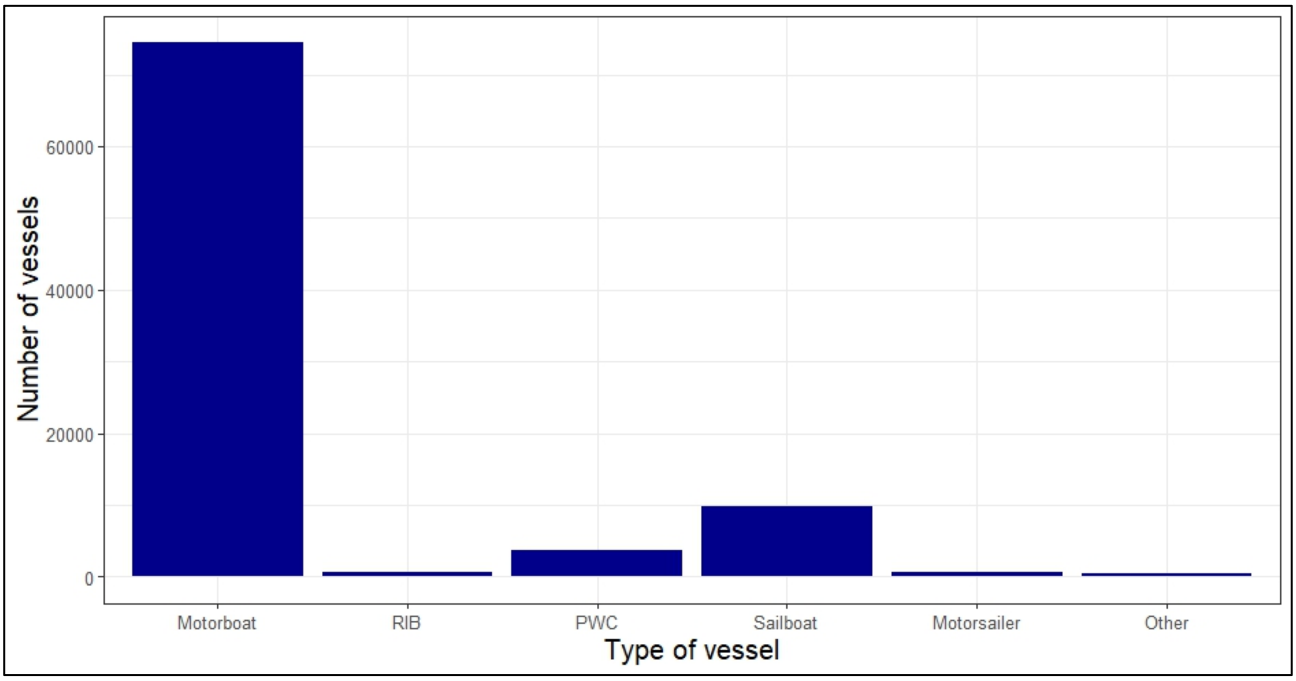

Figure 3. Total number of registered small vessels (<25m) per type of vessel in Southwestern Finland. RIB == Rigid Inflatable Boat; PWC == Personal Water Craft (water scooter).

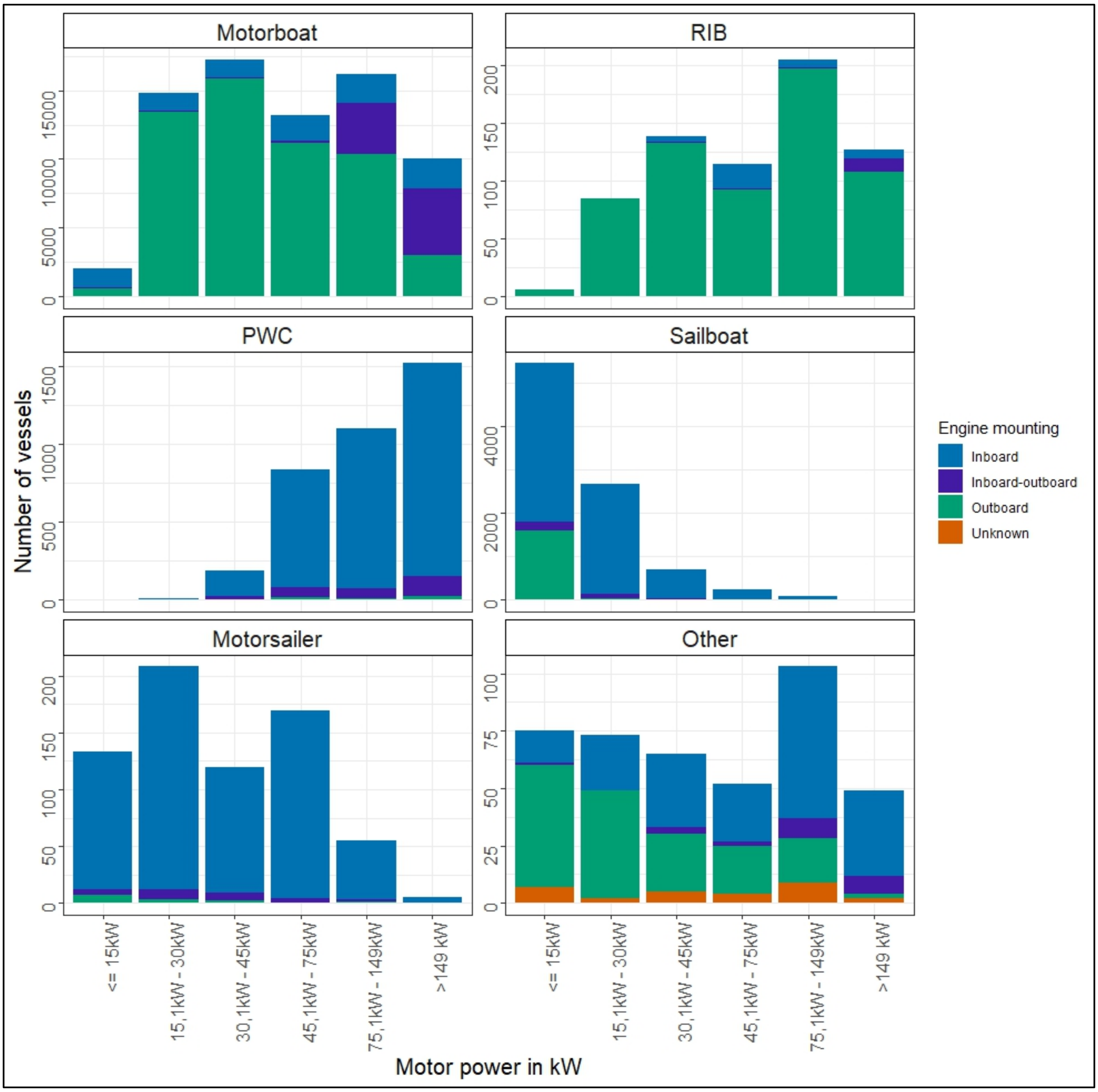

Figure 4. Number of registered small vessels (<25) in Southwestern Finland according to vessel type, engine power, and engine mounting. RIB == Rigid Inflatable Boat; PWC == Personal Water Craft (water scooter). Note different scales on y-axes. Source: Traficom.

3. Acoustic signatures of commercial ships and smaller vessels

All seaborne vessels generate sound and noise underwater. Propeller cavitation and onboard machinery are the main sources of underwater noise associated with commercial ships of >100m in length (Kinda et al., 2017; Southall et al., 2017). Sound pressure from ships of this size contributes primarily to the elevation of sound pressure levels (SPL) in lower, <1 kHz frequencies, even though higher frequency noise is also emitted at audible levels over shorter distances. In general, several previous studies, such as Kipple and Gabriele (2004), McKenna et al. (2012), Southall et al. (2017), and MacGillivray et al. (2019), have demonstrated that various types of commercial ships expose the underwater environment to different acoustic signatures and intensities of noise (Table 3).

Table 3. Source levels of underwater sound pressure at several frequency ranges from various ships. Table drafted after MacGillivray et al. (2019), although these data are equally supported by McKenna et al. (2012) and McKenna et al. (2013). All SPL values are presented as the mean monopole source levels at 1 meter distance from the source (According to ISO, 2017), and the unit is therefore dB re 1 µPa m for all vessel types and frequency ranges.

Ship type	Bandwidth			
	≤125Hz	125–500 Hz	500–1000 Hz	1–10 kHz
Bulk cargo vessels	175-193 dB	165-175 dB	160-165 dB	150-160 dB
Containerships	172-195 dB	168-170 dB	165-168 dB	155-165 dB
Cruise ships	160-183 dB	165-170 dB	159-166 dB	144-162 dB
Tankers	175-183 dB	167-175 dB	165-169 dB	152-162 dB
Vehicle carrier	170-182 dB	168-170 dB	165-168 dB	154-165 dB

While most underwater noise studies related to maritime traffic have focused on shipping, a limited but increasing number of recent studies have investigated underwater radiated noise created specifically by different types of smaller vessels (e.g., electric boats, rigid-hulled inflatable boats (RHIB), skiffs, monohull and sailing boats). Source levels vary significantly even within boat types, and more investigation is needed to understand this variability, but also to develop criteria for measurements (Parsons et al., 2021). Further, estimating underwater noise emissions from smaller (<25m in length) waterborne vessels is even more of a challenging task, since more factors in relation to vessel design affect the type and magnitude of noise emitted from these vessels.

Nevertheless, an increasing body of literature have reported noise intensities emitted by smaller vessels with different types of engines. In general, electric engines have been shown to produce lower noise levels compared to combustion engines (Svedendahl et al., 2021; Gaggero et al., 2024). However, while they are relatively quiet at low frequencies (<600Hz), they can produce narrow band harmonics even up to 40kHz (Svedendahl et al., 2021; Gaggero et al., 2024). In relation to speed of the boat among petrol, diesel, and electric engines, a motorboat fueled by petrol was the loudest at low, 5 knot speed, especially at lower frequencies (60–200Hz). On the contrary, at high speed (20 knots), the diesel boat was the loudest (Svedendahl et al., 2021). Vieira et al. (2020) compared different boat types and showed that for most types, the dominant frequencies were in the range of 200–2000Hz, and the boat noise exceeded the background noise levels on average by 20.7+- 4.6dB.

In small vessels, the engine mounting is most often either inboard or outboard. Picciulin et al. (2022) showed that the main noise emission for inboard diesel engine boats was in the frequency range of <1000Hz, whereas outboard gasoline engine produced high acoustic pressure levels up to 5kHz. Especially in the case of outboard engines, that are in direct contact with water, the engine-originated harmonics were the main source for the boat noise rather than the propeller. An older study measured noise levels in Lake Jyväsjärvi, Finland, and showed that outboard motor was loudest between 2.4 and 10kHz, whereas diesel boats were loudest between 2.5 and 6kHz (Seppänen and Nieminen, 2004). Overall, there are relatively large variations in the acoustic signatures produced by various types and sizes of smaller vessels, as also reported by Parsons et al. (2021). Further, vessel speed appears to have varying effects on the acoustic signatures of small vessels depending on size and type (Table 4).

Table 4. Source levels of underwater sound pressure from various types of smaller vessels sailing at different speed (Johansson et al., 2021; Svedendahl et al., 2021; Picciulin et al., 2022; Gaggero et al., 2024). All SPL values are reported as source levels at 1 meter distance from the source, and the unit is therefore dB re 1 µPa m.

Vessel type	Bandwidth		
	≤125Hz	125–1000 Hz	1–10 kHz
Motorboat (outboard, 50 horse powers)	5 knots: 105-138 dB 20 knots: 97-126 dB	5 knots: 99-128 dB 20 knots: 114-132 dB	5 knots: 91-107 dB 20 knots: 113-127 dB
Motorboat (inboard, 150 hp)	5 knots: 105-129 dB 20 knots: 105-126 dB	5 knots: 106-111 dB 20 knots: 123-131 dB	5 knots: 86-111 dB 20 knots: 115-131 dB
Motorboat (inboard electric engine, 300 hp)	5 knots: 97-106 dB 20 knots: 95-119 dB	5 knots: 95-110 dB 20 knots: 111-126 dB	5 knots: 97-109 dB 20 knots: 106-115 dB
Buster (outboard, 225 hp)	5 knots: 118-140 dB 15 knots: 120-147 dB	5 knots: 110-120 dB 15 knots: 120-130 dB	5 knots: 93-110 dB 15 knots: 95-120 dB
Buster (outboard, 115 hp)	5 knots: 118-142 dB 15 knots: 120-133 dB	5 knots: 97-113 dB 15 knots: 113-122 dB	5 knots: 80-102 dB 15 knots: 92-115 dB
Motorboat (inboard, 80 hp)	5 knots: 98-129 dB	5 knots: 90-98 dB	5 knots: 82-92 dB
Motorboat (inboard, 59 hp)	5 knots: 100-129 dB	5 knots: 95-102 dB	5 knots: 81-101 dB
Motorboat (inboard, 325 hp)	5 knots: 109-140 dB 15 knots: 120-147 dB	5 knots: 100-108 dB 15 knots: 121-135 dB	5 knots: 80-108 dB 15 knots: 110-122 dB
Motorboat (inboard, 30 hp)	5 knots: 98-125 dB	5 knots: 93-108 dB	5 knots: 79-93 dB
Jet ski (90 hp)	5 knots: 99-129 dB 15 knots: 100-120 dB	5 knots: 90-99 dB 15 knots: 90-105 dB	5 knots: 82-90 dB 15 knots: 78-92 dB
Trawler (inboard, 220 hp)	7 knots: 143-159 dB	7 knots: 142-149 dB	7 knots: 133-142 dB
Gillnetter (inboard 87,7 hp)	7 knots: 142-166 dB	7 knots: 148-156 dB	7 knots: 139-149 dB
Tour boat (inboard, 150 hp)	8 knots: 145-173 dB	8 knots: 156-173 dB	8 knots: 149-158 dB
5m RHIB (outboard, 100 hp)	15 knots: 140-162 dB	15 knots: 139-149 dB	15 knots: 139-150 dB
8m RHIB (Outboard, 250 hp)	19 knots: 149-159 dB	19 knots: 145-159 dB	19 knots: 141-160 dB
Motorboat (outboard, 15 hp)	6 knots: 148-173 dB	6 knots: 133-141 dB	6 knots:137-143 dB
Sailing boat on a motor (inboard 29,5 hp)	6 knots: 128-139 dB	6 knots: 122-133 dB	6 knots: 129-139 dB
Motorboat (outboard, 40hp)	6 knots: 161 dB	6 knots: 148-163 dB	6 knots: 144-148dB
Electric boat (outboard engine ~25 hp)	4 knots: 156 dB 6 knots: 158-161 dB	4 knots: 120-156 dB 6 knots: 138-161 dB	4 knots: 119-134 dB 6 knots: 135-144 dB

4. Potential operational mitigation measures

4.1 Speed reductions

Previous studies have shown that reducing vessel speed may be a useful operational measure to reduce noise levels emitted by marine vessels (Parsons et al., 2021; Sèbe et al., 2022; LaJaunie et al., 2023). Findlay et al. (2023) showed through a slowdown simulation that even with small speed reductions, noise levels can be reduced significantly – 20% and 50% slowdowns resulted in 6 and 18dB decreases in source levels, respectively. A unique opportunity to evaluate the impact of reduced marine traffic to real-life noise levels across the world presented itself during the Covid-19 pandemic. Dunn et al. (2021) showed that reduced ship traffic (both vessel quantity and speed) during the pandemic in the Northwest Providence Channel, northern Bahamas, yielded a 37% decrease in SPL in the area was overall achieved through a relatively small speed reduction (<2knots). Similarly, during the pandemic, Basan et al. (2021) measured a 13% decline in SPL in low frequencies, and Breeze et al. (2021) demonstrated a decrease in both noise levels and the number of recreational vessels near Port of Halifax, Canada.

In the absence of regulations, ships may be encouraged to reduce vessel speed through financial incentives. Voluntary vessel speed reduction programs have already yielded significant results in several regions globally. In Canada, the multi-year ECHO program coordinates two ship slowdown projects under the Port of Vancouver underwater noise reduction initiatives to protect the endangered Southern Resident Killer

Whale population (Port of Vancouver, 2024). The project operates yearly from June to November by incentivizing commercial ships to slow down their speed in the Haro Strait and Boundary Pass, Canada since 2017, and in Swiftsure Bank since 2021. Costs arising from increased pilotage time due to the slowdown are compensated through a reimbursement scheme. The project has had ≥80% participation rate each year and has successfully decreased noise levels up to 32–57% across years and locations. Similarly, the Santa Barbara Vessel Speed Reduction Program in California, USA, measured noise levels before and during the program and reported significant reductions in source levels of ships and sound exposure levels resulting from participation of ≥25% of the passing vessels in the program (ZoBell et al., 2021).

Generally, noise levels have been shown to decrease with decreasing speed. However, Svedendahl et al. (2021), and Parsons et al. (2021) have demonstrated that this relationship is non-linear for certain types of boats. Noise increase with speed is more linear and consistent with inboard motors than outboard motors (Svedendahl et al., 2021; FOI, unpublished data). Interestingly, Picciulin et al. (2022) also concluded that the positive linear relationship between speed and SPL may be true only in a limited frequency range and is very engine type dependent. For certain boats, speed increase may also lower noise intensity in low frequency bands (Bernardini et al., 2019). Engine type and power were more predictive of noise level than boat length and design, implying that even small boats can be very noisy (Picciulin et al., 2022). Overall, the noise produced by smaller vessels, both regarding intensity and frequency, is highly variable and depends not only on engine and boat characteristics, but also environmental factors and navigation maneuvers (Vieira et al., 2020). Hence, knowledge about specific boats used in the area, and expertise on the contribution of external factors to the noise emissions are of high importance.

4.2 Re-routing and no-go zones

Another mitigation approach to reduce underwater noise locally is re-routing of ships to other shipping lanes. In Kattegat, Denmark, the main shipping route into the Baltic was split and a new route was created in Swedish waters creating an opportunity to compare soundscapes pre- and post-re-routing in two areas (TANGO-program, Tougaard et al., 2023). The re-routing resulted in significant noise reduction in low frequencies, especially in the 125Hz decidecade band. Since 2018, the ECHO-program also operates a yearly re-routing program, the Strait of Juan de Fuca lateral displacement project, south of Vancouver Island, Canada, incentivizing different types of commercial vessels to move south of the original lane to create a no-go zone (Interim Sanctuary Zone) from June to November. Results show up to 3.7dB noise reduction during the displacement period (Vagle and Neves, 2019). Interestingly, Peterson (2023) reported the highest rate of non-compliance to the voluntary no-go zone among recreational vessels (50%) and highlighted the importance of public outreach to increase knowledge and awareness of no-go zones especially in the context of vulnerable areas. Seasonal avoidance areas also exist in the Finnish Archipelago Sea in the context of the Natura2000 network, established to protect vulnerable bird and seal sites during breeding seasons. However, the effectiveness of these avoidance zones in mitigation of underwater noise remains unclear and ongoing studies aim to investigate this issue.

5. Conclusions

The reviewed source levels of underwater sound pressure from commercial ships are generally louder than smaller vessels by at least 20 dB, particularly in lower frequencies. Considering the variation in intensity and frequency of noise created by both, larger ships and smaller vessels, and various types of boats and engines, potential effects of the underwater noise in the Archipelago Sea region can be highly variable and multifaceted, highlighting the need for further research. It is possible that the seasonal presence of recreational boat traffic in the Archipelago Sea, significantly affects the underwater soundscapes locally. In conclusion, the level of underwater noise and its effects are likely underestimated locally in the Archipelago Sea. Regional policies or management cannot be put in place effectively without this knowledge.

Nevertheless, previous studies have shown that speed reduction zones and re-routing can be effective operational measures, and such measures are readily applicable to mitigate this pressure preemptively.

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Appendix 1 – Volume of transported goods via Port of Naantali

Table 1. Volume of annually imported and exported goods through Port of Naantali from January 2020 to June 2024. Ten most transported categories of goods are listed, and the volumes are reported in tonnes of transported material. Source: Tilastokeskus.

	2020	2021	2022	2023	2024 (6 months)
Raw wood	246614	182442	114720	189635	95437
Metals	70	2417	9847	11899	4240
Crude oil	2198430	300034	0	0	0
Oil products	992598	491330	421572	216350	105953
Coal	106862	21502	203946	31169	34353
Chemicals	11074	7178	2876	16531	64
Minerals, cement	181983	245851	236471	165597	69619
Crops	315483	218612	218991	186333	122590
General cargo	1974942	2211355	1911355	1815969	1067920
Other goods	51012	72747	74517	41962	49280
Total	2353458	2317135	1984218	1632955	855970

Appendix 2 – Volume of transported goods via Port of Turku

Table 2. Volume of annually imported and exported goods through Port of Turku from January 2020 to June 2024. Ten most transported categories of goods are listed, and the volumes are reported in tonnes of transported material. Source: Tilastokeskus.

	2020	**2021**	**2022**	**2023**	**2024 (6 months)**
Timber	32664	35879	36589	40330	12924
Paper	9863	9669	10850	12382	4820
Plywood	9482	5972	8188	1544	592
Metals	320811	332419	308288	327982	164385
Oil products	52903	777	10878	7319	38321
Chemicals	13612	13700	17926	11509	7994
Minerals, cement	35812	45553	37313	38117	15210
Crops	5975	8733	6040	12700	5171
General cargo	1788642	1795399	1456204	1130408	582041
Other goods	83670	65330	91114	50269	24487
Total	6079068	3754254	3194585	2676080	1549823