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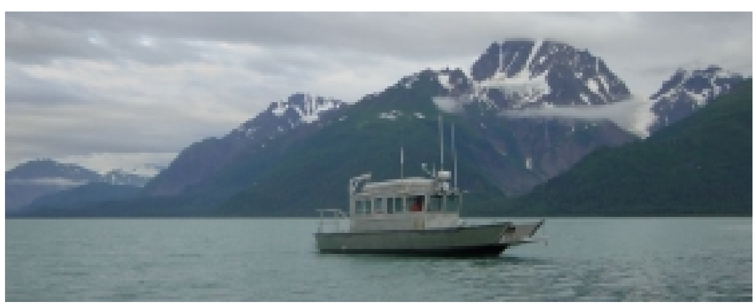
Glacier Bay National Park and Preserve

Glacier Bay Watercraft Noise



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Underwater acoustic noise levels of watercraft operated by Glacier Bay National Park and Preserve as measured in 2000 and 2002.

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ABSTRACT

Underwater noise levels of 14 vessels operated by Glacier Bay National Park and Preserve were measured in 2000 and 2002. The vessels tested were from 14 to 65 feet in length and engine power ratings ranged from 25 to 420 horsepower. Most boats were evaluated at speeds of 10, 14, and 20 knots. These watercraft generated peak one-third octave noise levels ranging from 150 to 177 dB re 1 microPa at 1 yard and sound levels from 157 to 181 dB re 1 microPa at 1 yard.

Noise levels depended on vessel type. All vessels but one, the 65 foot Nunatak, were classified as small craft with high-speed engines. As a group, skiffs under 20 feet in length and 100 horsepower produced the lowest sound levels, followed closely by the jet powered craft, which were the largest and highest powered small craft that were evaluated. Propeller powered small craft with engine power ratings over 100 horsepower produced the highest noise levels. Nunatak's noise levels were lower than those produced by many of the *over 100 horsepower propeller driven* group.

Noise levels also depended on vessel speed. On the average, vessel sound levels were about 4 dB greater at 20 knots compared to 10 knots. However, increases of up to 6 dB were observed for some vessels over this speed range.

In comparison with noise levels from large cruise ships, the small craft one-third octave noise levels were generally lower at lower frequencies. However, in some bands at frequencies above 1 kHz, the small craft noise levels were comparable to, or in some cases greater than, cruise ship noise levels.

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ACKNOWLEDGEMENTS

The authors would like to acknowledge the people at Glacier Bay National Park and Preserve who contributed to the success of this project. A number of vessel operators participated in the acoustic testing and others assisted with data collection and communication between the vessels and the shore-based measurement equipment. Without their support, it would not have been possible to obtain the measurements that are the subject of this report.

PROJECT DESCRIPTION

As part of an extensive program to establish typical underwater acoustic noise levels in Glacier Bay, Alaska, the underwater noise levels emitted by 14 watercraft were measured in 2000 and 2002. These vessels belong to the National Park Service and are used by Glacier Bay National Park and Preserve employees as part of their official duties in park waters. Vessels were sized from 14 to 65 feet in length and included open skiffs, cabin cruisers, a cabin workboat, a landing craft, and a live-aboard vessel. Engine power ratings ranged from 25 to 380 horsepower. A complete list of the vessels tested is given in Table 1. Vessel specifications are given in Table 2. All of the vessels but one were classified as small craft. Figure 1 contains photos of the watercraft that were tested.

Table 1 – List of Vessels Tested

Vessel	Date tested	Vessel type	Test speeds (kt)	Comment
Serac	2 Oct 2000	Cabin cruiser	10, 14 ,20	
Arete	3 Oct 2000	Cabin cruiser	10, 14, 20	
Lituya	11 Oct 2000	Open skiff	10, 14, 20	Data unusable due to system noise
Ogive	17 Oct 2000	Open skiff	10, 14, 20	
Mussel	18 Oct 2000	Open skiff	10, 14, 20	
Gumboot	18 Oct 2000	Open skiff	10, 14, 20	
Capelin	19 Oct 2000	Landing craft	10, 14, 20	
Alaria	2 Oct 2002	Open skiff	10, 13, 20	
Sigma T	2 Oct 2002	Cabin workboat	10, 13, 20	
Capelin	2 Oct 2002	Landing craft	10, 13, 20	Second test of Capelin
Rebound	2 Oct 2002	Cabin cruiser	10, 14, 20	
Talus	2 Oct 2002	Cabin cruiser	10, 13, 20	
Nunatak	2 Oct 2002	Military T-boat	6.7, 8.5	
Sand Lance	3 Oct 2002	Open	10, 13, 20	
Lituya	3 Oct 2002	Open skiff	10, 13, 20	Second test of Lituya
Ursa	3 Oct 2002	Open skiff	6.8, 13, 16.3	

Table 2 – Glacier Bay Watercraft Specifications

Vessel	Vessel type	Brand name	Length (ft)	Beam (ft)	Draft (ft)	Engine type	HP	Number engines	Hull Material
Ursa	Open skiff	Lund	14	4	2	2-cycle outboard	25	1	Aluminum
Gumboot	Open skiff	Lund	16	6	1	2-cycle outboard	30	1	Aluminum
Lituya	Open skiff	Lund	16	6	2	2-cycle outboard	60	1	Aluminum
Ogive	Open skiff	Boston Whaler	17	5	1.5	2-cycle outboard	60	1	Fiberglass
Alaria	Open skiff	Lund	16	6	1	4-cycle outboard	40	1	Aluminum
Mussel	Open skiff	Lund	18	6	1	4-cycle outboard	40	1	Aluminum
Sand Lance	Open skiff	SAFE Boat	19	8	2	4-cycle outboard	115	1	Aluminum
Rebound	Cabin cruiser	SeaSport	22	8	4	Inboard/ outboard	350	1	Fiberglass
Arete 1	Cabin cruiser	Bertram	25	9.5	1.9	Inboard/ outboard	380	1	Fiberglass
Capelin	Landing craft	Stanley Bullnose	26	9	2.5	Inboard/ outboard	350	1	Aluminum
Sigma T	Cabin workboat	Svendsen	26	9.2	2.5	4-cycle inboard	250	1	Aluminum
Talus	Cabin cruiser	Almar	30	10.5	2	Diesel jet drive	420	1	Aluminum
Serac	Cabin cruiser	Kvichak	34	12	2.2	Diesel jet drive	310 ea.	2	Aluminum
Nunatak	Military T boat	Not available	65	36	4	Diesel	375	1	Steel

NOISE MEASUREMENT APPROACH

Underwater noise levels were measured as each vessel was operated on a constant speed, straight-line course to the west of a calibrated underwater noise measurement system located in lower Glacier Bay. A chart showing the noise measurement location is given in Fig. 2 and the hydrophones themselves are shown in Fig. 3. The target distance for the closest point-of-approach (CPA) between the vessel and hydrophone was 419 yards in 2000 and 505 yards in 2002. Actual CPA distances ranged from 311 to 551 yards. Table 1 lists the test speeds for each vessel. Most boats were tested at speeds of 10, 14, and 20 knots, but there were several exceptions. Vessel speed and course were determined by GPS navigation. Target vessel courseline endpoints and CPA points that were used for the noise measurement runs are shown in Fig. 2. Park Service employees conducted the actual noise measurements and the acoustic data were reduced and analyzed by Naval Surface Warfare Center personnel.

Noise levels were measured from approximately 15 seconds before CPA to 15 seconds after CPA, as shown in Fig. 4, with the beam of the boat presented to the measurement hydrophone. Radio communications between the vessel under test and the noise measurement team in the shore-based laboratory were used to coordinate the noise measurements. Between the 2000 and 2002 measurements, the hydrophone was moved several hundred yards and relocated in shallower water. Water depth and vessel depth for each of the test scenarios is given in Table 3.

Table 3 – Hydrophone and Vessel Water Depth

Test date	Hydrophone depth (ft)	Water depth at vessel CPA (ft)
Oct 2000	164	200
Oct 2002	99	180

Criteria were established for vessel and sea conditions during conduct of the noise measurements:

1) sea state 0 to 2 (i.e. no whitecaps)

2) no other vessels within 3 miles, and document presence of other vessels beyond a distance of 3 miles
3) measurements in 2000 were conducted during slack tide (i.e. low current conditions), tide conditions were not considered in 2002
4) vessels maintain steady course and engine rpm.

The noise levels in this report are given in both one-third octave and overall sound levels at a projected range of 1 yard. Measured noise levels were corrected to 1-yard source levels using a correction for spherical spreading, or

Range correction = 20 * log(R)

where R is the range to the vessel (in yards) at the time of the measurement. For noise measurements where a noise source passes by a stationary sensor, it is common practice to use the geometric mean of the range at CPA and the range at the start of the measurement for the range correction calculation.

$$R = (R_1 * R_{CPA})^{1/2}$$

This approach was used for the measurements given in this report. No other noise propagation effects were taken into account in reporting the vessel noise levels.

In addition to measuring the noise levels from the vessels of interest, background noise levels were also measured before and after each vessel test. Measured vessel noise levels were then compared to the background levels to determine the degree of influence of background noise on the vessel noise measurements themselves. In all cases, any background noise influences on measured vessel levels were removed or corrected. As a result, the reported vessel noise levels in some one-third octave bands may be several dB below the measured levels. For bands where background noise levels were so great that they precluded meaningful correction, no band level is reported. In some cases, particularly for the 2000 measurements, the 63 Hz band vessel noise level is not reported due to influence from measurement system related 60 Hz electrical noise.

DISCUSSION OF NOISE SPECTRUM

It is a common practice to quote noise levels in terms of a single number. For example, the noise level from operation of a common lawn mower may be reported as 100 dB. Usually this number represents the sum of all of the noise energy that occurs within the frequency range of human hearing. However, if more information regarding the character of the noise source is desired, the sound level should be represented in spectral form. In this case the entire frequency range covered by the measurement is divided into smaller individual frequency bands and the level for each band is established.

Ship noise signatures are commonly represented in one-third octave spectrum form. This format shows the distribution of acoustic energy that is emitted by a ship over a wide frequency spectrum by plotting noise levels for each standard one-third octave band in a level versus frequency format. This representation graphically demonstrates the amount of noise energy that is present at low, mid, and high frequencies, and serves as a tool to identify the predominant noise sources that make up a ship's total acoustic signature. An example of a one-third octave noise spectrum is shown in Fig. 5.

The noise spectrum representation is also useful as a noise source ranking tool. For example, if a noise spectrum shows that high noise energies are present near 3 kHz, this result would be important to humans because human hearing is especially sensitive to noises that occur at frequencies near 3 kHz. On the other hand, significant noise energies at 100 Hz might be less important because human hearing sensitivity at this frequency is relatively low. Use of the noise spectrum in addition to single number sound levels provides more information regarding the noise source itself and its potential effects on a creature exposed to that noise.

To supplement the approach described above, limited narrowband frequency analysis was also used to assess watercraft noise character. Compared to the one-third octave representation, narrowband frequency analysis provides more detail of a noise source's frequency characteristics because of its greater ability to resolve closely spaced frequency components. Figure 5 shows an example of a narrowband noise spectrum.

NOISE LEVELS IN WATER

When assessing the significance of underwater noise levels, it is important to recognize that in-water noise levels are measured on a different scale than in-air levels, and that they represent different sound intensities than in-air noise levels. This means that the sound intensity of a 100 dB noise in air is not equal to that of a 100 dB noise in water. In part, this effect is due to the use of different reference pressures in airborne acoustics versus underwater acoustics. This difference in scales is illustrated in Fig. 6, which shows a comparison between the underwater noise decibel scale and some familiar in-air decibel levels. Figure 6 demonstrates that the reader must resist the temptation to interpret underwater noise levels based on more familiar in-air decibel levels without accounting for the difference between the two scales.

The following information may also be useful when assessing differences in noise levels:

1) Humans can distinguish sound level differences of about 3 dB.
2) A 10 dB increase is <u>perceived</u> as a doubling in sound intensity.
3) The difference between the peak noise of a single vehicle passing by and heavy traffic is about 10 dB.

BACKGROUND INFORMATION

Typical underwater ambient noise fields in open water environments are variable in terms of noise levels and contributing noise sources. At a given time and location the observed acoustic noise may be entirely due to natural sources such as wind generated surface noise. A short time later noise from marine vessel operations may become the primary contributor of noise energy. Noise from marine life may also affect the observed noise spectrum.

Wind related noise has been studied extensively and has long been recognized as a primary source of undersea ambient noise. The noise itself is due to wind agitation of the water surface and the resulting wave, turbulence, droplet, and bubble activity. Deep ocean wind noise level and spectral dependence on sea state or wind speed has been established by a number of investigators. The widely recognized Knudsen wind noise spectra (ref. 1) show that wind related noise levels may increase more than 20 dB when sea states progress from calm conditions to wind speeds near 30 knots. Wind related noise is typically the most pervasive source of underwater noise in ocean environments.

In the absence of oceanographic surveying, oil rig operations, etc., marine vessel noise is the primary source of manmade underwater noise and is typically due to engine, propulsion system, and propeller related noise. These mechanical systems produce narrowband and broadband noise that is characteristic of vessel and engine type. Small craft with high-speed engines and propellers generally produce higher frequency noise while large vessels can generate substantial low frequency noise because of their size and large, slow speed engines and propellers. All vessels equipped with propellers have the ability to produce propeller cavitation noise, which occurs at higher frequencies and is broadband in nature. An additional important aspect of vessel noise is that levels are typically speed dependent with noise levels increasing at higher ship speeds.

RESULTS

This report section contains the one-third octave noise spectra for the watercraft that were evaluated. Discussions of noise dependence on vessel speed and type, and comparisons of park vessel noise levels and cruise ship noise levels are also given.

Watercraft Underwater Noise Levels

The measured noise levels for each boat are given in Figs. 7 through 21. Noise levels are expressed as one-third octave band levels in dB re 1 microPascal at 1 yard. For each vessel, the one-third octave noise spectrum for each test speed is given on a single plot. In some cases, particularly at lower frequencies, noise levels for some one-third octave bands are not reported due to interference from ambient noise or system related noise.

Except for the largest vessel, the Nunatak, the one-third octave spectra exhibited some similarities in character. For a given spectrum, the highest levels typically occurred in the 1250 to 5000 Hz frequency region. In this region, higher level noise energy was typically distributed over a number of frequency bands in a relatively smooth distribution. On the other hand, below 1 kHz, noise levels were lower and more inclined to exhibit peaks in noise energy related to propulsion system rotational noise components. The speed dependence of these peaks is evident in that the frequencies where the peaks occur typically increase with increases in vessel speed.

With the exception of the Nunatak, all of the vessels in this study are classified as small craft due to their hull size and high-speed engines. The Nunatak - with its 65 foot steel hull, inboard diesel engine, and low RPM[*] propulsion system – is classified as a medium sized vessel. Nunatak's one-third octave spectra peaked at 400 to 630 Hz, significantly lower in frequency than the peak bands for the small craft noise spectra. Like the smaller craft, Nunatak's noise spectrum was relatively smooth at frequencies above 1 kHz.

The Capelin, a 26-foot aluminum hull landing craft, was tested in both 2000 and 2002. Capelin's 2002 one-third octave noise levels were up to 15 dB higher than the 2000 levels. In addition, the 2002 noise spectrum contained numerous narrowband signature components at frequencies corresponding to engine firing rate and a significant peak in

[*] Nunatak's engine RPM during acoustic testing was 725 RPM at 6.7 knots, and 900 RPM at 8.5 knots. The RPM for the other craft that were evaluated ranged from 2000 to 5800 RPM.

the 2 to 2.5 kHz region which were not present in 2000. Noise peaks in the 100 to 125 Hz bands were also higher in level. These differences between the 2000 and 2002 Capelin noise levels indicate a significant change in the mechanical condition of the vessel.

Figure 22 shows the peak one-third octave noise level for each vessel at each test speed. Based on peak one-third octave noise levels, the Capelin (in 2002) exhibited the highest noise levels – 177 dB at 20 knots. Peak one-third octave levels for other vessels ranged from 150 to 171 dB. All vessels exhibited a general increase in noise level with increasing speed, with the exception of Lituya, Alaria, and Capelin 2000, which showed a slight decrease in level when going from 10 to 13 knots.

Using the one-third octave noise spectra, the overall sound levels* for each vessel were also established. The sound levels for each vessel are compared in Fig. 23 and the ranking of sound levels in the graph is similar to the ranking by peak level. Like the peak level results, the highest sound levels were associated with the Capelin (in 2002), and the lowest were attributed to the Mussel. Sound levels ranged from a low of 157 dB to a high of 181 dB.

<u>Effect of Vessel Speed</u>

For all types of marine vessels, noise is almost always strongly dependent on vessel speed. As stated above, Figs. 22 and 23 show that noise levels from Glacier Bay watercraft typically increased with increasing speed. Figure 24 plots overall sound level versus vessel speed for each boat tested. On average, both the sound level and peak levels increased about 4 dB when going from 10 to 20 knots. In some cases the sound level increased up to 6 dB over this speed range. Rebound and Sand Lance exhibited the least degree of sound level speed dependence. In fact, Sand Lance sound levels were actually lower at 20 knots than at 10 knots due to low frequency propulsion system noise

* The sound level is a number that represents the sum of all of the measured acoustic energy represented in a single one-third octave spectrum. It is equivalent to adding all of the one-third octave band levels in an individual one-third octave plot. As a result, the sound level is generally several dB greater than the peak one-third octave band level.

components. Nunatak and Talus showed the greatest degree of noise dependence on vessel speed.

Effect of Vessel Type

Vessel noise levels were trended by various vessel specifications to identify noise dependence on vessel size, equipment, etc. No absolute dependence on vessel size, engine horsepower, or engine type was identified, but some general trends were observed. Figure 23 shows that several of the higher horsepower (over 100 H.P.) propeller-driven boats produced the highest noise levels, including Capelin, Rebound, Sigma T, and Sand Lance. The noise levels from these craft were higher than those produced by the lower powered skiffs. A significant observation was that noise levels of the high-power jet propelled craft, Talus and Serac, were comparable to those of the low powered skiffs.

Based on the above observations, vessels were grouped in the categories listed below and the minimum and maximum sound level for each category was graphed in Fig. 25.

1) Skiffs – less than 20 feet and 60 H.P. or less
   (Ursa, Gumboot, Lituya, Ogive, Alaria, and Mussel)
2) Sand Lance – 19 feet, 115 H.P.
3) Over 200 H.P. with propeller – 22 to 26 feet, 250 to 380 H.P.
   (Rebound, Arete, Capelin, and Sigma T)
4) Jet propulsion – 30 to 34 feet, 310 (2 engines) to 420 H.P.
   (Talus, and Serac)

Results from all of the test speeds are included in the graph. The maximum sound level for skiffs was 5 dB lower than Sand Lance and 12 dB lower than for the *over 200 H.P. with propellers* category. The jet drive category logged the lowest maximum sound level, and these were the largest of the small craft that were tested. The lowest level overall, 157 dB, occurred in the skiff category.

Four-cycle outboard engines powered three of the smaller vessels that were tested. Two of these vessels, Mussel and Alaria, were among the lowest noise level craft evaluated. Compared to similar horsepower 2-cycle powered vessels, 4-cycle noise levels were several dB lower. This difference was most notable at higher speeds, especially 20 knots.

Comparison of inboard/outboard powered craft with outboard engine powered boats was complicated by the fact that the inboard/outboard craft were typically larger (over 20 feet in length), higher horsepower vessels. However, the inboard/outboard propeller equipped vessels were noisier than the comparable horsepower, jet-propelled Talus and Serac. At 10 knots the jet powered Talus was more than 10 dB quieter than several of the inboard/outboard vessels. The lower noise levels for the high powered, jet-propelled craft indicate that the propeller itself is an important noise source for the inboard/outboard propeller equipped vessels.

One-third octave noise envelopes describing the maximum and minimum noise levels for the groups of vessels listed above were developed to show the range of noise levels that were observed. These envelopes are given in Figs. 26 through 30.

Noise levels from six large cruise ships that sail Southeast Alaskan waters, including Glacier Bay, were measured at the U.S. Navy's Southeast Alaska Acoustic Measurement Facility near Ketchikan, Alaska in 1999 and 2001. The results from these measurements were reported in ref. 2. The one-third octave noise envelope for the cruise ships at speeds of 10 to 19 knots is compared to the Glacier Bay watercraft noise envelopes in Figs. 26 through 30. These comparisons show that cruise ship noise levels were generally higher at lower frequencies, but small craft noise and noise from Nunatak rivaled, or even exceeded, cruise ship noise at frequencies above 1 kHz. In particular, maximum noise levels from the higher powered (greater than 100 H.P.) propeller driven craft exceeded the maximum cruise ship noise levels in some bands above 1 kHz. At 2500 Hz the high-power propeller driven craft envelope exceeded the cruise ship envelope by 13 dB. This result is at least partly due to the fact that large, low RPM vessels tend to generate and radiate noise more intensely at lower frequencies while noise from small, high RPM craft typically peaks at higher frequencies.

In terms of overall sound level, cruise ships typically generated more acoustic energy than the most of the small craft discussed in this report. Cruise ship sound levels from ref. 2 ranged from 175 dB to 195 dB. Figure 23 shows that only the Capelin (2002), Rebound, and Sigma T had sound levels that exceeded 175 dB.

SUMMARY AND CONCLUSIONS

Using a bottom-mounted hydrophone in Lower Glacier Bay, the underwater noise levels of 14 vessels were established. Thirteen of these vessels were classified as small craft. They were from 14 to 34 feet in length and their engine power ratings ranged from 25 to 420 horsepower. One 65-foot vessel, the Nunatak, was classified as a medium size craft. All of these boats belong to the National Park Service and are operated by Glacier Bay National Park and Preserve personnel. Vessel types included open skiffs, cabin cruisers, a cabin workboat, a landing craft, and a large live-aboard vessel. Most vessels were tested at speeds of 10, 14, and 20 knots.

Peak one-third octave band noise levels ranged from 150 to 177 dB re 1 microPa at 1 yard. Overall sound levels from 157 to 181 dB re 1 microPa at 1 yard were measured. The highest levels were associated with the Capelin (in 2002), a 26-foot, 350 H.P. landing craft. The Mussel, an 18-foot, 40 H.P. skiff had the lowest noise levels.

The noise character among the small craft was generally similar. At lower frequencies the noise spectrum contained narrowband components associated with engine and propulsion system mechanical noise. At frequencies above 1 kHz, the spectrum was smoother and contained more distributed noise. This energy was probably related to propeller broadband noise, including propeller cavitation. Small craft noise levels peaked in the 1250 to 5000 Hz region. Due to its size and lower RPM propulsion system, Nunatak noise levels peaked at considerably lower frequencies – 400 to 630 Hz.

On average peak noise levels and sound levels increased about 4 dB when going from 10 to 20 knots. Increases of up to 6 dB were observed over this speed range. Nunatak and Talus exhibited the greatest degree of noise dependence on speed. Rebound and Sand Lance were the least speed dependent.

One vessel, the Capelin, was tested twice. From 2000 to 2002, Capelin's noise levels increased up to 15 dB in some bands. The narrowband character of the noise spectrum was also different between the 2000 and 2002 tests, indicating a change in the mechanical condition of the vessel's propulsion system.

Based on noise level and noise character, the small craft were grouped into the following categories: (a) skiffs (less than 20 feet and 60 H.P. or less), (b) Sand Lance (19 feet, 115 H.P.), (c) over 200 H.P. with propeller (22 to 26 feet, 250 to 380 H.P.), and (d) jet propulsion (30 to 34 feet, 310 to 420 H.P.). As a group the skiffs logged the lowest sound level, however several of these boats were actually noisier than the bigger, higher powered, jet-propelled craft. For their size and horsepower, the jet-propelled vessels were the most acoustically benign of the vessels that were tested. The highest sound level logged by a jet boat was 167 dB. The highest sound level for the skiffs was 169 dB.

The *over 200 H.P. with propeller* category exhibited the highest sound levels. The maximum sound level for this group was 181 dB. The distinct difference between the high-horsepower propeller equipped vessels and the jet-propelled craft indicates that the high-speed propellers are probably an important source of underwater noise.

When comparing small craft equipped with outboard engines of comparable horsepower ratings, 4-cycle engines were several dB quieter than 2-cycle engines. This difference was most apparent when comparing 20-knot noise levels.

Using one-third octave noise envelopes, noise from the 14 Glacier Bay vessels was compared to the noise from large cruise ships. In these comparisons, cruise ship noise levels were typically higher overall, and at lower frequencies. At frequencies above 1 kHz, small craft noise was comparable to, or in some cases greater than, cruise ship levels. In some bands above 1 kHz, the highest noise levels from the higher powered (greater than 100 H.P.), propeller driven craft exceeded the maximum cruise ship levels by up to 13 dB. This result is not surprising given that noise from large, low RPM vessels usually peaks at lower frequencies while noise from small, high RPM craft is typically highest at frequencies above 1 kHz.

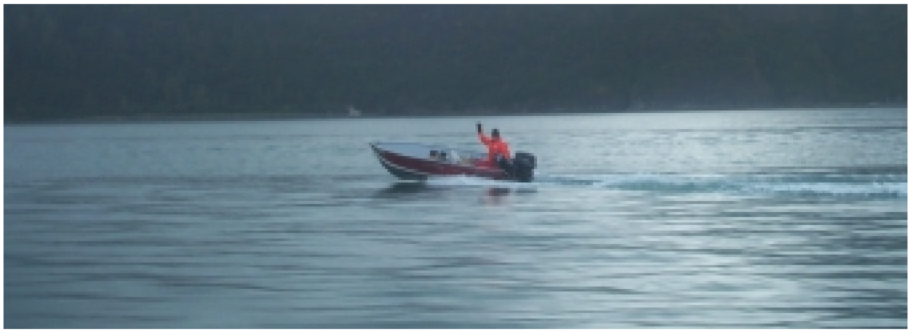
This report has documented the noise levels from a significant number of small craft of various types and sizes. Only a single medium size craft was evaluated, so measurement of noise levels from additional medium size craft is recommended. Candidate vessels might include the Alaskan Gyre, Spirit of Alaska, Spirit of Adventure, and perhaps several private vessels that frequent the Bartlett Cove area. In addition to the small and medium sized vessels, as part of this project, noise levels from six large cruise ships were reported in ref. 2. In combination, these data will be an important resource for characterizing the underwater noise environment in Glacier Bay. Also, in conjunction with the appropriate marine mammal auditory data, these noise levels will be a necessary component for assessing the effects of vessel noise on marine mammals.

REFERENCES

(1) Knudsen, V.O., et. al., "Underwater Ambient Noise", Journal of Marine Research, 7:410 (1948).

(2) Kipple, B.M., "Southeast Alaska Cruise Ship Underwater Acoustic Noise", Naval Surface Warfare Center Technical Report NSWCCD-71-TR-2002/574 (2002).

FIGURES



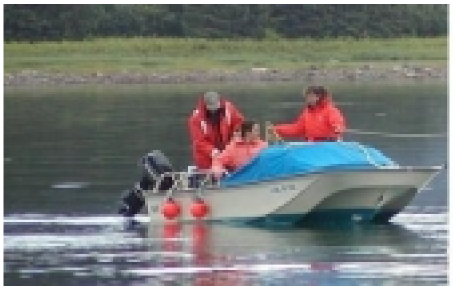
Ursa

Gumboot

Not available for photo

Lituya

Fig. 1 Glacier Bay National Park and Preserve Watercraft



Ogive

Alaria

Mussel

Fig. 1   Glacier Bay National Park and Preserve Watercraft (cont'd)

Sand Lance

Rebound

Arete

Fig. 1 Glacier Bay National Park and Preserve Watercraft (cont'd)

Capelin

Sigma T

Talus

Fig. 1 Glacier Bay National Park and Preserve Watercraft (cont'd)

Serac

Nunatak

Fig. 1 Glacier Bay National Park and Preserve Watercraft (cont'd)

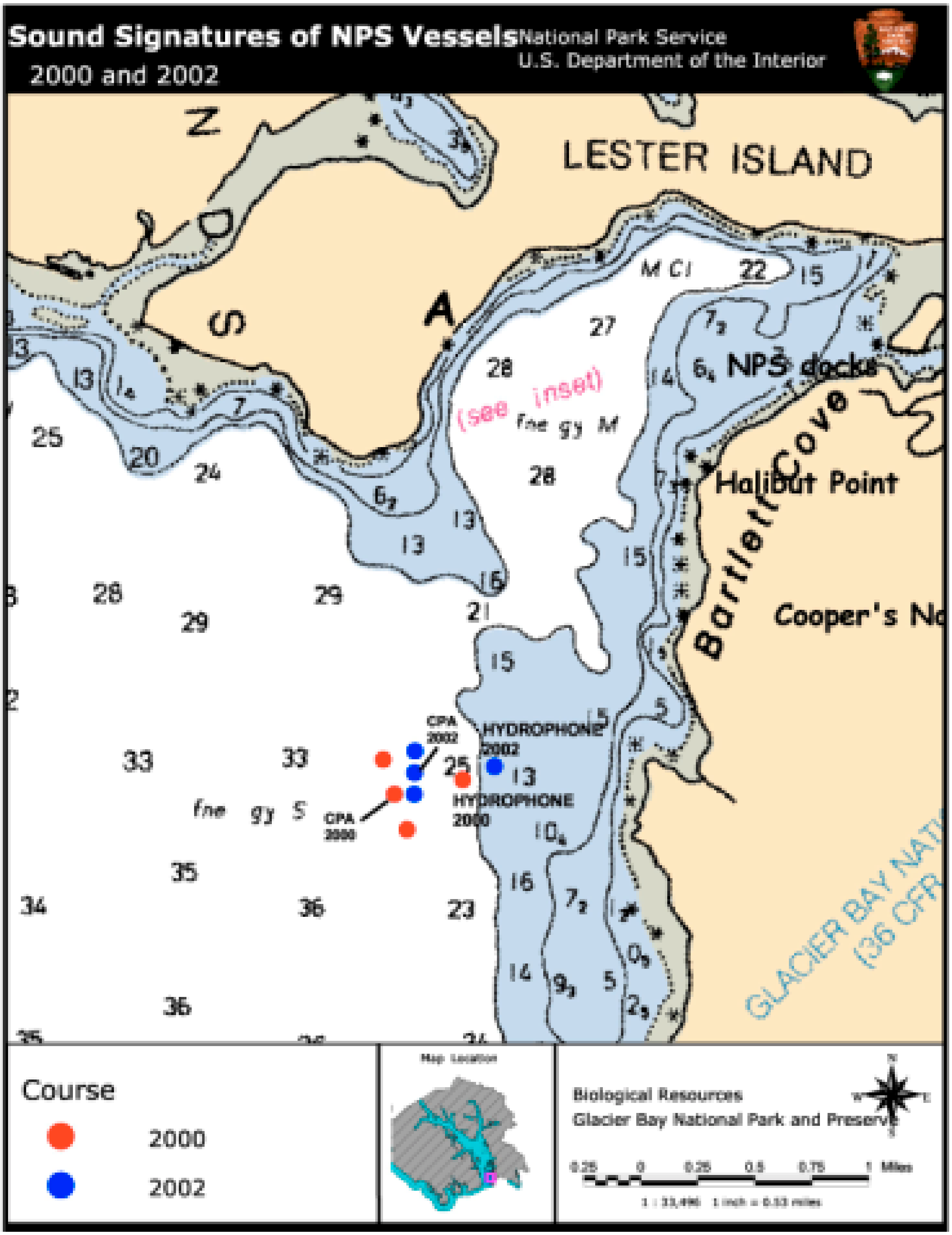


Fig. 2 Noise Measurement Location in Lower Glacier Bay

2000 hydrophone

2002 hydrophone

Fig. 3 Noise Measurement Hydrophones

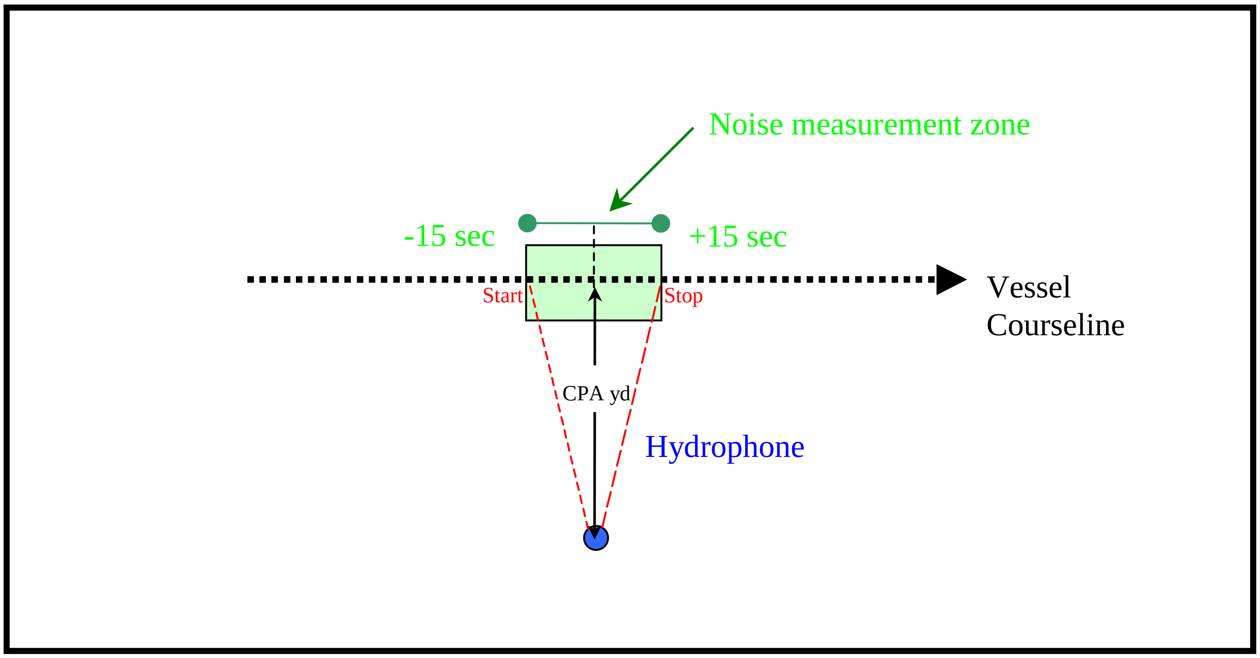
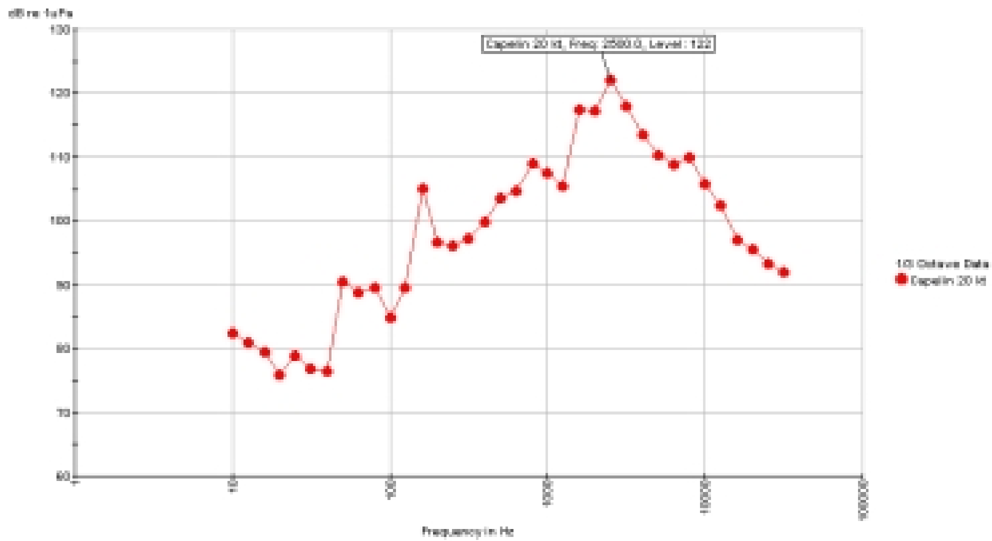
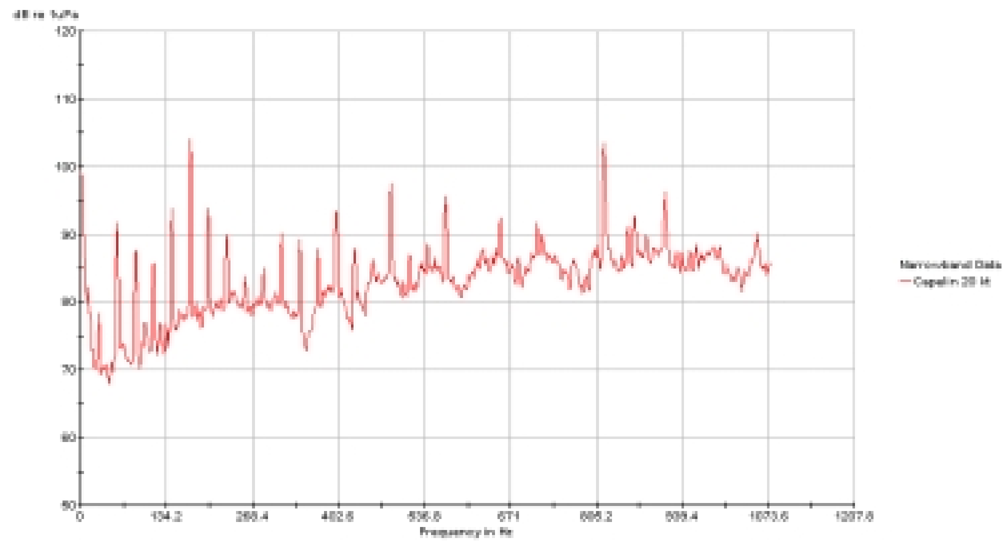


Fig. 4 Noise Measurement Geometry

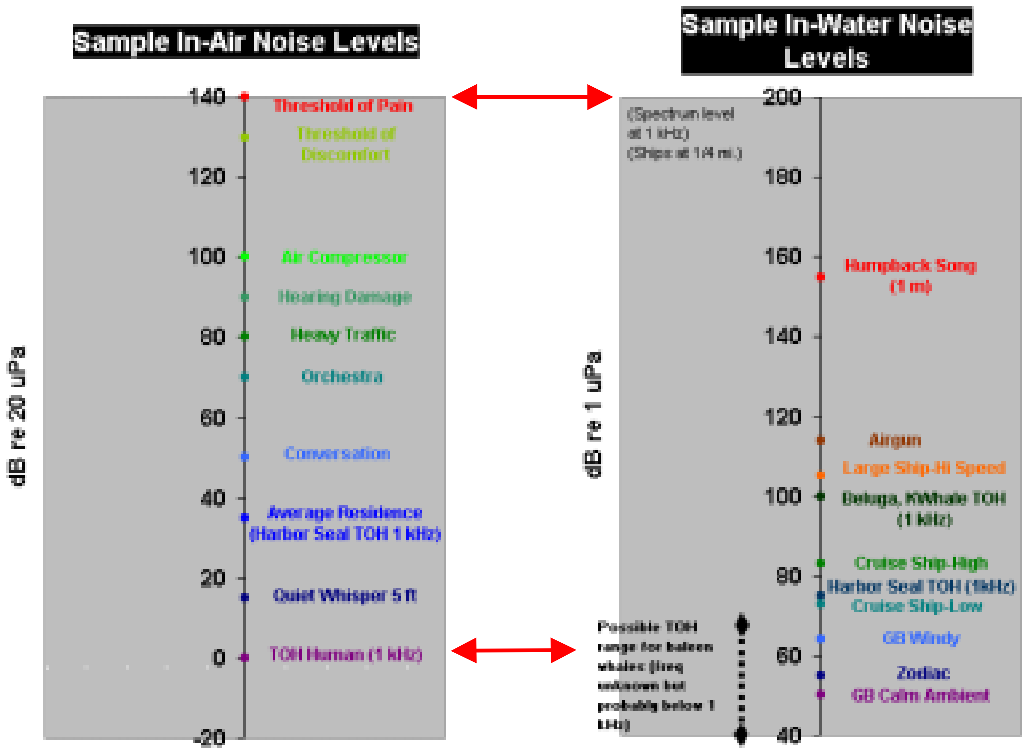


Representative One-Third Octave Plot



Representative Narrowband Plot

Fig. 5 Representative One-Third Octave and Narrowband Noise Spectra



(TOH = threshold of hearing)

Fig. 6 Sample In-Water and In-Air Noise Scales

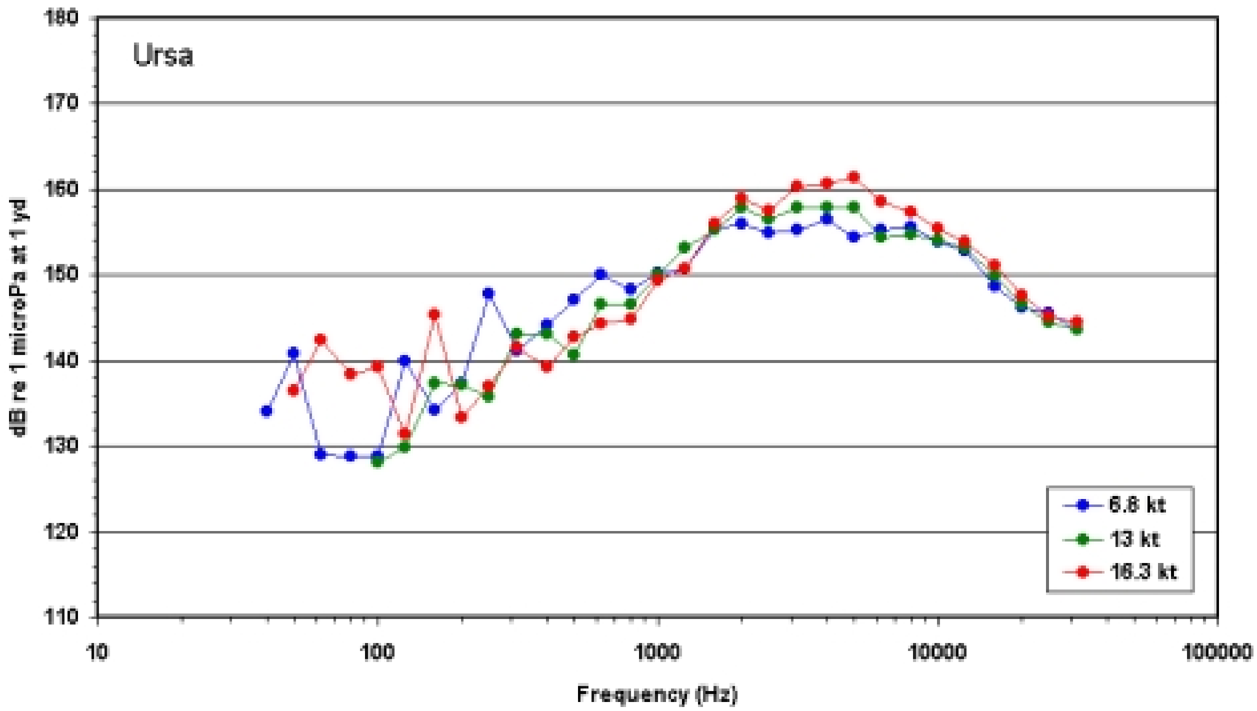


Fig. 7 Ursa Radiated Noise

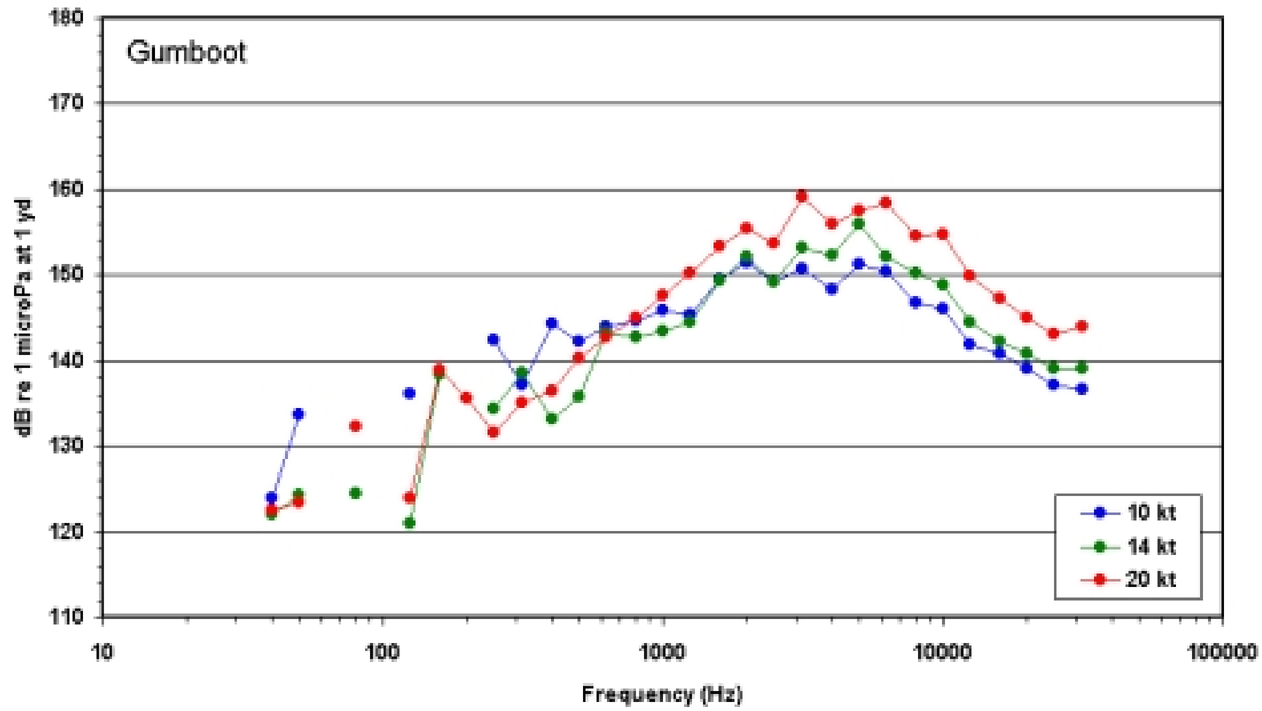


Fig. 8 Gumboot Radiated Noise

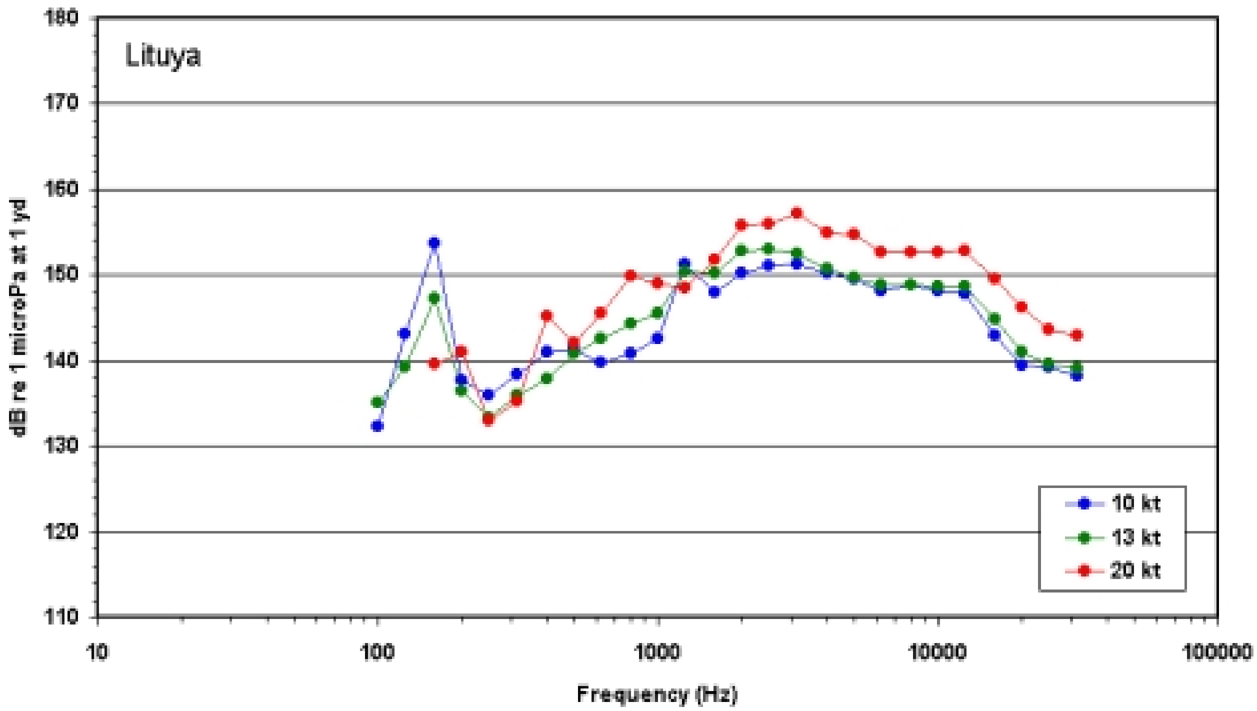


Fig. 9 Lituya Radiated Noise

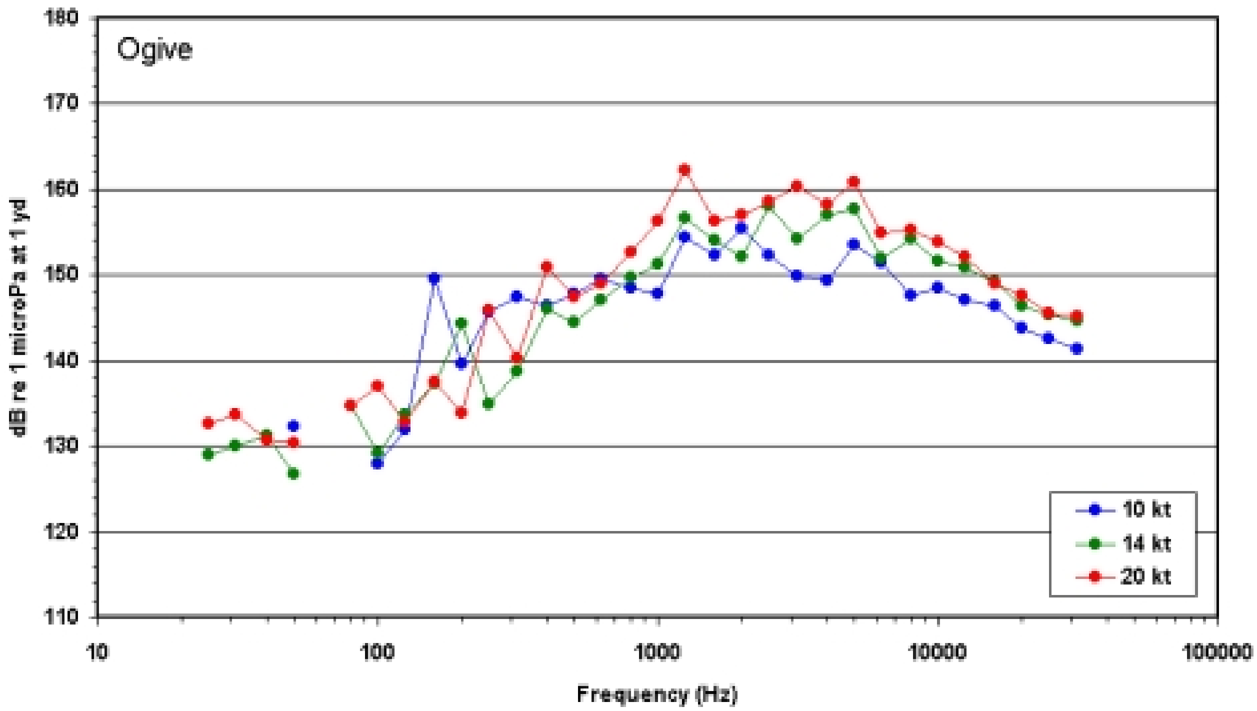


Fig. 10 Ogive Radiated Noise

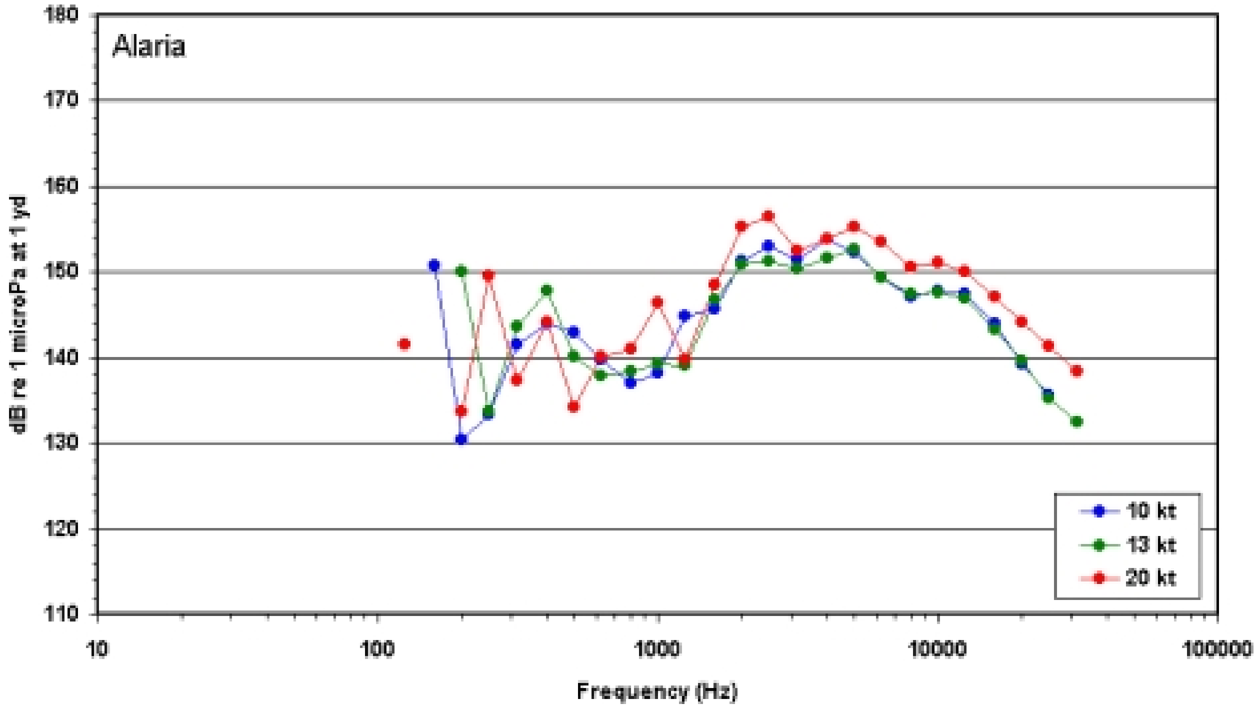


Fig. 11 Alaria Radiated Noise

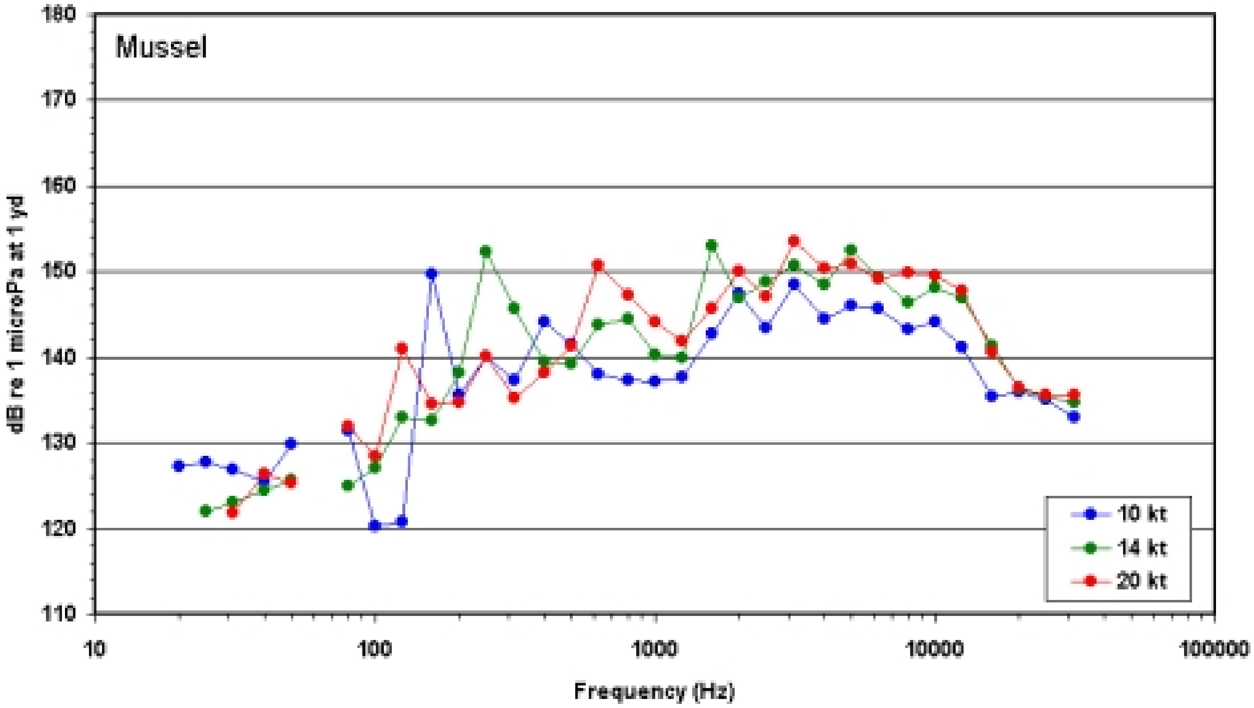


Fig. 12 Mussel Radiated Noise

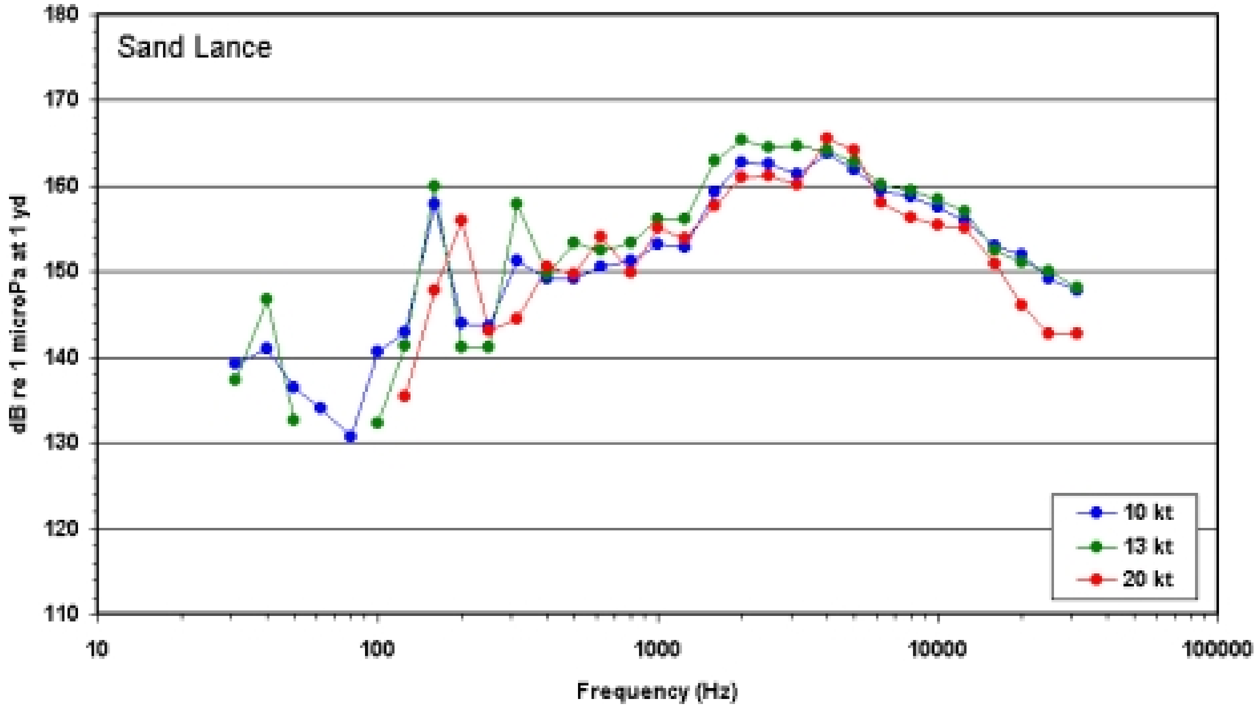


Fig. 13   Sand Lance Radiated Noise

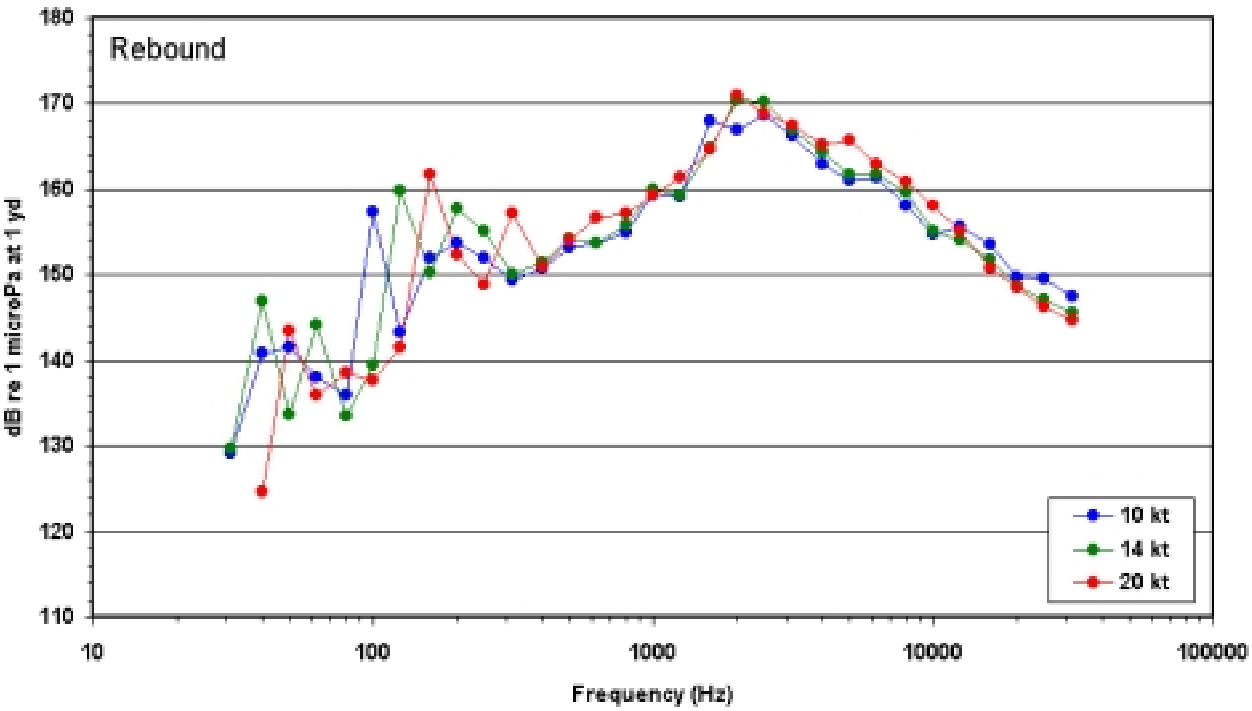


Fig. 14 Rebound Radiated Noise

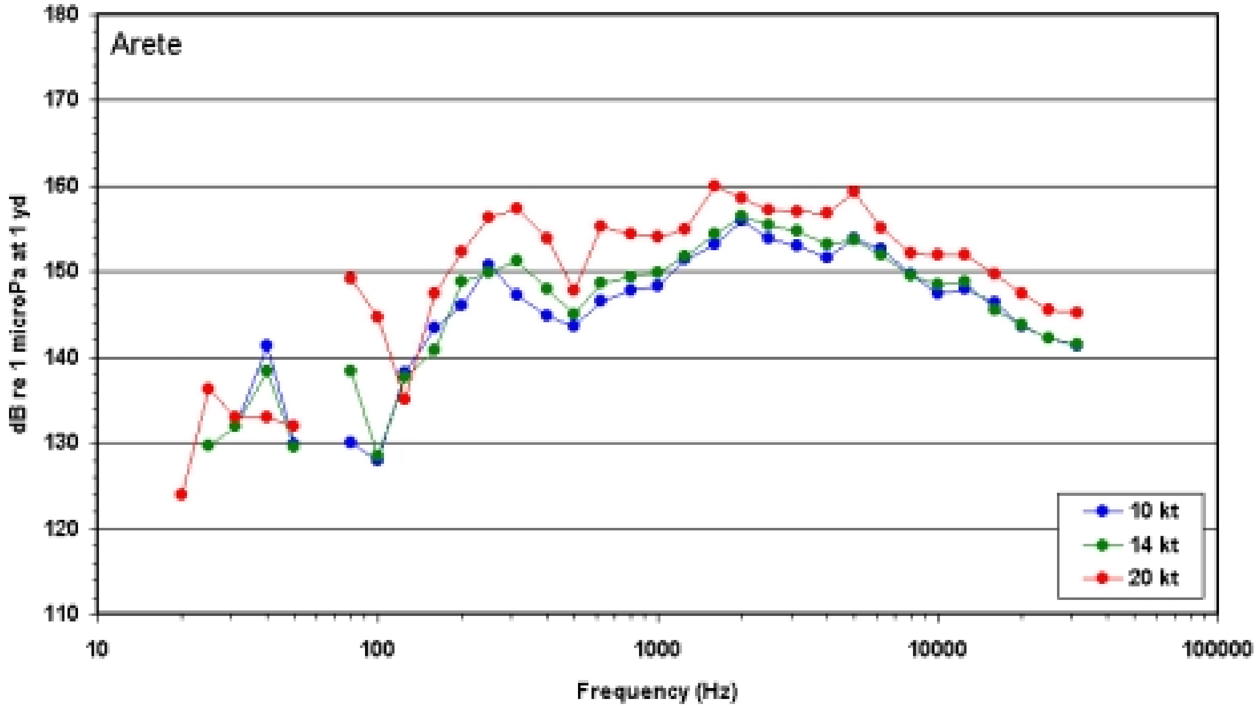


Fig. 15 Arete Radiated Noise

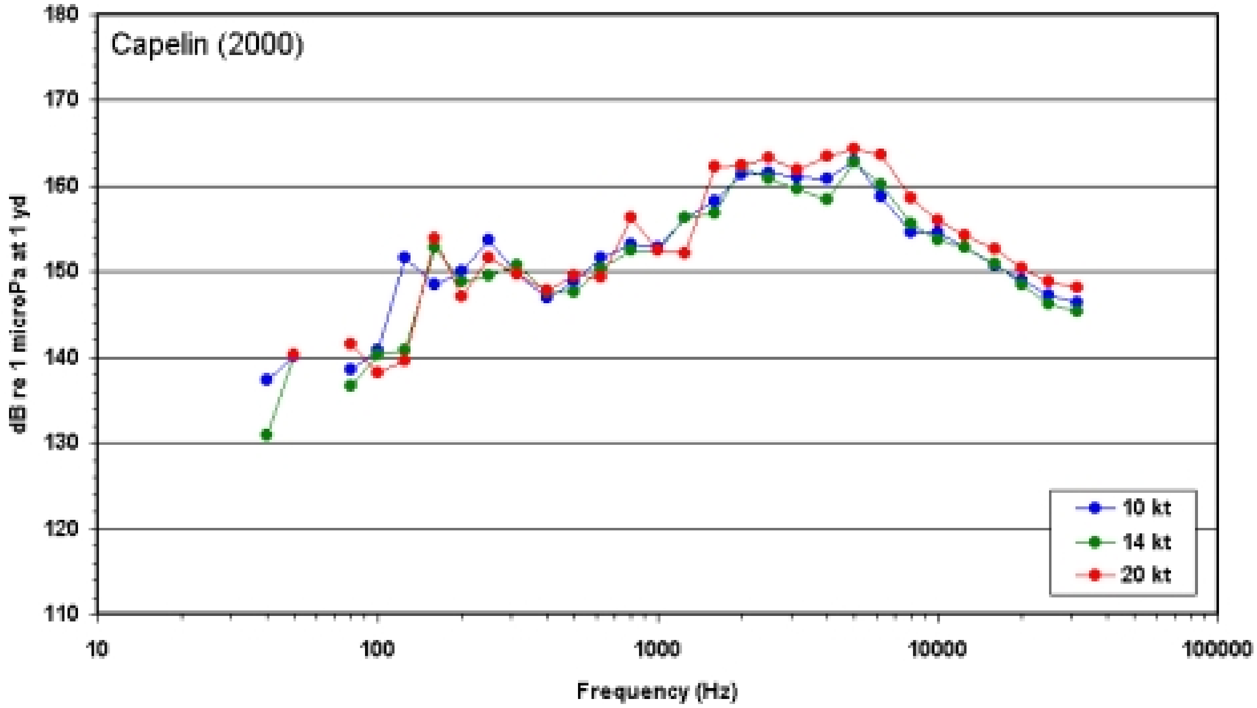


Fig. 16 Capelin (2000) Radiated Noise

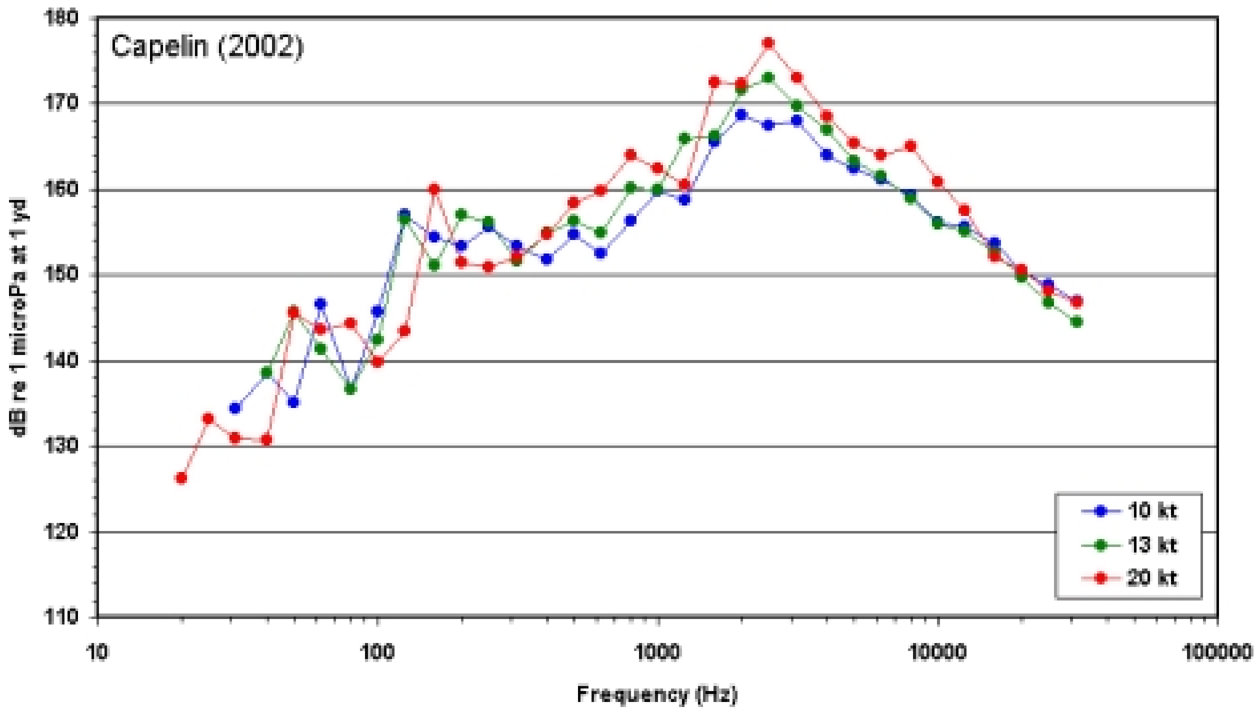


Fig. 17 Capelin (2002) Radiated Noise

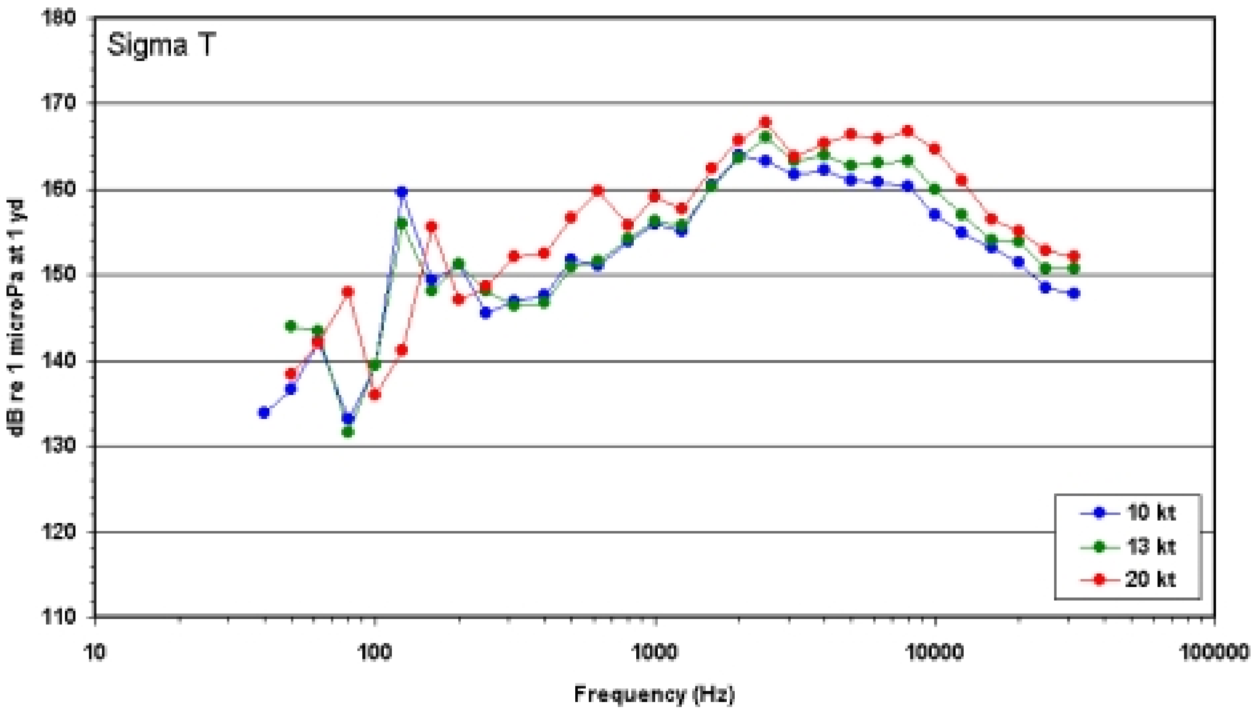


Fig. 18 Sigma T Radiated Noise

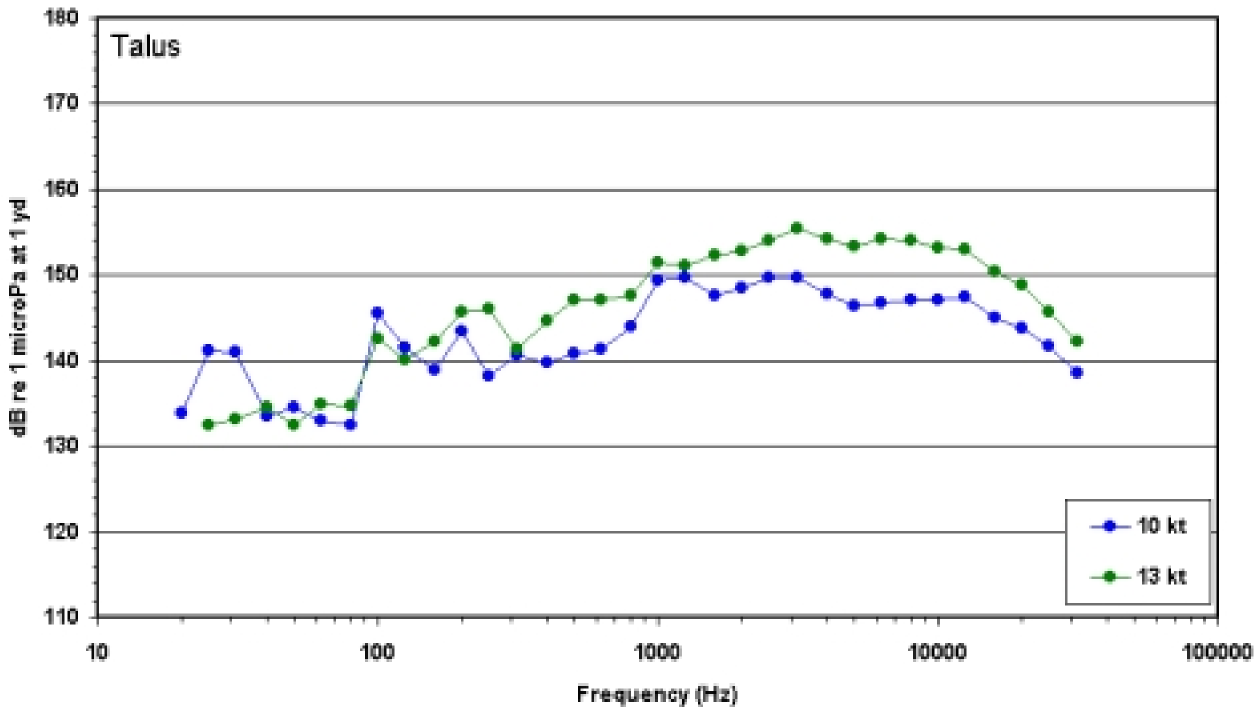


Fig. 19 Talus Radiated Noise

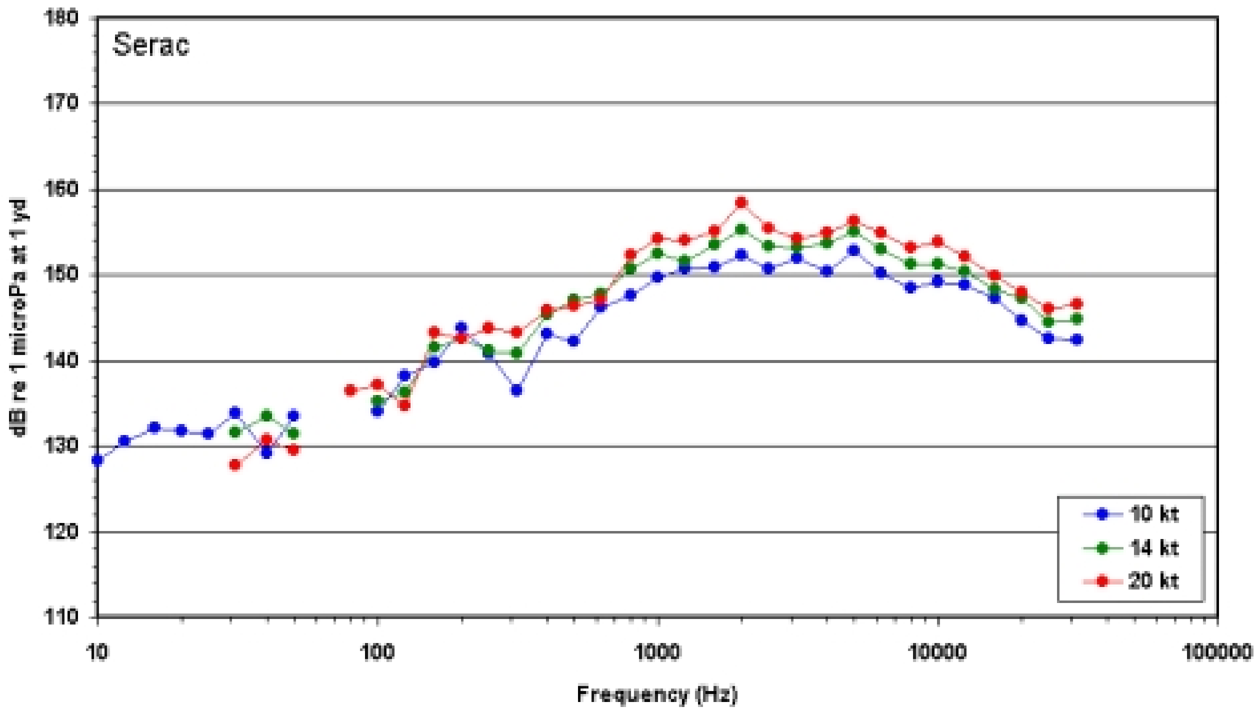


Fig. 20 Serac Radiated Noise

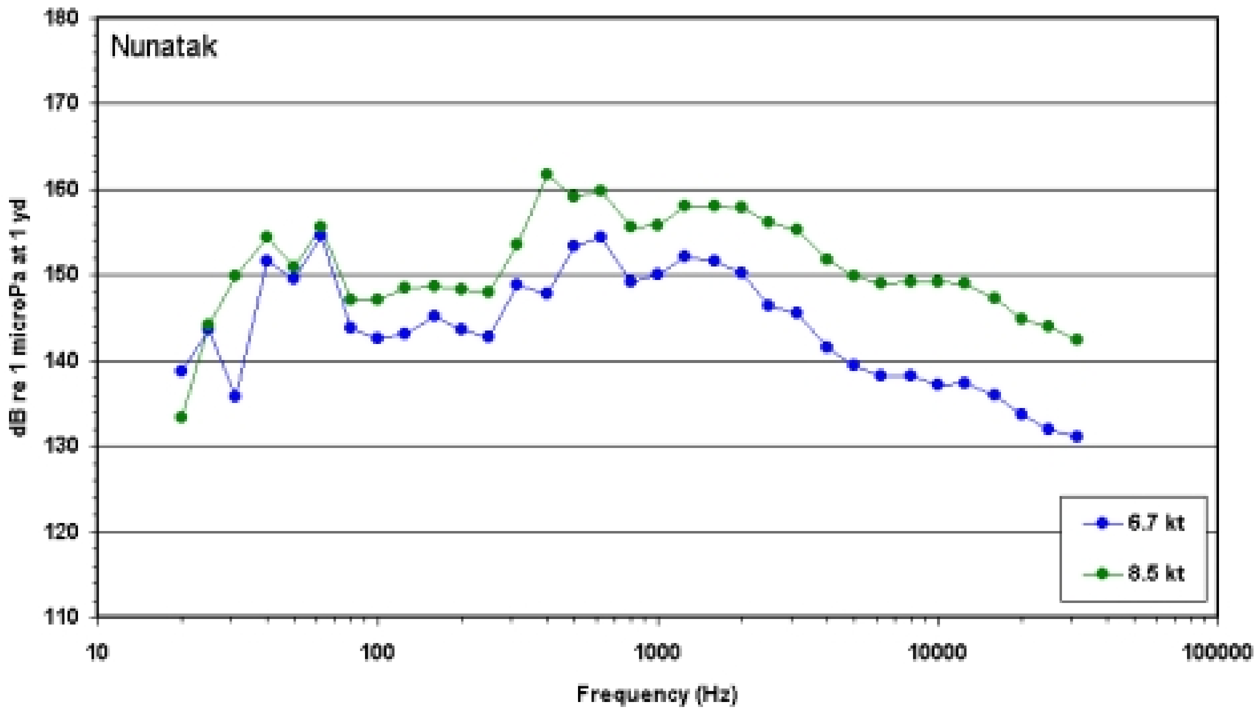


Fig. 21 Nunatak Radiated Noise

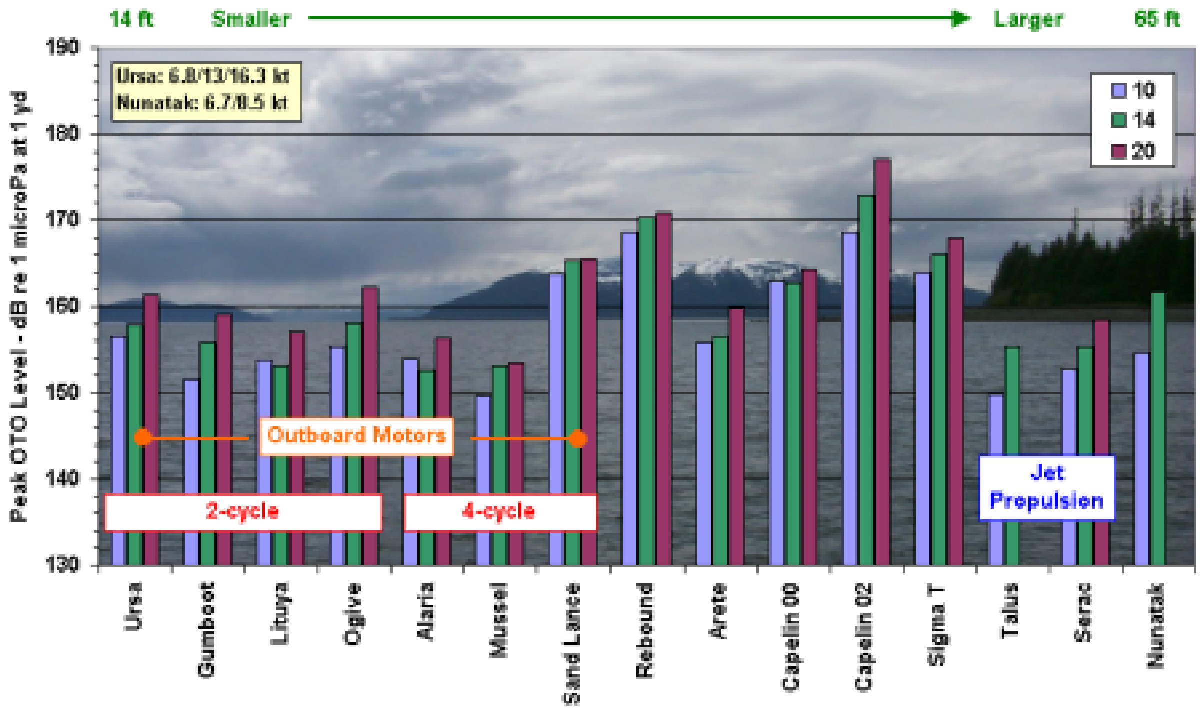


Fig. 22 Peak One-Third Octave Noise Levels

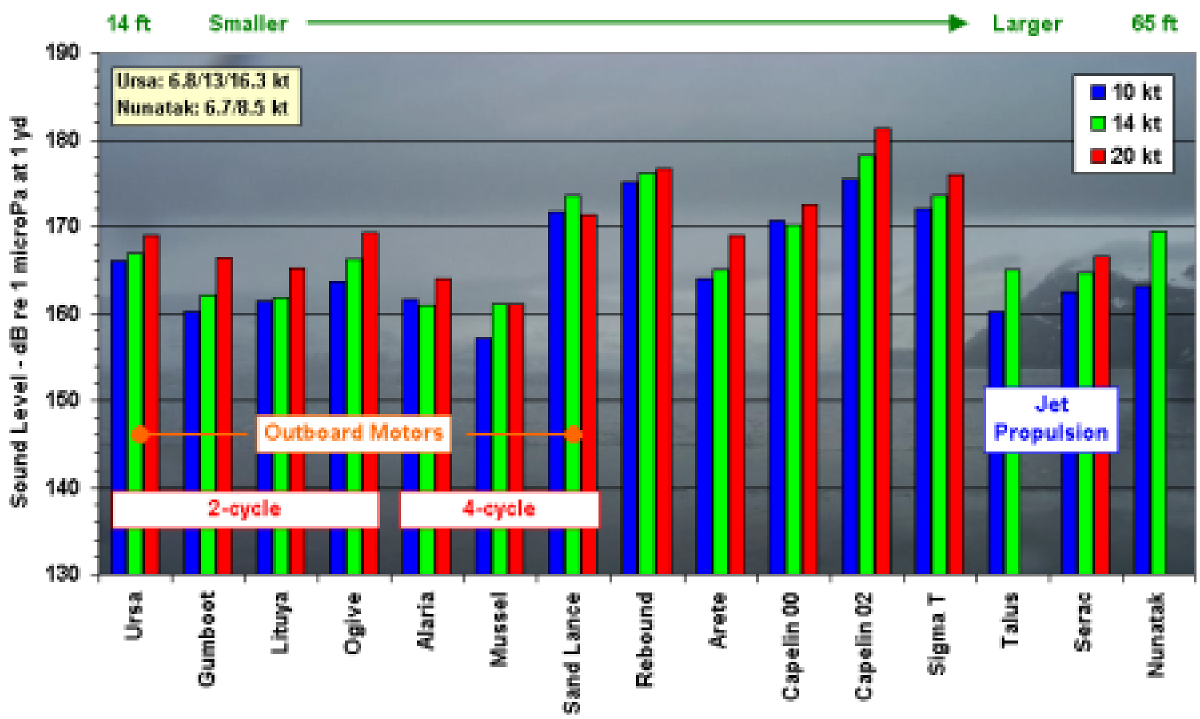


Fig. 23 Sound Levels

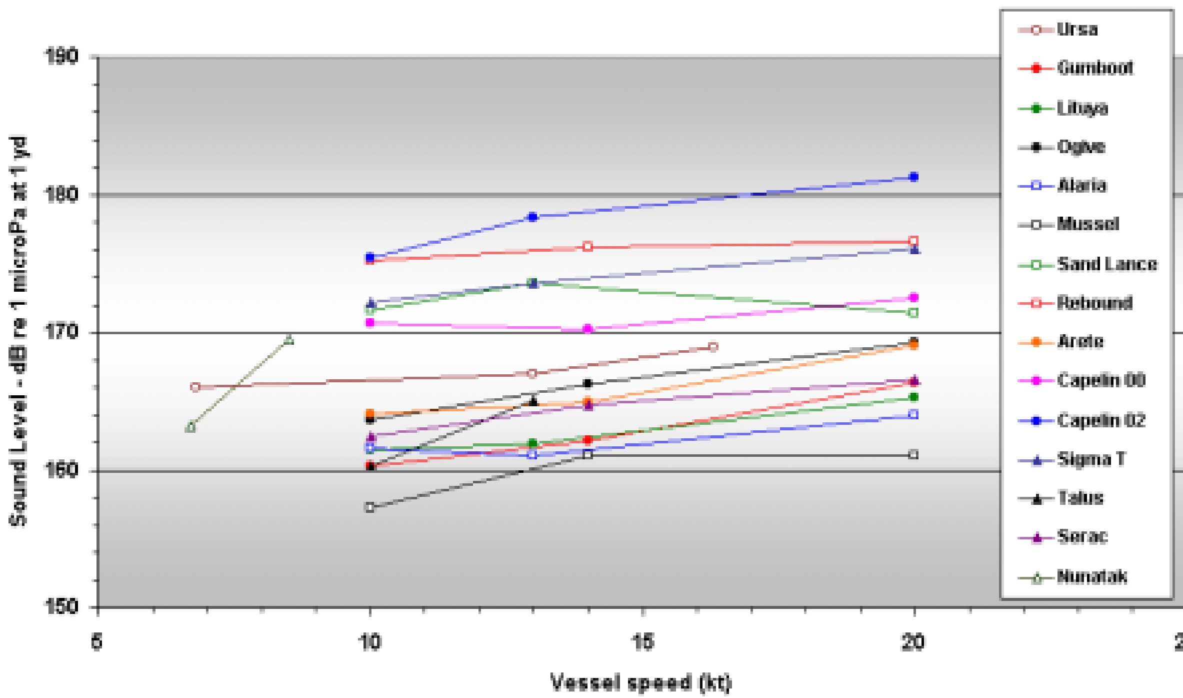


Fig. 24 Sound Level Vs. Vessel Speed

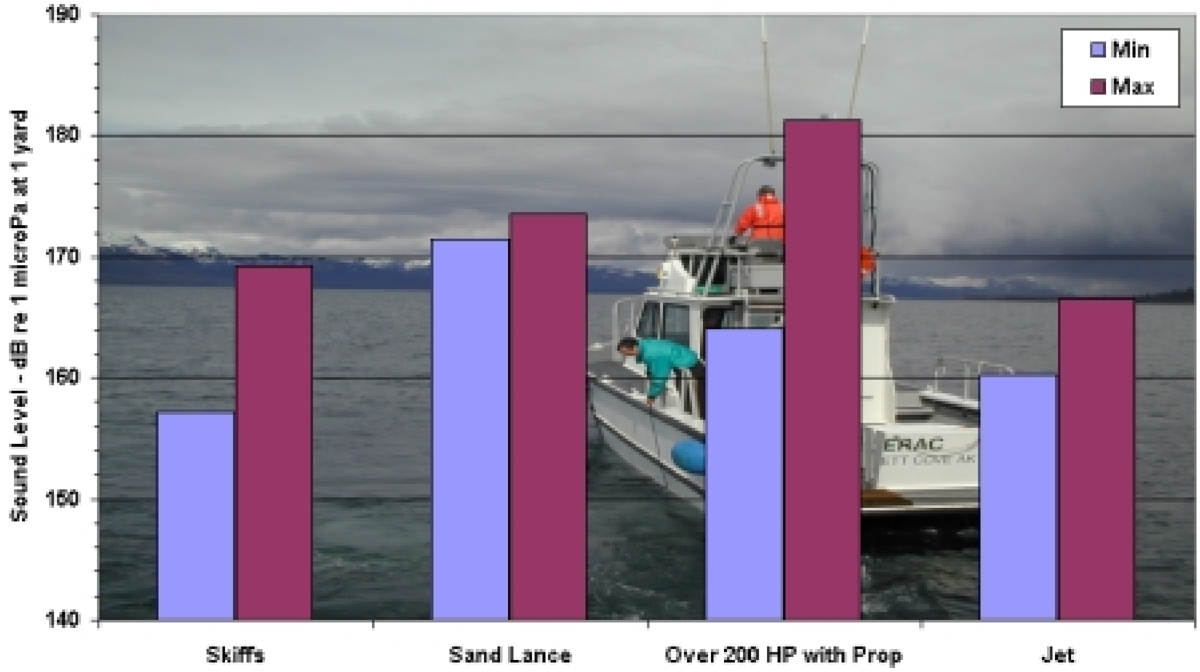


Fig. 25 Sound Level by Vessel Type

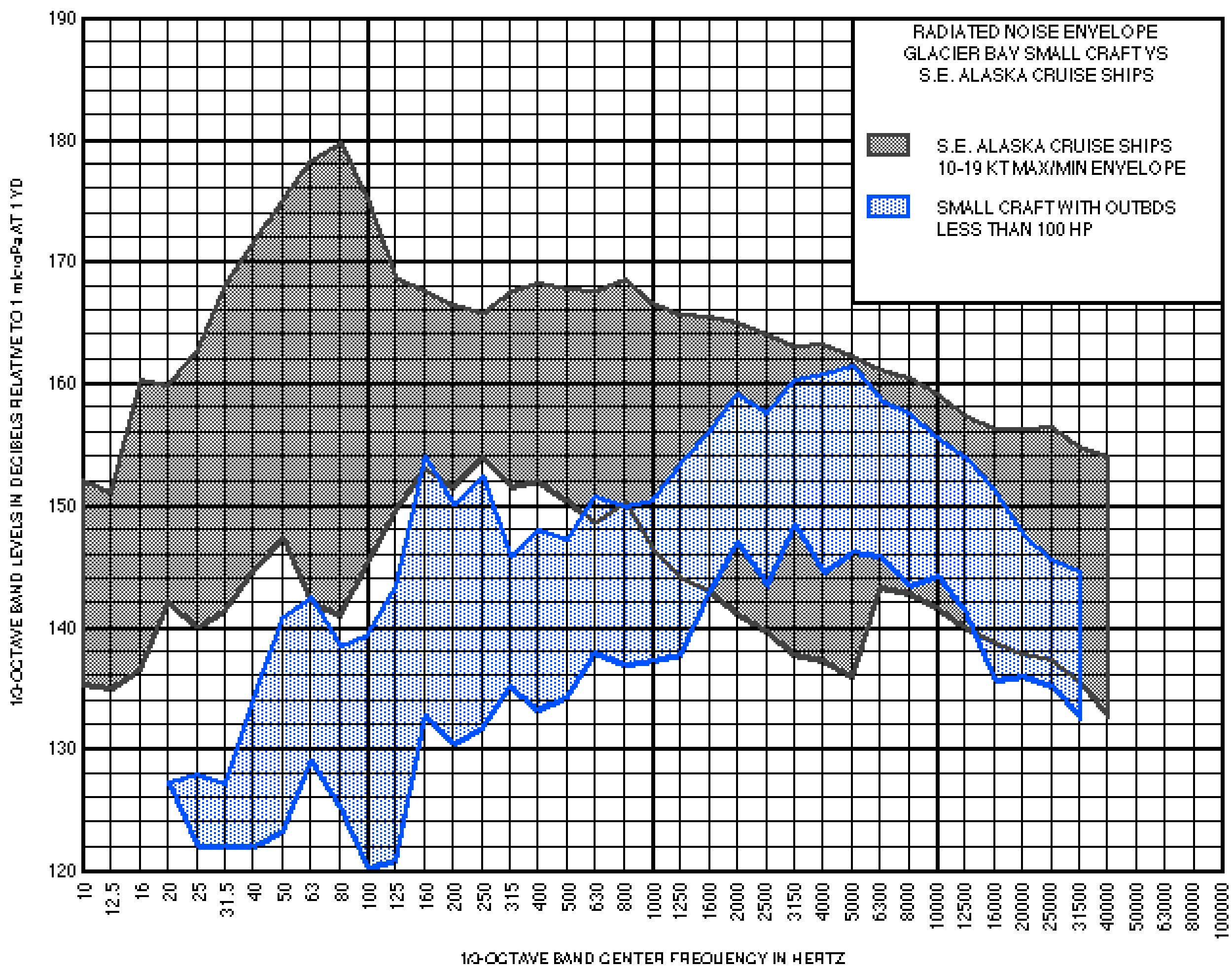


Fig. 26 One-Third Octave Noise Envelope – Small Craft
Less Than 100 H.P. Vs. Cruise Ships

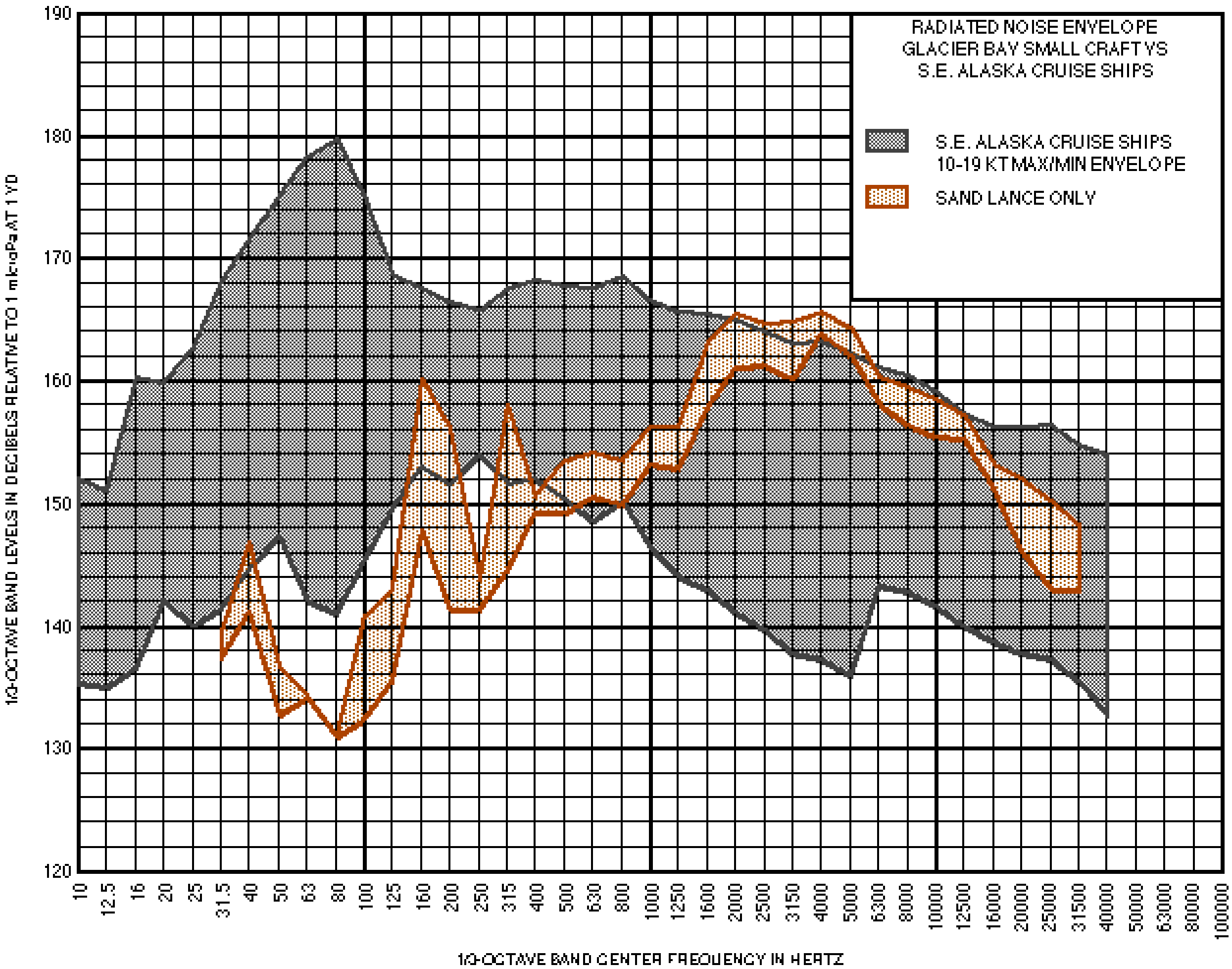


Fig. 27 One-Third Octave Noise Envelope – Sand Lance

Vs. Cruise Ships

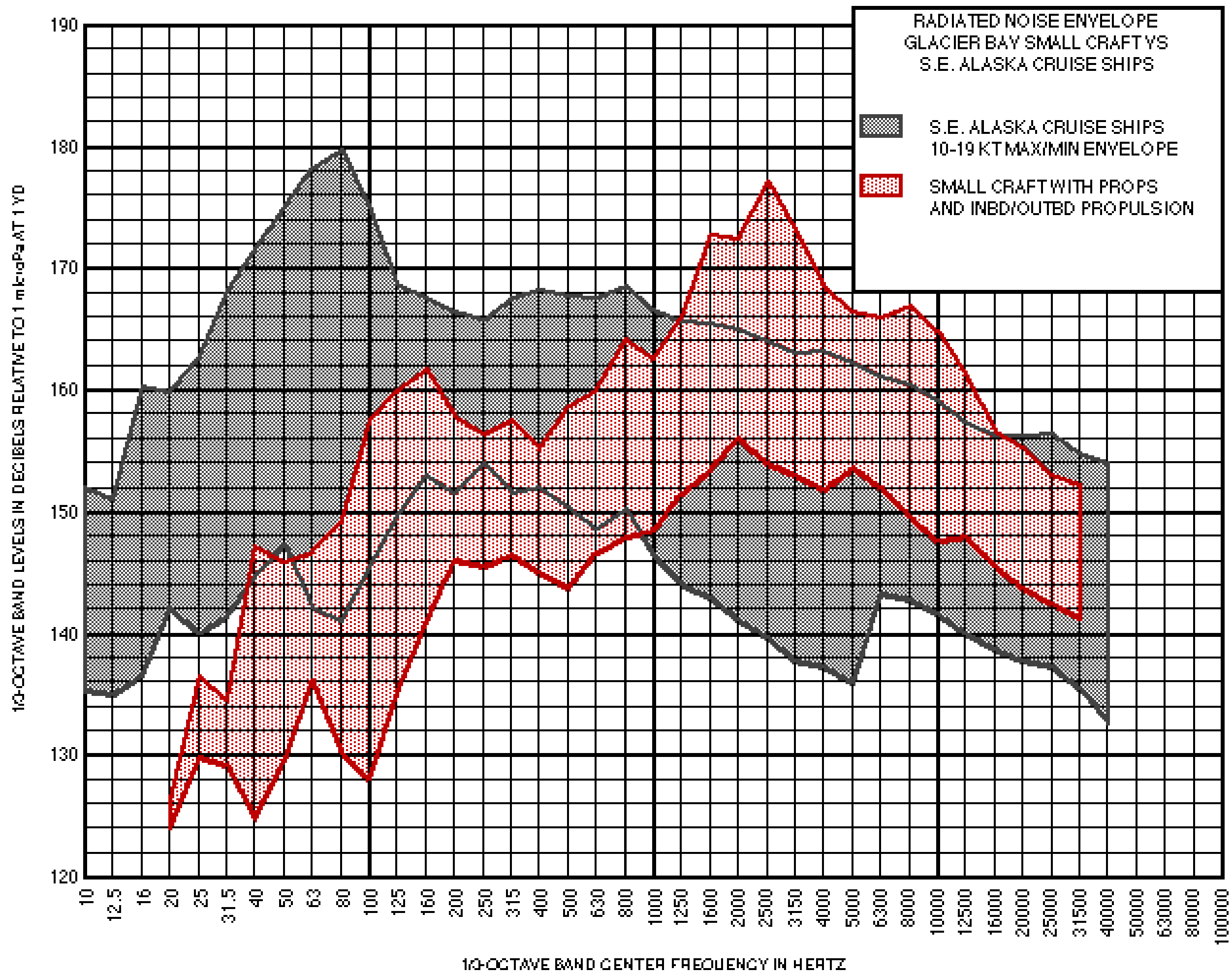


Fig. 28 One-Third Octave Noise Envelope – Small Craft

With Inboard/Outboard and Propellers Vs. Cruise Ships

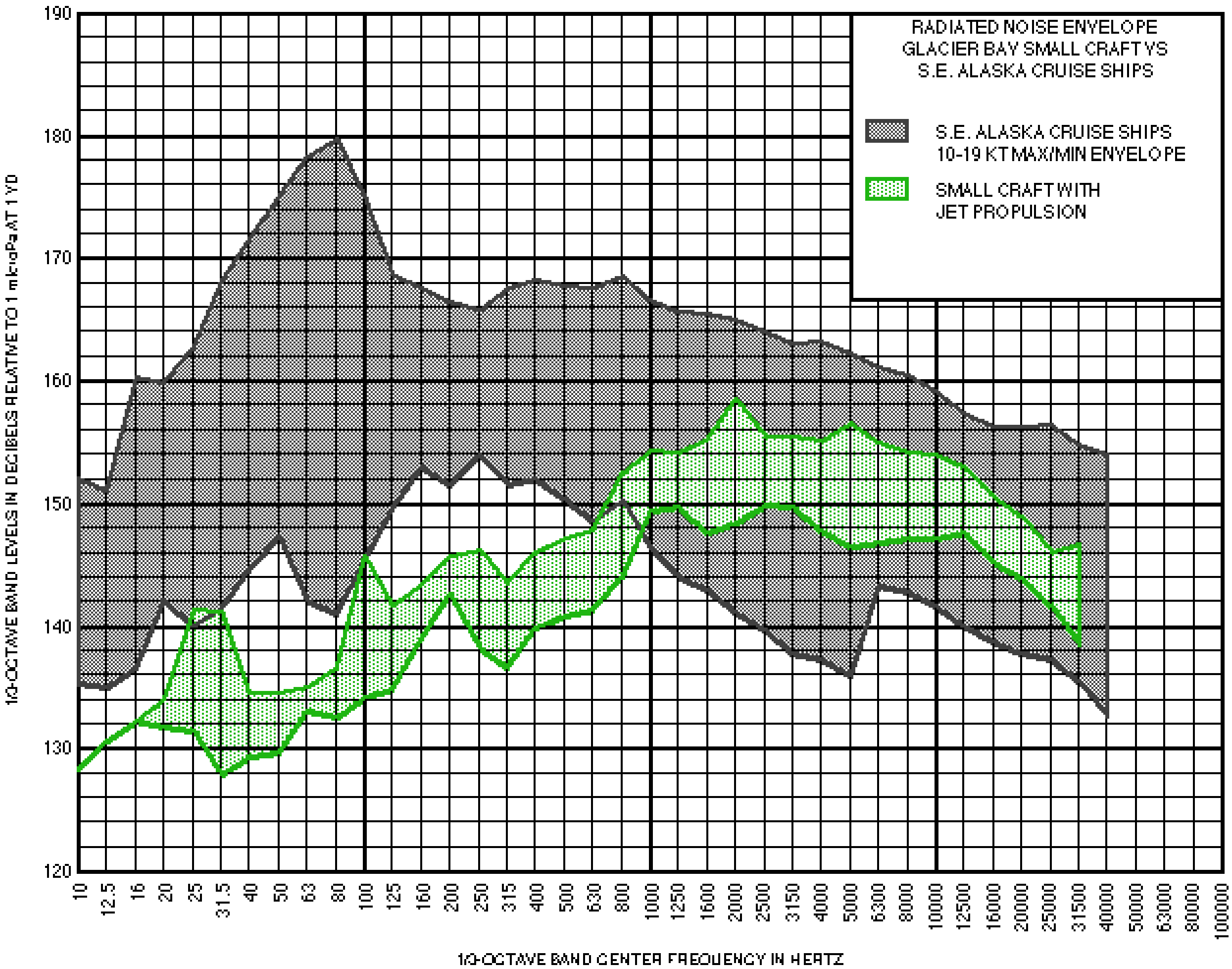


Fig. 29 One-Third Octave Noise Envelope – Jet Powered Small Craft Vs. Cruise Ships

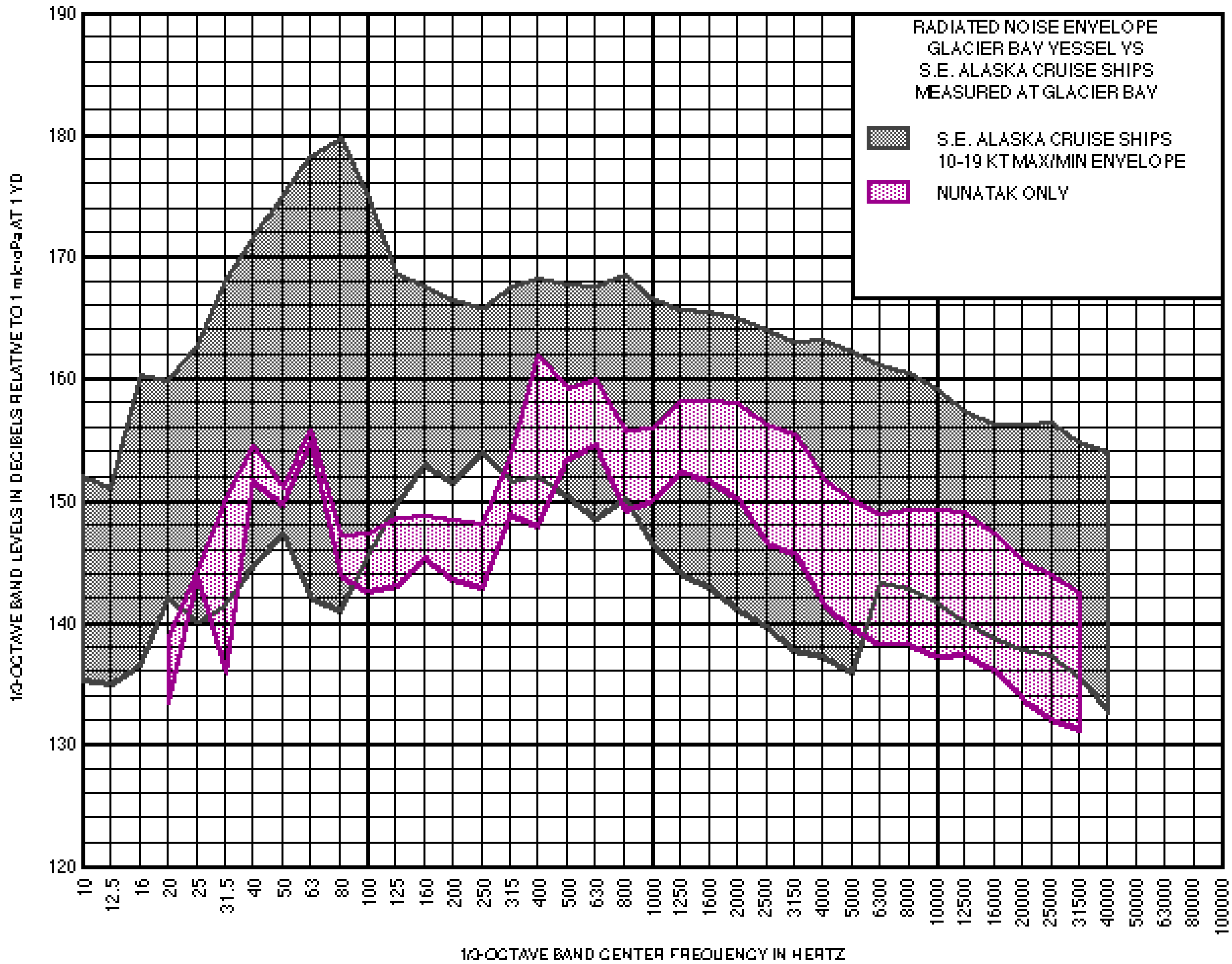


Fig. 30 One-Third Octave Noise Envelope – Nunatak Vs. Cruise Ships

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