

Article

# Analysis of Ship Noise Characteristics Generated According to Sailing Conditions of the G/T 1000-ton Stern Fishing Trawler

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**Abstract:** In this study, we conducted onboard noise measurement experiments under the conditions of anchoring, sailing, casting, and hauling to determine whether noise generated in the G/T 1000-ton fishing trawler triggers zone-specific effects upon vessel operation. It was shown that most accommodation areas of the trawler comfortably met the IMO acceptance criteria regardless of the sailing condition, but most of the stern area, where the fishing actually occurs, exceeded the permitted limit of 75 dB (A). Furthermore, the statistical analysis revealed a significant difference ( $p < 0.05$ ) only in the bow and the stern, which are both open areas. In the case of the former, improvements were deemed possible due to the influence of the fluid emission noise from the seawater piping in the bow, and the acceptance criteria were also appropriate. However, in the case of the latter, a significant difference was seen in hauling conditions, and on-site analysis confirmed frictional noise from hydraulic oil in the trawl winch and between the chains and the metal hull, leading to the conclusion that various improvements are required, such as the mandatory wearing of safety equipment by workers and stricter legal standards for permitted noise levels.

**Keywords:** trawl vessel; ship noise; winch drum; analysis of variance; engine control room (ECR); fishing vessel; otter board; poop deck; international maritime organization (IMO)



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## 1. Introduction

Since vessels operate in isolation in the sea unlike typical mainland mechanical facilities or plant systems, sailors who are on board for long periods experience stress and anxiety arising from exposure to intense levels of work under poor conditions (i.e., deck, bridge, engine room), such as in the cramped cabins, isolation, and physical fatigue, which negatively influence a healthy sailing life [1].

Most ocean-going vessels continuously sail for the transportation of cargo and passengers or undergo jobs involving acquisition of marine resources from the sea. Therefore, sailors on said ships are constantly exposed to noise and vibrations generated from the operation of the main engine and various assistive mechanical devices [2].

In the case of fishing vessels, marine resources in open waters must be continuously acquired, meaning that the workers must undergo repetitive fishing work and are exposed to intensive work environments. This implies that the sailors' health is directly related to the performance of the boat. In fact, many Korean sailors working on fishing vessels are voicing their concerns regarding the lack of onboard space and the irregular and insufferable work environments [3].

Therefore, to regulate noise generated in vessels, the International Maritime Organization (IMO) has adopted and applied a code that has a limit for tolerable noise generated in areas such as cabins, accommodation areas, and the engine room [4].

Furthermore, the noise generated by the vessel has been shown to affect marine life as it is also emitted underwater [5], and the IMO has recommended procedures for reducing the level of radiation emitted underwater [6].

As stated previously, noise generated in vessels exerts a negative influence on the sailors' health and/or marine life, depending on the source, suggesting a high need for reduction of noise levels.

If the human body is exposed to noise for a long period of time, various complex side effects, such as hearing loss, deafness, tinnitus, cardiovascular effects, sleep disturbances, and learning difficulties, can arise [7]. In accommodation areas, residents will feel uncomfortable if the noise level exceeds 55 dB (A). Their ability to listen will be disrupted if the noise level exceeds 65 dB (A), and if it exceeds 90 dB (A), they might suffer from deafness [8].

As mentioned, noise has a huge effect on the human body, but over 40% of sailors working on ships do not regard the environmental issues of noise as important, which means there is a need to improve the perception of sailors to motivate them to protect their health from noise in the ship [9].

Moreover, whereas marine transportation via ship is gradually increasing, studies on port noise from ships and relevant regulations are insufficient, compared to railroads, roads, and airfields. For this reason, some EU countries investigated noise outside of ships and suggested environmental improvement plans through the INTERREG maritime program [10,11].

Environmental pollution caused by oil, exhaust gas, fouling paints, etc. from ships has been strictly controlled for years, but awareness of environmental issues regarding noise only recently came to the fore. Accordingly, the EU supported the FP7-SILENV project from 2010 to 2012 [12], and systematic studies on the effect of environmental noise on ports were conducted focusing on certain advanced European countries [13–15]. They also analyzed the effect of noise from ships moving in a port on the port itself and on residents living in surrounding accommodation sites [16,17].

Recently, various studies to improve the noise problem in vessels have been conducted. Park et al. suggested the application of a separate side-branch resonator to resolve the blade passing frequency (BPF) noise generated in air conditioning facilities and axial fan devices, which are essential in vessels, to suppress vessel noise [18].

Kim et al. acknowledged the need to introduce regulations regarding noise control in naval ships smaller than 24 m that are not passenger or merchant ships, and they suggested that noise can be measured using the ISO-14509-1 pass-by measurement procedures [19].

Some researchers attempted to conduct noise analysis based on the load operation of the generator in a 1500-ton electrically-powered oceanographic research vessel, and they suggested the need for various regulatory standards of noise that occur in different types of vessels since the mechanism of vessel propulsion is continuously evolving [20].

The aforementioned research was mainly relevant to merchant ships, warships, and special ships rather than fishing vessels.

Moreover, according to a comparative study on the noise of merchant ships, such as general cargo and ro-ro-ship, berthed in ports, the noise varied highly depending on the type and weight of the ship [21].

Although a similar study was conducted on the noise effect on sailors of a 1700-ton fishing trawler in the accommodation area, only noise during the sailing of the fishing trawler was measured, which did not provide any details on the noise generated during fishing [22].

As basic research to establish the noise acceptance criteria for fishing vessels, a study on indoor noise generated in a 300-ton squid-fishing vessel was conducted to compare and determine whether the suitability of the IMO acceptance criteria for ordinary merchant ships holds up indoors. As a result, it was suggested that the setting for the fishing vessel is approximately 5 dB (A) higher than that of the general ship [2].

Another interesting study was conducted by Park, where they researched the ship-board noise caused by the sailors hitting the hull with metal bats or the engine idling during a fishing operation involving attracting anchovies to the surface with a fishing lamp in a 6-ton FRP vessel near Jeju Island of South Korea [23]. However, this was a very special case of subminiature fishing vessels belonging to local fishermen of a traditional fishing background, meaning that this case is somewhat irrelevant to our research.

The general research trend regarding noise in fishing vessels, as the above, suggests a lack of detailed research on noise in relation to the work of the vessel. Studies involving small and high-speed fishing vessels exist, but those related to 1000-ton fishing vessels do not.

This is due to the fact that unlike merchant ships that require stable sailing at a constant speed, fishing vessels achieve profitability by repeatedly acquiring catches at sea, suggesting tight operation times and high safety risks, making it realistically difficult to conduct smooth noise measurement experiments.

Therefore, in this study, we compared and analyzed characteristics of actual noise generated in a 1000-ton stern trawl fishing vessel with sailing straight at 85% engine load, when undergoing trawling (casting and hauling) and when at anchor. Moreover, this study aims to clarify the purpose of protecting the health of sailors from ship noise and explain diverse cases of noise depending on the operating conditions of fishing vessels.

## 2. Materials and Methods

### 2.1. The selected Fishing Trawler

The target vessel of this study is a 999-ton stern trawler with a total length of 70.57 m, a typical crew of 20–30 but with a maximum capacity of 108 passengers, and a main engine output of 3300 hp. The maximum speed of the main engine is 650 rpm, and hull and engine mounts are equipped with vibration dampers that can reduce vibrations. The trawl winch is operated by fixing a hydraulic clutch to the main engine [24], and the data and specifications of the experimental vessel are shown in Table 1 [24,25].

**Table 1.** Principal particulars of trawl fishing vessel.

List	Type	Specification
Length	<i>L<sub>OA</sub></i>	70.57 m
	<i>L<sub>BP</sub></i>	60.60 m
Breadth	<i>MLD</i>	12.30 m
Depth	Upper deck	7.40 m
	2nd deck	5.00 m
Gross tonnage	National	999 t
	International	1358 t
Ship speed	85% MCR (for Sea trial)	14.11 knot
Crew	Max. on board	108 p
Main engine	6MG34HX	3300 ps
Aux engine	S165L-EN	600 ps
Propeller	KT-32B C.P.P	4-blade

Trawl fishing vessels acquire catches by casting nets attached with heavy otter boards below sea level through a winch mounted on the stern deck, followed by hauling the net by winding it up at a speed of 3–4 knots. The number of daily operations varies depending on the size of the fishery and the vessel, but the average is 3–4 times, with one operation taking approximately 4 h to complete, although the duration is dependent on geographical, environmental, and other vessel characteristics [26].

During trawl fishing, resistance occurs in the net and the otter board connected to a warp of a length of a few hundred meters, which is dropped in the direction of the stern underwater or to the seafloor depending on the water depth [27]. This is believed to also influence the machine loading and vessel noises. Figure 1 illustrates the schematic diagram of a fishing operation of a trawl fishing vessel [26].

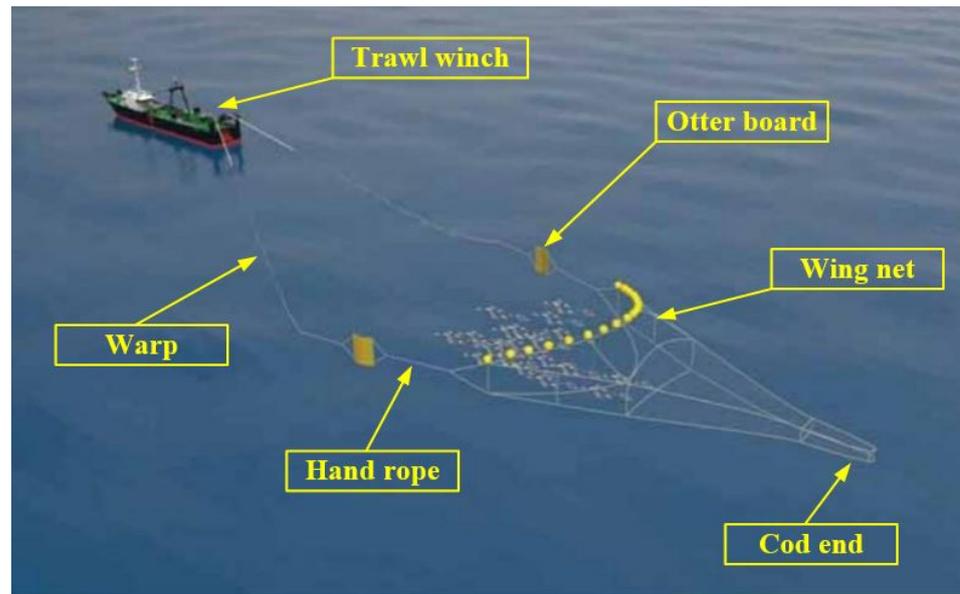


Figure 1. Schematic diagram of fishing operation of stern fish trawler.

To conduct this study, we designated 10 areas within the vessel and allocated symbols N1 to N10 to each of the areas, set as areas where the crew spends a lot of their time, as shown in Figure 2. In the case of the cabins, the one located below sea level from the center of the vessel was referred to as Cabin (A), and the one above sea level as Cabin (B). The selected open areas were those of the bow and the stern. However, open areas of IMO are presented as open recreation areas. In the case of a stern, the trawler is a working area, therefore, IMO guidelines need to be updated. In the case of the engine areas, the central section and trawl winch clutch area of the engine room were selected. Since the regulatory standards for vessel noise vary by area, the IMO noise regulation criteria and locations that correspond to the tonnage of the vessel are briefly listed in Table 2 [28].

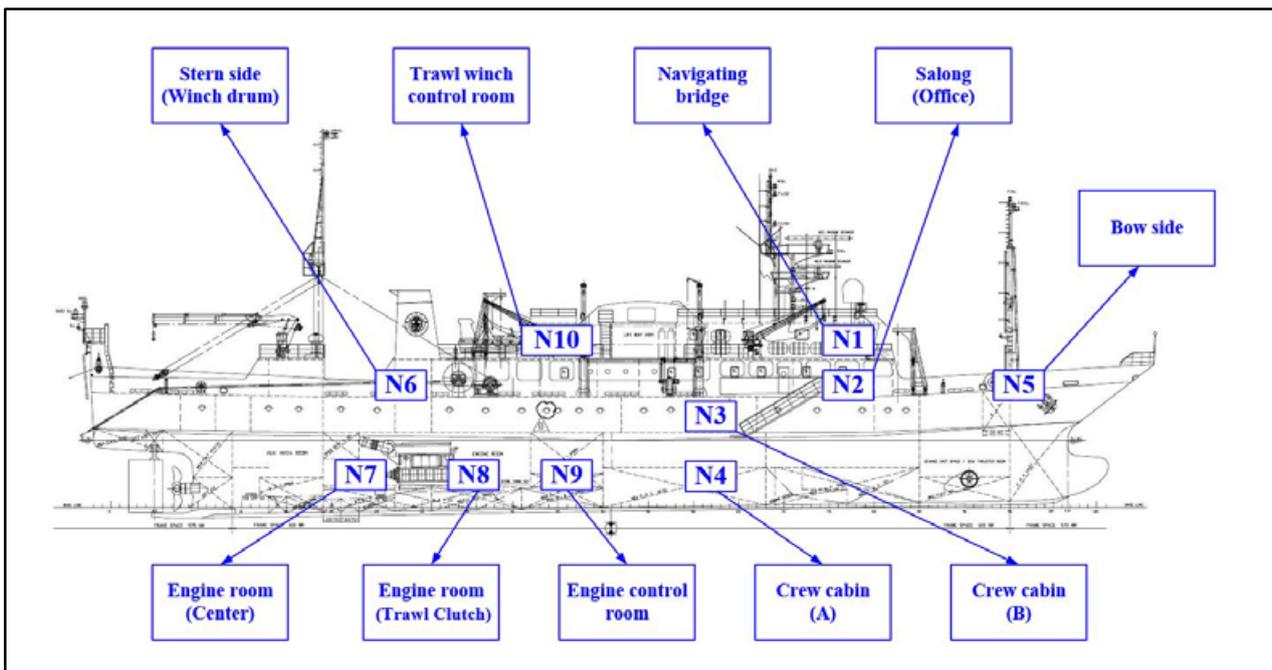


Figure 2. Location and area code of areas where noise measurements are taken.

**Table 2.** Areas for measurements in the trawl fishing vessel according to IMO noise acceptance criteria for each location.

Location	Limits (dB (A))	Number	Measurement Trawl Vessel Zone
Navigating bridges	60	N1	Bridge
Offices	65	N2	Salong
Cabins	60	N3, N4	Cabin (A), (B)
Open deck recreation areas	75	N5, N6	Bow side, Stern side
Machinery spaces	110	N7, N8	E/R center, E/R trawl clutch
Machinery control rooms	75	N9	Engine control room (ECR)
Control stations	65	N10	Trawl winch control room (TCR)

2.2. Experimental Equipment and Procedures

The sound level meter to be used in the vessel must satisfy the IEC 61672-1 condition of IMO, and the microphone must be equipped with a windscreen to minimize wind intervention [29]. Table 3 portrays the brief specifications of the sound level meter. Its measurement range is 24–139 dB (A), and weighted measurements can be taken in unit time. The 1:3 octave band (6.3–20,000 Hz) function can be used, and calibration is possible before usage [30].

**Table 3.** Specifications of the sound level meter.

List	Specification	Unit
Type	CR:171B	Class 2
Applicable standard	IEC-61672-1:2013	-
A-Weighted Range	24–139	dB (A)
Resolution	0.1	dB (A)
1:3 Octave band	6.3–20,000	Hz
Weight	300	g

It can also be presented as octave bands between 31.5–8 kHz if necessary, and the measurement time must be over 15 s so that a stable value can be obtained. The measurement height must be within 1.2–1.6 m, and the device must be always at least 0.5 m from the boundary. These main standards for noise measurement using IMO MSC. 337(91) are equally applied by the Korean Register of Shipping, the domestic authorized ship inspection company [29].

Figure 3 illustrates the sailing route used in the actual experiment. The vessel took the sea route near the sea coordinates of N 33.30'000"–E 127.30'000" in the vicinity of the southwestern sea of Korea. The sea conditions satisfied noise measurement standards during the actual experiment, and the experimental conditions including detailed operational conditions of the vessel are listed in Table 4.

**Table 4.** Experimental condition of the trawler.

List	Item	Anchoring	Sailing	Casting	Hauling	Unit
Weather	Wind scale			3–4		beaufort
	Wave height			0.5–1.5		m
	Water depth			40–90		m
	Weather			Cloudy		-
Ship condition	Speed	0.0	14.25	3.35	3.65	knot
	Engine load	0.0	86.50	24.50	25.70	%
Experiment date				10 May 2021–18 May 2021		

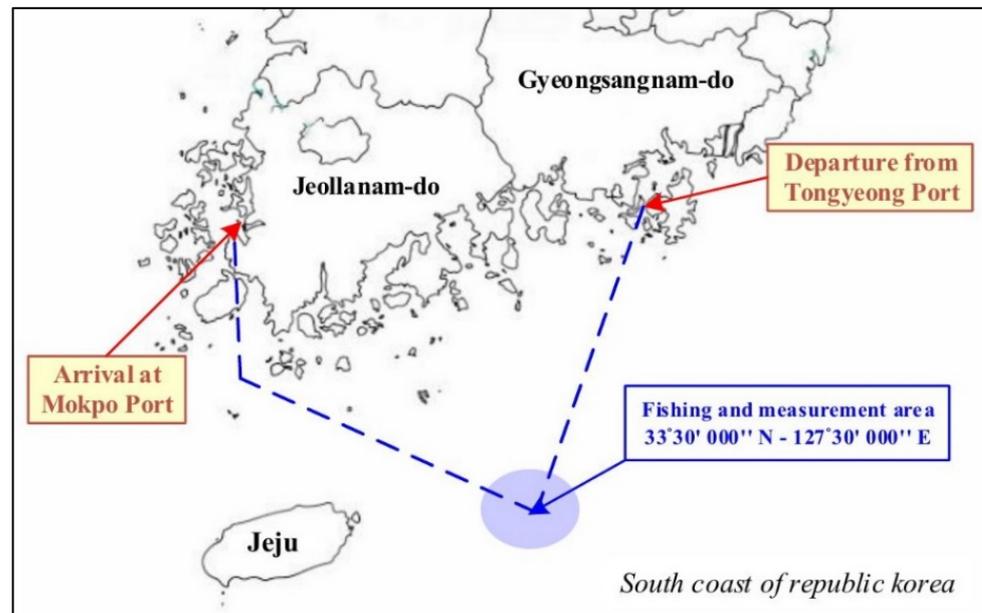


Figure 3. Noise measurement zone and sailing route.

The schematic experimental diagram is briefly illustrated in Figure 4. Noise measurements were taken in compliance with measurement standards when fishing work and sailing of the vessel were being conducted in a stable state. The data were transferred to a PC, and statistical analysis using actual measurement results and open-source software were subsequently conducted [31].



Figure 4. Schematic diagram of the noise measurement experiment.

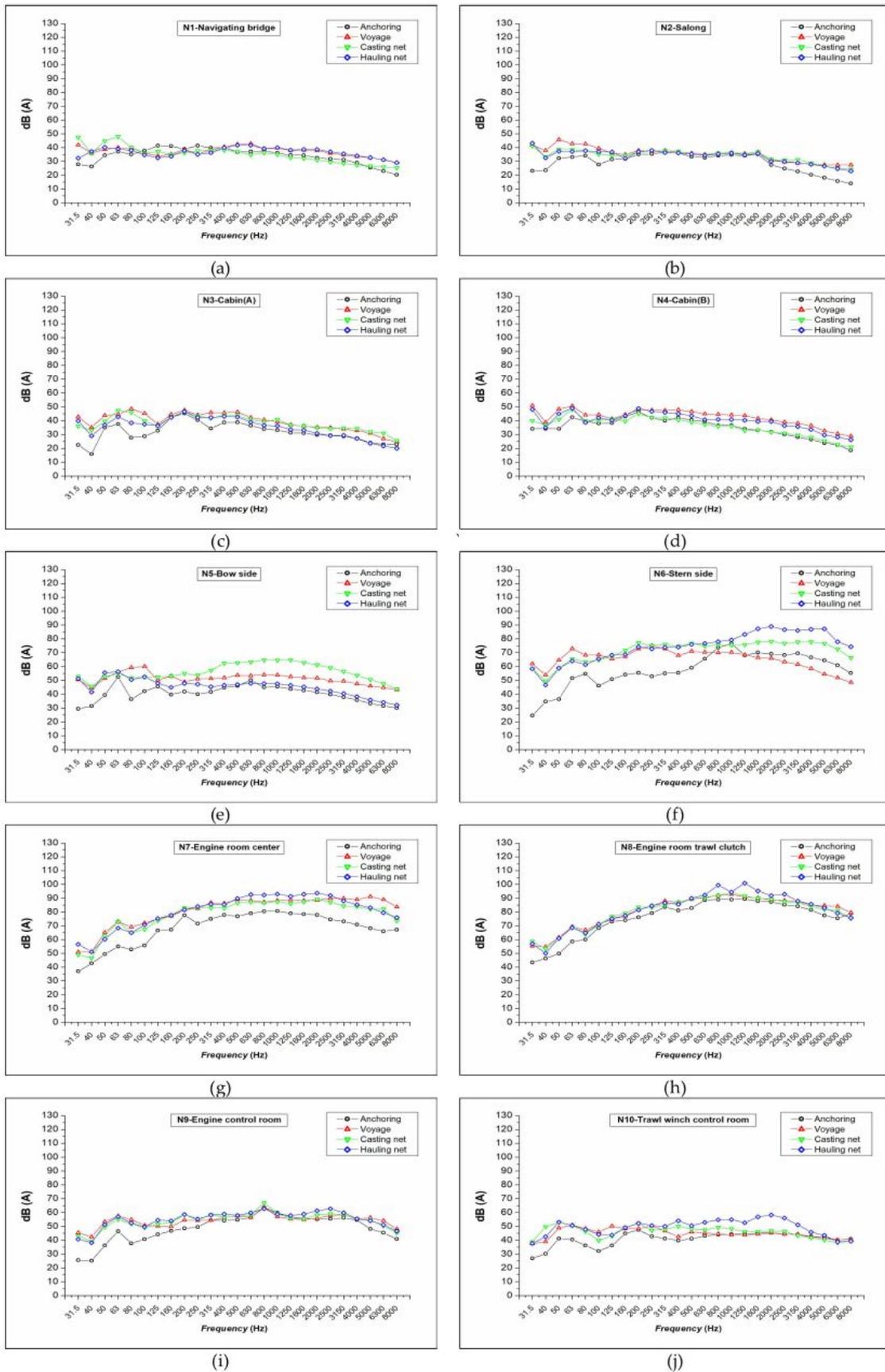
### 3. Results and Discussion

#### 3.1. Noise Characteristics for Each Area According to Sailing Conditions

Figure 5a–j shows the classification of noise characteristics for each sailing condition of the fishing vessel by area and then their conversion into 1:3 octave bands.

The results show that the vessel did not exceed the IMO vessel noise acceptance limit in frequency bands of most areas, but the open deck recreation area of the stern (N6) partially exceeded the permitted limit of 75 dB (A), and a band of over 200 Hz was formed in an area. This suggests that the noise level generated in the stern where actual fishing operations take place is higher than the permitted levels for typical vessels, and therefore, safety regulations such as the mandatory wearing of safety equipment or legal regulations regarding noise in fishing vessels must be made to protect the hearing of sailors as soon as possible.

Furthermore, the accommodation areas excluding the open deck recreation area exhibited adequate soundproof effects. Even the engine room areas and the engine control room, the areas most affected by noise, resulted in bands forming in the permitted range between 110 dB (A) and 75 dB (A), satisfying the regulations regardless of sailing conditions.



**Figure 5.** The 1:3 octave band results for each area. (a) navigating bridge; (b) salong; (c) cabin A; (d) cabin B; (e) bow side; (f) stern side; (g) engine room center; (h) engine room trawl clutch; (i) engine control room; (j) trawl winch control room.

Overall, the values showed a higher tendency when the vessel was sailing at full speed and during fishing operations compared to anchoring where only essential operational equipment is in use. This phenomenon can be explained by the large load on the main engine during sailing and the winch drum noise, the chain and the lifter, various other devices, and the operation itself impacting the noise levels. Figure 6 summarizes the equivalent synthetic noise.

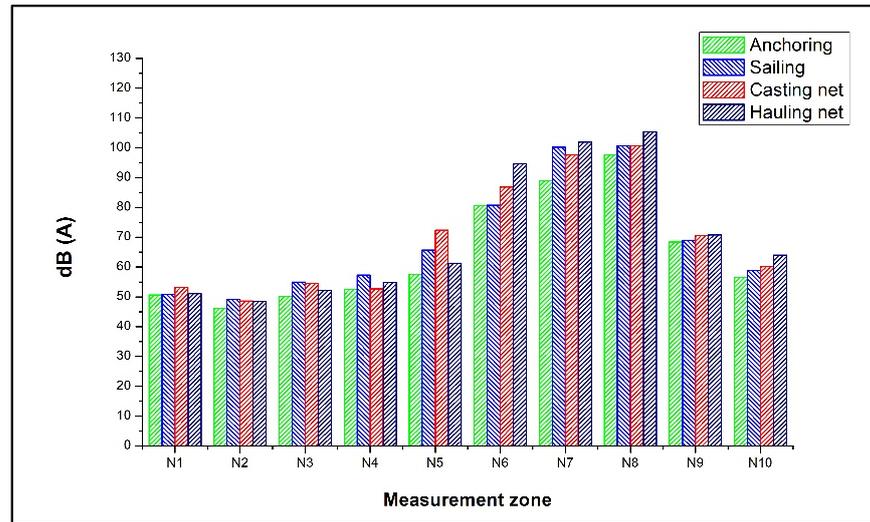


Figure 6. Comparison of synthetic noise for each sailing condition.

### 3.2. One-Way Analysis of Variance (ANOVA)

A computational statistical analysis was conducted based on the practical data acquired. A one-way analysis of variance (ANOVA) was performed to determine whether statistically significant differences exist in noise between areas according to the sailing conditions of the fishing trawler. Since the comparative data satisfy the normality and the number of samples for each group is identical, the Tukey method was used for post-validation [32]. An open-source software specializing in statistical analysis was selected as the analytical program [33].

Table 5 shows the results of the one-way ANOVA of N1-N10. The analytical results showed a statistically significant difference at the level ( $p < 0.05$ ) between the open deck recreation areas, N5 of the bow side, and N6 of the stern side. Figure 7 represents the standard deviation and synthetic noise of the two areas that exhibited this significant difference. These two areas are marked on their corresponding graphs with red stars.

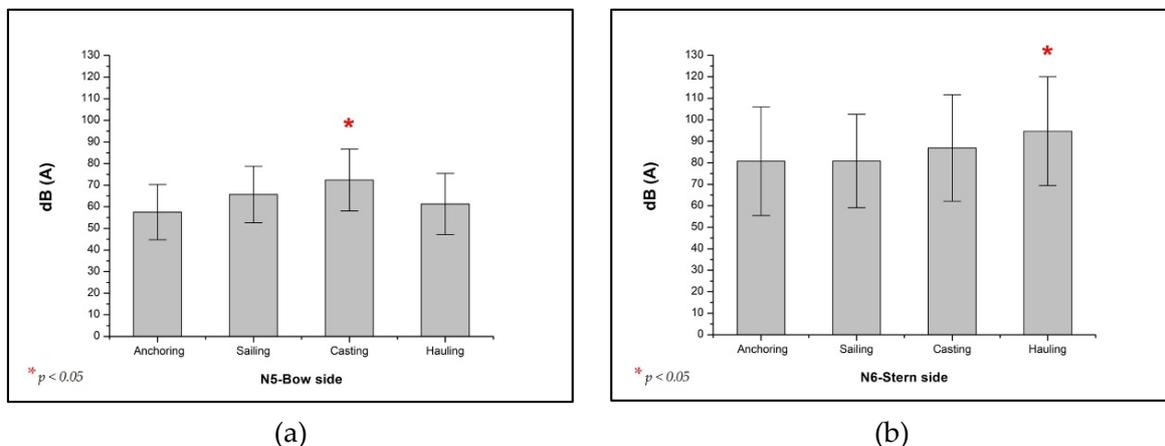


Figure 7. Significance and post-validation results for each area. (a) Bow side; (b) stern side.

**Table 5.** Computerized statistical and analytical results of noise for each area.

Zone	Mean (dB (A))				SD	F	p-Value	Post-Hoc(Tukey)
	Anchoring	Sailing	Casting	Hauling				
N1	50.7	50.8	53.2	51.1	16.557	0.634	0.595	-
N2	46.1	49.2	48.6	48.4	15.096	2.082	0.109	-
N3	50.2	55.0	54.5	52.2	17.697	1.636	0.188	-
N4	52.5	57.3	52.7	54.9	17.693	1.257	0.295	-
N5	57.5	65.7	72.4	61.3	13.247	3.653	0.016 *	A < C
N6	80.7	80.8	86.9	94.7	25.277	3.177	0.029 *	A < H
N7	89.0	100.2	97.6	101.9	27.739	1.333	0.270	-
N8	97.6	100.7	100.6	105.3	25.917	0.277	0.842	-
N9	68.4	69.0	70.5	70.8	21.736	0.627	0.600	-
N10	56.5	58.9	60.1	64.0	18.586	0.899	0.446	-

\*  $p < 0.05$ .

In the case of N5, the post-validation results showed differences in anchoring and casting, and repeated on-site verification showed that in this fishing vessel, a seawater sanitary pump was operated in the engine room to provide seawater, which enabled smooth winding of the dry net during the casting operation.

At this point, the seawater piping is also connected to the anchor washing on the bow side of the vessel, meaning that the difference arises from the fluid friction noise of seawater only emitted during the casting procedure. However, the noise can be easily remedied by blocking the valve that supplies anchor washing, and the N5 area was then found to have comfortably satisfied the tolerable standards of IMO noise of 75 dB (A) in all sailing conditions.

In the case of N6, the actual operation zone in the stern area, the experimental noise value exceeded the permitted limits used in this study, and statistical analysis also showed distinct differences between noise, followed by the post-validation showing significant differences between the anchoring and casting conditions. This resulted in a greater trawl winch load during hauling compared to during casting where the net is lowered below sea level consequently creating greater frictional noise of the hydraulic oil, which was generated at this point.

The chains and plastic buoys that supported the net were deemed to be simultaneously affected by the spontaneous metallic crash and frictional noise, crew voices, and loudspeaker noise within the hull. The actual measurement values were also shown to exceed the IMO permitted levels in the stern area where trawl fishing occurs. Therefore, it was inferred that noise regulations for particular areas within the stern fishing trawlers are required as soon as possible.

The other eight areas all contained deviations but showed no statistically significant differences. This shows that the difference in noise caused by fishing operations or sailing is insignificant in the accommodation areas and control room, which are enclosed areas within the fishing vessel, and all measured values sufficiently satisfied the permitted standard, implying that the indoor accommodation areas of the fishing trawler have adequate soundproof properties.

#### 4. Conclusions

After measuring, comparing, and analyzing the noise generated in different sailing conditions of the G/T 1000-ton stern fishing trawler, the following conclusions can be reached.

Since the noise of commercial trawler fishing vessels is very difficult to measure, it appears necessary to make regular noise measurement mandatory after dock repair.

Among the 10 measured areas of the fishing vessel, the stern, where actual fishing operations take place, was found to generate noise in the 80 dB (A) band, thus exceeding the permitted limit of 75 dB (A). The other nine areas sufficiently satisfied the IMO acceptance criteria regardless of the sailing conditions. Therefore, it was determined that clear IMO noise regulations for fishing vessels are necessary.

The computational statistical results showed a significant difference ( $p < 0.05$ ) between the open deck recreational areas of the bow and the stern, suggesting that it contributed to the increase in the effect of noise generated during the fishing operation in the fishing vessel. For the bow, the cause of noise was the hydrodynamic noise emitted due to the pump discharge pipe, operated during casting, being connected to the bow, and this can be remedied by blocking the valve. For the stern, there was a difference in noise generated during the hauling operation, where the load of the trawl winch is heavily increased. This was confirmed as frictional noise of the hydraulic oil and metallic frictional noise between the chains and the hull. Therefore, it was deemed necessary for sailors to wear protective equipment in the stern, and related noise regulations must be applied.

The enclosed accommodation areas excluding the bow and the stern did not exhibit any differences regarding noise generated for the fishing operation and sailing conditions of the vessel and satisfied the permitted standards, meaning that the soundproof properties were sufficiently confirmed.

This study was conducted with the aim to improve the sailing environment in terms of the noise generated in the fishing vessel, which could experimentally determine the noise characteristics of the fishing trawler for different sailing conditions. In the future, a variety of further comparative studies on G/T 3000-ton fishing trawlers and extra-large G/T 5000-ton fishing trawlers will be conducted.

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