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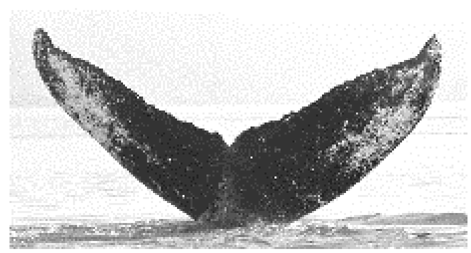
Glacier Bay Underwater Noise – Interim Report



by
Blair Kipple

Underwater noise trends and levels in lower Glacier Bay from acoustic samples acquired during 14 months between August 2000 and June 2002.

Naval Surface Warfare Center – Detachment Bremerton
530 Farragut Avenue
Bremerton, Washington 98314-5215

Director: (360)476-4335

ABSTRACT

Both manmade and naturally occurring underwater noise in lower Glacier Bay was studied using over 5200 hourly noise samples obtained during 14 months between August 2000 and June 2002. The primary contributor of natural noise was wind generated surface noise, which averaged 83 dB re 1 microPa at 1 kHz and ranged from 67 to a maximum of 100 dB. Average monthly wind noise levels were not widely variable by season. Noise from rainfall was present in an average of 2.1 out of 24 samples per day and was not especially prevalent in winter versus other seasons. Rain noise levels at 16 kHz averaged 89 dB and ranged as high as 110 dB.

Humpback whales were the most common source of biologic noise. These sounds included various grunts, whoops, and squeaks as well as songs. They were most common from August through November. Seventy-percent of all humpback songs were logged in October 2000.

Marine vessel noise was the only identifiable source of manmade noise that was observed. On the average it was present in 7.9 out of 24 samples per day, but it ranged from a low of 1.7 samples per day in December 2000 to a high of 16.5 per day in August 2000. Not surprisingly, vessel noise was most common in summer.

Peak vessel noise levels averaged 94 dB, 11 dB greater than the average wind noise level. The highest vessel level recorded was 130 dB, but only about 1% of the peak vessel noise levels exceeded 120 dB at the hydrophone. Medium sized vessels were most prevalent at all times of year. They constituted 62% of all vessel types observed. At most, large ships were observed in 4 samples per day. Noise from small craft was most common from May to September. Average large vessel noise levels were 2 to 5 dB higher than average small and medium craft levels. Vessel noise levels were markedly lower during August 2000 where a 10-knot speed limit was in effect compared to August 2001 which had a 20-knot speed limit.

A heavy rolling transient noise was observed in more than 20 samples per day in June and July. The source of this noise was not identified, but its presence was strongly dependent on season.

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PROJECT DESCRIPTION

Since May 2000, a hydrophone has been in place in lower Glacier Bay continuously monitoring underwater noise levels as part of an effort to characterize Glacier Bay's underwater acoustic environment. The hydrophone is connected to a shore-based data acquisition system that acquires a 30-second noise sample once per hour, 24 hours per day. These samples are archived and later retrieved for analysis and entry into a database. Using these data, underwater noise levels were trended and typical sources of underwater noise were identified. Some of the issues of interest include: contributions, types, and prevalence of natural sources of underwater noise; prevalence, types, and effects of manmade sources of noise; and frequency of occurrence and types of noise from marine life. Seasonal trends of these types of underwater noise are also of interest.

This project is being executed in phases. First, a portion of the database was developed that roughly encompassed 14 months of data, although some months were not covered in entirety. This effort will be followed by completion of a more extensive database and report. The results derived from the first database, the *interim database*, are the subject of this report. The results from the more extensive final database will be forthcoming in 2003. The project is a collaborative effort between personnel at Glacier Bay National Park and Preserve, Gustavus, Alaska; and the Naval Surface Warfare Center Detachment in Bremerton, Washington.

Two separate hydrophone locations and installations have been used for this project. In both cases the hydrophone was located along the eastern side of Lower Glacier Bay, just south of the entrance to Bartlett Cove, as shown in Fig. 1. For the original hydophone installation, the hydrophone was bottom mounted in 164 feet of water. This installation was in place from 17 May 2000 to 15 May 2001. On 17 May 2001 the hydrophone was replaced and relocated to a new location in 99 feet of water. This hydrophone is still installed and data acquisition is continuing. The hydrophone mounts used in both installations are shown in Fig. 2.

The underwater noise data acquisition system uses an ITC type 8215A wideband omni-directional hydrophone to measure absolute sound pressure levels. The system is setup to acquire data on an hourly basis. Samples are acquired on the hour, or on the quarter, half, or three-quarter hour to minimize bias due to regular vessel schedules. For each sample the following data are archived:

1) 10 Hz to 31.5 kHz one-third octave spectrum
2) 1 kHz baseband narrowband spectrum
3) 1 kHz narrowband waterfall display
4) 40 kHz baseband narrowband spectrum
5) 40 kHz narrowband waterfall display
6) 30 second wav file (for aural analysis).

Figure 3 shows examples of several of these data types. The narrowband spectra (items 2 and 4 above) are generated by averaging over the duration of the sample. As a result, they represent the average frequency character and noise level over the 30-second sample period. The one-third octave spectrum is derived from the narrowband spectra.

Levels in this report are one-third octave band levels in dB re 1 microPa as measured at the hydrophone face. For *point sources* such as marine vessels, the measured noise levels depend strongly on the distance from the source to the hydrophone. For this reason, the measured levels are *received* levels, not *source* levels. To derive source levels for noise sources such as vessels and whales, the distance from the hydrophone to the source must be known so that acoustic spreading loss can be accounted for and the appropriate range correction applied. No attempt was made to range correct noise levels for sources such as vessels and whales. For *local distributed sources* such as wind and rain noise, the distance to the source is not particularly meaningful. One exception might be for rain noise controlled by a localized rain squall located at some distance from the hydrophone, rather than by rain uniformly distributed over a large area around the hydrophone.

The validity of the measured levels also depends on whether the noise of interest is steady state or transient in nature. As mentioned above, the data acquisition system used for this project acquired samples that were 30 seconds in length. This duration works well for steady state noise where levels and frequency character do not change much within 30 seconds. Examples of steady state noise include wind noise, rain noise, and distant marine vessels operating at constant speed. In these cases the measured noise levels are reliable.

For transient noises the 30-second sample duration is more of a problem in terms of logging accurate noise levels. Because the system is basically creating a noise level average over a 30-second duration, if a transient noise of interest lasts only 5 seconds, the average level will be erroneously low. To properly measure the transient noise level, only the transient noise itself should be captured. The problem is further complicated if the noise changes frequency during the sample. For these reasons caution must be exercised when discussing transient noise levels from sources such as vessels passing by at close range, vessels at unsteady speeds, whale vocalizations, etc.

The database used to trend the noise levels and seasonal noise character was generated using Microsoft Access 97. The one-third octave levels from each sample in the data acquisition system archive were loaded into the Access database. Also, characterizations of each sample were filed with the individual sample records in the database. Using the narrowband spectra, one-third octave spectra, narrowband waterfalls, and audio files, each sample was reviewed by an acoustic analyst to determine the following:

1) usability of the sample
2) wind noise content
3) rain noise content
4) marine vessel content
5) biologic noise content
6) presence of unidentified acoustic noise
7) presence of system related noise*.

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* System related noise pertains to noise due to the measurement system itself rather than actual underwater acoustic noise. Examples of system noise include: interference from 60 Hz electrical power and electrical crackling noise.

This information was entered into the Access database to characterize the noise content of each sample.

DATA SAMPLE COVERAGE

For the purposes of this interim report, data samples from August 2000 through June 2002 were included in the database. This entire time period was not covered due to gaps in sample coverage and because the interim report contains only a subset of the data that will be included in the final report. Table 1 contains a tabulation of the months covered in this time period, and the number of days included per month.

Table 1 Days of Data Coverage by Month

	2000	Comment	2001	Comment	2002	Comment
Jan			0	Data load problem		NC
Feb			15	Remainder deferred		NC
Mar			8	System limitations		NC
Apr			0	System limitations	14	Remainder deferred
May		NC	4	System limitations	6	Remainder deferred
Jun		NC	11	System limitations	12	Remainder deferred
Jul		NC	25	System limitations		NC
Aug	21	System limitations	31	Full coverage		NC
Sep	26	System limitations		NC		NC
Oct	30	Full coverage		NC		NC
Nov	30	Full coverage		NC		NC
Dec	31	Full coverage		NC		NC

NC = not covered in this report

A total of 9605 samples were included in the interim database. Of this number, 5891 samples (61%) were reviewed and 5220 (89%) were determined to be usable. The total number of samples was substantially greater than the number of reviewed samples because, for some months, the data acquisition sample schedule was acquiring more than one sample per hour. Figure 4 shows the total number of samples that were reviewed (analyzed for inclusion in the database) per month and the number of usable samples per month. In some cases samples were considered unusable due to interference from measurement system related noise. For both October and December 2000, the high number of unusable samples was due to interference from system related, electrical, crackle noise.

For February 2001, and April, May, and June of 2002, only a portion of the month's data was analyzed for the interim report. Analysis for these months will be completed later and full results for these months will be included on the final report.

For months where data coverage was sparse due to data acquisition system outage, additional data will be analyzed and incorporated into the final report. For example, since only a small number of samples were obtained in April, May, and June of 2001 due to hydrophone cable damage, portions of April, May, and June of 2002 were also included in the interim database.

A computer software problem was encountered recovering the data from January 2001. Further attempts will be made to recover the data for this month. If these efforts are unsuccessful, data from January 2002 will be used in place of January 2001 data in the final report.

Some overlap in monthly coverage occurred for August (2000 and 2001) and for May and June (2001 and 2002). Additional overlap is planned for the final report.

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 contribute to 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) in Fig. 5 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. With regard to the 30-second time samples that were used in this study, wind noise should be thought of as steady state noise, since its levels and character do not change measurably in such a short time span.

Rainfall is also an established source of naturally occurring undersea noise. Rain noise levels are dependent on rainfall intensity and they typically peak at frequencies above 10 kHz. Like wind noise, rain noise would also be considered steady state noise for the purposes of this study.

For this investigation, underwater acoustic energy originating from biologic sources such as whales is also important. In Glacier Bay, humpback whales, and occasionally killer whales, are the main biologic sources of underwater noise that are observed. Humpback whale singing and grunting have been observed. These noises are characterized as transient noises because they change in character over a short time and often may not persist for more than a few seconds at a time.

Manmade noise in Glacier Bay is primarily due to motorized marine vessel traffic. Typical vessels range from small outboard engine powered semi-rigid inflatable craft; to small pleasure craft, work-boats, and open skiffs; to fishing boats and trawlers with inboard diesel engines; to small 200-foot cruise ships; to large cruise ships over 600 feet in length. For craft operating at a constant speed, vessel noise is typically considered steady state noise relative to the data acquisition system’s 30-second sample duration.

Vessel noise 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 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 discusses the results of the noise investigations that were conducted using the Glacier Bay interim database. The prevalence of natural and manmade sources of underwater noise is discussed as well as the actual noise levels that were attributed to these sources. The degree to which these noise sources affected Glacier Bay noise levels at various times through the year is addressed by tracking noise trends on a monthly basis.

Noise from Natural Sources

In the absence of manmade noise, such as noise from marine vessel traffic, natural noise sources like wind and rain dominated the noise field in Glacier Bay. At times, noise from other natural sources, such as whales, was also present. The database was queried to determine the number of samples that were free of manmade noise. It was also queried to trend wind and rain noise levels by month.

Figure 6 shows the percentage of samples that were free of marine vessel-related noise on a monthly basis. Since marine vessel noise was the only source of identifiable manmade noise that was observed, this graph provides a measure of the prevalence of manmade noise sources versus natural noise sources. Months from October through April were roughly 90% free of manmade noise sources. Thus, natural noise sources such as wind were dominant in 90% of the samples during these months. In May 2001 48% of the samples were free of manmade noise, and 70% of the samples in May 2002 contained no manmade noise. In the months of June, July, and August, 31% to 45% of the samples were free of manmade noise. Approximately 60% of the samples in September 2001 contained only noise from natural sources.

For months where the percentage of vessel-free samples was similar, statistics were combined and four seasonal time periods were established. These results, drawing from the data in Fig. 6 and graphed in Fig. 7, show a definite distinction between the influence of manmade noise sources in the winter, spring, summer, and fall seasons. In the summer months about 40% of the noise samples were free of vessel noise compared to about 90% in winter. The fall and spring season samples were about 60% free of vessel noise. A notable result is that the winter season, in terms of vessel-free samples, is extended in that it encompasses months from October through April. Also, the spring and fall periods are compressed because they only include May and September. Marine vessel noise statistics will be discussed in greater detail later in this report.

<u>Wind Noise</u>

Wind noise statistics were compiled on a monthly basis using all of the wind dominated, usable data contained in the interim database. Wind noise level statistics were based in 1 kHz one-third octave band levels and only samples whose 1 kHz levels were controlled by wind noise were included in these statistics. Wind noise controlled the 1 kHz one-third octave band level in 62% of all usable samples. A representative, wind dominated, one-third octave noise spectrum is shown in Fig. 8. Wind noise minimum, average, and maximum level statistics are listed in Table 2 and graphed in Fig. 9. Standard deviation and number of samples are also included.

Wind noise levels occurred at levels considered typical for open water areas. The overall average wind noise level was 83 dB*. The minimum observed level was 67 dB

* This level is comparable to average wind noise levels for other areas that have been studied by NSWC including: Ketchikan, Alaska; Southern California; Hawaii; and Bahamas.

and the maximum level was 100 dB. These levels are reasonable for a hydrophone located in approximately 100 feet of water.

Table 2 Wind Noise Statistics

	Min	**Avg**	**Max**	**Std Dev**	**Count**	**% Wind Controlled**
Overall	67	83	100	6.8	3247	62%
Aug-00	68	81	93	6.2	113	28%
Sep-00	68	81	98	7.1	324	62%
Oct-00	72	86	97	5.7	350	70%
Nov-00	69	82	96	6.5	581	89%
Dec-00	68	82	100	7.2	400	91%
Feb-01	74	86	98	5.4	243	76%
Mar-01	67	81	96	8.0	135	92%
May-01	72	81	92	5.2	42	50%
Jun-01	73	82	95	5.5	84	38%
Jul-01	74	84	93	4.2	126	25%
Aug-01	70	82	96	6.1	339	48%
Apr-02	69	88	98	6.3	274	91%
May-02	70	84	99	8.6	103	74%
Jun-02	68	81	93	6.0	133	48%

Wind noise level variation by month is shown in Fig. 9 along with the overall average (yellow dashed line) and overall +/- one-standard deviation (white dashed lines) levels. A significant result is that the average wind noise levels for each month were generally within a few dB of the overall average level. Also, the maximum levels for each month ranged from 92 to 100 dB with the highest recorded, not surprisingly, in December. But non-winter months also recorded high maximum levels with September 2000 and May 2002 recording 98 and 99 dB, respectively. The maximum level in August 2001 was 96 dB. Likewise, low minimum wind noise levels were not reserved just to summer months. March 2001 recorded a 67 dB level and 68 dB was observed in December 2000.

The distribution of wind noise levels over the entire period covered by the database was examined by generating a histogram of 1-kHz wind noise levels. Figure 10 graphs the frequency of occurrence of wind noise levels in 2 dB increments. Note that the distribution is skewed towards higher values with a steep slope on the high level end and a more gradual slope on the lower level end. The distribution shows that a substantial proportion (40%) of levels occurred in the 84 to 90 dB range.

Because of the prevalence of marine vessel noise in summer, a lower number of samples were controlled by wind noise in summer compared to winter. As a result, the summer wind noise statistics were based on fewer samples than the winter wind noise results. The percentage of samples per month where the 1 kHz band was controlled by wind noise is given in Table 2.

Rain Noise

Noise samples containing rain noise were tracked on a monthly basis and rain noise statistics were developed. Rain noise statistics were based on 16 kHz one-third octave band levels because rain noise normally caused a peak in the spectrum at this band. A typical one-third octave spectrum containing rain noise is shown in Fig. 11.

The number of samples containing rain noise was tallied for each month covered by the database. Using these data, the number of samples containing rain noise per 24 samples, or per “day”, was established and plotted by month in Fig. 12. The results show that the months with the highest number of rain samples per day were fall, winter, or spring months, with the exception of June 2002, which had more samples per day containing rain noise than any other month evaluated.

Figure 13 shows minimum, average, maximum, and standard deviation rain noise levels plotted by month. These data are also listed in Table 3. The noise levels in Fig. 13 indicate that the most intense rain related noise occurred in June 2001, with levels up to 110 dB recorded. Rain noise intensity did not appear to exhibit strong seasonal dependence. Average rain noise levels were within a few dB of the overall average level (89 dB), with the exception of February 2001 at 4 dB above average, and March 2001 and June 2002 at 5 dB below average. No samples containing rain noise were logged in April 2002, but only 14 days from this month were included in the interim database. This result for April is consistent with NOAA weather records for Glacier Bay, which show no rainfall for April 1 through 18. For May 2002, only 6 days were included in the interim database and no samples containing rain noise were logged. Complete results for February 2001, and April, May, and June 2002 will be included in the final report.

Table 3 Rain Noise Statistics

	Min	Avg	Max	Std Dev	Samples per "day"
Overall	69	89	110	7.5	2.1
Aug-00	73	92	99	6.3	1.1
Sep-00	72	90	100	6.0	2.8
Oct-00	79	90	100	5.1	3.0
Nov-00	71	90	99	6.7	1.9
Dec-00	69	89	103	8.8	3.2
Feb-01	88	93	100	4.1	1.3
Mar-01	69	84	93	7.6	1.8
May-01	83	92	97	5.2	2.3
Jun-01	78	90	110	9.2	1.8
Jul-01	74	92	100	5.8	1.8
Aug-01	73	90	106	7.4	1.9
Apr-02					0.0
May-02					0.0
Jun-02	71	84	100	9.2	3.6

A histogram showing the distribution of rain noise levels logged over the entire period covered by the interim database is shown in Fig. 14. This distribution shows that a substantial number of samples contained rain noise at levels greater than the average level (89 dB).

<u>Biologic Noise</u>

Undersea noises from whales and other marine life are considered natural. Noise samples containing biologic noise were logged in the database in the following categories:

1) humpback whale song
2) humpback whale other
3) killer whale
4) unknown whale
5) other type of biologic noise.

Samples containing biologic noise were tallied for each month covered by the database. Using these data, the number of samples containing biologic noise per 24 samples, or per "day", was established and plotted by month. Based on the above categories, the incidence of occurrence of biologic noise was sub-categorized according to the following types:

1) humpback whale song
2) humpback whale other
3) biologic other than humpback

The *humpback whale song* category covers cases where actual humpback whale song vocalizations were audible. Humpback whale songs were characterized by narrowband vocalizations, often at varying frequencies, that were continuous for several seconds and often repeated during the sample. Other humpback sounds like *grunts*, *whoops*, and other sounds believed to be related to humpbacks were listed under the *humpback whale other* category. Any other sounds believed to be related to marine life but not related to humpbacks were listed under the *biologic other than humpback* category. This category contained killer whale sounds, other sounds believed to be whale sounds, and any other sounds that were unidentified but believed to be from a biologic source. The results from sorting these data are listed in Table 4 and shown graphically in Fig. 15.

Table 4 Samples per "day" containing biologic noise

	All types	**Humpback whale song**	**Humpback whale other**	**Biologic other than humpback whale**
Overall*	325	24	219	82
Aug-00	2.4	0.1	2.2	0.1
Sep-00	2.2	0.1	1.1	1.0
Oct-00	5.1	0.8	4.0	0.2
Nov-00	1.9	0	1.3	0.6
Dec-00	0.2	0	0.1	0.1
Feb-01	0.1	0.1	0.1	0
Mar-01	0	0	0	0
May-01	0.3	0	0	0.3
Jun-01	0.5	0.1	0.3	0.1
Jul-01	0.1	0	0	0.1
Aug-01	1.6	0.1	1.1	0.4
Apr-02	0	0	0	0
May-02	0	0	0	0
Jun-02	0	0	0	0

* Overall is total samples containing the specified biologic noise over the entire database.

The results show that biologic noise was most common in late summer and early fall, essentially August through November. Humpback whale sounds, including song vocalizations, were most frequent in October 2000, followed by August 2000, September 2000, and August 2001. A total of 17 samples were logged containing humpback whale songs in October 2000. This number accounts for 70% of all of the humpback songs that were logged through the entire period covered by the database.

Two samples were logged containing humpback songs in months that are not considered humpback season in Glacier Bay: one in February 2001 and one in June 2001. In both cases the vocalizations were faint and the one in February 2001 was difficult to determine whether it originated from a killer or humpback whale.

The late summer and early fall also logged the greatest number of samples containing *humpback other* sounds. Descriptions of these sounds included: *grunts, groans, honks, whoops, burps,* and *squeaks*. The most frequent sound descriptor used for this category was *grunt*.

Whale distribution is an important factor in the frequency of occurrence of whale calls logged in this study. Because these distributions vary from year-to-year, whale noises in the lower Glacier Bay/Bartlett Cove area are expected to be more prevalent in some years compared to others. Gabriele and Hart (ref. 2), and Doherty and Gabriele (ref. 3) have reported that humpback whales were not frequently sighted in the Bartlett Cove area in both 2000 and 2001. These observations indicate that, in some years, whales may be more vocal in summer than indicated by this study.

The number of samples containing biologic noise was compared to the number containing vessel noise to examine the relative frequency of occurrence of the two conditions. This comparison, graphed in Fig. 16, shows that vessel noise was more common than biologic noise in all months of the study, except for the month of October 2000. In this month vessel noise was infrequent, relative to summertime, and biologic noise was more frequent than at any other time in the study.

A total of 56 samples contained both marine vessel and biologic noise in the same sample. Figure 17 shows the number of these samples that occurred per “day” on a monthly basis. The greatest number of samples satisfying this combined condition occurred in August 2000 at a rate of 1.2 samples per day, followed by September 2000 and August 2001 at 0.5 and 0.4 samples per day, respectively.

Biologic noise levels are not addressed in this report because they are typically transient in nature. Because of their short duration, and because their levels and frequencies vary significantly within the overall duration of the vocalization, a 30-second noise measurement will typically not be conducive to establishing an accurate noise level.

Marine Vessel Noise

The only identifiable source of manmade noise encountered in this study was noise from marine vessels. Vessel noise from all sizes and types of motorized vessels that operate in Glacier Bay was observed. Typical noise sources included inboard propulsion plants of various types, outboard motors, propellers, etc. In the database, marine vessel noise was separated into five categories:

1) small craft
2) medium craft
3) large craft
4) multiple types present at same time
5) other type of vessel noise.

Vessel noise exhibiting characteristics attributable to high speed propellers was categorized as small craft noise. Examples of small craft include pleasure craft, small work boats, semi-rigid inflatable boats, etc. Since these craft were identified by their underwater acoustic signatures, and since their distinguishing characteristic was high speed propeller and high speed engine noise, this category primarily consisted of craft powered by outboard, or inboard/outboard motors.

Noise exhibiting indications of mid-speed propellers and perhaps diesel engine noise was identified as medium vessel noise. This vessel category included the smaller tour vessels, working fishing boats, tugs, larger research craft, etc. Sizes of vessels in this category would run roughly from 50 to 200 feet in length. Since these vessels were identified with noise from mid-speed propellers and larger inboard propulsion plants, this type of propulsion plant would be characteristic of vessels in this category.

Vessel noise characteristic of slow speed propeller operation along with noise that contained substantial low frequency noise (on the order of 100 Hz) was categorized as large vessel noise. Given these noise attributes, these vessels would typically be powered by very large, low rpm, diesel engines and would be roughly over 200 feet in length. Propulsion systems might include direct-diesel drive, diesel-electric, steam plant, gas turbine-electric, etc. Examples of large craft audible in Glacier Bay include large cruise ships and possibly large Alaska state ferries.

Marine vessel noise characterization was accomplished using a combination of aural analysis and narrowband frequency analysis. Properly identifying these vessels requires a degree of experience in underwater noise analysis. Most vessel classification was straightforward, but in some cases it was accomplished by consensus among several noise analysts or by using a best guess approach. Usually the more difficult cases involved discriminating between medium vessels and large vessel. Also, for samples where vessel noise was faint, but clearly present based on narrowband frequency character, it was often difficult to assign a vessel category to the sample. In these cases the sample was often logged under the *other type of vessel noise* category. A representative one-third octave spectrum containing large vessel noise is shown in Fig. 18.

Noise samples containing marine vessel noise were compiled on a monthly basis, and overall and monthly vessel noise statistics were developed. Marine vessel noise statistics were based on the maximum one-third octave band level attributable to vessel noise for a given sample. The one-third octave band frequency at which this maximum level occurred was also logged for each sample containing marine vessel noise.

The number of samples containing marine vessel noise was established for each month covered by the database and the number of samples containing vessel noise per "day" (per 24 samples) was developed and plotted by month. Table 5 lists these results for all vessels, i.e. the results are for all vessel types lumped into a single category.

Table 5 Marine Vessel Noise Statistics – All Types

	Min	**Avg**	**Max**	**Std Dev**	**Samples per "day"**
Overall	71	94	129	9.6	7.9
Aug-00	72	93	115	9.2	16.5
Sep-00	72	93	123	9.5	9.2
Oct-00	78	92	111	7.7	2.4
Nov-00	74	90	117	8.9	1.8
Dec-00	74	88	118	10.0	1.7
Feb-01	74	91	107	7.5	2.0
Mar-01	75	87	110	9.8	2.5
May-01	76	96	120	10.1	12.3
Jun-01	78	97	117	8.7	15.0
Jul-01	79	96	121	8.6	13.2
Aug-01	74	95	129	9.7	13.1
Apr-02	71	85	104	9.1	2.5
May-02	76	93	123	11.6	7.2
Jun-02	76	94	121	9.8	12.4

For all samples where vessel noise was present, the peak one-third octave level and corresponding one-third octave frequency were logged to develop marine vessel noise level and noise frequency statistics. Figure 19 contains a histogram that shows the frequency of occurrence of marine vessel noise levels. Frequency of occurrence is plotted as the percentage of samples that contained a peak noise level within each 2 dB interval. The overall average marine vessel noise level of 94 dB from Table 5 is reflected on the plot as well as the levels representing +/- one-standard deviation from the average.

Some observations from Fig. 19 and Table 5 include:

1) Only about 1% of the samples containing marine vessel noise exhibited levels exceeding 120 dB.

2) No vessel noise levels exceeded 130 dB at the hydrophone.
3) Vessel noise levels from the average minus one-standard deviation to the average plus one-standard deviation ranged from 84 to 104 dB.
4) On the average, vessel noise was present in 7.9 samples per "day", but this number varied by month and season.
5) On the average, vessel noise levels were higher than in samples where noise levels were dominated by wind only. The average wind noise level was 83 dB compared to 94 dB for marine vessels.

Result (5) above is further elaborated in Fig. 20, which shows that observed vessel noise levels were typically higher than 1 kHz wind noise levels. Note however, that a greater number of low level vessel noise occurrences would be expected if wind noise levels were lower on average, because wind noise is present constantly and presumably frequently masks low level noise from distant vessels. Figure 20 also illustrates the relative presence of wind noise versus vessel noise, although this statistic is better represented in Fig. 6, because some samples represented in Fig. 20 contain both wind and vessel noise.

Figure 21 shows wind noise levels versus marine vessel levels on a monthly basis. The average 1 kHz wind level for each month is plotted along with the monthly average of the maximum vessel level from each sample. The bars on each data point in the graph show the range between the average level and the maximum level for each month. In this way both the average and the maximum levels for both wind and vessel noise may be compared. This graph shows that, for each month, the average wind noise level was lower than the average vessel level, with the exception of April 2002, which had the lowest vessel levels of any month. Figure 21 also shows that the maximum wind noise levels were lower than the maximum vessel noise levels in every month covered by the database. In summer months, maximum wind noise levels were lower than, or comparable to, the average vessel levels, because maximum wind noise levels were typically lower than in other months, and average vessel levels were usually higher than in non-summer months.

For samples containing vessel noise, statistics were developed to trend the one-third octave band frequency at which the highest vessel noise occurred. These data were used to determine whether certain portions of the underwater noise frequency spectrum were affected more than others when marine vessels were present. A histogram showing the distribution of highest level one-third octave band frequencies is given in Fig. 22. This histogram shows that about 95% of the highest level one-third octave bands occurred in the 80 to 5000 Hz range. Also, about 45% of the highest level one-third octave bands occurred in the 630 to 3150 Hz range, and 32% occurred in the 100 to 250 Hz range.

Note that Fig. 22 does not trend all of the frequency bands that were affected by vessel noise in each sample. Rather, it trends the *highest level* frequency band for each sample containing vessel noise. In many cases vessel noise, when present, controlled the noise levels in all, or most, of the one-third octave frequency bands.

Another question regarding the frequency distribution of vessel noise is: Does noise at higher frequencies or lower frequencies generally occur at higher levels? To address this question, Fig. 23 shows vessel noise level plotted versus vessel frequency band for all of the samples that contained vessel noise. Again, the vessel noise level for each sample is the vessel noise controlled level from the peak one-third octave band in the sample. The frequency band is the corresponding peak one-third octave frequency band for each sample. For each sample there is a peak level and a corresponding frequency band.

For each *highest level* frequency band, Fig. 23 plots the average of all the peak levels logged for that band and the corresponding +/- one-standard deviation levels (indicated by bars). The general *flatness* of the graphed levels, and their grouping about the overall average vessel noise level (94 dB), indicates that levels that peaked in any particular frequency region or band were not preferentially high or low in terms of noise level. Exceptions include levels below 31 or 40 Hz, where levels were consistently lower than average. This result may be indicative of acoustic propagation effects tending to de-emphasize noise at lower frequencies, but recognize that only a very few samples were represented at these frequencies (there were only 8 data points at frequencies below 31 Hz). Also, levels from 40 to 125 Hz were consistently higher than average, perhaps due to levels from large vessels in this frequency range.

Noise by Vessel Type

The number of samples containing marine vessel noise was also trended by vessel type: small, medium, and large. Figure 24 shows the frequency of occurrence of samples containing vessel noise by type. Samples containing noise from medium vessels outnumbered all other vessel types combined. Medium vessels accounted for about 62% of all vessels observed, while large and small vessels accounted for 19% and 15%, respectively.

The number of samples per "day" that contained vessel noise was also plotted by type on a monthly basis. Figure 25 shows that, as expected, vessel traffic was greatest in summer with up to almost 16 samples per day averaged in August 2000. This graph also shows that medium vessel traffic was the most prevalent type in all months except with the possible exception of June 2002. Large vessel traffic, i.e. generally large cruise ships, peaked at an average of about 4 samples per day in August 2000 and June 2002. This rate corresponds to two cruise ship entries and exits per day, as regulated by the National Park Service. Also, as expected, small vessels were most prevalent in the May through September period.

Vessel noise levels were also trended by vessel type. Figure 26 shows that large vessels were, on average, louder than medium and small vessels. The average large vessel level (average maximum one-third octave level for each sample) was 98 dB, versus 96 and 93 dB for small and medium vessels, respectively. Large vessels also logged the highest maximum level at 129 dB. The maximum level for both small and medium vessels was 126 dB. Overall and monthly statistics for each vessel type are listed in Tables 6, 7, and 8. Note that, because of the hydrophone location in lower Glacier Bay, large vessels, particularly large cruise ships, do not operate close to the hydrophone. It is unlikely that they would ever approach to within 1 mile of the hydrophone. On the other hand, medium and small vessels operate throughout lower Glacier Bay and it is possible that, in some cases, they might pass close to, or directly over, the hydrophone. Also, since Bartlett Cove is the primary port for small and medium vessels to dock and access Park facilities, this type of vessel traffic is further concentrated in this area.

Table 6 Large Marine Vessel Noise Statistics

	Min	Avg	Max	Std Dev	Count
Overall	72	98	129	10.3	323
Aug-00	72	96	113	8.8	73
Sep-00	78	96	116	9.3	54
Oct-00	82	90	93	5.3	4
Nov-00	79	98	117	12.4	8
Dec-00	79	84	88	3.8	5
Feb-01	94	94	94		1
Mar-01	89	92	95		2
May-01	105	109	114	4.7	3
Jun-01	95	106	116	7.0	13
Jul-01	86	105	121	8.8	26
Aug-01	75	98	129	11.0	70
Apr-02					0
May-02	83	107	123	13.4	7
Jun-02	78	96	117	9.3	56

Table 7 Medium Marine Vessel Noise Statistics

	Min	Avg	Max	Std Dev	Count
Overall	72	93	126	8.9	1071
Aug-00	74	92	115	9.1	157
Sep-00	72	91	123	9.3	131
Oct-00	79	92	111	8.2	38
Nov-00	74	89	104	7.5	40
Dec-00	74	90	118	10.6	23
Feb-01	81	93	107	7.5	19
Mar-01	75	86	110	10.2	13
May-01	83	94	106	7.8	24
Jun-01	78	96	117	8.2	102
Jul-01	79	95	121	8.1	162
Aug-01	74	93	126	8.9	274
Apr-02	87	94	104	5.6	6
May-02	76	89	107	8.9	34
Jun-02	77	93	116	8.7	48

Table 8 Small Vessel Noise Statistics

	Min	Avg	Max	Std Dev	Count
Overall	78	96	126	8.6	262
Aug-00	81	95	113	7.9	35
Sep-00	85	96	114	8.0	15
Oct-00	88	93	103	5.1	8
Nov-00	87	87	87		1
Dec-00	78	87	96		2
Feb-01	83	88	91	3.5	4
Mar-01					0
May-01	85	95	107	6.1	13
Jun-01	80	96	110	8.9	22
Jul-01	83	97	117	7.9	87
Aug-01	84	98	126	9.9	40
Apr-02	88	94	100	6.1	3
May-02	99	99	99		1
Jun-02	80	98	121	10.5	31

The histogram in Fig. 19 showed the distribution of marine vessel noise for all vessels and Fig. 26 showed that received levels for large vessels were, on average, slightly greater than for other vessel types. To show the relative noise level distribution between large vessel noise and the statistics for all vessels, a histogram of large vessel noise levels was graphed in Fig. 27 along with the histogram for all vessels from Fig. 19. This comparison shows that the distribution of large vessel noise levels was weighted slightly towards higher levels than the entire population. It also demonstrates that a minority of samples contained large vessel noise, as previously shown in Fig. 25.

Similar histograms were generated for medium and small vessel noise levels. These plots are also included in Fig. 27. Note that the distributions of levels in these cases were weighted more towards the middle of the population. Also, the relative number of samples for each type is evident, showing that medium vessels accounted for most of the vessel that were observed (as previously shown in Fig. 25).

To assess the frequency content of acoustic energy associated with each vessel type, similar plots were developed that show the number of vessel samples that had peak levels in each one-third octave frequency band. These plots show whether certain vessel types were more likely to produce noise energy in particular parts of the frequency spectrum. Figure 28 shows that large vessels typically had peak levels at lower frequencies, especially in the 80 to 200 Hz bands. Medium vessel peak frequencies were widely distributed, most peak levels occurred in the 125 to 3150 Hz range. This wide distribution was due to some medium vessels exhibiting peak levels at propeller cavitation frequencies above 1 kHz, some peaking at propulsion plant frequencies below 1 kHz, and some peaking at frequencies corresponding to noise items unique to a certain vessel – propeller singing, for example. Small vessel noise energy typically peaked at frequencies above 800 Hz. This tendency to peak at higher frequencies was due to the noise character of small, high speed engines and propellers, and the relative inability of small-size sources to radiate noise efficiently at lower frequencies.

Hourly Variation of Vessel Noise

The frequency of occurrence of marine vessel noise was compiled on an hourly basis to determine whether vessel noise influence was more prevalent at particular times-of-day. These statistics were generated by season, based on the seasonal vessel noise pattern shown in Fig. 7:

(a) winter (October-April)
(b) spring (May)
(c) summer (June-August)
(d) fall (September)

Figure 29 shows that late P.M. and early A.M. noise samples were less likely to contain vessel noise compared to samples collected at other times-of-day. In any given season, 87-90% of the samples containing vessel noise occurred between 5 A.M. and 9 P.M. The graphs also show that vessel noise occurrence exhibited a somewhat peaked distribution for winter, spring, and fall. In summer the distribution was flatter, but still showed less vessel activity between 9 P.M. and 4 A.M.

Vessel Speed Limit Effects

When humpback whales are present in lower Glacier Bay, the Park Superintendent typically imposes a 10-knot speed limit on all vessel traffic. In addition, every year between 15 May and 31 August, a 20-knot speed limit is in place. In 2000, a

10-knot speed limit was imposed between 23 June and 21 September. In 2001, the 10-knot speed limit was not imposed until 31 August. Thus, by comparing the vessel noise levels logged from 1 to 30 August of 2000 and 2001, the effect of a 10-knot versus 20-knot speed limit could be investigated. Figure 30 shows the minimum, average, and maximum vessel noise levels for these time periods for all vessels (overall), and for each vessel type individually. The +/- one-standard deviation levels are indicated by bars in the graph. These levels are also listed in Table 9, along with the number of samples containing vessel noise per "day".

Table 9 10-knot versus 20-knot Vessel Noise Levels

Speed Limit	Vessel Type	Min	Avg	Max	Std Dev	Samples per "day"
10	**Overall**	72	93	115	9.2	16.0
20	**Overall**	74	95	129	9.8	12.7
10	**Large**	72	96	113	8.9	4.2
20	**Large**	75	98	129	11.1	2.4
10	**Med**	74	92	115	9.2	9.0
20	**Med**	74	93	126	8.9	9.0
10	**Small**	81	94	109	7.4	1.9
20	**Small**	84	98	126	9.9	1.4

The speed limit comparison shows that, on the average, the minimum, average, and maximum vessel levels were all lower, to some degree, during August 2000 when the speed limit was 10 knots. This trend was observed for all vessels, and for each vessel category. The minimum and average noise levels were up to 4 dB lower during the 10-knot speed limit period. Notably, the maximum vessel levels were the most dramatically affected. They were 11 to 17 dB lower, depending on the category, for the period when the 10-knot speed limit was in effect.

Unidentified Noise

A total of 1277 samples contained some type of acoustic noise from sources that were not unidentified. Most of these noises were short duration, transient events. Descriptions of these sounds included: *bang, rumble, bump, slap, drum beat, thump, clank, clunk, pop, splash,* and *gurgle*. A small number of sounds were continuous and may have been distant vessels that barely affected noise levels. On several occasions noise samples appeared to contain acoustic energy from fathometers at frequencies above 20 kHz. In June and July 2001, some samples contained energy at 28.5 kHz that was characteristic of a survey sonar.

Of the 1277 samples that contained unidentified noise, 954 samples (or 75%) contained a rolling or knocking sound that peaked noise levels in the neighborhood of 100 Hz. This sound was transient in nature and was reminiscent of a bowling ball rolling slowly along a wood floor. It was also described like the sound of a heavy trunk or wood box being dragged across the wooden deck of a ship. It was often heard when no vessel noise was present. On several occasions it was accompanied by humpback whale whumps or groans. When this noise was present, levels at 100 and 125 Hz averaged 91 and 93 dB, respectively. With a standard deviation of about 7 dB, its variability was comparable to wind noise, but less than vessel noise, however this statistic is complicated by the transient nature of this sound. Maximum levels reached up to 109 dB. Figure 31 shows that the noise was almost never heard outside of summertime and that it was most prevalent in June and July. On average, it was present in more than 20 samples per day in June and July of 2001. Its seasonal occurrence may mean that it was biologic in nature, however further investigation will be required to identify the source of this common summertime noise.

SUMMARY AND CONCLUSIONS

Over 5200 underwater noise samples collected during 14 months between August 2000 and June 2002 in lower Glacier Bay were used to characterize the underwater acoustic environment of the area. Each of these samples, which were collected on an hourly basis, were reviewed by an underwater acoustic analyst and the characteristics for each sample were logged in a Microsoft Access database. Statistics for noises from both natural and manmade sources were developed, and the noise levels and the frequency of noise occurrence for each noise type were trended.

As is typical for most areas, the dominant natural source of underwater noise was wind generated surface noise. In 62% of the usable samples, the 1 kHz one-third octave band level was controlled by wind noise. The average wind noise level over the entire period was 83 dB (1 kHz one-third octave band level), which is comparable to levels observed in many ocean areas of the world. Wind noise levels ranged from a minimum of 67 dB to a maximum of 100 dB. The average wind noise levels for each month were not widely variable, they were generally within a few dB of the overall average level of 83 dB.

Rainfall was another important source of natural noise. Noise levels from rainfall were tracked by logging the 16 kHz one-third octave band level, since rain typically caused a peak in the one-third octave spectrum at this frequency band. Over all samples containing rain noise, the average level was 89 dB. Levels as high as 110 dB were recorded. Rain noise was not distinctly prevalent in winter versus other seasons. Months logging more frequent rain noise included September, October, and December of 2000, but June 2002 averaged 3.6 out of 24 samples per day containing rain noise, the highest number of any month. Over the entire period covered by the database, the number of samples per day containing rain noise averaged 2.1.

Noise from marine life was also tracked. Humpback whales were the most common source of biologic noise. Humpback whale grunts, groans, whoops, squeaks, and other similar sounds were present in 219 samples, and 24 samples contained humpback whale song sounds. Eighty-two samples contained sounds from other biologic sources such as killer whales. Humpback whale sounds were most common in the August through November time period. Seventy-percent of all humpback songs were observed in October 2000. The frequency of occurrence of biologic noise was compared to that of marine vessel noise. Except for October 2000, vessel noise was more common in all months.

The sole source of identifiable manmade noise in this study was related to operation of motorized marine vessels. As expected, vessel noise was most common during summer. In summer, about 40% of the noise samples were free of vessel noise; while in winter, October through April, roughly 90% contained no vessel noise. In May and September, approximately 60% of the samples logged no vessel noise. On average, over the entire database, 7.9 out of 24 samples per day contained vessel noise. The rate of vessel noise presence ranged from a low of 1.7 samples per day in December 2000 to a high of 16.5 in August 2000.

Vessel noise levels were tracked by logging the level of the highest amplitude one-third octave frequency band controlled by vessel noise in each sample. The corresponding one-third octave band frequency was also logged. On the average, vessel noise levels exceeded wind noise levels. Overall the average vessel noise level was 94 dB, 11 dB greater than the average wind noise. No vessel noise levels exceeded 130 dB at the hydrophone and only about 1% of the samples containing vessel noise had levels above 120 dB.

Vessel noise character was used to categorize marine craft according to small, medium, and large types. Medium sized vessels were the most common type. They comprised 62% of all the vessels observed. Large vessels and small craft were present in 19% and 15% of all samples containing vessel noise, respectively. Of all vessel types, medium vessel noise was most prevalent in essentially all months. In August 2000 and June 2002, large vessel noise, i.e. large cruise ships, reached an average of about 4 samples per day. Small craft noise was most common in the May through September period.

On the average, large vessels were slightly louder at the hydrophone than medium and small craft. Large vessels averaged 98 dB, while the average noise levels for medium and small vessel were 93 and 96 dB, respectively. A large vessel logged the highest level, 129 dB. The maximum level for both medium and small vessels was 126 dB.

Large vessel noise spectra typically peaked at lower frequencies relative to other vessel types. Their peak levels usually occurred in the 80 to 200 Hz frequency range. Medium vessel peak frequencies were more varied, but most occurred between 125 and 3150 Hz. Small craft noise typically peaked at frequencies above 800 Hz.

Effects of the 10-knot vessel speed limit in August 2000 were examined. Minimum and average vessel noise levels were up to 4 dB lower during the 10-knot period compared to the 20-knot period. Maximum vessel levels were as much as 17 dB lower when the 10-knot speed limit was in effect.

Over 1200 samples contained some form of noise from an unidentified source. Most of these sounds were transient in nature. One particular sound, a heavy rolling sound like a heavy bowling ball rolling on a wood floor, was present in 75% of the samples that contained unidentified noise. This sound peaked noise levels in the 100 to 125 Hz range, and it was almost never observed outside of the summer months. It was most prevalent in June and July, and, on average, it was observed in more than 20 out of 24 samples per day in June and July 2001. Additional investigation will be required to identify the source of this common summer noise.

The effort described in this interim report will be followed by a more complete and extensive investigation and report. Analysis for months partially covered in this report will be completed and data for additional months will be included. The more extensive report will be issued in 2003. Some of the results covered in this report may be superceded by information contained in the final report, particularly for months that were only partially covered. In the meantime, the results presented here will be useful for understanding noise trends and noise levels for both manmade and naturally occurring noise in lower Glacier Bay.

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(2) Gabriele, C.M. and T. Hart, "Population characteristics of humpback whales in Glacier Bay and adjacent waters: 2000", Glacier Bay National Park (2000).

(3) Doherty, J.L. and C.M. Gabriele, "Population characteristics of humpback whales in Glacier Bay and adjacent waters: 2001", Glacier Bay National Park (2001).

FIGURES

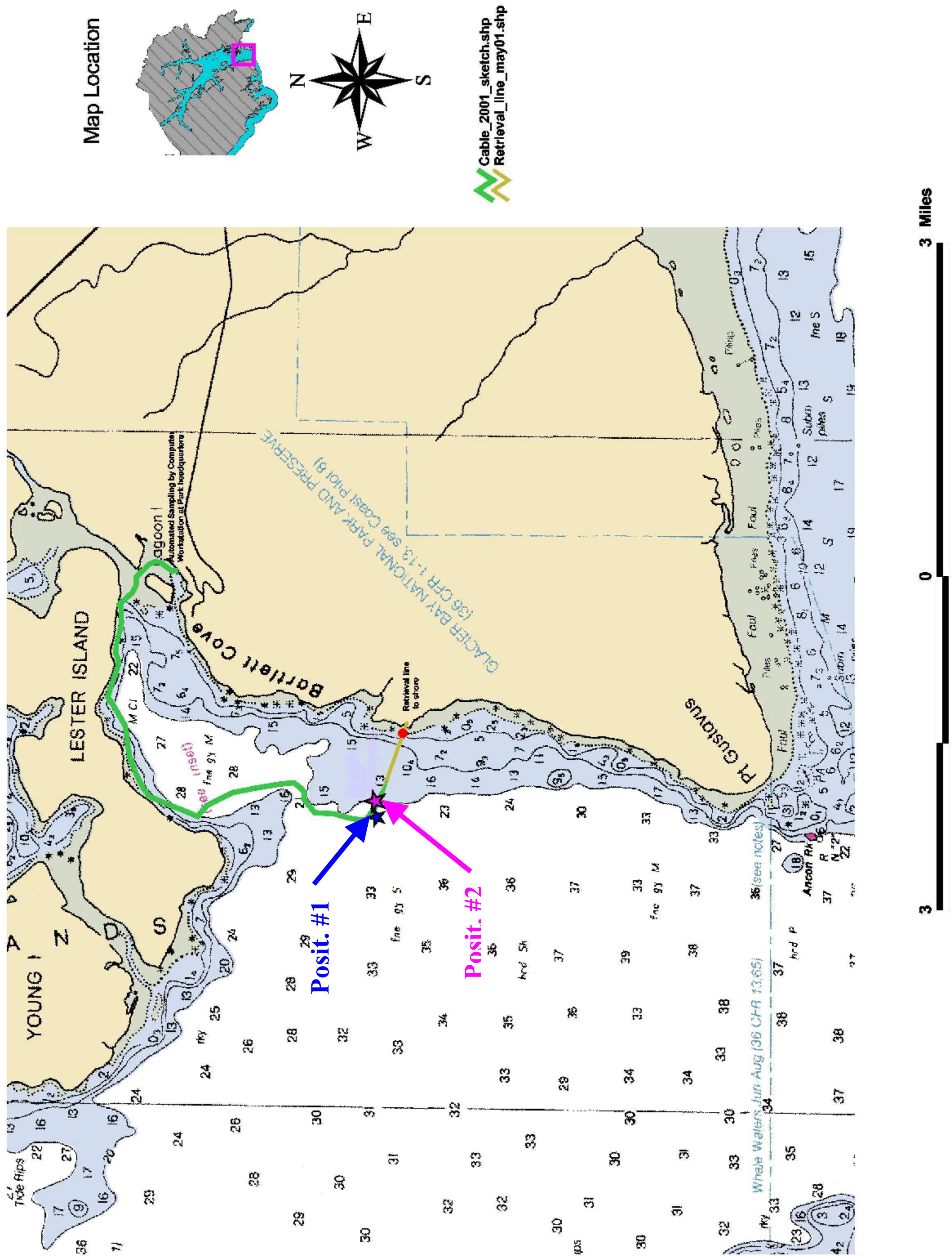
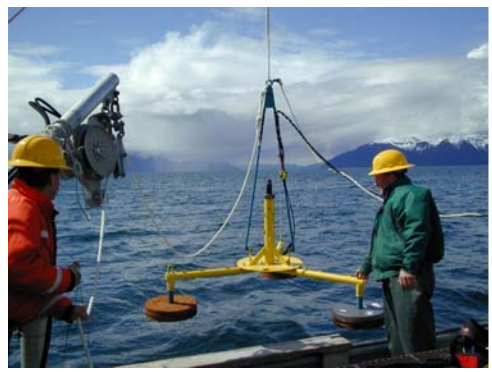


Fig. 1 Hydrophone Location in Lower Glacier Bay



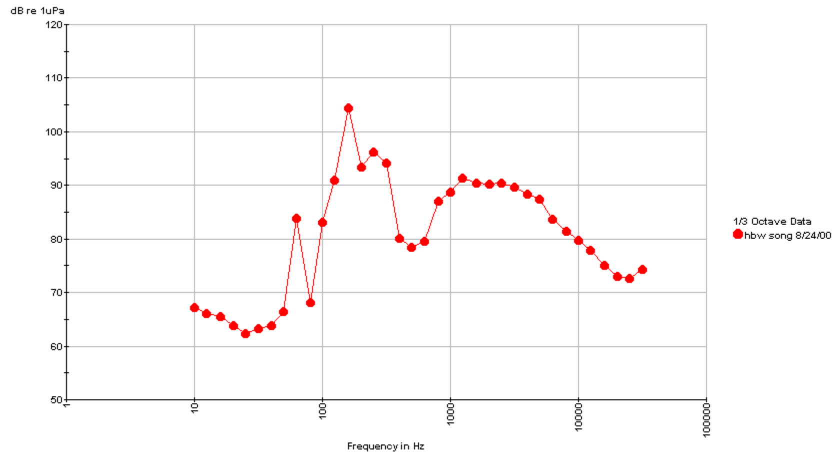
Original hydrophone installation

17 May 2000 – 15 May 2001

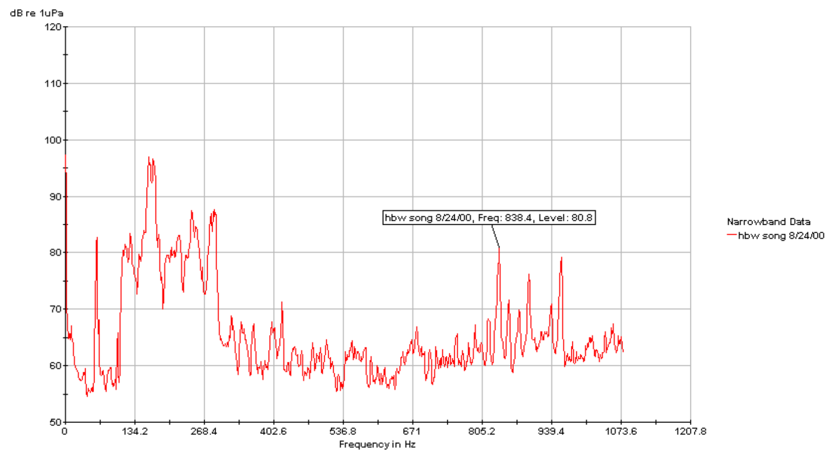
Present hydrophone installation

17 May 2001 - present

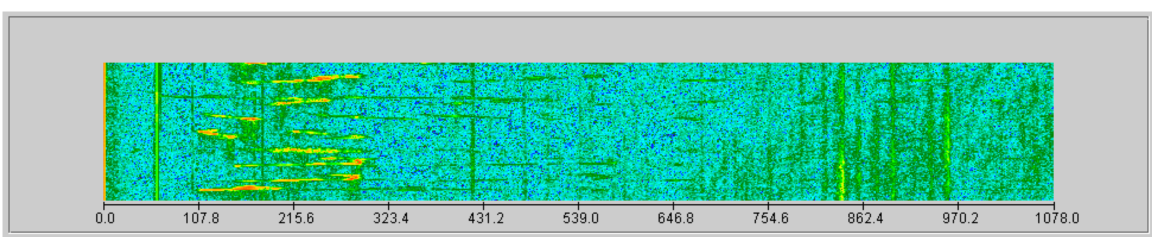
Fig. 2 Hydrophone Installation



Representative One-Third Octave Plot



Representative Narrowband Plot



Representative Waterfall Plot

Fig. 3 Glacier Bay Acoustic Data Acquisition System

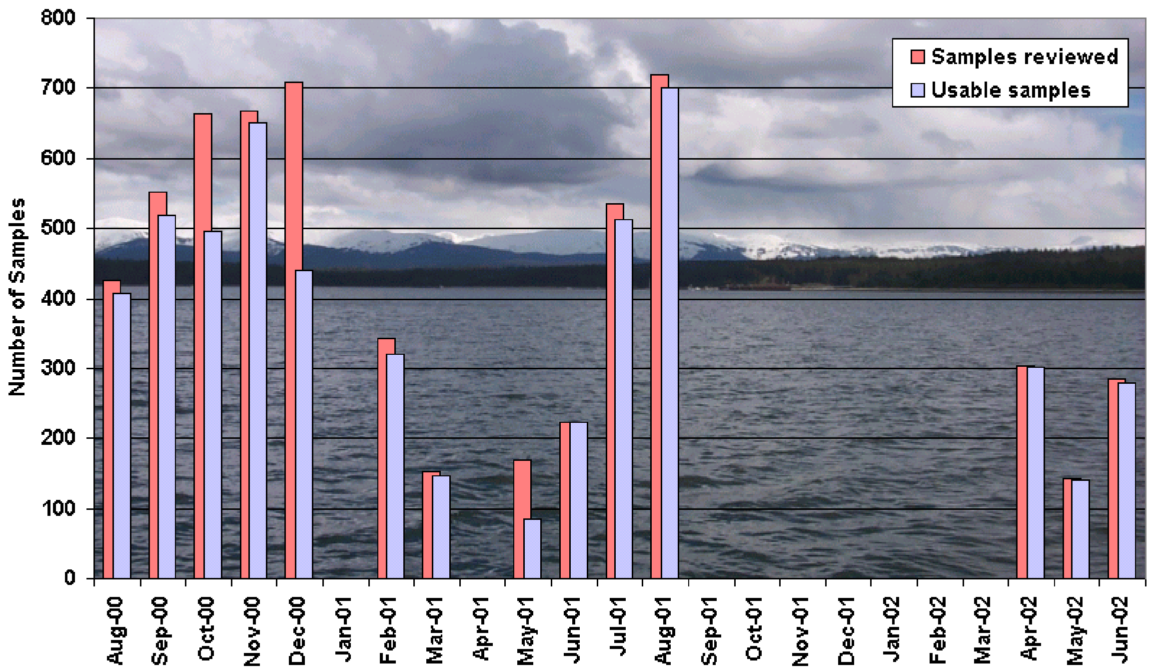


Fig. 4 Reviewed and Usable Samples

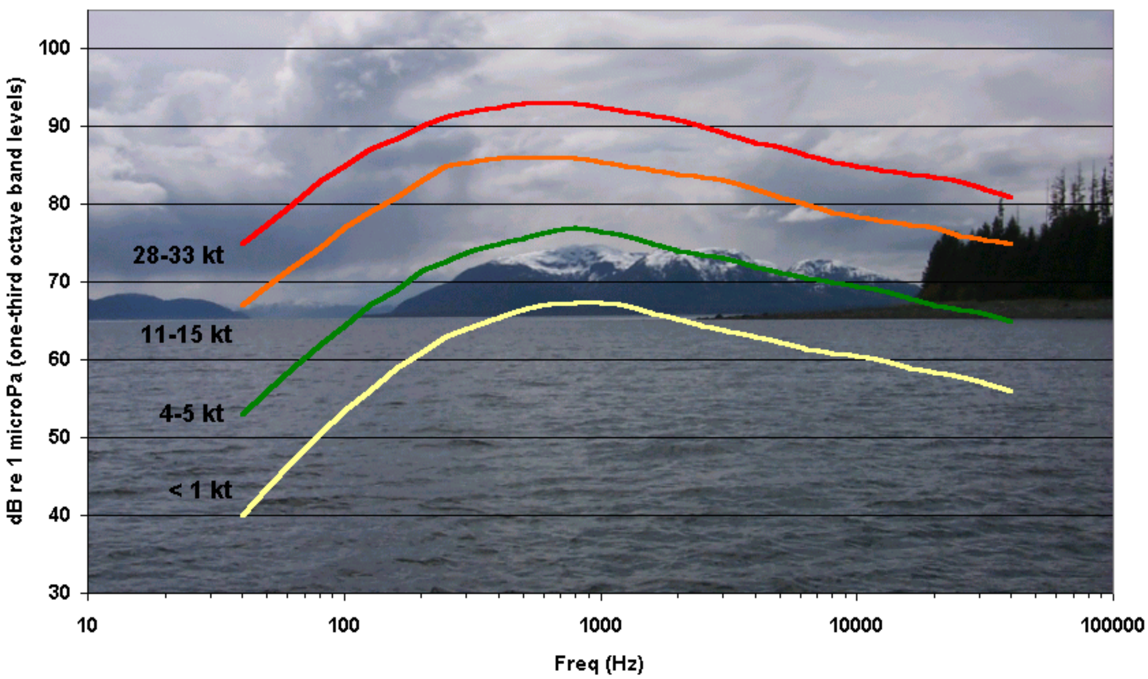


Fig. 5 Knudsen Wind Noise Spectra

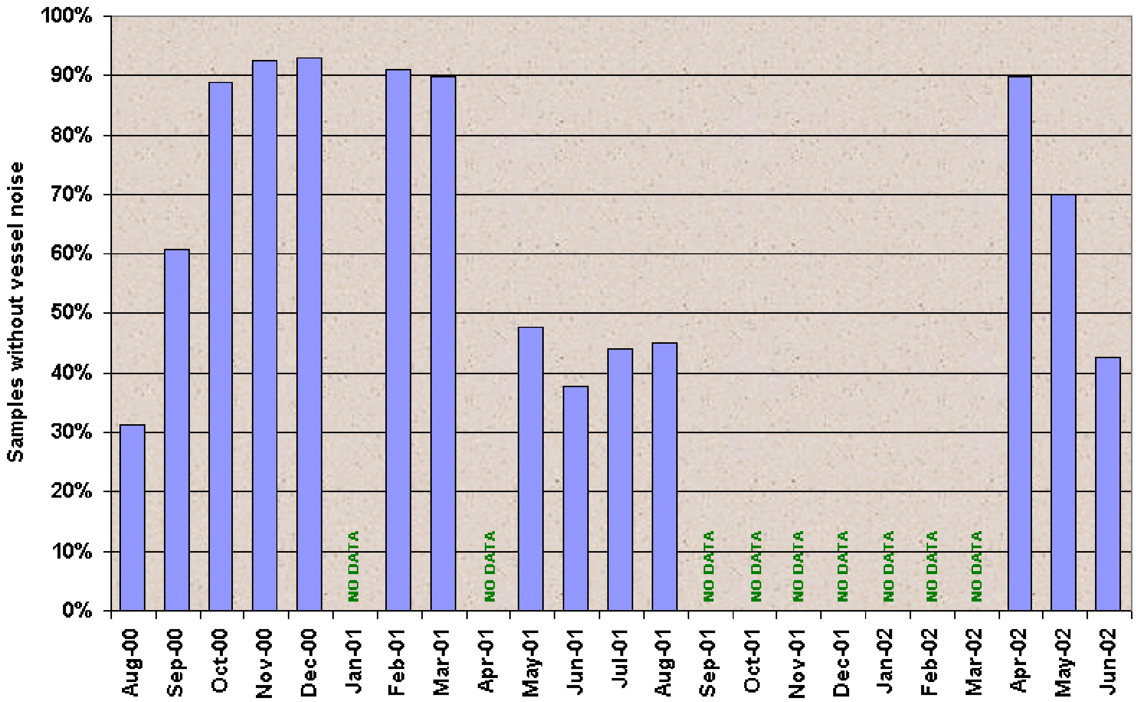


Fig. 6 Samples without Marine Vessels

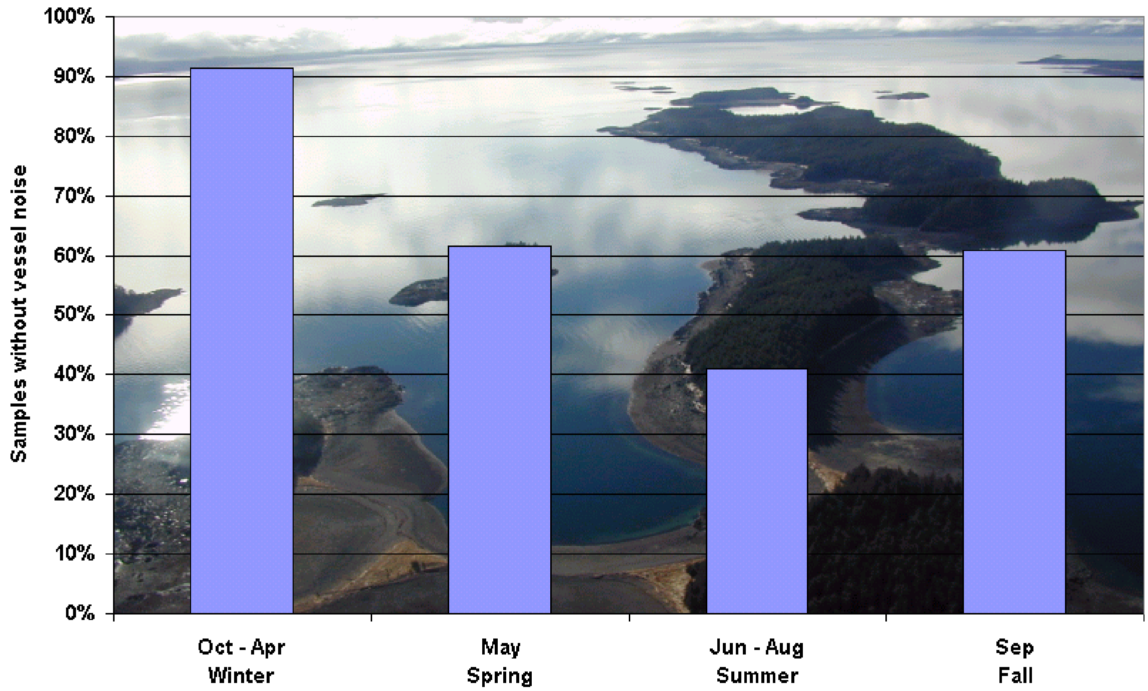


Fig. 7 Samples without Marine Vessels by Season

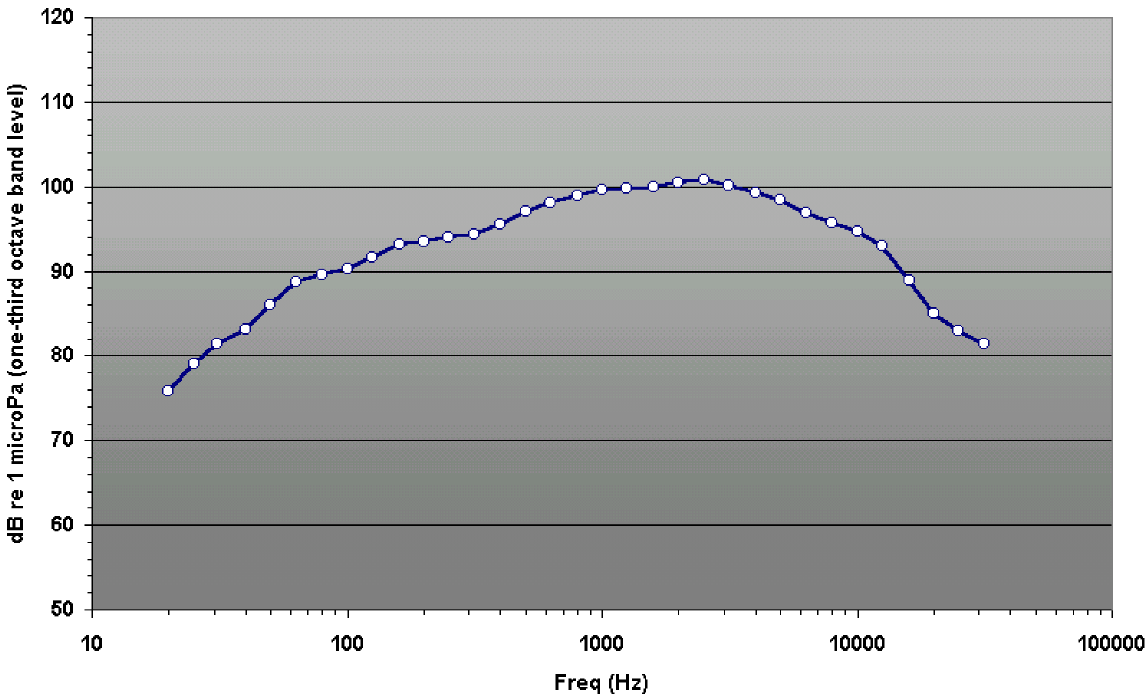


Fig. 8 Representative Glacier Bay Wind Noise Spectrum

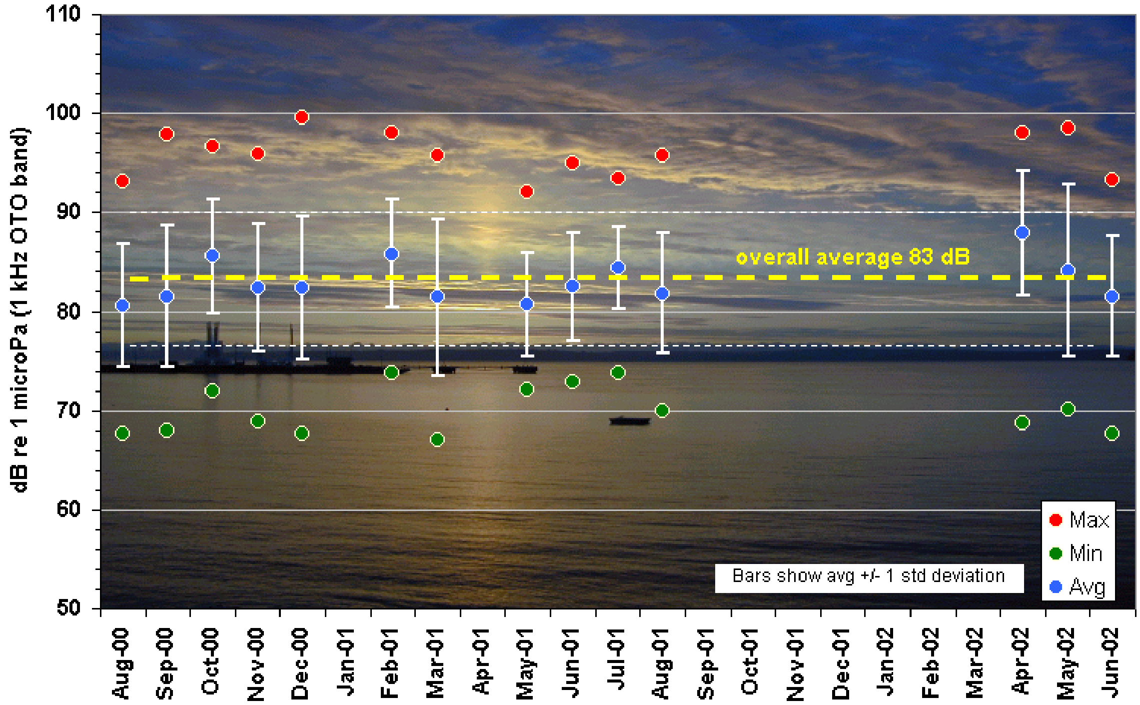


Fig. 9 Wind Noise Level by Month

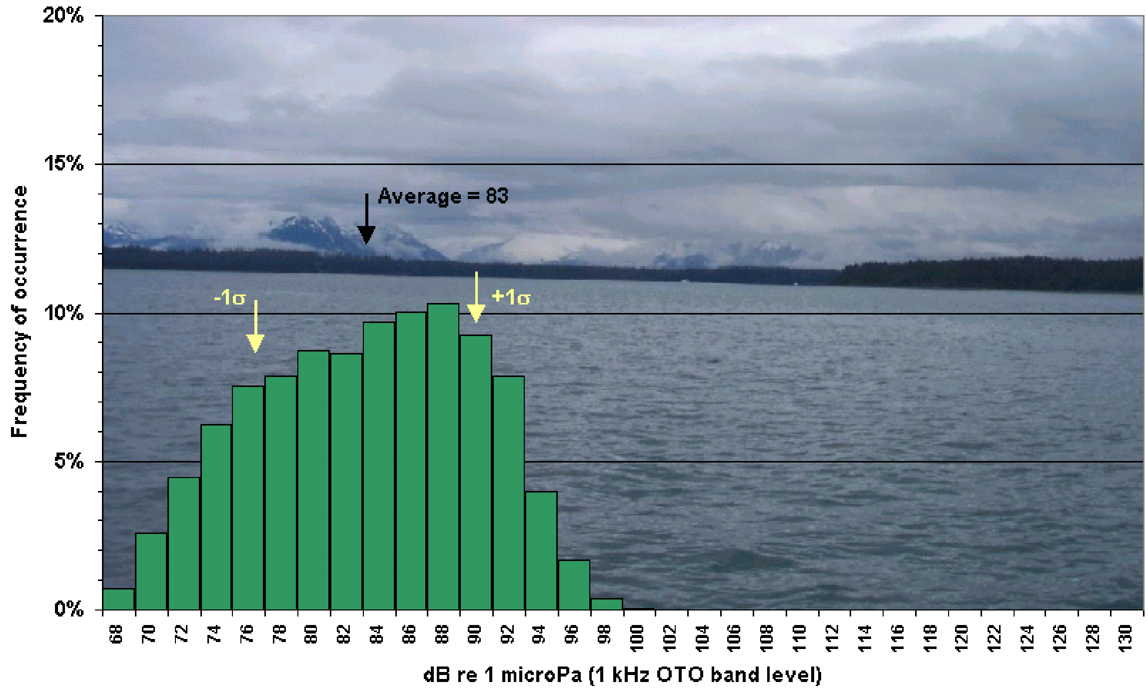


Fig. 10 Distribution of Wind Noise Levels

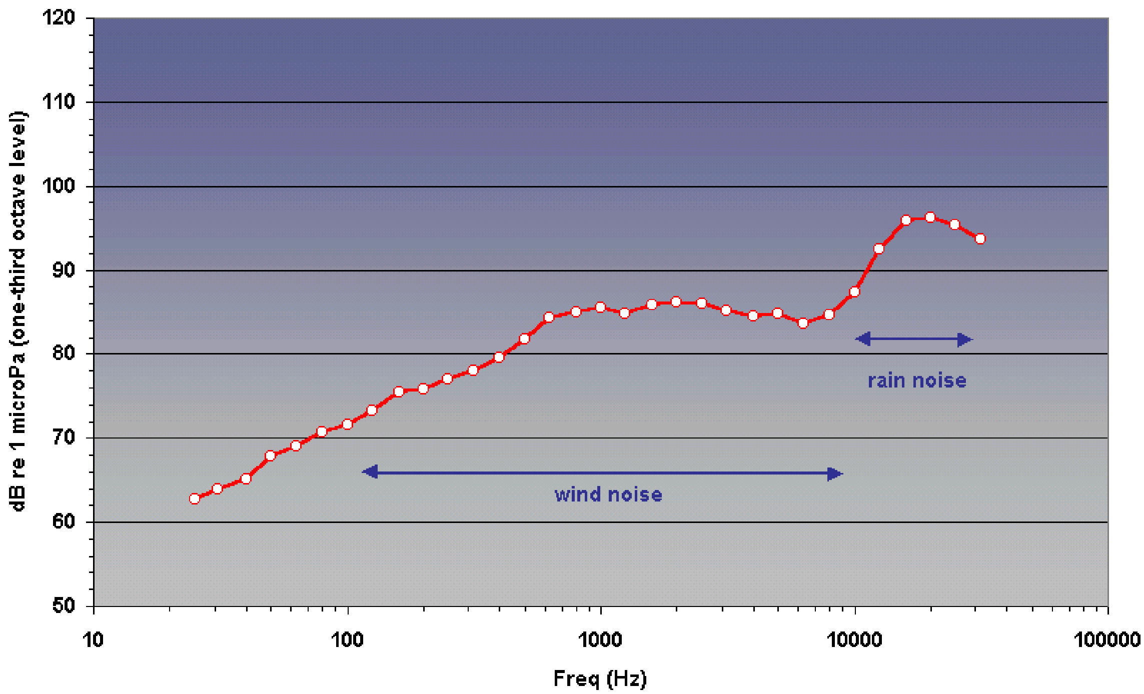


Fig. 11 Representative Rain Noise Spectrum

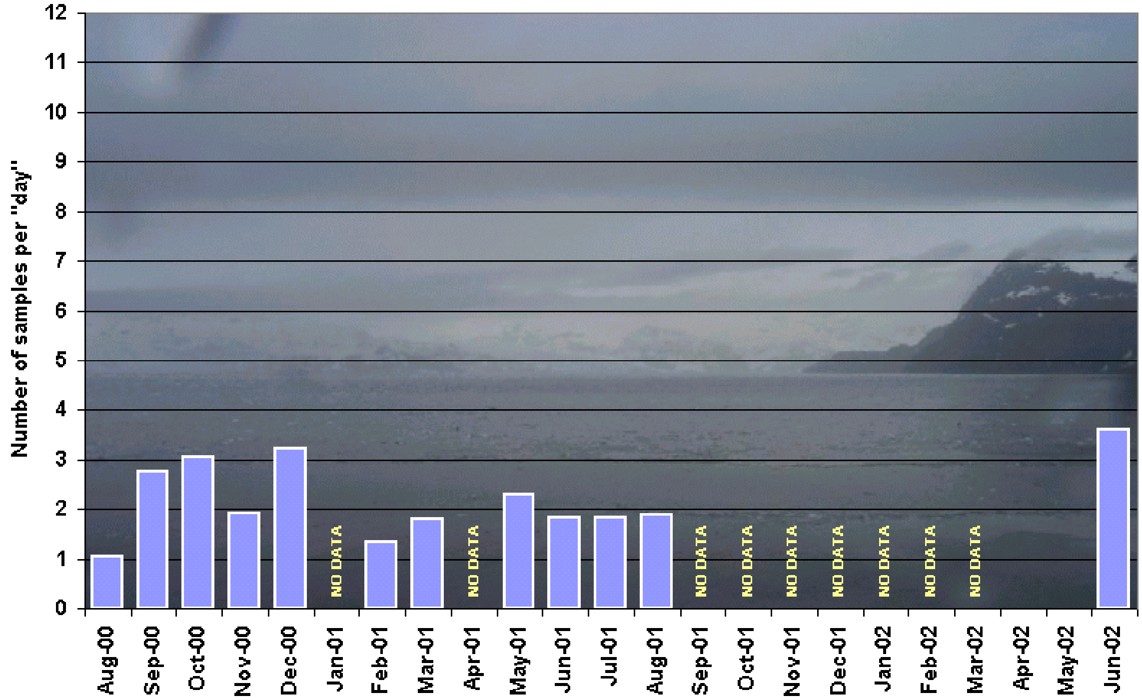


Fig. 12 Samples per Day Containing Rain Noise

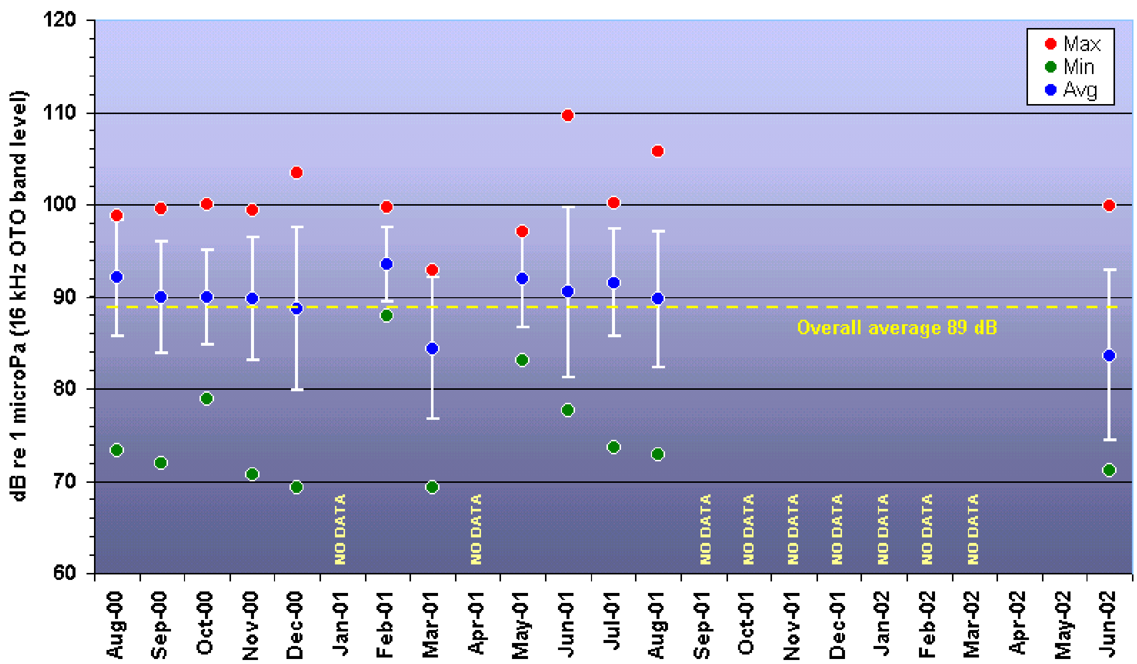


Fig. 13 Rain Noise Levels by Month

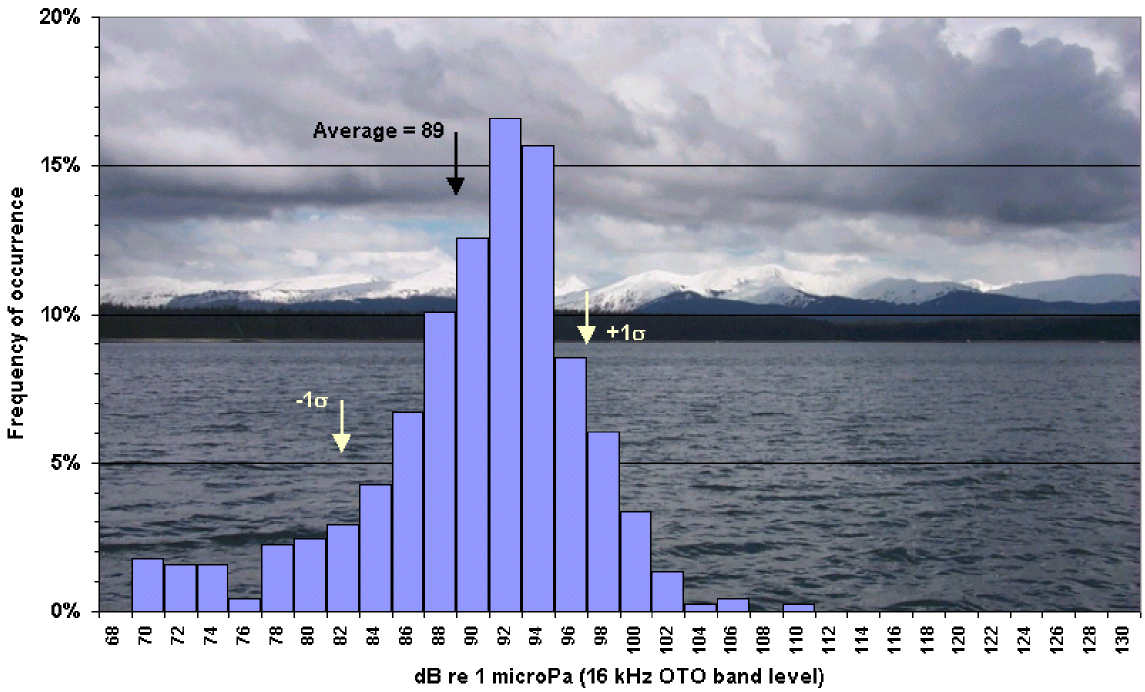


Fig. 14   Distribution of Rain Noise Levels

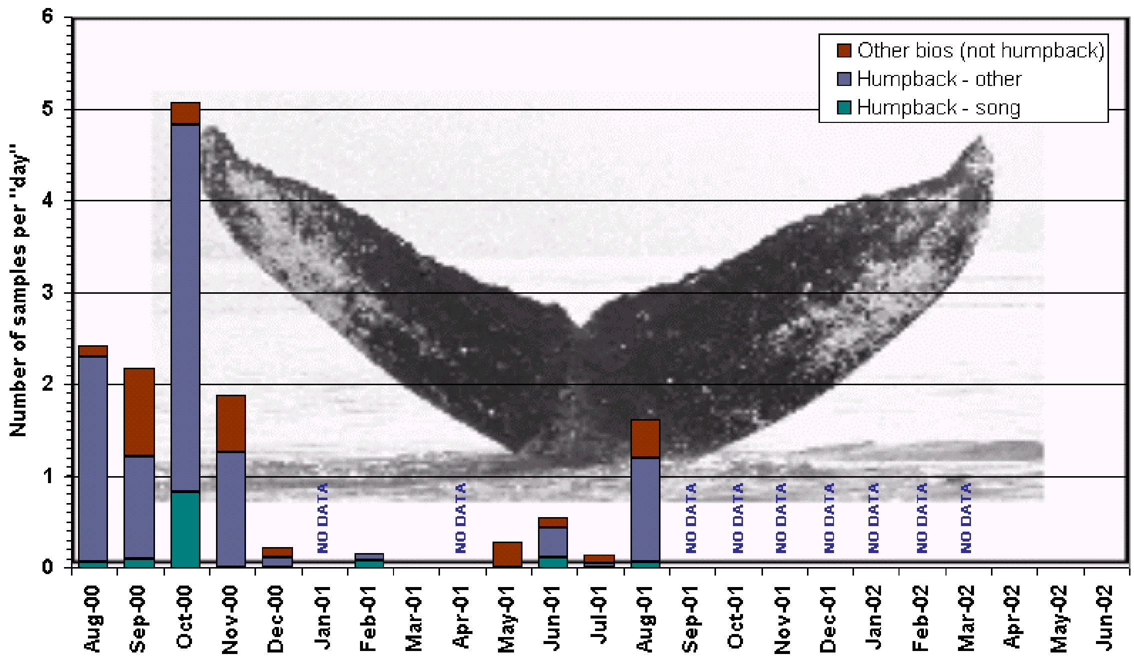


Fig. 15 Samples per Day Containing Biologic Noise

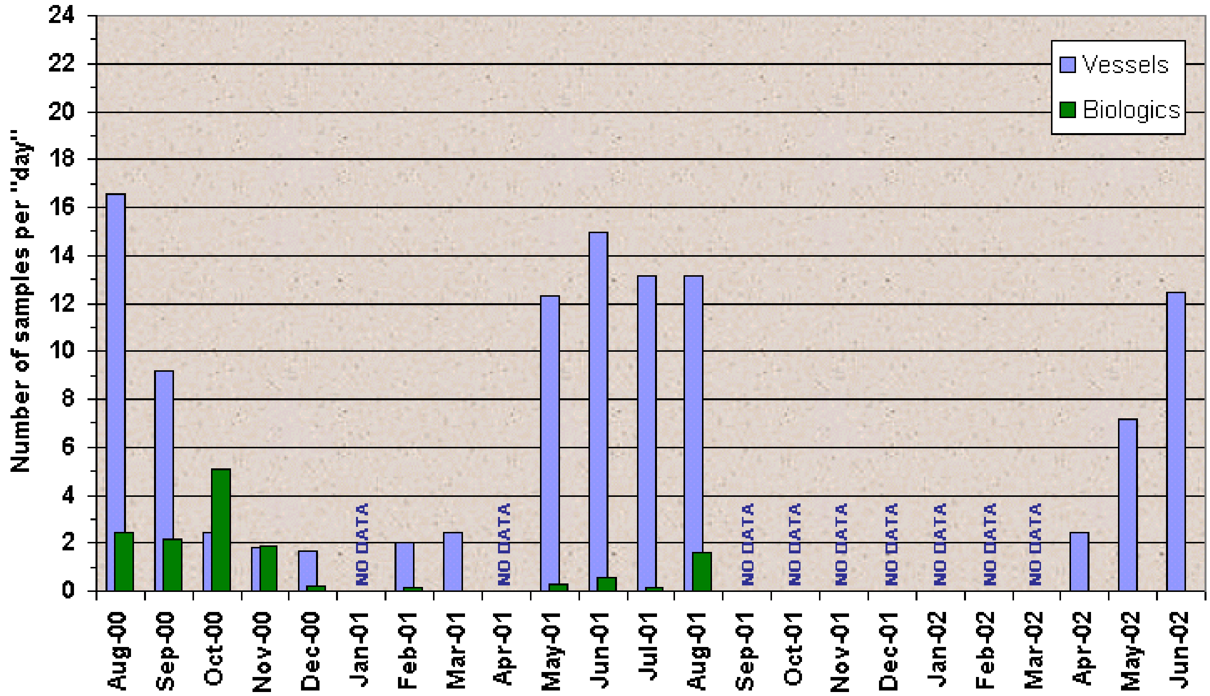


Fig. 16 Samples per Day – Vessels vs. Biologic

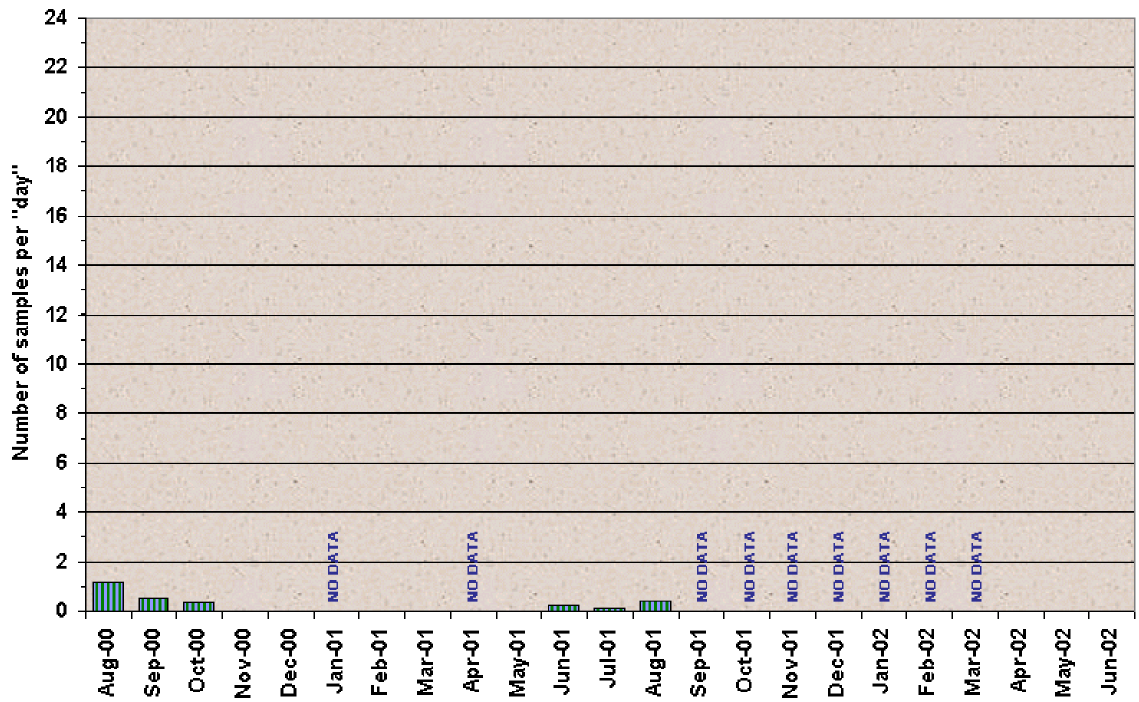


Fig. 17 Samples per Day – Vessels and Bilogic

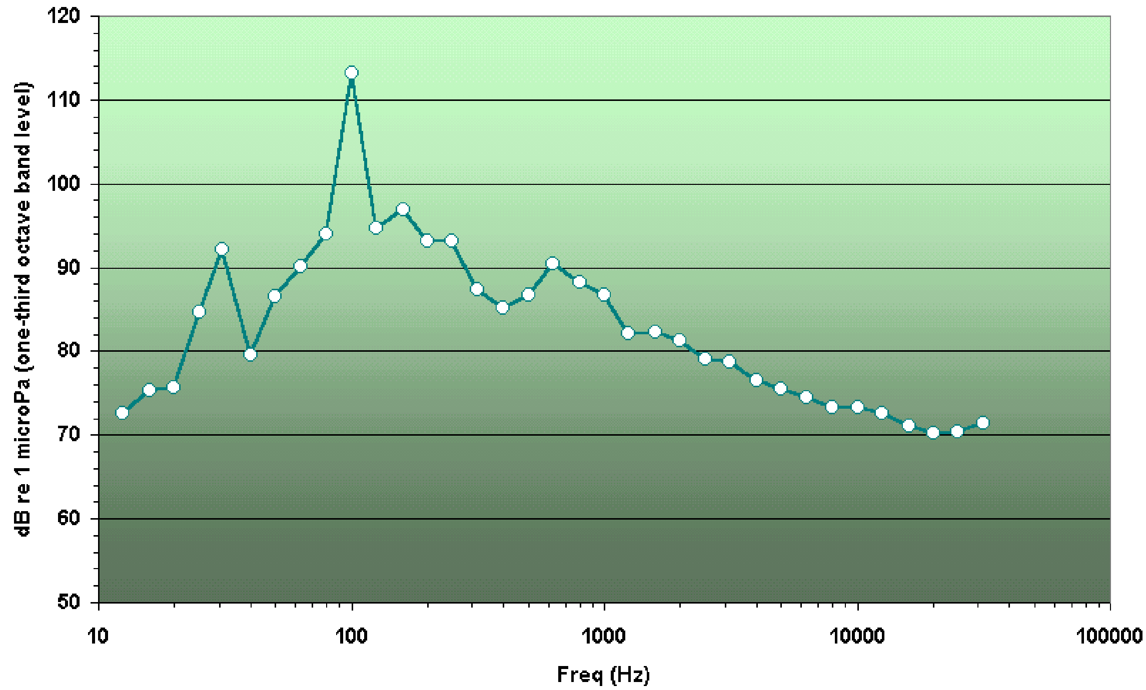


Fig. 18 Representative Marine Vessel Noise Spectrum

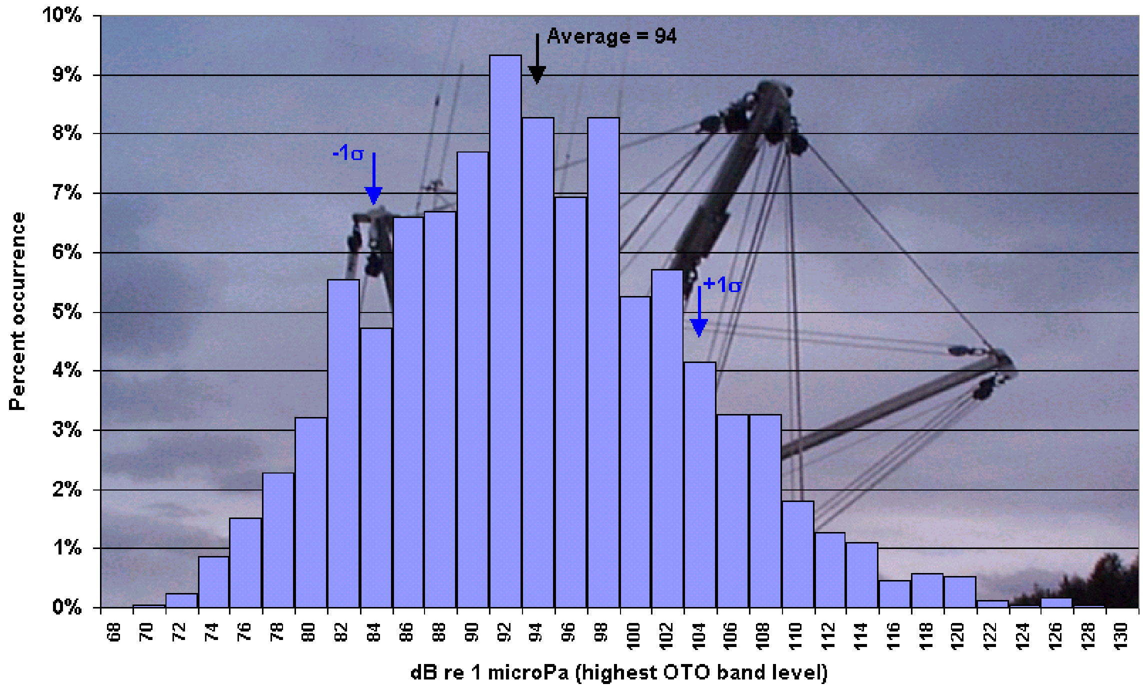


Fig. 19 Distribution of Vessel Noise Levels

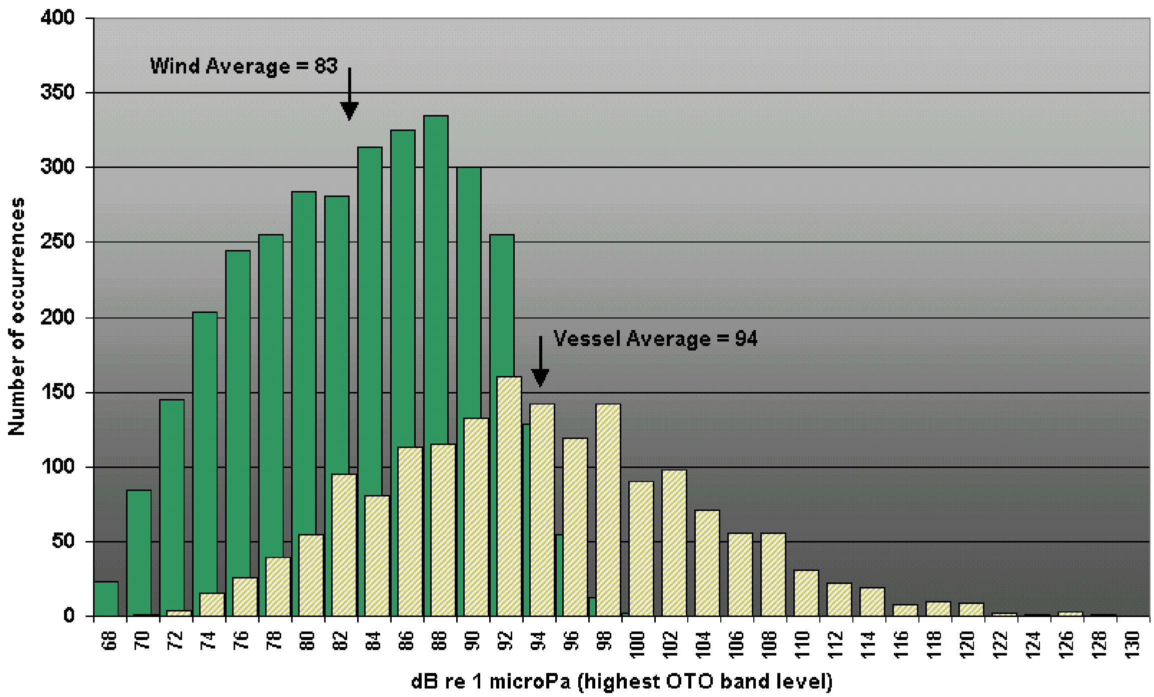


Fig. 20 Distribution of Noise Levels – Wind vs. Vessels

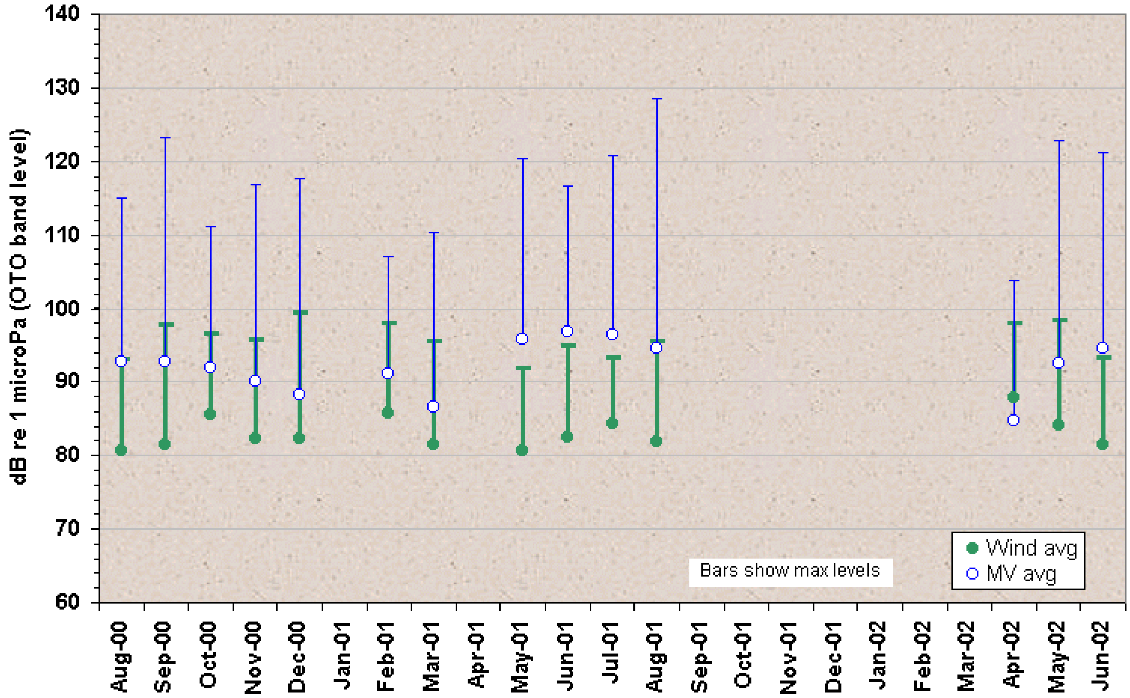


Fig. 21 Wind Noise and Vessel Noise Levels by Month

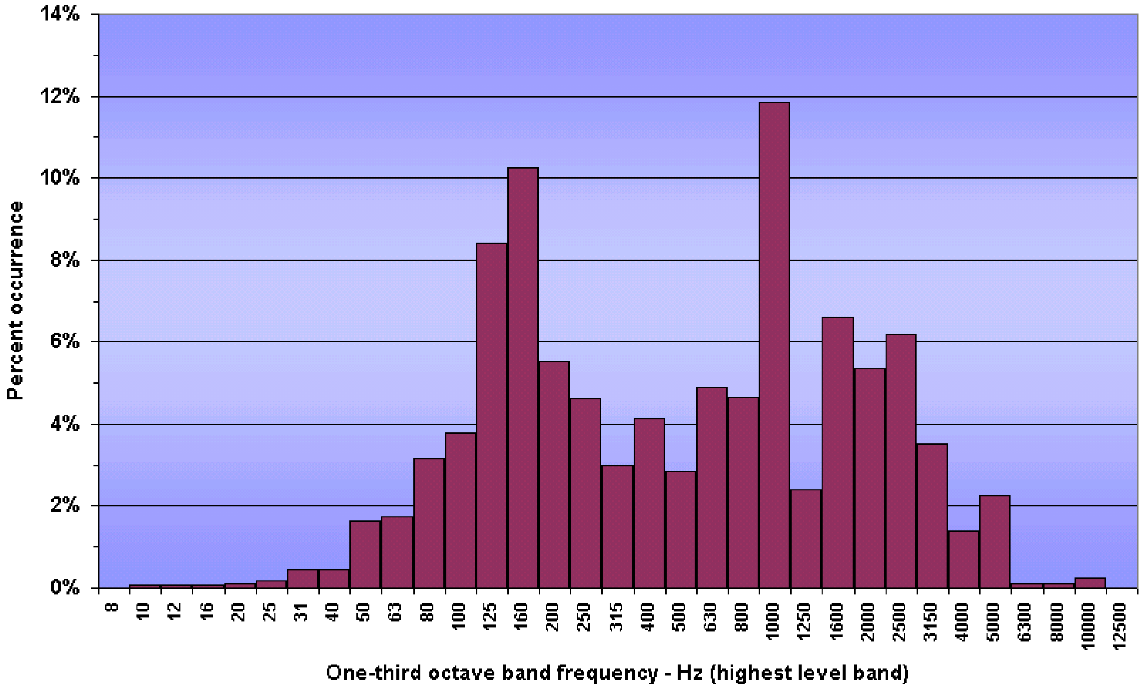


Fig. 22 Distribution of Vessel Noise Peak Frequencies

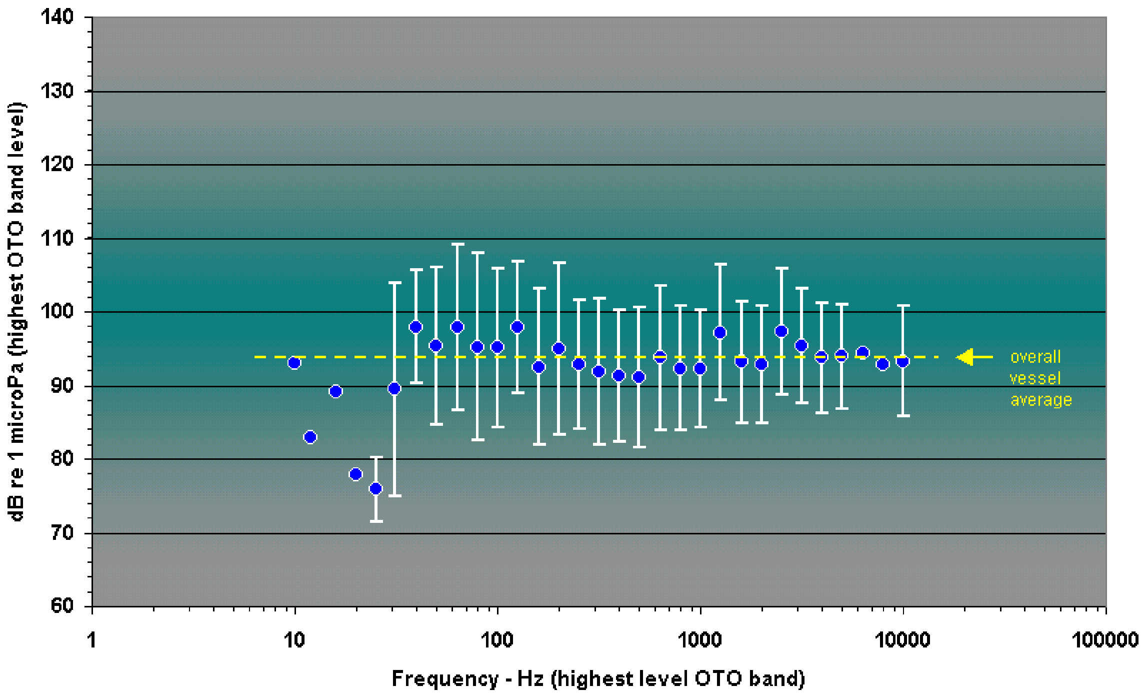


Fig. 23 Vessel Noise Level vs. Frequency

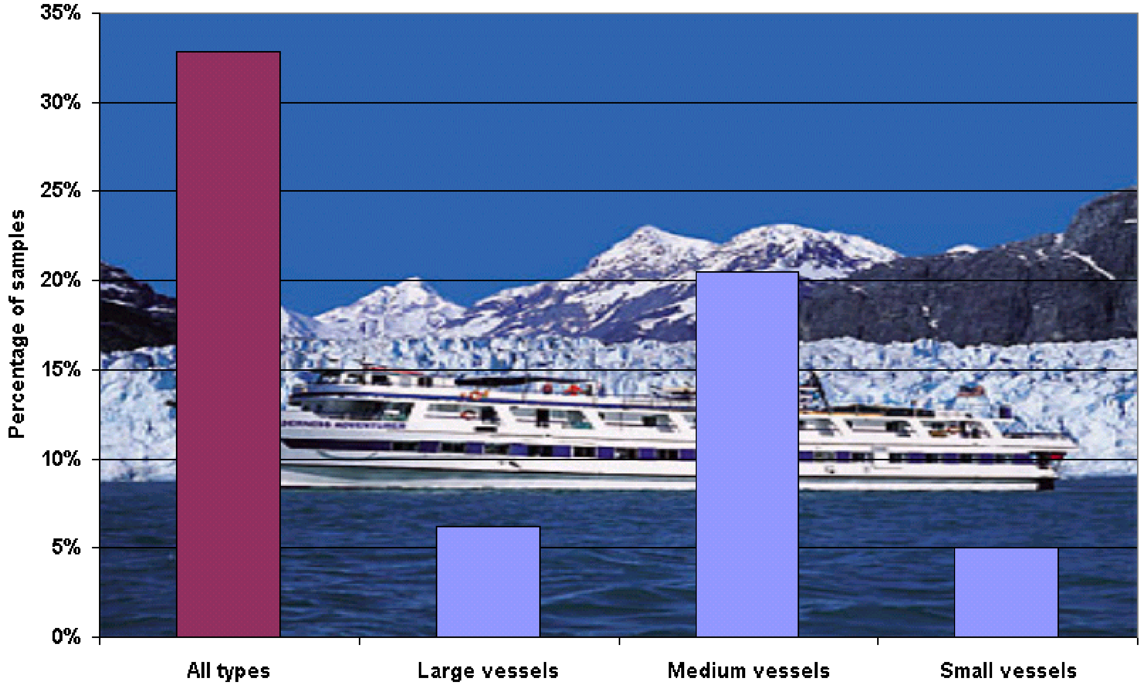


Fig. 24   Samples Containing Vessel Noise by Type

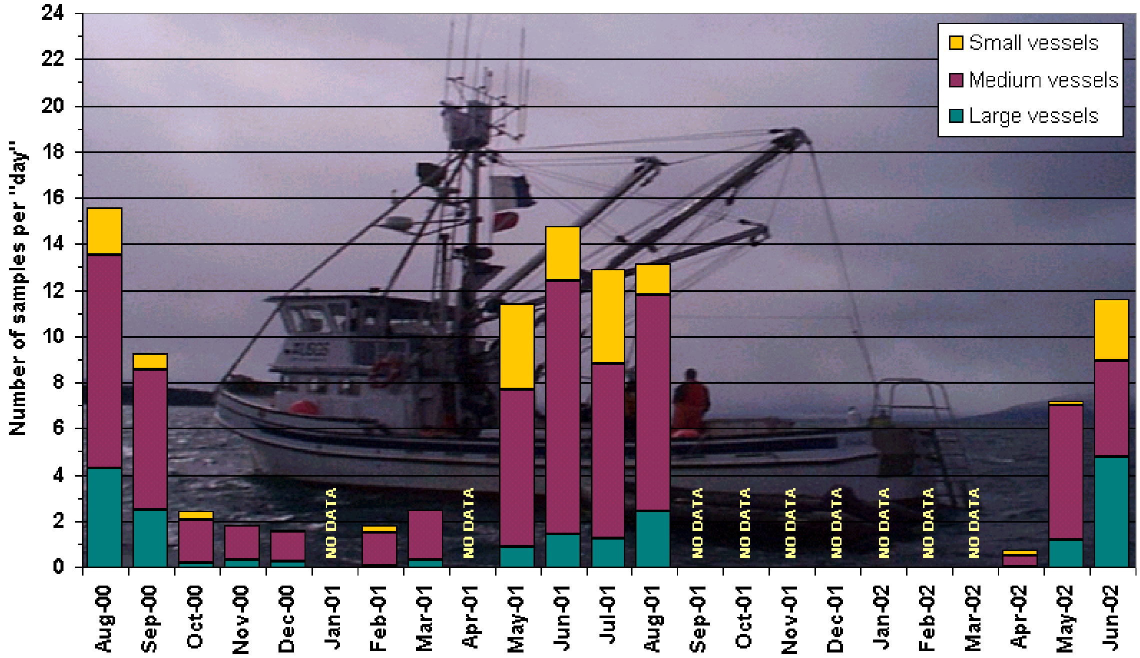


Fig. 25 Samples per Day Containing Vessel Noise

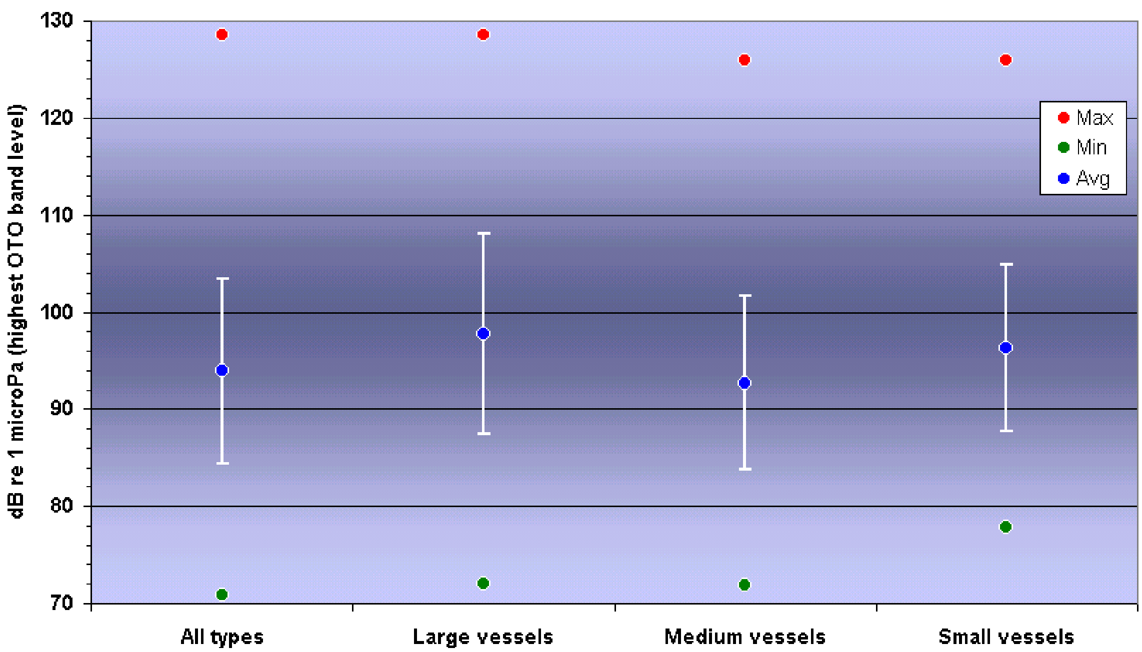


Fig. 26 Noise Statistics by Vessel Type

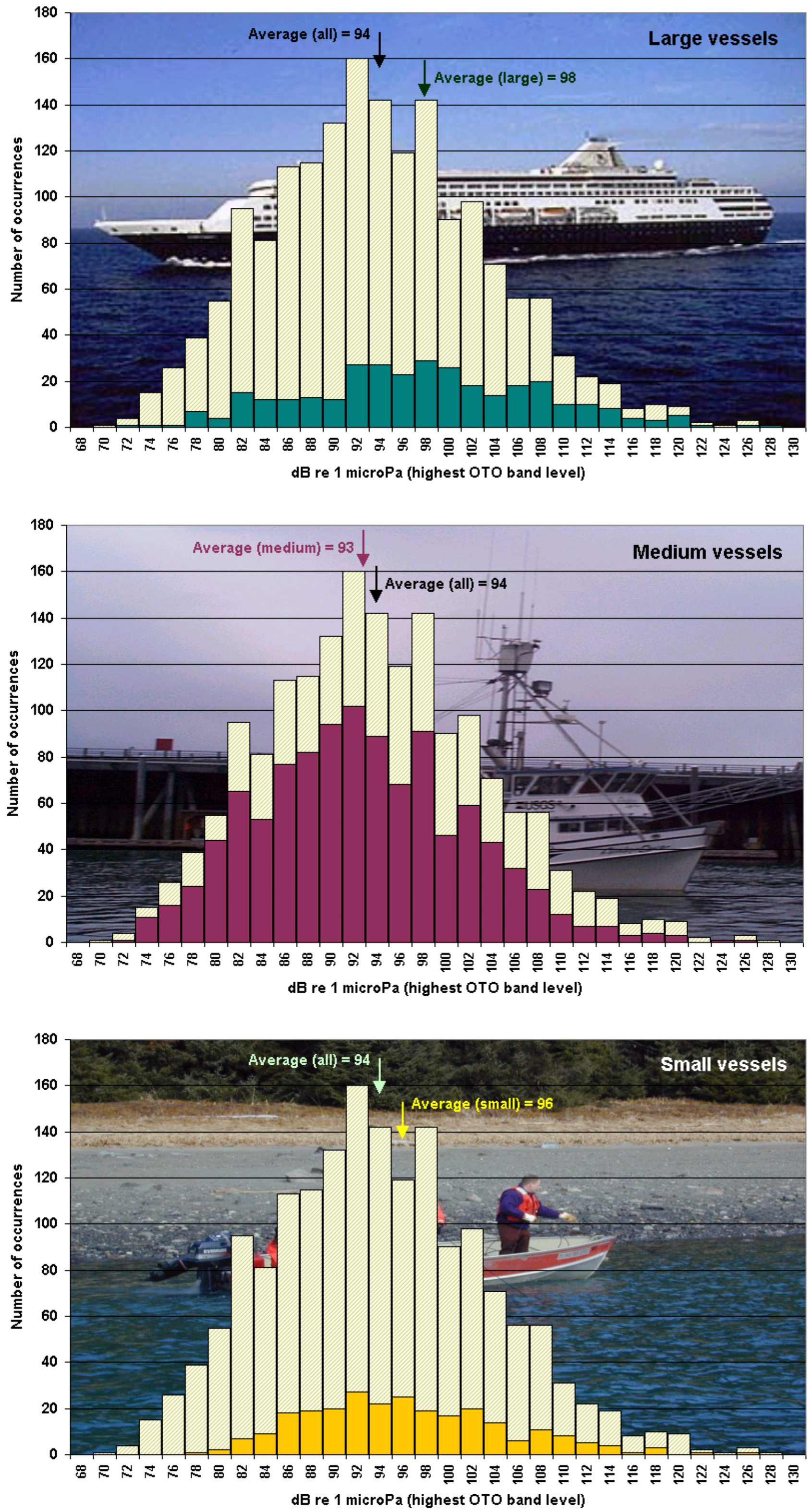


Fig. 27 Distribution of Vessel Noise Levels by Type

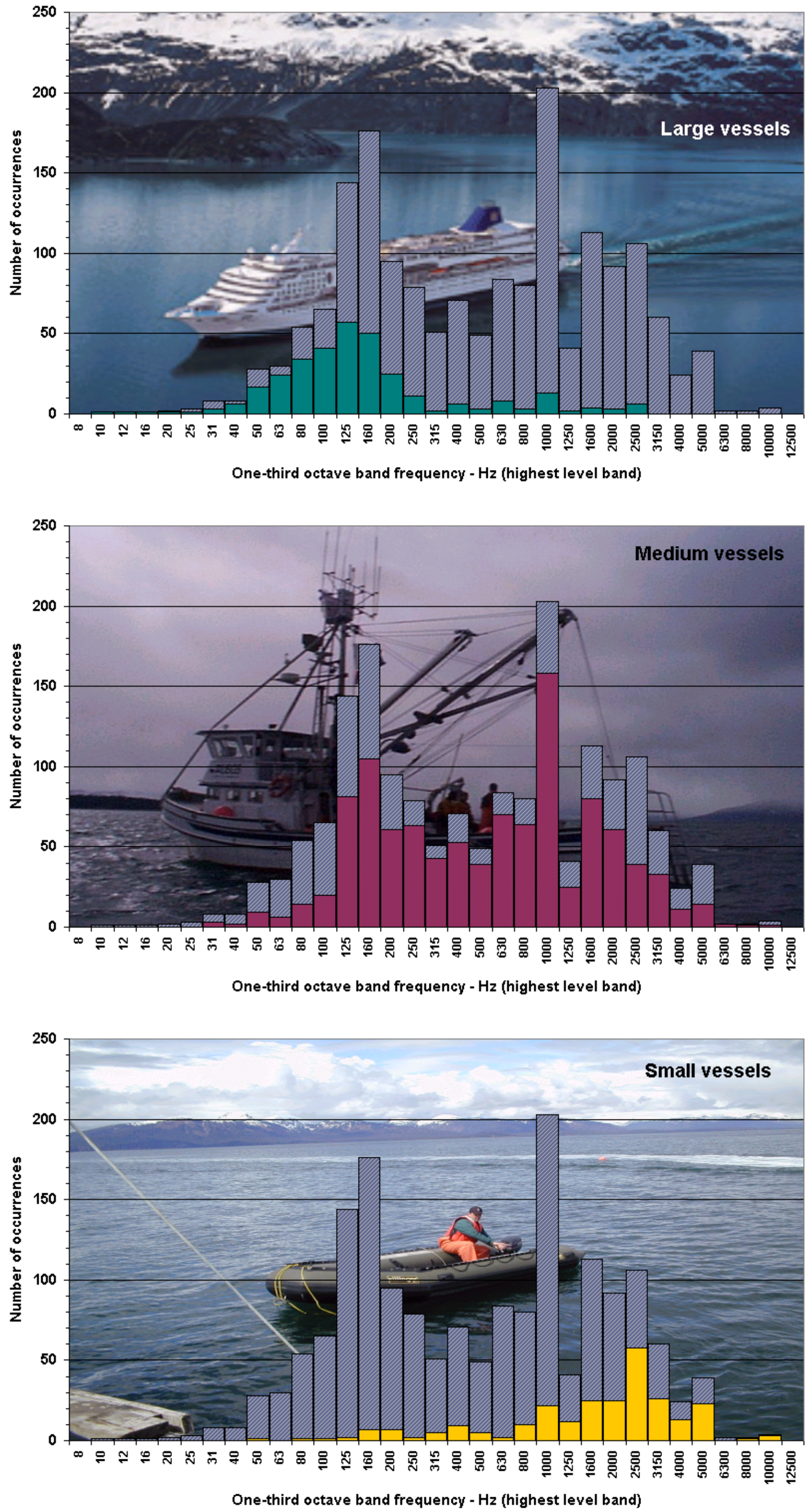
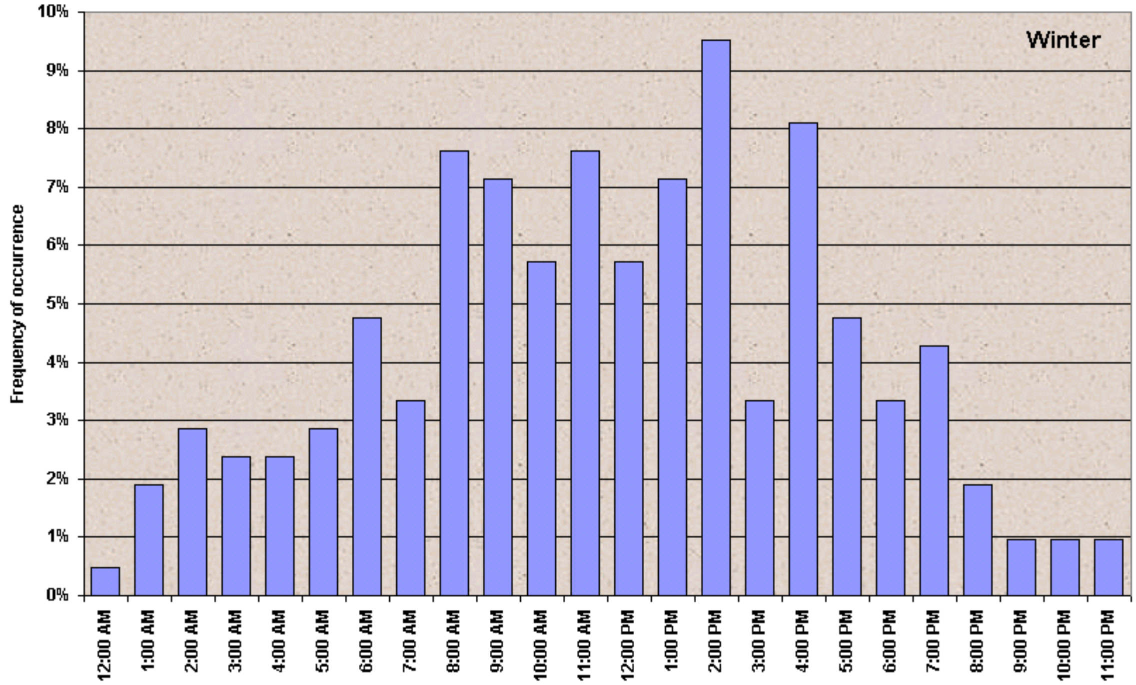


Fig. 28 Distribution of Vessel Noise Peak Frequencies by Type



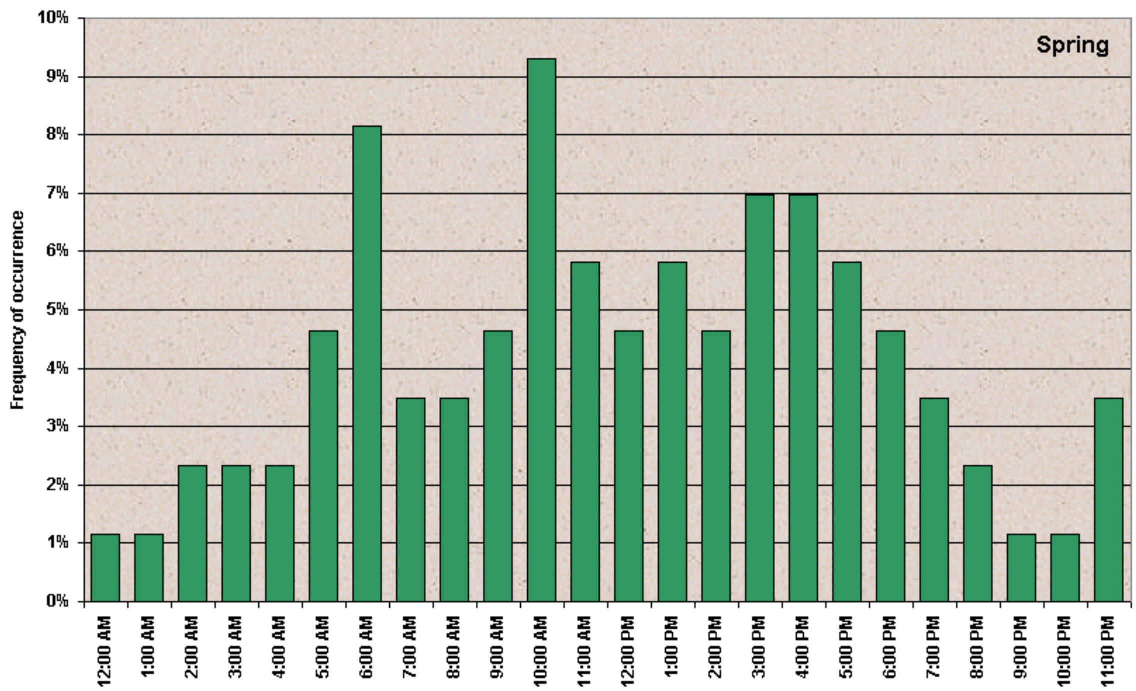
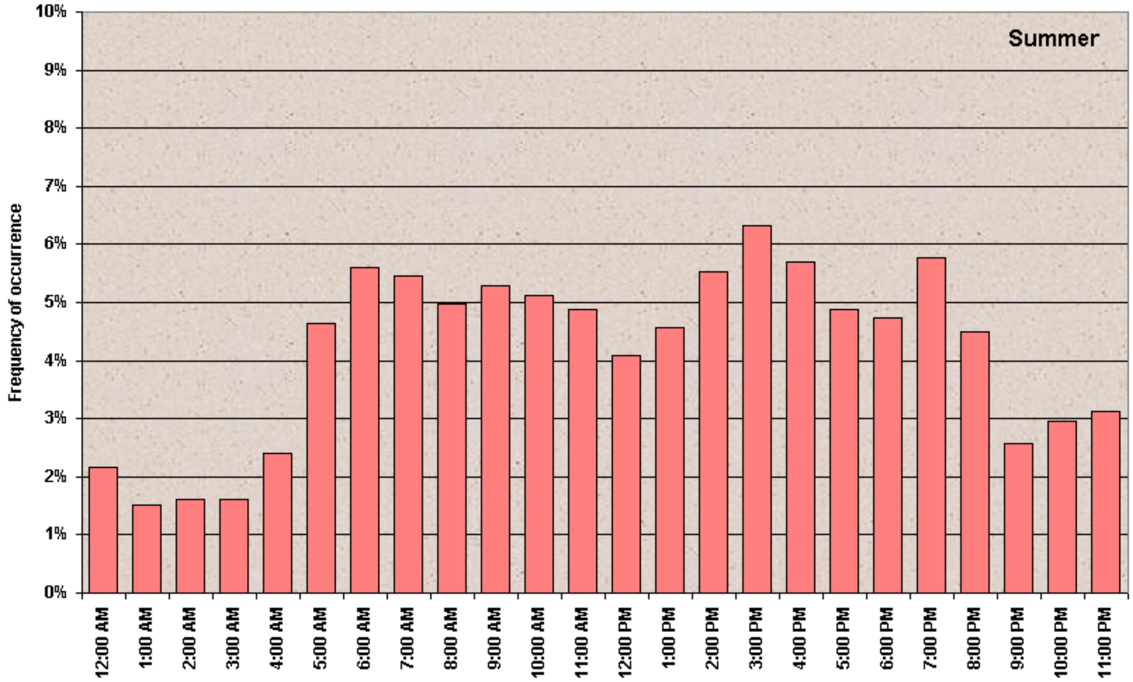


Fig. 29a Vessel Noise Frequency of Occurrence – Hourly – By Season



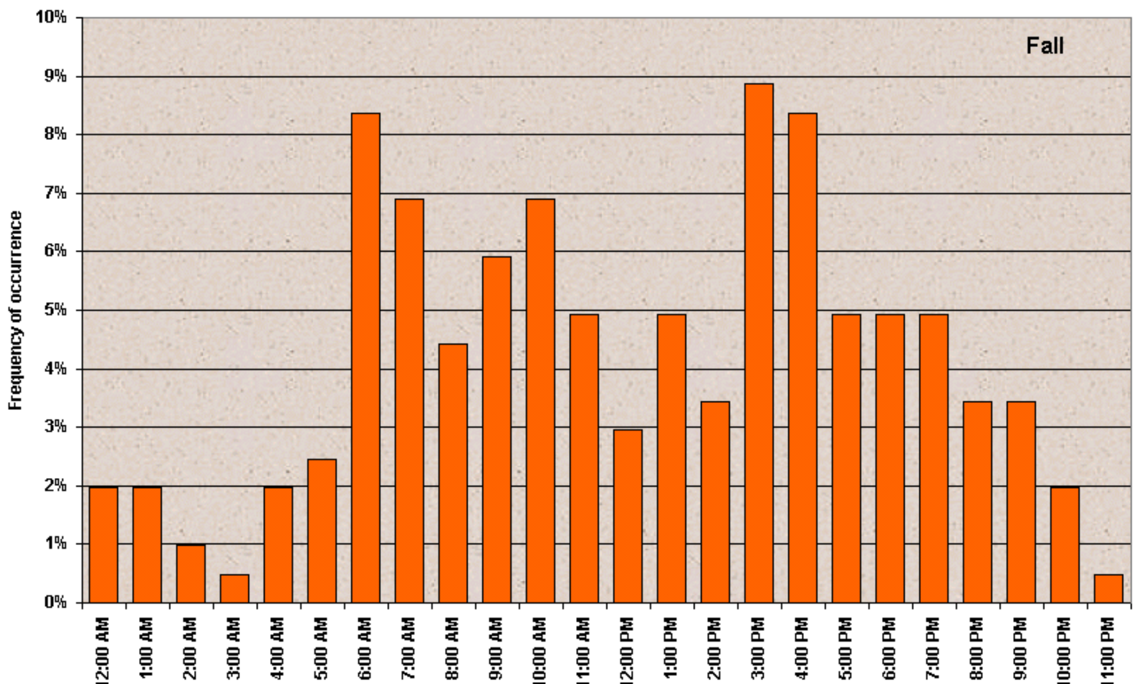


Fig. 29b   Vessel Noise Frequency of Occurrence – Hourly – By Season

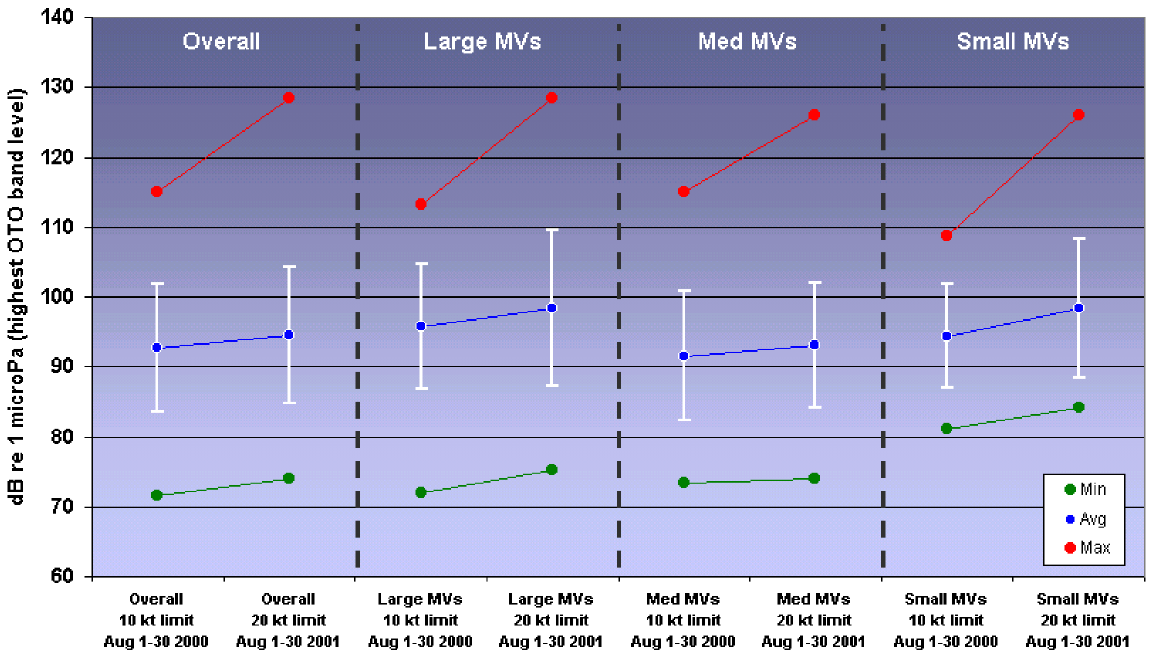


Fig. 30 10-Knot vs. 20-Knot Speed Limit Levels

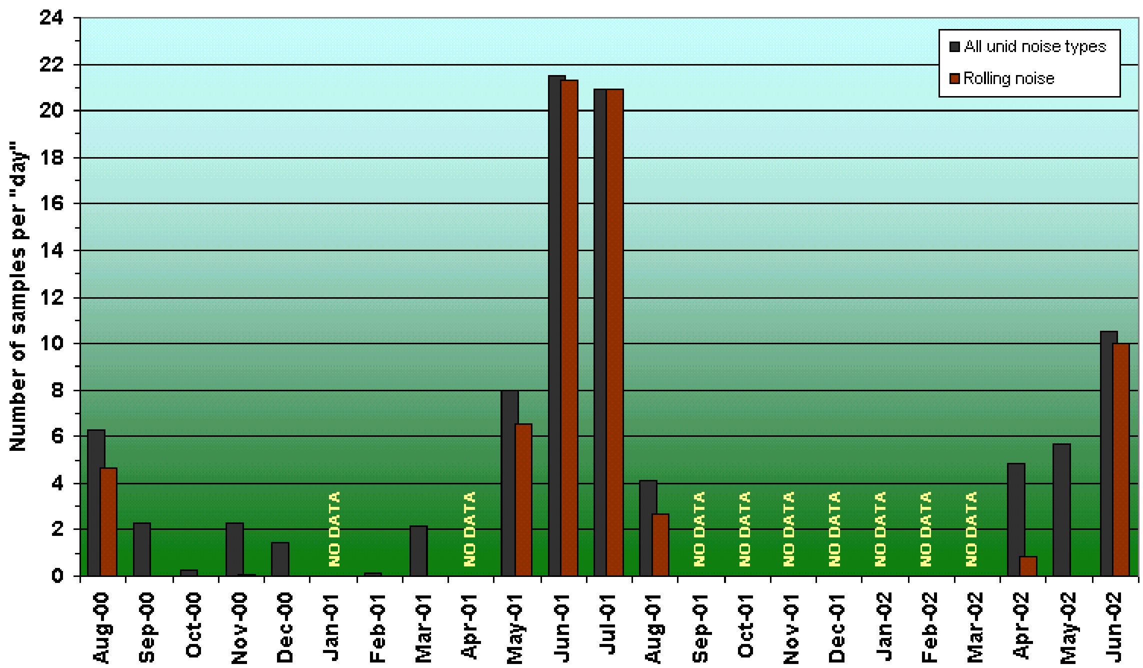


Fig. 31 Samples per Day Containing Unidentified Noise

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