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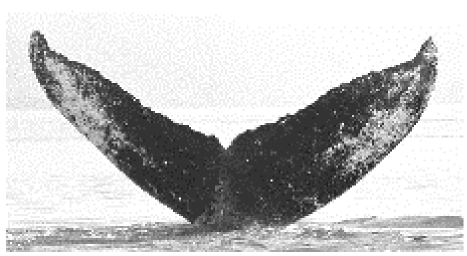
Glacier Bay Underwater Noise – August 2000 Through August 2002



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Underwater noise trends and levels in lower Glacier Bay from acoustic samples acquired during 20 months between August 2000 and August 2002.

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ABSTRACT

Both manmade and naturally occurring underwater noise in lower Glacier Bay was studied using almost 10,000 hourly noise samples obtained during 20 months between August 2000 and August 2002. The primary contributor of natural noise was wind generated surface noise, which averaged 84 dB re 1 microPa at 1 kHz and ranged from 67 to a maximum of 102 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 91 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. Sixty-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 average it was present in 7.7 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, 10 dB greater than the average wind noise level. The highest vessel level recorded was 129 dB, but only about 5% of the peak vessel noise levels exceeded 110 dB at the hydrophone. Medium sized vessels were the most prevalent vessel type at all times of year. They constituted 68% 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 August. The average large vessel noise level was 2 dB higher than the average small vessel level and 7 dB higher than the average medium craft level. Vessel noise levels were lower during periods when a 10-knot speed limit was in effect, especially for large and small vessels.

On average, a heavy rolling transient noise was observed in 75% of the samples acquired 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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ACKNOWLEDGEMENTS

The authors would like to acknowledge that a number of people at both Naval Surface Warfare Center and Glacier Bay National Park and Preserve contributed to the success of this project. Russ Dukek of Mantech Corporation, an engineering services contractor to Naval Surface Warfare Center, was primarily responsible for the unique underwater noise measurement and data acquisition system that continues to be used for the project. In addition, many dedicated people at Glacier Bay National Park and Preserve have made important contributions with regard to measurement system installation and maintenance, collecting vessel scan data in lower Glacier Bay, and overall care for the system and the project. Numerous personnel at Naval Surface Warfare Center, including the Southeast Alaska Acoustic Measurement Facility, have also performed valuable work on system installation and maintenance and on the extensive data analysis tasks involved with this effort.

PROJECT DESCRIPTION

This report is part of an ongoing collaborative project between Glacier Bay National Park and Preserve, Gustavus, Alaska; and the Naval Surface Warfare Center Detachment in Bremerton, Washington to characterize Glacier Bay's underwater acoustic environment. Since May 2000, a hydrophone has been in place in lower Glacier Bay continuously monitoring underwater noise levels. 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 level trends were investigated 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.

To date, this project has been executed in two phases. In the first phase, an *interim database* containing 5891 samples was developed that roughly encompassed 14 months of data acquired between August 2000 and June 2002. Some of the months in the interim database were not covered in entirety. The results derived from the interim database were reported by Kipple (2002).

After the interim report was issued, additional data were analyzed and compiled, and the database was expanded to almost double the size of the interim database. The results discussed in this report cover data collected over 20 months from August 2000 to August 2002. Over 10,800 data samples were reviewed. In this report also, some months were not covered completely.

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

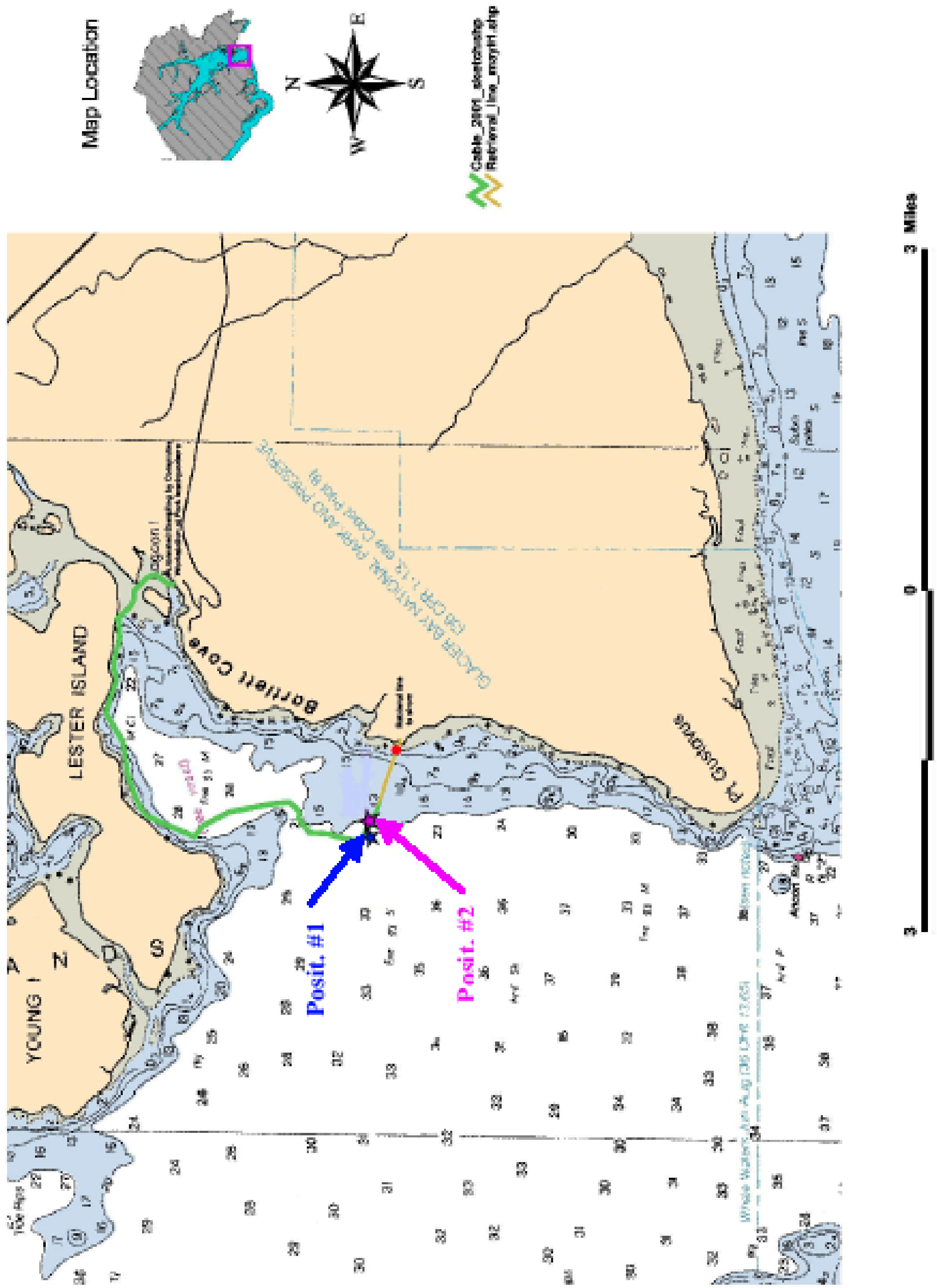


Fig. 1 Hydrophone Location in Lower Glacier Bay

hydrophone 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.

Original hydrophone installation

17 May 2000 – 15 May 2001

Present hydrophone installation

17 May 2001 - present

Fig. 2 Hydrophone Installation

The underwater noise data acquisition system, Fig. 3, uses an ITC type 8215A wideband omni-directional hydrophone, Fig. 4, to measure absolute sound pressure levels. The system is set up to acquire data on an hourly basis. Samples are acquired on the hour, or quarter, half, or three-quarter hour to minimize bias due to regular vessel schedules. For each sample the following data are archived:

Fig. 3 Acoustic Data Acquisition System

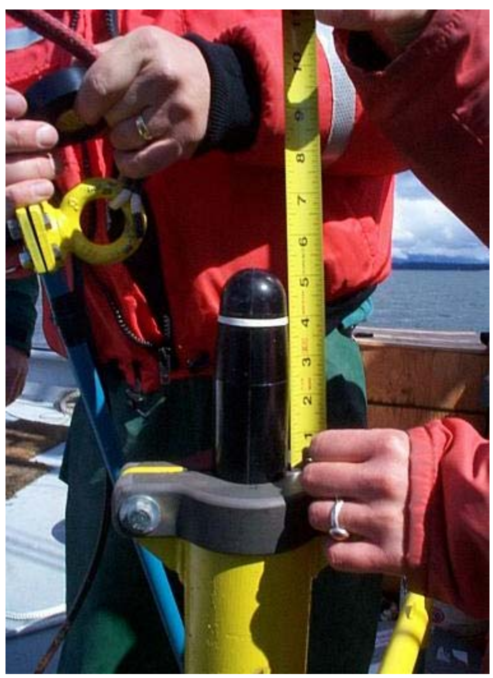


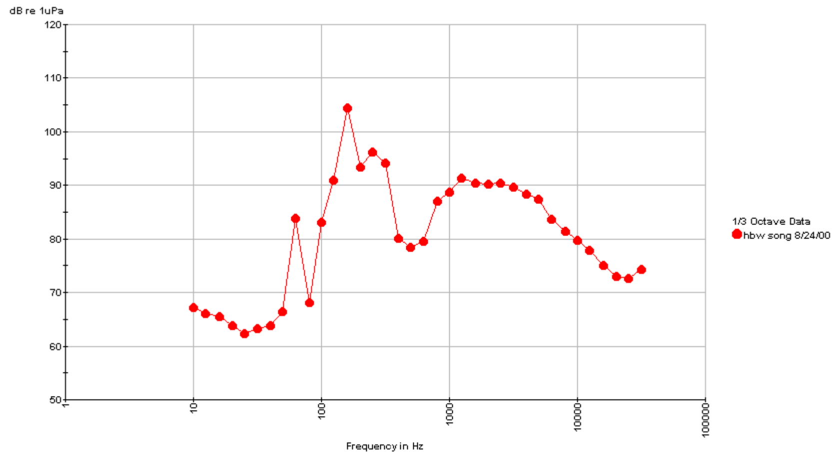
Fig. 4 Noise Monitoring Hydrophone

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).

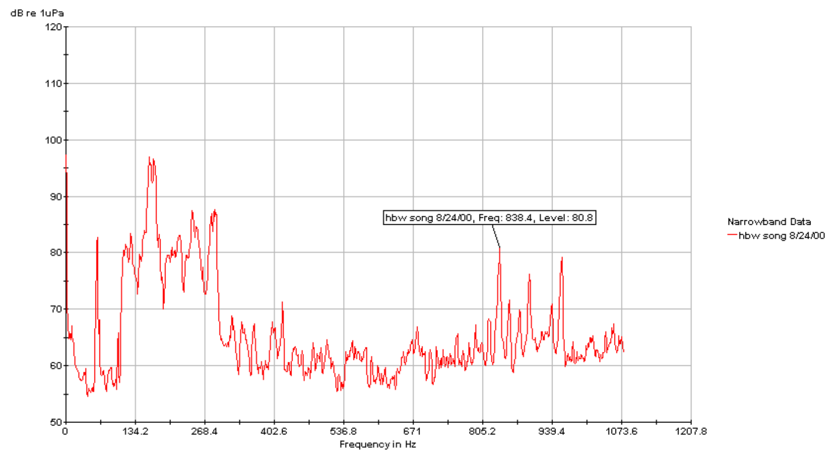
Figure 5 shows examples of several of these data types. The narrowband spectra (items 2 and 4 above) are generated by averaging over the duration of the sample. As a result, they represent the average frequency character and noise level over the 30-second sample period. The one-third octave spectrum 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 establish source levels for sources such as vessels and whales. For *local distributed sources* like wind and rain noise, the distance to the source is not particularly meaningful. One exception might be rain noise controlled by a localized rain squall at some distance from the hydrophone, rather than by rain uniformly distributed over a large area around the hydrophone.

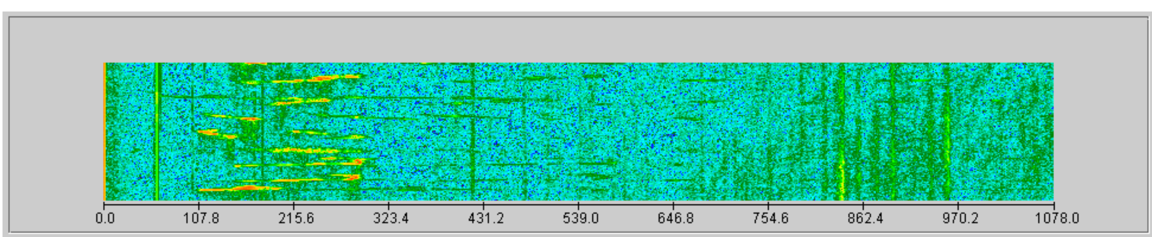
The validity of the measured levels also depends on whether the noise of interest is steady state or transient in nature. As mentioned above, the data acquisition system used for this project acquired samples that were 30 seconds in length. This duration works well for steady state noise where levels 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.



Representative One-Third Octave Plot



Representative Narrowband Plot



Representative Waterfall Plot

Fig. 5 Examples of Data Types

For transient noises the 30-second sample duration is more tenuous in terms of logging accurate noise levels. Since the system is basically creating a noise level average over a 30-second duration, if a transient noise of interest lasts only 5 seconds and one is interested only in the transient event, the average level will be erroneously low because it is also affected by the noise conditions that occurred in the remaining 25 seconds of the sample. 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 investigate noise trends 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[*].

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

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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.

DATA SAMPLE COVERAGE

Data samples from the time of system installation in May 2000 through August 2002 were included in the database, although the May 2000 through July 2000 entries are present in raw, unanalyzed form only. As a result, the effective period of coverage is from August 2000 to August 2002. In addition, this time period was not covered entirely due to gaps in sample coverage related to system downtime. Also, because of greater interest in summer months, samples from the winter 2001-2002 months were not analyzed (however, they are included in raw form in the Access database). 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			29	Full coverage	30	Raw data only
Feb			28	Full coverage	27	Raw data only
Mar			8	System limitations	31	Full coverage
Apr			0	System limitations	31	Full coverage
May	12	Raw data only	4	System limitations	30	Full coverage
Jun	19	Raw data only	11	System limitations	21	System limitations
Jul	24	Raw data only	25	System limitations	8	System limitations
Aug	21	System limitations	31	Full coverage	31	Full coverage
Sep	26	System limitations	30	Full coverage		
Oct	30	Full coverage	28	Full coverage		
Nov	30	Full coverage	28	Raw data only		
Dec	31	Full coverage	31	Raw data only		

A total of 15,070 samples were included in the database. Of this number, 10,776 samples (72%) were reviewed and 9804 (91% of those reviewed) were determined to be usable. The total number of samples was substantially greater than the number of reviewed samples because, for some months, only the *raw data* were included in the database. The raw data are samples that were not reviewed and categorized, but the measured levels and the date and time associated with the sample were included in the database. These data were not used in the data analysis conducted for this report for a number of reasons, including: insufficient sound and waterfall data due to data collection system limitations, focusing of data analysis efforts on high priority months as described above (i.e. summer coverage versus winter coverage), and cases where more than one sample per hour was collected.

Figure 6 shows the total number of samples that were acquired and reviewed (i.e. 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 October and December 2000, and January 2001, the high number of unusable samples was due to interference from system related, electrical, crackle noise.

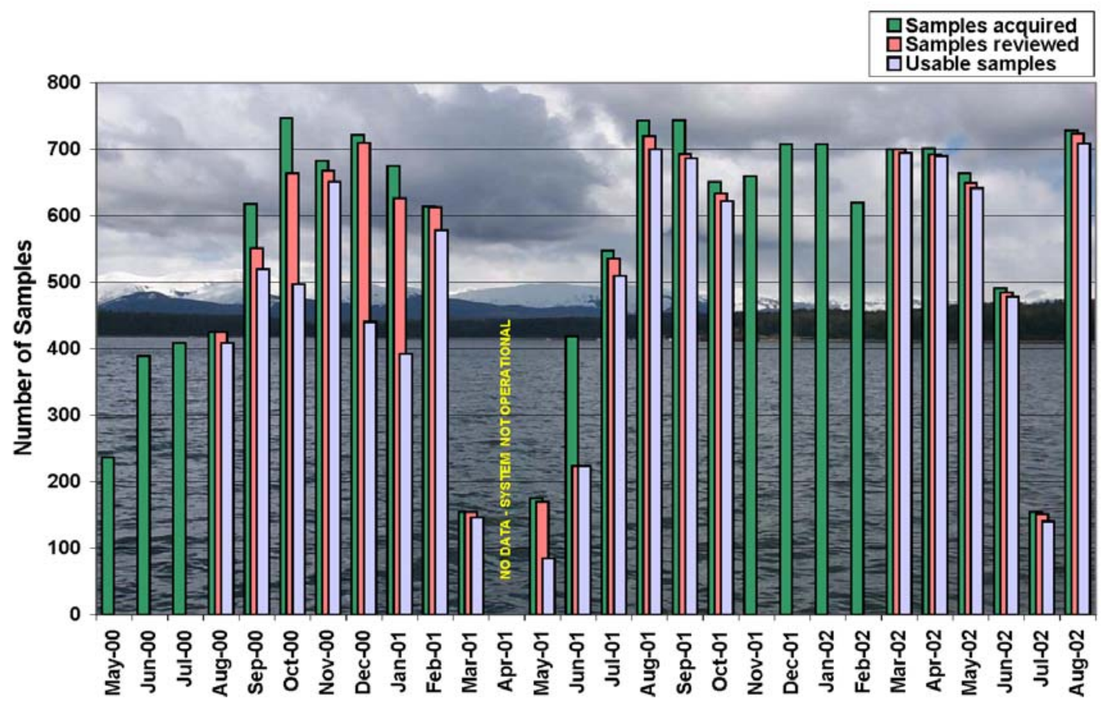


Fig. 6 Acquired, Reviewed, and Usable Samples

For the two years of coverage, some overlap in monthly coverage occurred for summer and fall months, and only one month each was included for November through

February. Data analysis efforts were focused on the summer and fall months because vessel and biologic noise sources that are of particular interest occur in these seasons.

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. Within a short time, 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 from Knudsen (1948) in Fig. 7 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.

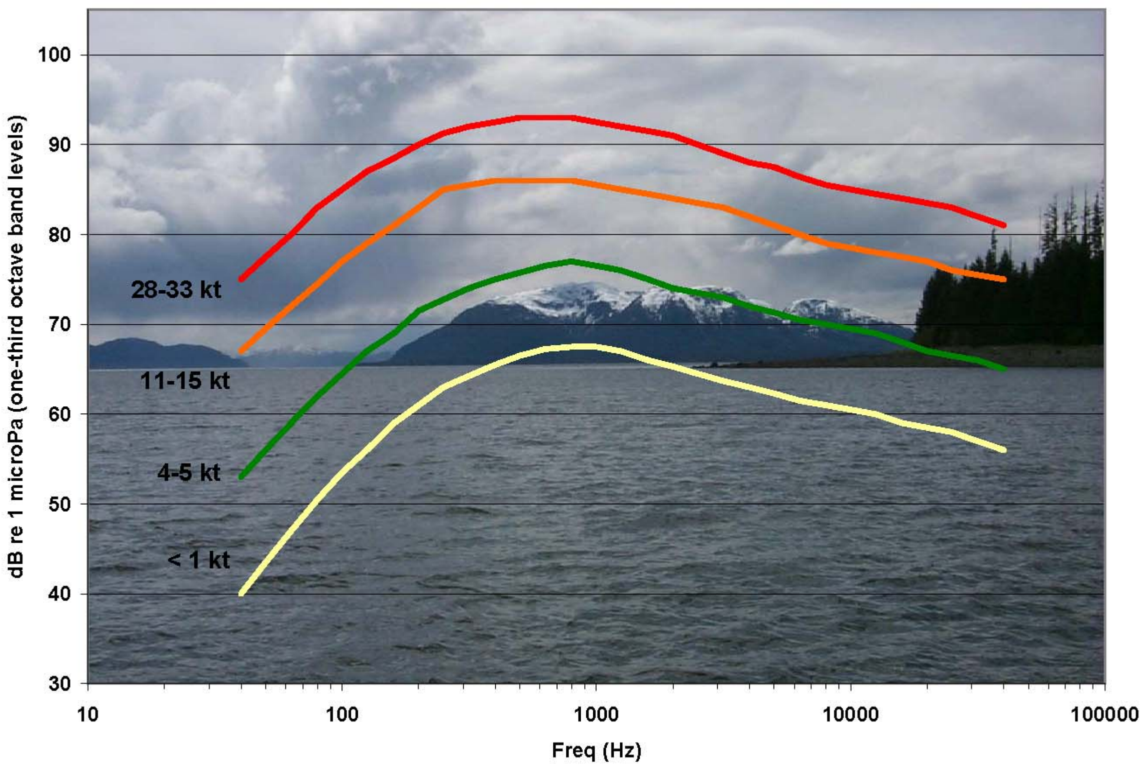


Fig. 7 Knudsen Wind Noise Spectra

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 their character changes over a short time and they 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 pleasure craft, work-boats, and open skiffs; to fishing boats 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 their 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 – ACOUSTIC DATABASE VALIDITY

Several checks were performed to assess the ability of the acoustic monitoring system and the acoustic database to correctly identify events that occurred in lower Glacier Bay. These checks were conducted by comparing the contents of the acoustic database with observations from independent sources of data regarding weather conditions, presence of watercraft, and presence of whales in lower Glacier Bay. A positive correlation between these independent sources of data and conclusions derived via acoustic means served as confirmation that the acoustic-based approach was valid for logging vessel traffic, detecting acoustic whale activity, and classifying various meteorological conditions.

Marine Vessel Traffic

A database developed and maintained by Glacier Bay National Park personnel called the Vessel Scan Database (VSDB) was used as an independent source of information regarding vessel presence in lower Glacier Bay. Vessel data as well as other information were logged into this database by park personnel operating on lower Glacier Bay. For each observation, the following information was logged:

1) Presence of vessels
2) Vessel type

3) Vessel size
4) Vessel speed
5) Distance of vessel from monitoring hydrophone
6) Identity of Park vessel from which the observation occurred
7) Sea-state
8) Presence of rain

Vessel presence and vessel characterizations from the VSDB were compared to those derived from the acoustic database for the periods 1-13 August 2000 and 1-13 August 2002. In both months, all vessel observations reported via the VSDB had corresponding vessel detections from the acoustic database, i.e. no vessel detections obtained visually were missed by the acoustic system. Note that vessel scans and acoustic samples, in general, were not synchronous because the vessel scan observer did not know the times that acoustic samples were captured. As a result, for the purposes of this comparison, vessel scans that occurred within 30 minutes of the recording of the acoustic sample were used.

Cruise ships, tour boats, and cabin cruisers that were visually reported at distances up to 5 miles[*] from the monitoring hydrophone were routinely detected by acoustic means. Vessel scan coverage was much less comprehensive than acoustic coverage (acoustic sampling occurred hourly, around the clock). The August 2000 and 2002 periods that were reviewed contained a total of 47 vessel scan (i.e. visual) reports. The same period contained 622 records from the acoustic database.

When multiple vessels were visually reported, the acoustic database typically under-reported vessel numbers due to masking of quieter, or more distant vessels, by the acoustically dominant vessel. Also, in some cases, vessel types that were visually reported as small craft were sometimes classified as medium vessels via acoustics. This

[*] The maximum distance logged in the VSDB was 5 miles. This is the distance from the hydrophone to the entrance of Sitakaday Narrows. Based on possible line-of-sight distances to the hydrophone, vessel detections should be possible at distances up to 7 miles (i.e. past Pt. Corolus).

mischaracterization was most prevalent with the jet-powered small craft. A summary of these comparisons is given in Table 2.

Table 2 Comparison of Visual and Acoustic Detections of Marine Vessels

Vessel type	Visual	Acoustic	Not identified acoustically because of masking*	Missed by acoustics	Mischaracterized by acoustics
Large	22	10	12	0	0
Medium	20	16	4	0	0
Small	30	8	15	0	7

* In all of these cases multiple vessels were reported visually.

Wind Noise

Wind speeds for lower Glacier Bay were not logged by any local meteorological data collection stations. The United States Geological Survey (USGS) weather database did not contain wind speed data for lower Glacier Bay. The closest available wind speed collection locations were Juneau and Haines, both about 60 miles from lower Glacier Bay. In the absence of direct wind speed measurements, the Vessel Scan Database cited above was used to obtain sea-state levels.

As described above, NPS vessel operators logged presence of marine vessels, sea-state conditions, etc. in the VSDB whenever vessels were sighted in lower Glacier Bay. To check the correlation between visual sea-state conditions, and underwater acoustic wind noise levels, the VSDB sea-state conditions and the wind noise levels from the acoustic database were compared. One shortcoming of this approach is that for many of the entries in the VSDB the observation was recorded when at least one vessel was present. As such, in these cases, the corresponding noise levels logged in the acoustic database were mostly dominated by vessel noise, and wind noise was masked. This was particularly true for the cases when low sea-states, and hence low wind noise levels, were present. Only acoustic database entries where wind noise dominated the 1 kHz one-third octave band level were included in this comparison.

The correlation between observed sea-state levels and wind noise levels was checked for May and June 2002. The 1 kHz one-third octave band underwater noise levels from samples where this frequency band was controlled by wind noise were used to determine wind noise levels. If a wind noise level was logged within 2 hours of the VSDB data point, the two data points were used for the correlation comparison. Figure 8 shows a plot of wind noise level versus sea-state for both months.

This plot shows a trend of increasing noise levels with increasing sea-state conditions, which is expected. Is also shows that sea-state 0 conditions corresponded to noise levels in the low 70 dB range, and that wind noise levels in the mid 80 to mid 90 dB range occurred with sea-states 3 and 4. These levels were comparable to those given by Urick, (1983), as shown in Table 3. Note that the level for sea-state 0 in Table 3 is several dB lower than the Glacier Bay level because it was established for deep water locations where the hydrophone was deeper than the Glacier Bay hydrophone and there was probably less influence from sloshing noise originating at the surface.

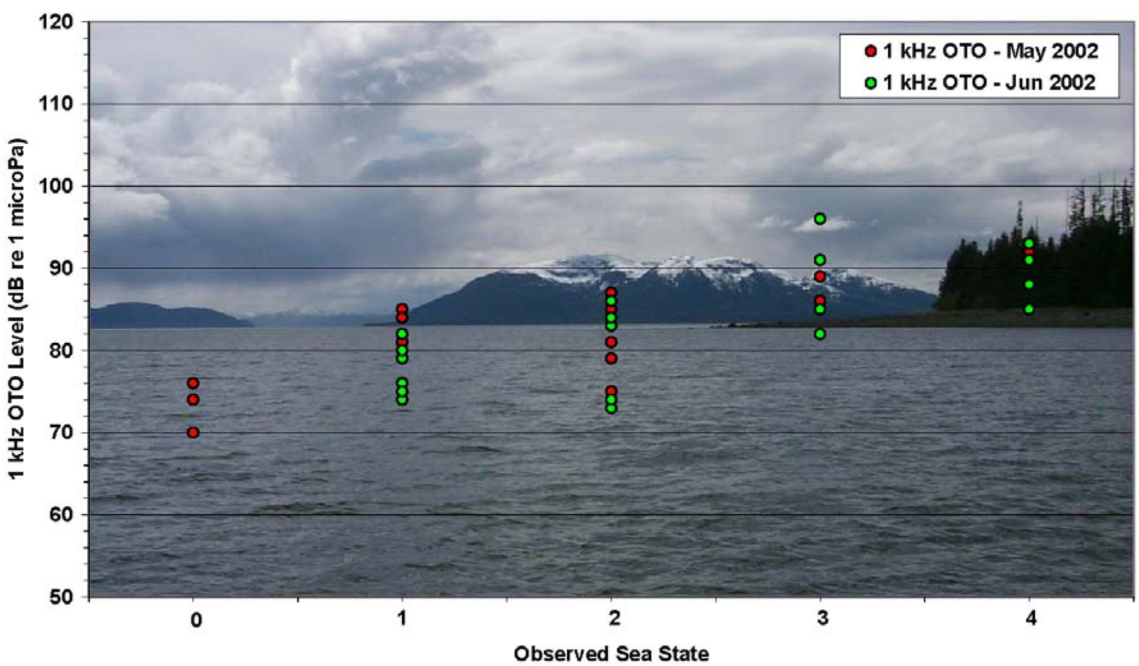


Fig. 8 Glacier Bay Wind Noise Levels vs. Sea-State

Table 3 Wind Noise Levels From Urick (1983)

Wind speed (kt)	Sea-state	1 kHz 1/3 Octave Level (dB)	Water depth (ft)
<1	0	67	Deep water
3	0-1	74	150
6	1	82	150
12	3	89	150

Another notable characteristic of the data plotted in Fig. 8 is that levels for sea-states 1, 2, and 3 were more dispersed than those at sea-states 0 and 4. This result may be due to difficulty in visually establishing actual sea-state level.

Rainfall

Rainfall observations from USGS data for December 2000 were compared to results from the acoustic database to ascertain the ability of the acoustic monitoring system to reliably detect the presence of rain. The USGS data were reported as total daily rainfall amounts in centimeters. USGS data were recorded daily and acoustic data were logged hourly.

The USGS and acoustic databases were in agreement for presence of rainfall for 23 days in December 2000. For 2 days, no USGS data were reported. The USGS database reported rainfall for 21 days in December 2000. For 15 days where USGS reported rainfall, the acoustic database also logged samples with rain noise present. For 8 days where USGS reported no rain, the acoustic database also logged no rain noise. On days when the acoustic database logged rain noise, the USGS database also showed measurable rainfall. Table 4 lists daily reports of rainfall from both databases.

The only disagreements between the databases on rainfall occurred for 6 days where the USGS database showed rainfall but the acoustic database did not. For each of these days the amount of rainfall reported by USGS was low (less than .25 cm), and/or the acoustic database only logged a limited number of samples for that day. For days where the rainfall amount reported by USGS was low, it is possible that the hourly

Table 4 Daily Occurrence of Rainfall – Dec 2000

Date	USGS	Acoustic	Comment
1	**Yes**	**Yes**	
2	**Yes**	**Yes**	
3	Yes	No	Low rainfall amount
4	**Yes**	**Yes**	
5	**Yes**	**Yes**	
6	**Yes**	**Yes**	
7	**Yes**	**Yes**	
8	**Yes**	**Yes**	
9	**No**	**No**	
10	Yes	No	Low rainfall amount
11	**No**	**No**	
12	Yes	No	Low rainfall amount and only 3 acoustic samples this day
13	**No**	**No**	
14	**No**	**No**	
15	**No**	**No**	
16	**No**	**No**	
17	---	No	No USGS data this day
18	---	Yes	No USGS data this day
19	Yes	No	Only 7 acoustic samples this day
20	**Yes**	**Yes**	
21	**No**	**No**	
22	**No**	**No**	
23	Yes	No	Low rainfall amount and only 5 acoustic samples this day
24	**Yes**	**Yes**	
25	**Yes**	**Yes**	
26	**Yes**	**Yes**	
27	**Yes**	**Yes**	
28	**Yes**	**Yes**	
29	**Yes**	**Yes**	
30	**Yes**	**Yes**	
31	Yes	No	Only 3 acoustic samples this day

samples simply did not occur when a short-term rain shower was present, or that rain showers may have been local to the USGS measurement point, but did not occur in the vicinity of the hydrophone. For some days, especially where only a few acoustic samples were logged, it is thought that the acoustic sample coverage was simply too sparse and rainfall happened to occur when no samples were being acquired.

Biologic Noise

The occurrence of noise related to humpback whales was checked against the annual humpback whale surveys performed and reported by Glacier Bay National Park personnel Gabriele and Hart (2000), and Doherty and Gabriele (2001, 2002). The monthly number of acoustic detections of humpback whale noise correlated well with periods where the greatest number of humpbacks was visually observed in the lower bay. Additional details regarding the comparison of acoustic detections and visual observations of humpback whales are given later in this report.

RESULTS – STATISTICS AND TRENDS

The report sections below discuss the results of the noise investigations that were conducted using the Glacier Bay 2000-2002 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 establish wind and rain noise level trends by month.

Figure 9 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 vessel noise. Months from October through April were 84 to 93% free of manmade noise sources. Thus, natural noise sources such as wind were dominant in about 90% of the samples during these months. In the months of June, July, and August, 31 to 47% of the samples were free of manmade noise. In May 2001 and 2002, 48 to 60% of the samples were free of manmade noise, and 62% of the samples in September 2000 and 2001 contained no manmade noise.

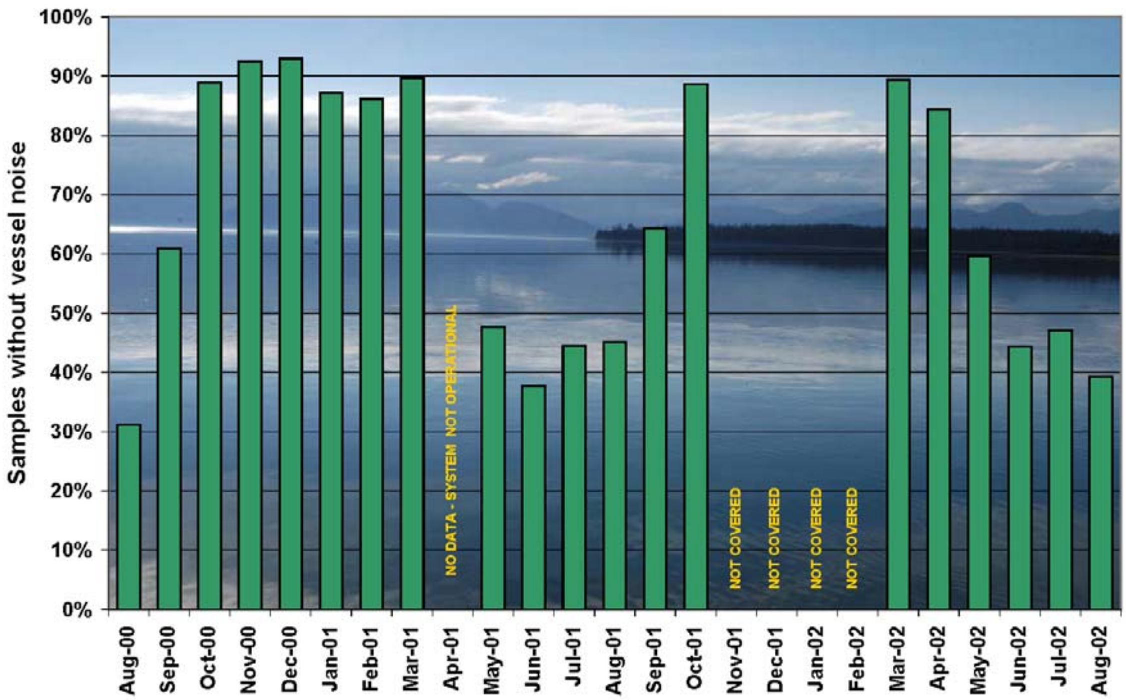


Fig. 9 Samples without Marine Vessels

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. 9 and graphed in Fig. 10, 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 roughly 60% free of vessel noise. Note 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, as defined here, include just one month each. Marine vessel noise statistics will be discussed in greater detail later in this report.

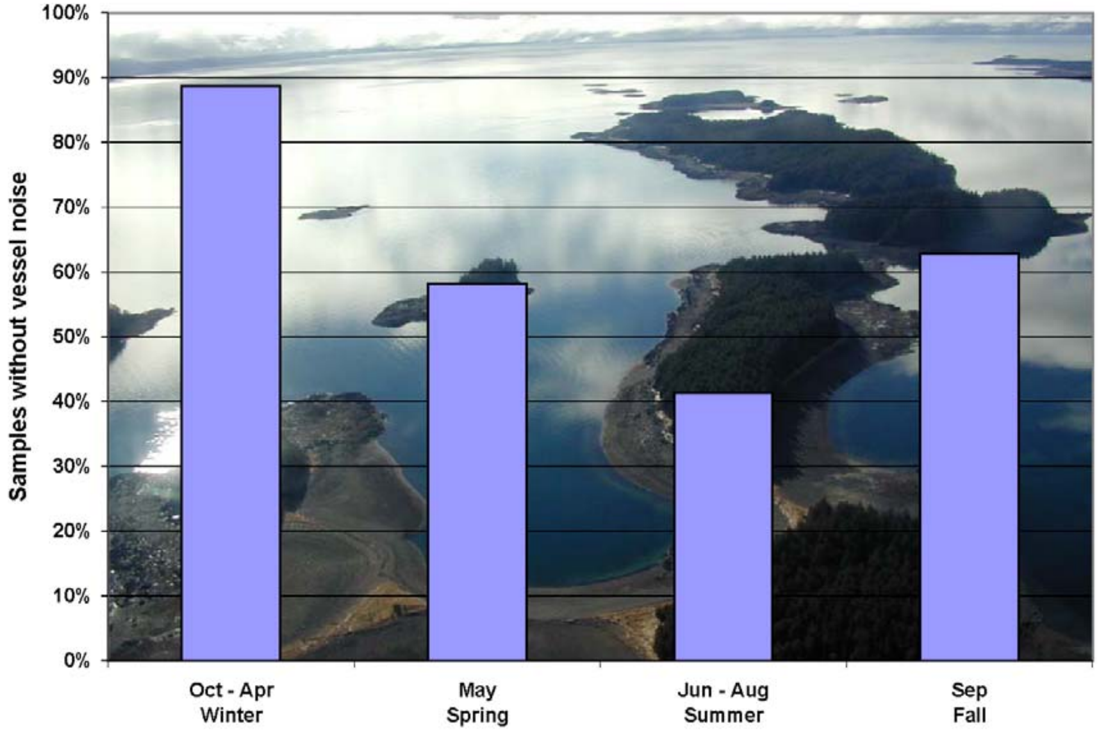


Fig. 10 Proportion of Ambient Noise Samples without Vessel Noise by Season

Wind Noise

Wind noise statistics were compiled on a monthly basis using all of the wind dominated, usable data contained in the acoustic database. Wind noise level statistics were based on 1 kHz one-third octave band levels and only samples whose 1 kHz levels were controlled by wind noise, as opposed to vessel noise, were included in these statistics. Wind noise controlled the 1 kHz one-third octave band level in 64% of all usable samples. In almost all of the other samples, marine vessel noise controlled the 1 kHz band level. A representative, wind dominated, one-third octave noise spectrum for higher level wind noise is shown in Fig. 11. Wind noise minimum, average, and maximum level statistics are listed in Table 5 and graphed in Fig. 12. Standard deviation and number of samples are also included.

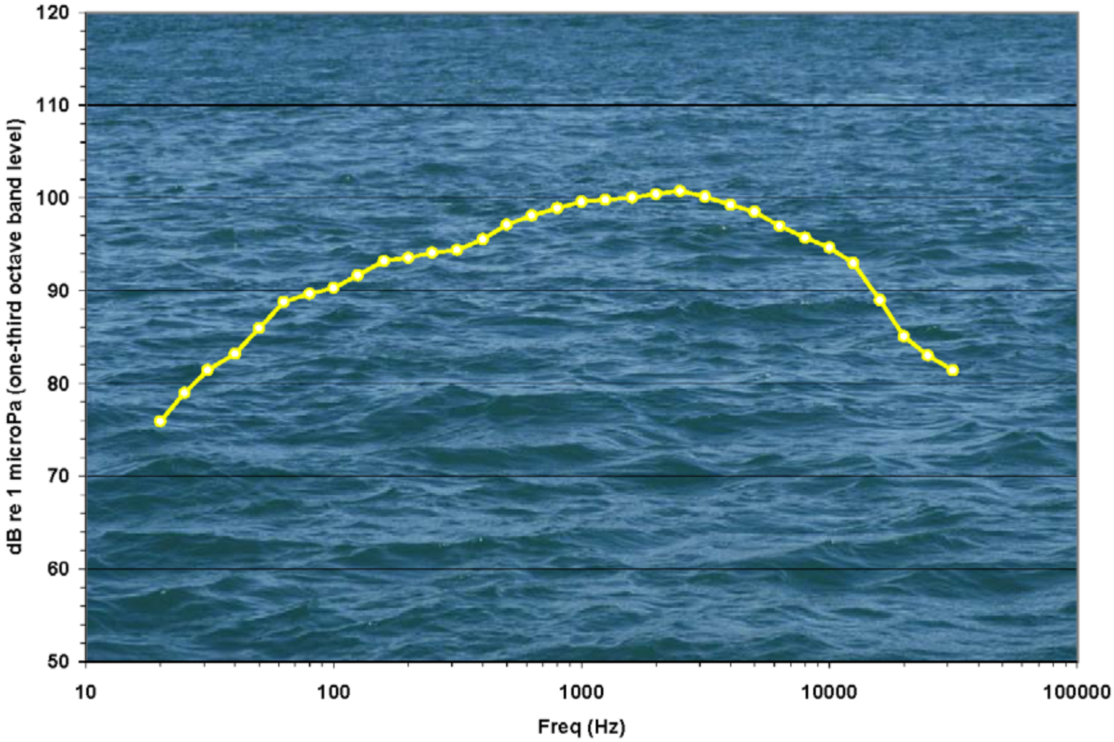


Fig. 11 Representative High-level Glacier Bay Wind Noise Spectrum

Table 5 Wind Noise Statistics

	Min (dB)	Avg (dB)	Max (dB)	Std Dev (dB)	Count	% Wind Controlled
Overall	67	84	102	6.9	6252	64%
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%
Jan-01	73	86	98	5.0	335	86%
Feb-01	67	85	98	6.7	384	66%
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%
Sep-01	71	84	102	6.7	428	62%
Oct-01	69	84	102	6.8	524	84%
Mar-02	68	86	99	7.8	620	89%
Apr-02	69	86	98	6.8	596	87%
May-02	69	82	99	7.3	385	60%
Jun-02	69	82	97	6.4	216	45%
Jul-02	74	87	97	5.3	32	23%
Aug-02	70	84	97	6.2	238	34%

Wind noise occurred at levels considered typical for open water areas. The overall average wind noise level was 84 dB*. The minimum observed level was 67 dB and the maximum level was 102 dB. These levels are reasonable for a hydrophone located in approximately 100 feet of water.

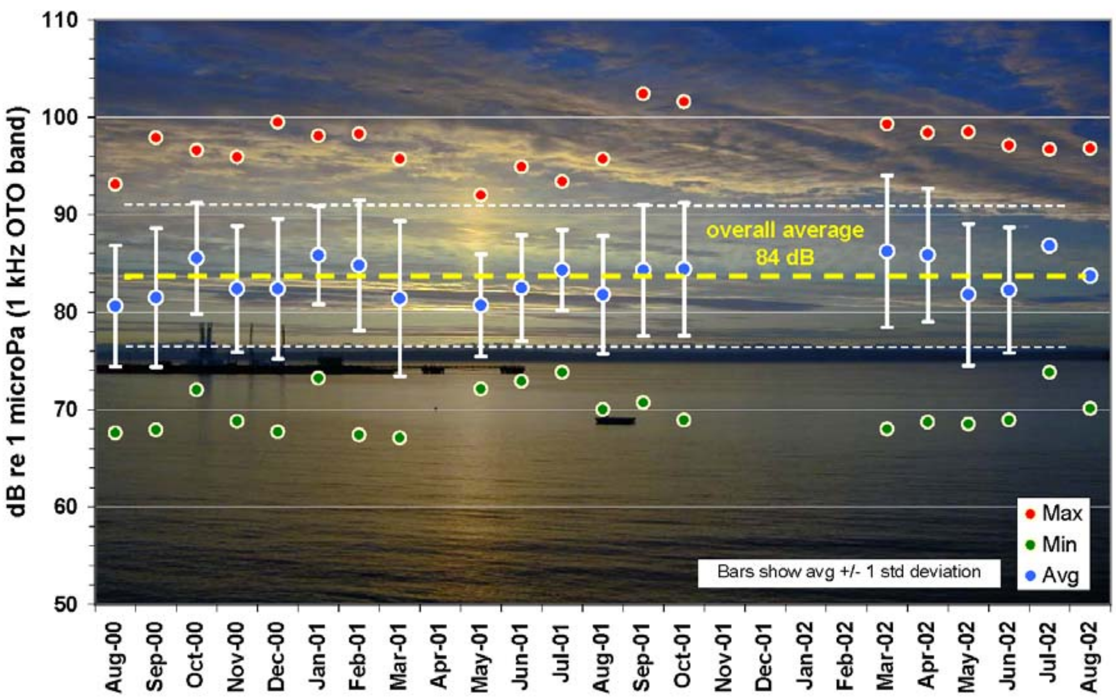


Fig. 12 Wind Noise Level by Month

Wind noise level variation by month is shown in Fig. 12 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 102 dB with the highest recorded in early September 2001 and mid October 2001. Summer months generally recorded somewhat lower maximum levels with August 2000, and May and July 2001 logging maximums of 92 to 93 dB. Low minimum wind noise levels were not reserved just to summer months. February and

* 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.

March 2001 recorded minimum levels of 67 dB and 68 dB was observed in December 2000 and March 2002.

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 13 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

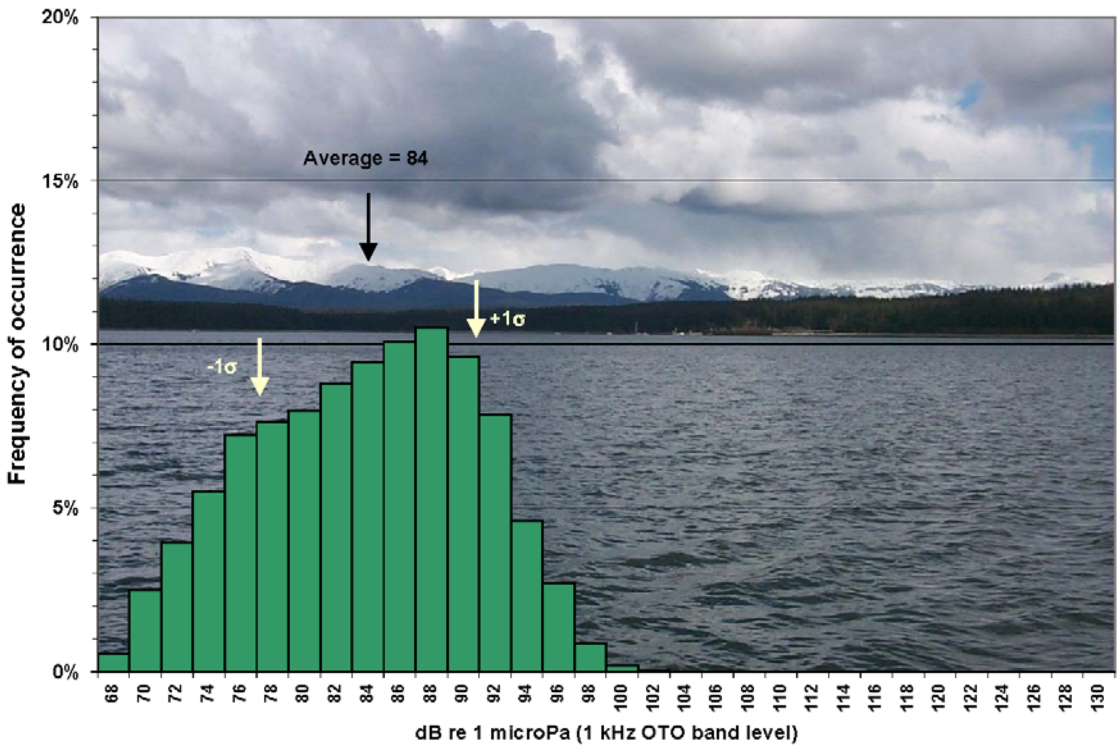


Fig. 13 Distribution of Wind Noise Levels

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. Several additional results regarding distribution of wind noise levels include:

a) 52% of logged wind noise levels occurred at levels above the mean level of 84 dB
b) 47% of logged wind noise levels were below the mean

c) 27% of logged wind noise levels occurred in a 6 dB range centered about the mean (i.e. 84 dB +/- 3 dB).

Percentile statistics for wind noise were also developed based on the 1 kHz one-third octave band levels for samples where this band was controlled by wind noise. These results are listed in Table 6 and shown in Fig. 14. The percentile ranking indicates the percentage of samples where wind noise was logged below a certain level. For example, the data in Table 6 show that 30% of all samples where the 1 kHz band was controlled by wind noise logged a 1 kHz wind noise level below 79.7 dB. If the data compiled in the acoustic database are representative of lower Glacier Bay underwater noise, one could then infer that, *when wind noise controls the 1 kHz band level*, wind noise levels below 79.7 dB will only be logged about 30% of the time. The data listed in Table 6 for a limited number of percentile values is shown on a continuous curve in Fig. 14.

Table 6 1 kHz Band Wind Noise Percentile Rankings

Percentile	**1 kHz One-third Octave Wind Noise Level (dB)**
99%	97.2
95%	94.4
90%	92.6
80%	90.2
70%	88.3
60%	86.3
50%	84.3
40%	82.2
30%	79.7
20%	77.1
10%	74.2
5%	72.1
1%	69.6

Based on these percentile rankings, a series of wind noise curves were established to represent the wind noise spectra that might be expected for the 10, 30, 50, 70, and 90% values that are listed in Table 6. For example, Fig. 15 shows the wind noise spectrum corresponding to the 30% 1 kHz band level of 79.7 dB. This curve is an average based on all samples where the 1 kHz wind noise level fell within 79.7 +/- 1 dB.

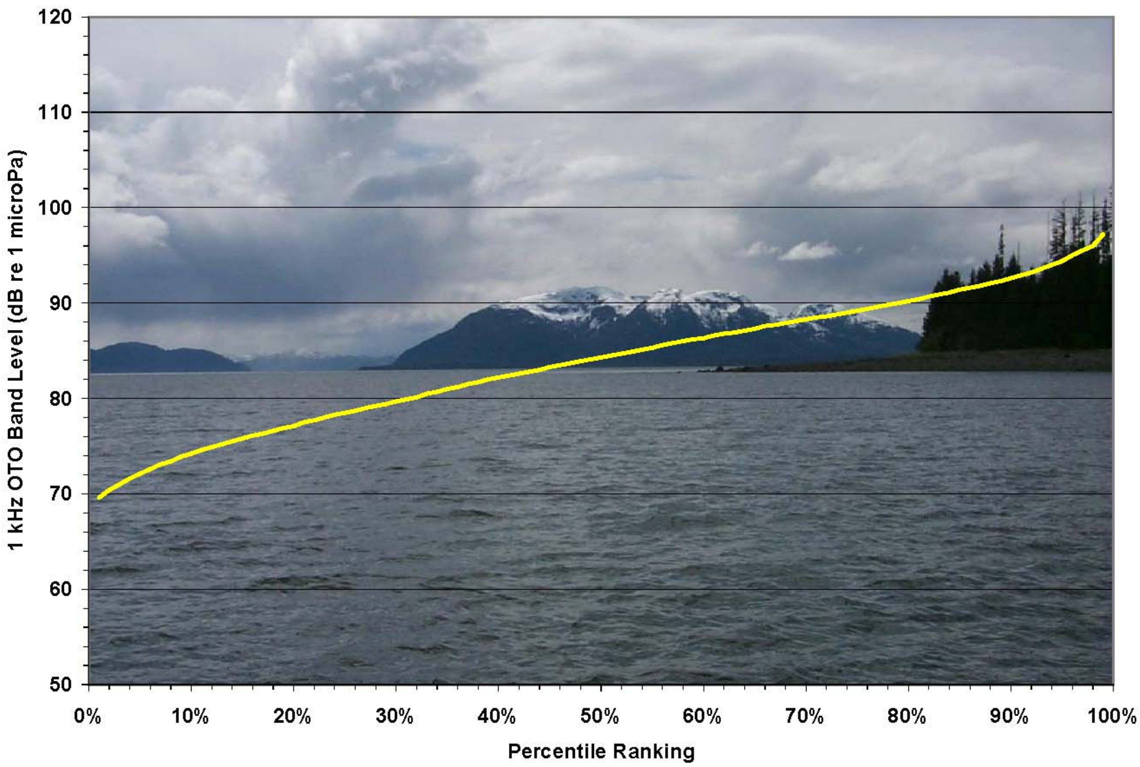


Fig. 14 1 kHz Wind Noise Level Percentile Ranking

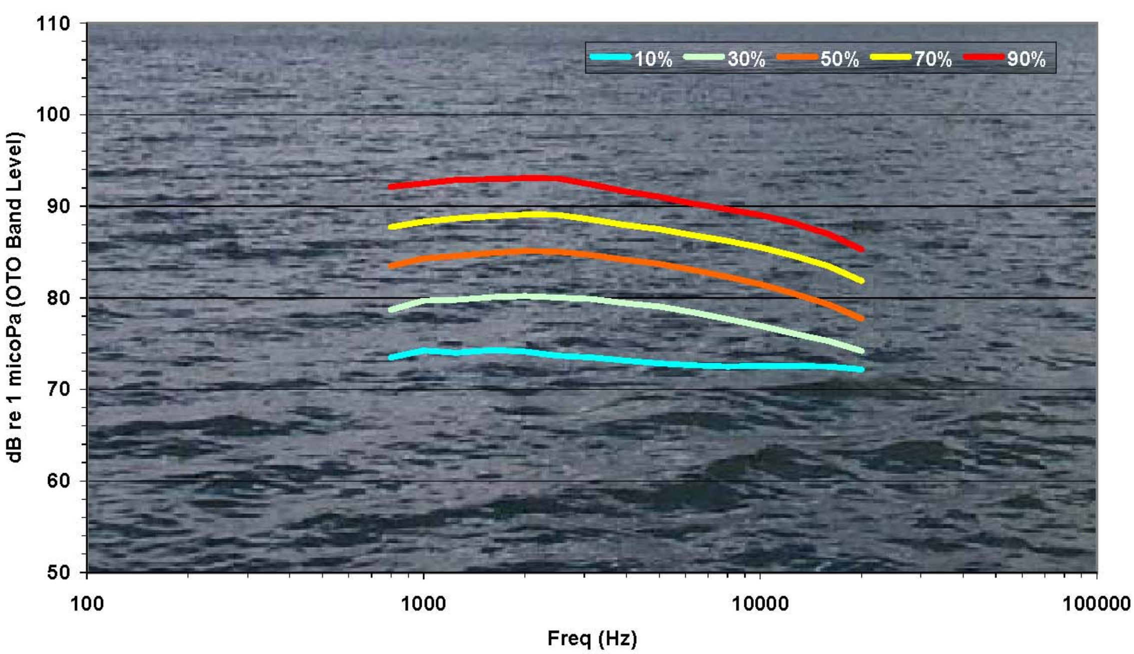


Fig. 15 Wind Noise Percentile Spectra

These curves show that the shape of the wind noise spectra at 30, 50, 70, and 90% is typical of the traditional deep water Knudsen wind noise spectra shown in Fig. 7, except that the peak in a typical Glacier Bay spectrum occurs at 2 to 2.5 kHz versus 1 kHz in the Knudsen curves. The location of Glacier Bay's wind noise peak agrees with extensive NSWC data collected in the Behm Canal area near Ketchikan, Alaska. Figure 15 also shows that the 10% curve is distinctly flatter than the higher wind noise curves. This flattening is due to the presence of other surface noise that becomes more apparent as wind noise levels drop. The other surface noise is audible as sloshing and gurgling. Hence, at lower wind speeds, the wind noise curve would be more aptly described as a combination of wind noise and other surface generated noise.

One additional note regarding Glacier Bay wind noise statistics: because of the prevalence of marine vessel noise in summer, fewer samples were controlled by wind noise in summer compared to winter. As a result, the summer wind noise statistics were based on a lower number of 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 5.

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 the 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. 16.

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. 17. In a rough sense, the results show that the months with the highest number of rain samples per day were the fall, and early-winter months. Yet, some summer months, as in 2002, exhibited more frequent rain noise than some of the lower rainfall winter months. The most frequent

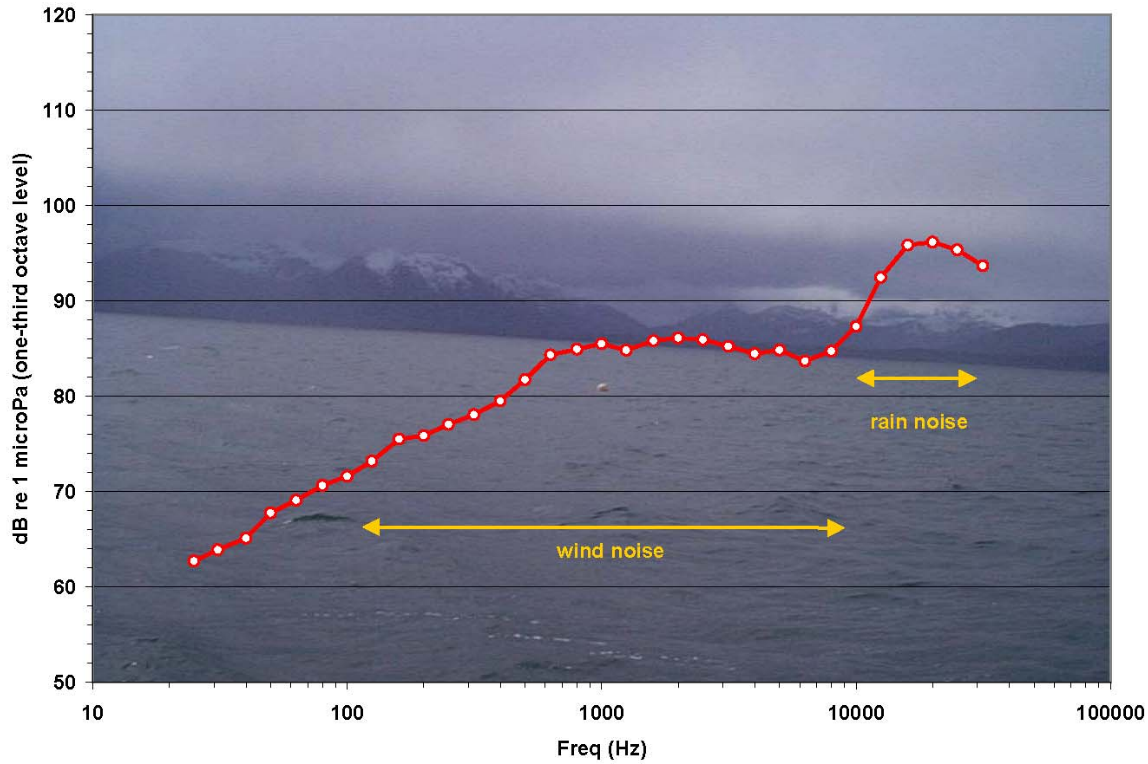


Fig. 16 Representative Rain Noise Spectrum

rainfall noise month was September 2001 (also a high maximum wind noise month). The least frequent rainfall noise months were March and April 2002.

Figure 18 shows minimum, average, maximum, and standard deviation rain noise levels plotted by month. These data are also listed in Table 7. The noise levels in Fig. 18 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 of 91 dB, with the exception of March 2001 at 6 dB below average (as per Table 1, this month only recorded 8 days of samples due to system damage).

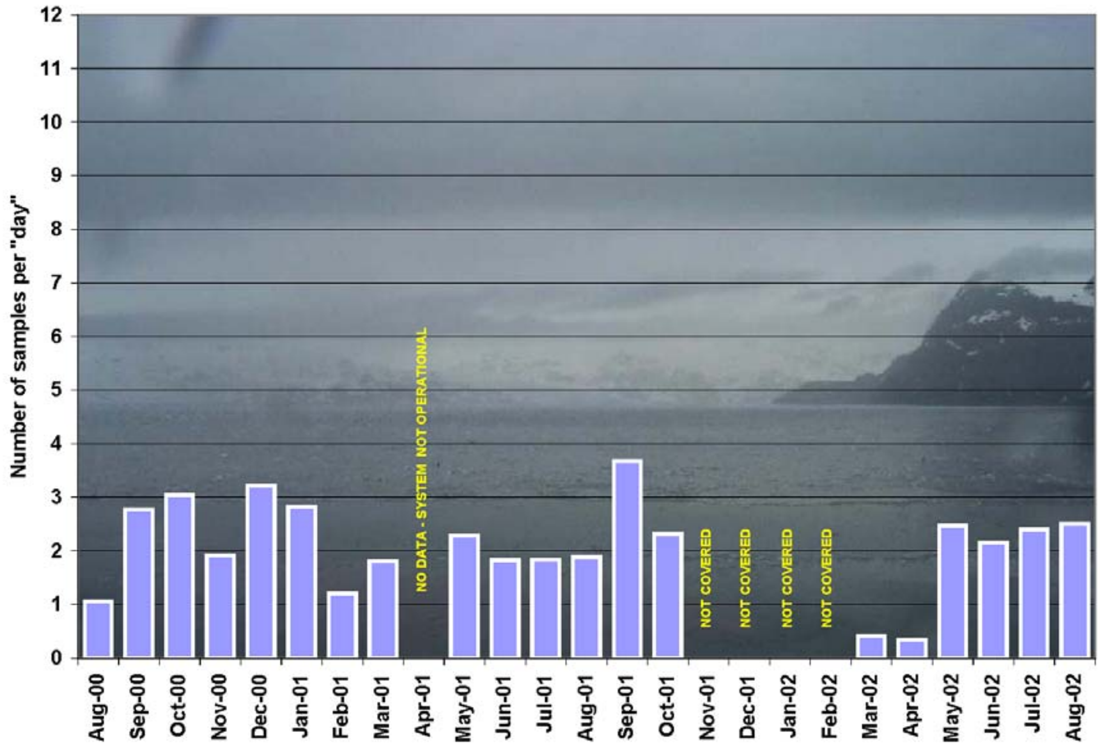


Fig. 17 Samples per Day Containing Rain Noise

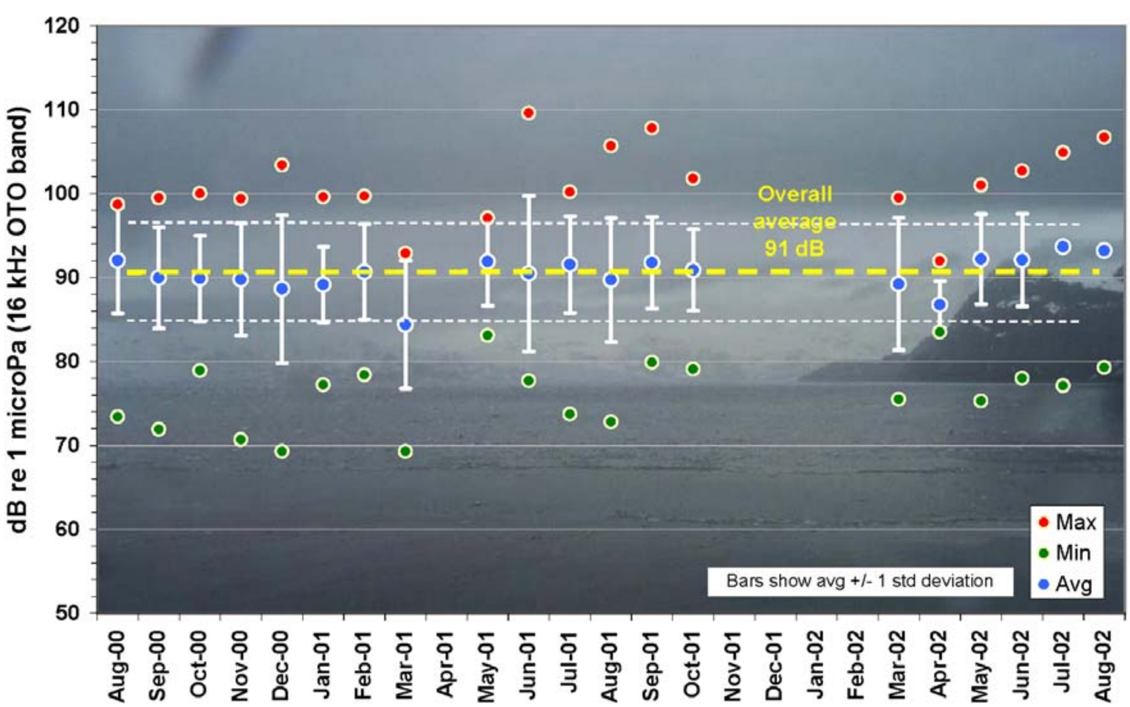


Fig. 18 Rain Noise Levels by Month

Table 7 Rain Noise Statistics

	Min (dB)	Avg (dB)	Max (dB)	Std Dev (dB)	Samples per "day"
Overall	69	91	110	6.3	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
Jan-01	77	89	100	4.5	2.8
Feb-01	78	91	100	5.7	1.2
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
Sep-01	80	92	108	5.5	3.7
Oct-01	79	91	102	4.8	2.3
Mar-02	76	89	100	7.9	0.4
Apr-02	84	87	92	2.8	0.3
May-02	75	92	101	5.4	2.5
Jun-02	78	92	103	5.5	2.2
Jul-02	77	94	105	8.3	2.4
Aug-02	79	93	107	5.2	2.5

A histogram showing the distribution of rain noise levels logged over the entire period covered by the interim database is shown in Fig. 19. This distribution shows that a substantial number of samples contained rain noise at levels greater than the average level (91 dB).

For rain noise, 45% of the 16 kHz one-third octave band levels occurred below the rain noise mean level. Fifty-five percent occurred at levels above the mean. The distribution of rain noise levels shown in Fig. 19 was more centralized than the wind noise level distribution in Fig. 13. Forty-two percent of 16 kHz rain noise levels were logged at levels within 3 dB of the mean (i.e. mean level +/- 3 dB).

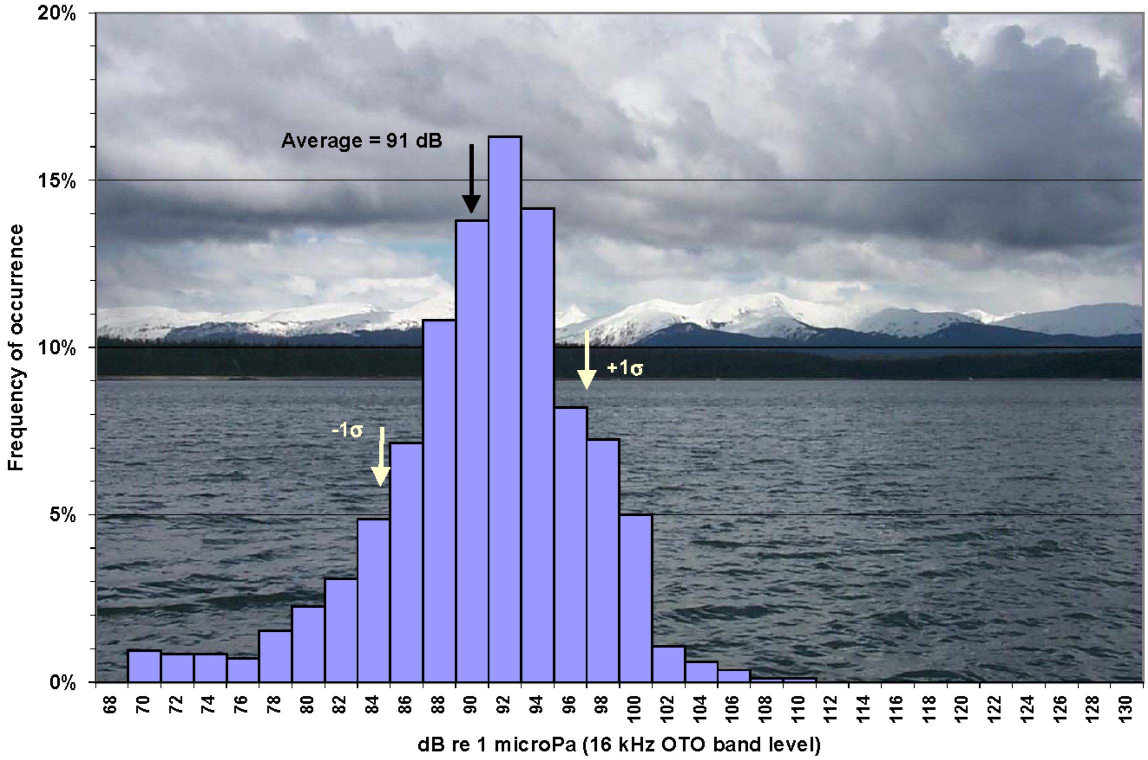


Fig. 19 Distribution of Rain Noise Levels

<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 grouped 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 non-patterned humpback whale 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 8 and shown graphically in Fig. 20.

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 September 2001, August 2000, and September 2000. A total of 17 samples were logged containing humpback whale songs in October 2000. This number accounts for 61% 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.

Table 8 Samples per “day” containing biologic noise

	All types	Humpback whale song	Humpback whale other	Biologic other than humpback whale
Overall*	438	28	313	97
Aug-00	2.4	0.06	2.24	0.12
Sep-00	2.2	0.09	1.11	0.97
Oct-00	5.1	0.82	4.01	0.24
Nov-00	1.9	0.00	1.25	0.63
Dec-00	0.2	0.00	0.11	0.11
Jan-01	0.0	0.00	0.00	0.00
Feb-01	0.1	0.04	0.04	0.00
Mar-01	0.0	0.00	0.00	0.00
May-01	0.3	0.00	0.00	0.29
Jun-01	0.5	0.11	0.32	0.11
Jul-01	0.1	0.00	0.05	0.09
Aug-01	1.6	0.07	1.13	0.41
Sep-01	3.5	0.14	2.59	0.80
Oct-01	0.8	0.00	0.62	0.19
Mar-02	0.1	0.00	0.03	0.07
Apr-02	0.0	0.00	0.00	0.00
May-02	0.1	0.00	0.04	0.04
Jun-02	0.2	0.00	0.00	0.15
Jul-02	0.0	0.00	0.00	0.00
Aug-02	0.1	0.00	0.07	0.00

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

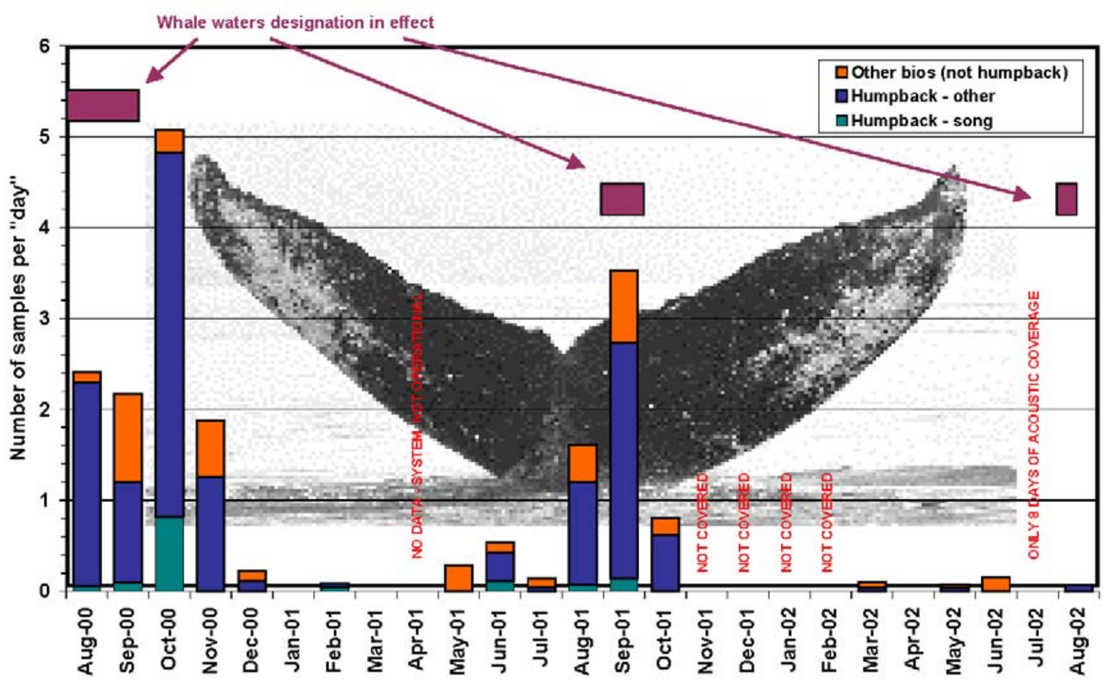


Fig. 20 Samples per Day Containing Biologic Noise

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 noises 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 (2000), and Doherty and Gabriele (2001, 2002) have reported the results of humpback whale surveys conducted by NPS in the spring, summer, and autumn months of 2000, 2001, and 2002. In each of these years, it was reported that humpback whales were not frequently sighted in the Bartlett Cove area. A summary of the results of these surveys with respect to lower Glacier Bay is given in Table 9.

Table 9 Summary of Humpback Whale Visual Surveys

Year	Vessel Survey Period	Lower Bay Whale Waters Speed Restriction	Additional Notes
2000	30 May – 18 Oct	13 Jun – 20 Sep	August to September: very high number of whales in lower bay.
2001	18 May – 23 Oct	31 Aug – 28 Sep	Whale numbers low until mid-August when numbers increased to typical levels.
2002	14 Apr – 21 Nov	1 – 16 Aug	Whales present mostly in late July to mid-August.

Data from Gabriele and Hart (2000), and Doherty and Gabriele (2001, 2002)

Comparison of the data from the visual humpback whale surveys correlates well with acoustic detections of whale sounds. The relatively high number of acoustic detections in August and September 2000 corresponds to the period when the whale waters speed limit was in effect and when “a very high number of whales were present in the lower bay”. Also, the peak in whale noise detections that occurred in August and September 2001 corresponded to the period when whales were most prevalent in the lower bay. In 2002, whales were only reported in significant numbers in lower Glacier Bay in the first half of August, but it was also reported that “for the second year in a row, whales were not abundant in lower Glacier Bay”. During this month only two acoustic detections were reported, and they occurred on the same day (18 August), one hour apart. In July 2002, acoustic data were limited. In this month acoustic data were only available for 8 days.

Another notable finding was that a high number of acoustic detections occurred in October and November 2000, after the main part of the surveying season concluded. This result may reflect a tendency toward increased vocalization activity at the end of the whale season in Glacier Bay, but humpback related sounds were logged less frequently in October 2001. Additional data are required to assess this pattern from year-to-year. Further discussion of the discovery of humpback whale singing in Glacier Bay, its occurrence in late season, and its significance is given by Gabriele and Frankel (2002).

Also, Fig. 20 shows an overall higher number of acoustic detections in 2000 than in 2001 (and possibly in 2002, also). This result may be indicative that whales were more populous in the area of the hydrophone in 2000, or that they were simply more vocally active in 2000. With the existing data coverage and the variability in population distribution in the 2000, 2001, and 2002 seasons, a “typical” level of whale acoustic activity is, at present, difficult to ascertain.

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. 21, 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 summer, and biologic sounds were more frequent than at any other time in the study.

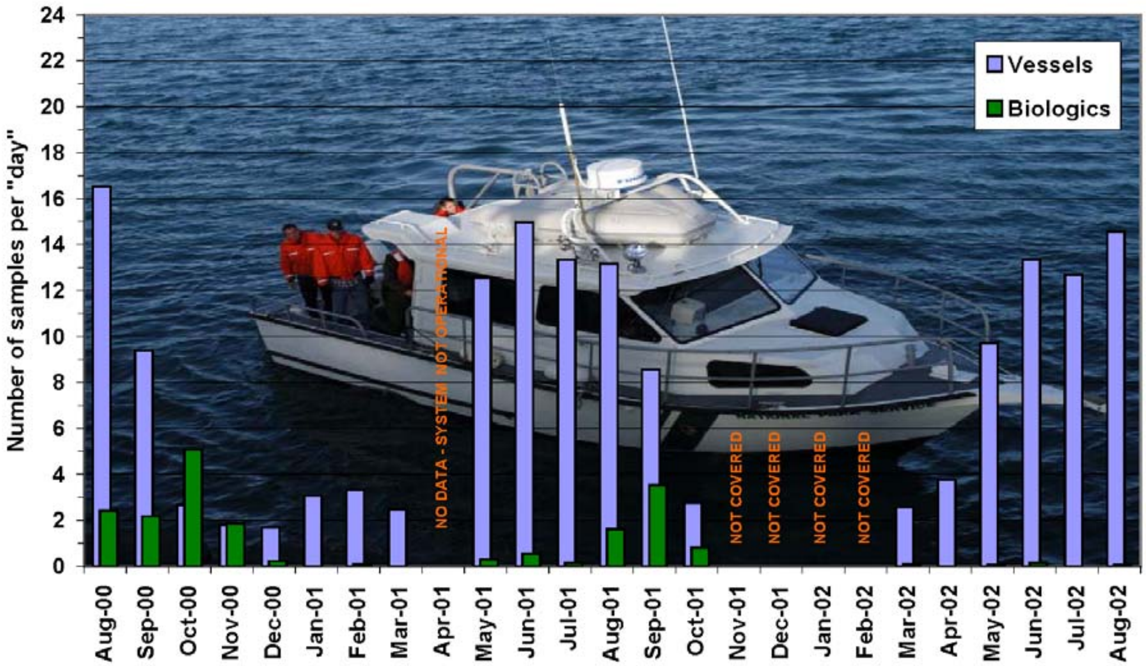


Fig. 21 Samples per Day – Vessels vs. Biologic

A total of 77 samples contained both marine vessel and biologic noise in the same sample. Figure 22 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 2001 at 0.7 samples per day. Note that, in some cases, vessel noise may mask whale vocalizations that would have been audible otherwise. As a result, these analyses may under-represent the co-occurrence of whales and vessels.

Biologic noise levels are not addressed in this report because biologic noise is 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 average noise measurement will typically not be conducive to establishing an accurate acoustic level.

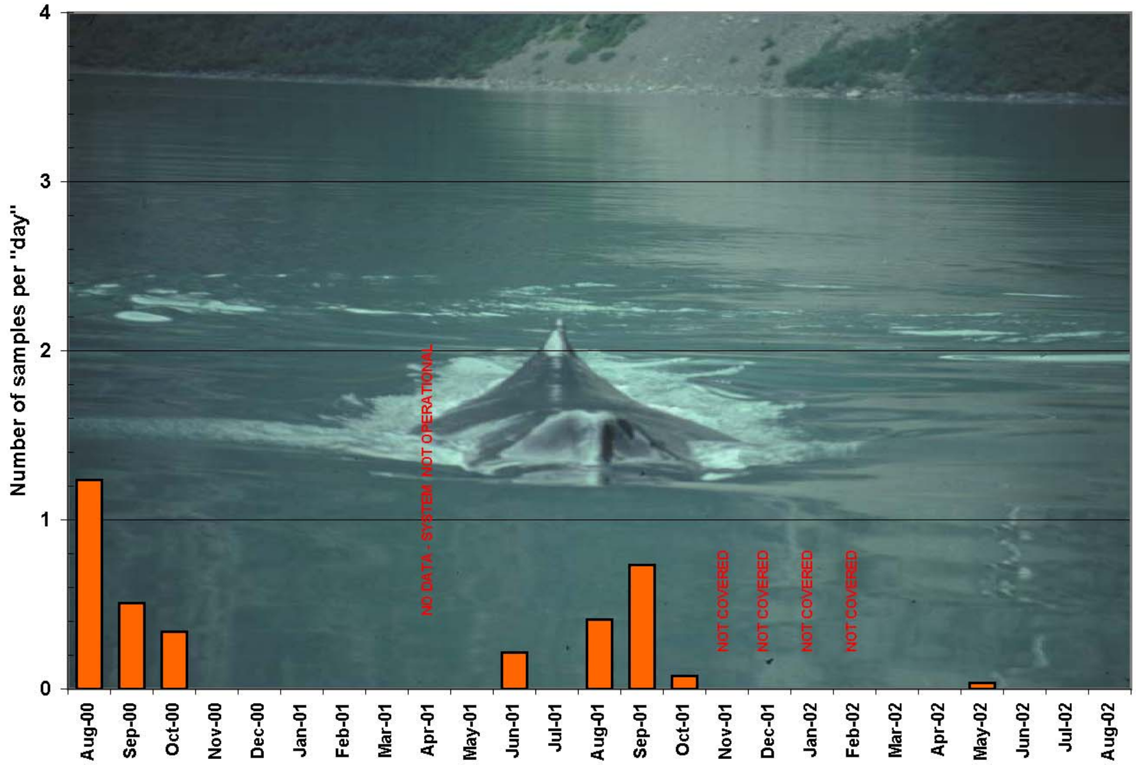


Fig. 22 Samples per Day – Vessels and Biologic

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 outboard driven skiffs, and inboard- or outboard-driven workboats and pleasure craft. 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. Vessels in this category would typically run from 14 to 30 feet in length.

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, commercial fishing boats, larger research vessels, 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 and 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 200 to 1000 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, large Alaska state ferries, and visiting vessels from NOAA, USCG, and the Navy .

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. Representative one-third octave spectra containing small, medium, and large vessel noise are shown in Figs. 23, 24, and 25. In separate studies conducted for Glacier Bay National Park and Preserve, Kipple and Gabriele (2003), and Kipple (2002) investigated noise levels and noise character of both small vessels and cruise ships common to Southeast Alaska waters. See these reports for additional information on these vessel types.

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 peak 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. Using Fig. 25 as an example, the peak level would be 113 dB and the frequency band at which this peak occurred would be 100 Hz.

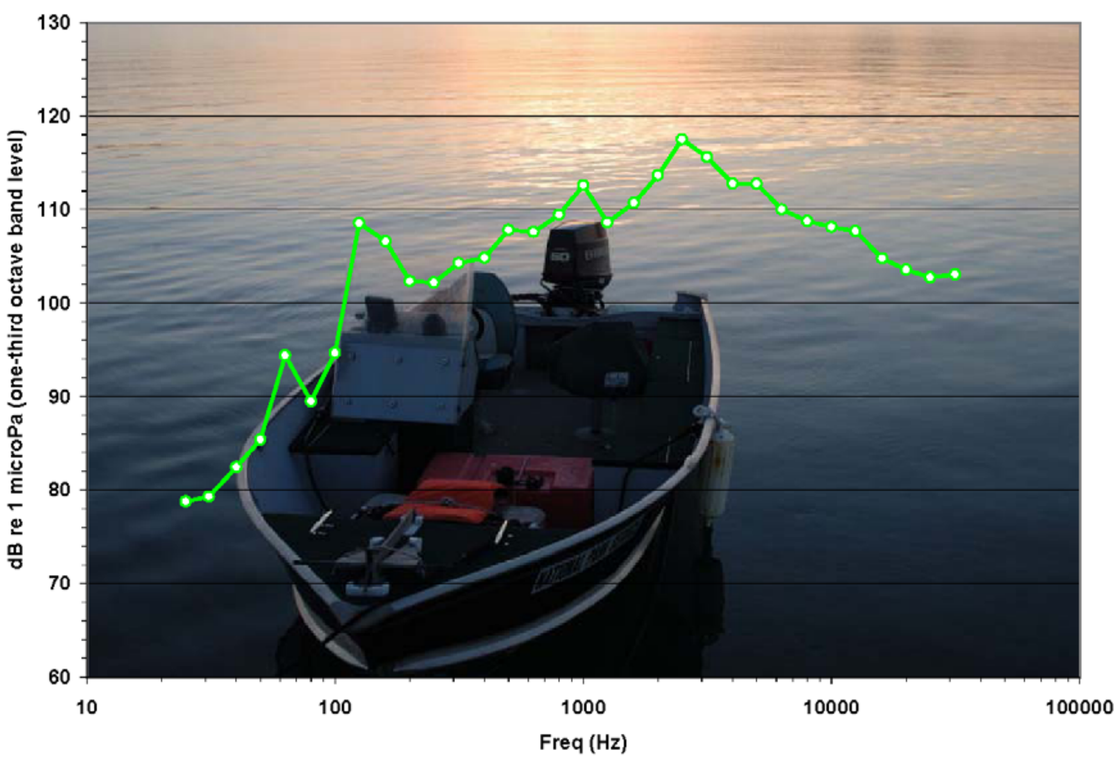


Fig. 23 Representative Small Marine Vessel Noise Spectrum

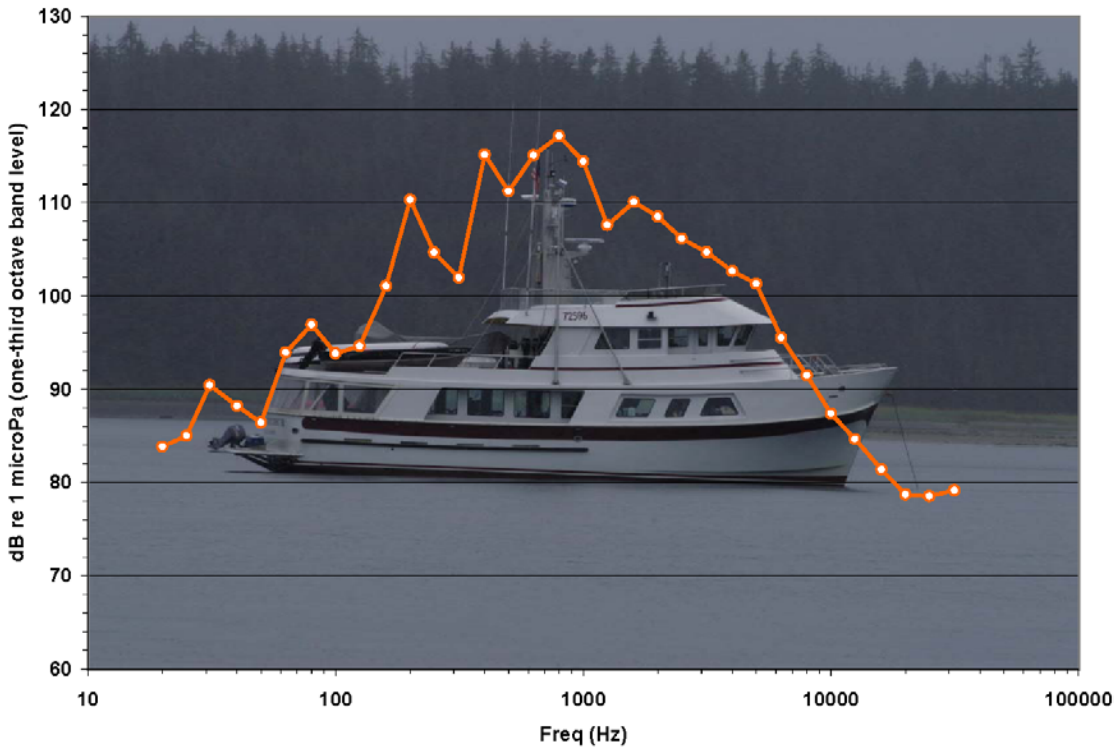


Fig. 24 Representative Medium Marine Vessel Noise Spectrum

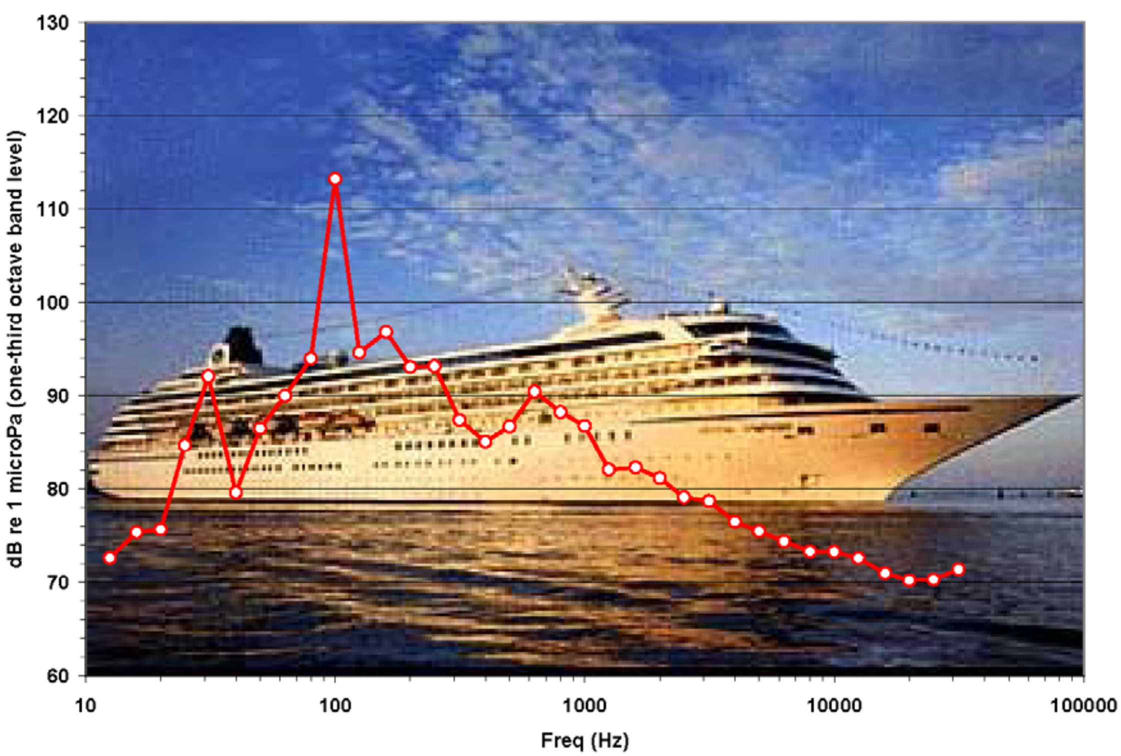


Fig. 25 Representative Large Marine Vessel Noise Spectrum

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 10 lists these results for all vessels lumped into a single category.

Table 10 Marine Vessel Noise Statistics – All Types

	Min (dB)	Avg (dB)	Max (dB)	Std Dev (dB)	Samples per "day"
Overall	70	94	129	9.5	7.7
Aug-00	72	93	115	9.2	16.5
Sep-00	72	93	123	9.5	9.4
Oct-00	78	92	111	7.7	2.7
Nov-00	74	90	117	8.9	1.8
Dec-00	74	88	118	10.0	1.7
Jan-01	75	85	99	5.6	3.1
Feb-01	73	90	107	7.8	3.3
Mar-01	75	87	110	9.8	2.5
May-01	76	96	120	10.1	12.6
Jun-01	78	97	117	8.7	15.0
Jul-01	79	96	121	8.6	13.3
Aug-01	74	95	129	9.7	13.2
Sep-01	74	94	117	8.7	8.6
Oct-01	73	89	121	8.9	2.7
Mar-02	70	87	114	9.5	2.6
Apr-02	70	87	119	10.3	3.8
May-02	75	96	123	10.3	9.7
Jun-02	74	95	122	9.7	13.4
Jul-02	78	97	114	7.8	12.7
Aug-02	78	94	123	8.1	14.6

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 26 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 10 is reflected on the plot as well as the levels representing +/- one-standard deviation from the average.

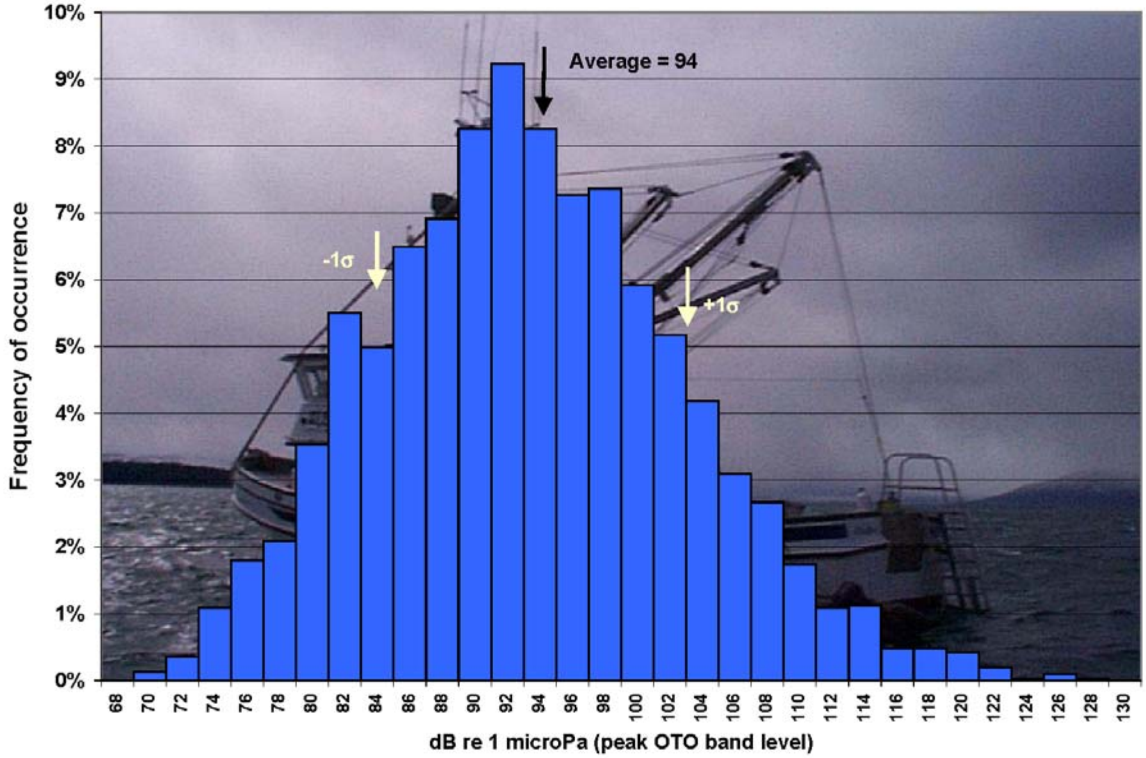


Fig. 26 Distribution of Vessel Noise Levels

Some observations from Fig. 26 and Table 10 include:

1) 0.6 % of the samples containing marine vessel noise exhibited levels exceeding 120 dB.
2) 47% of logged vessel noise levels were above the mean vessel noise level.
3) 52% of logged vessel levels were below the mean.
4) 25% of logged vessel noise levels occurred in a 6 dB range centered about the mean (i.e. 94 dB +/- 3 dB).
5) No vessel noise levels exceeded 130 dB at the hydrophone.
6) Vessel noise levels within one-standard deviation of the mean ranged from 84 to 103 dB.
7) On the average, vessel noise was present in 7.7 samples per "day", but this number varied by month and season.

8) On the average, vessel noise levels were higher than those in samples where noise levels were dominated by wind only. The average wind noise level was 84 dB compared to 94 dB for marine vessels.

Percentile statistics for marine vessel noise were also developed based on the peak one-third octave band level for samples where vessel noise was present. These results are listed in Table 11. The percentile ranking indicates the percentage of samples where vessel noise was logged below a certain level. For example, the data in Table 11 show that for 20% of all samples where vessel noise was present, the peak band level was below 85.3 dB. If the data compiled in the acoustic database are representative of lower Glacier Bay underwater noise, one could then infer that, *when vessel noise is present*, vessel noise levels below 85.3 dB will only be logged about 20% of the time.

Table 11 Peak Vessel Noise Percentile Rankings

Percentile	Peak One-third Octave Vessel Noise Level (dB)
99%	117.8
95%	110.0
90%	106.0
80%	101.5
70%	98.1
60%	95.5
50%	93.0
40%	91.0
30%	88.2
20%	85.3
10%	81.6
5%	79.0
1%	74.3

Result (8) above is further elaborated in Fig. 27, 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 is presumed to frequently mask low level noise from distant vessels. Figure 27 also illustrates the relative presence of wind noise versus vessel noise, although this point is better represented in Fig. 9, because some samples represented in Fig. 27 contain both wind and vessel noise.

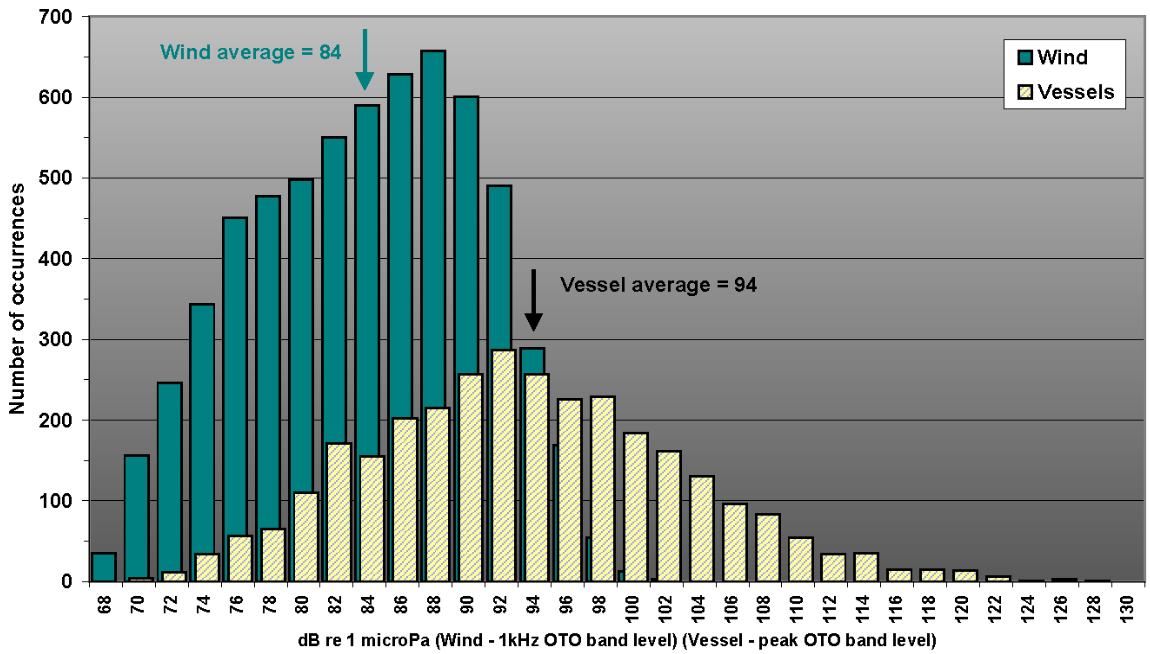


Fig. 27 Distribution of Noise Levels – Wind vs. Vessels

Figure 28 shows wind noise levels versus marine vessel levels on a monthly basis. The average and maximum 1 kHz wind level for each month is plotted along with the monthly average and maximum vessel level. 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 January 2001 and March 2002, where the average wind and vessel noise levels were nearly comparable. Figure 28 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 mostly lower than, or comparable to, the average vessel levels, because

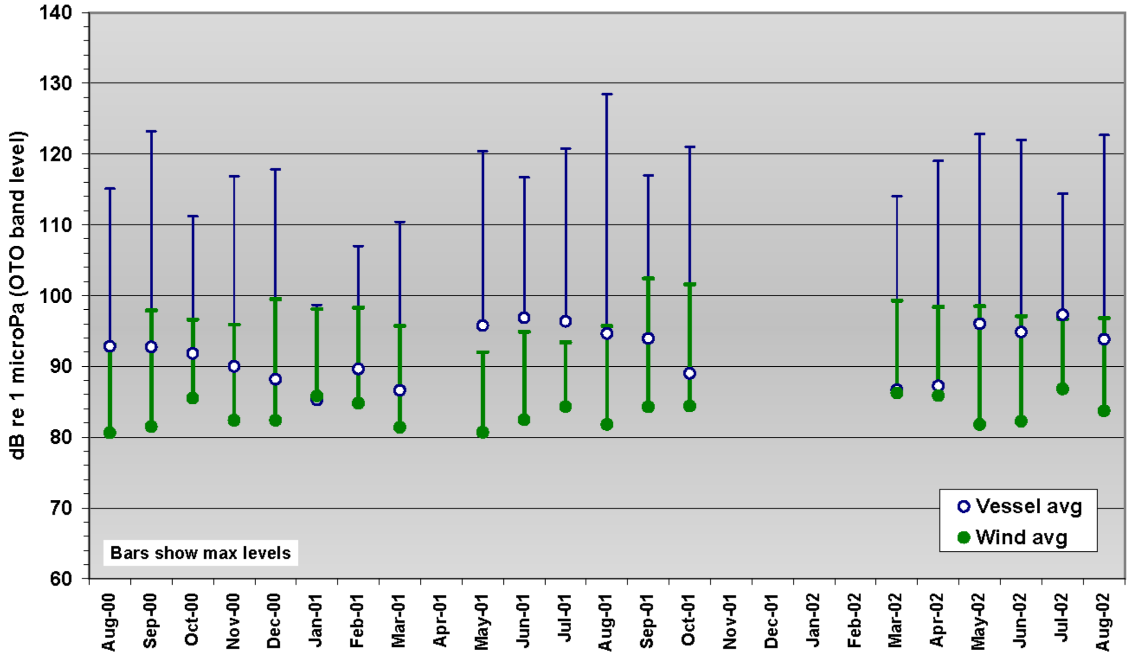


Fig. 28 Wind Noise and Vessel Noise Levels by Month

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 track 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 the peak one-third octave band frequencies is given in Fig. 29. This histogram shows that about 95% of the highest level one-third octave bands occurred in the 80 to 5000 Hz range. Also, about 44% of the peak 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. 29 does not address all of the frequency bands that were affected by vessel noise in each sample. Rather, it tracks the *highest level* (or peak) 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.

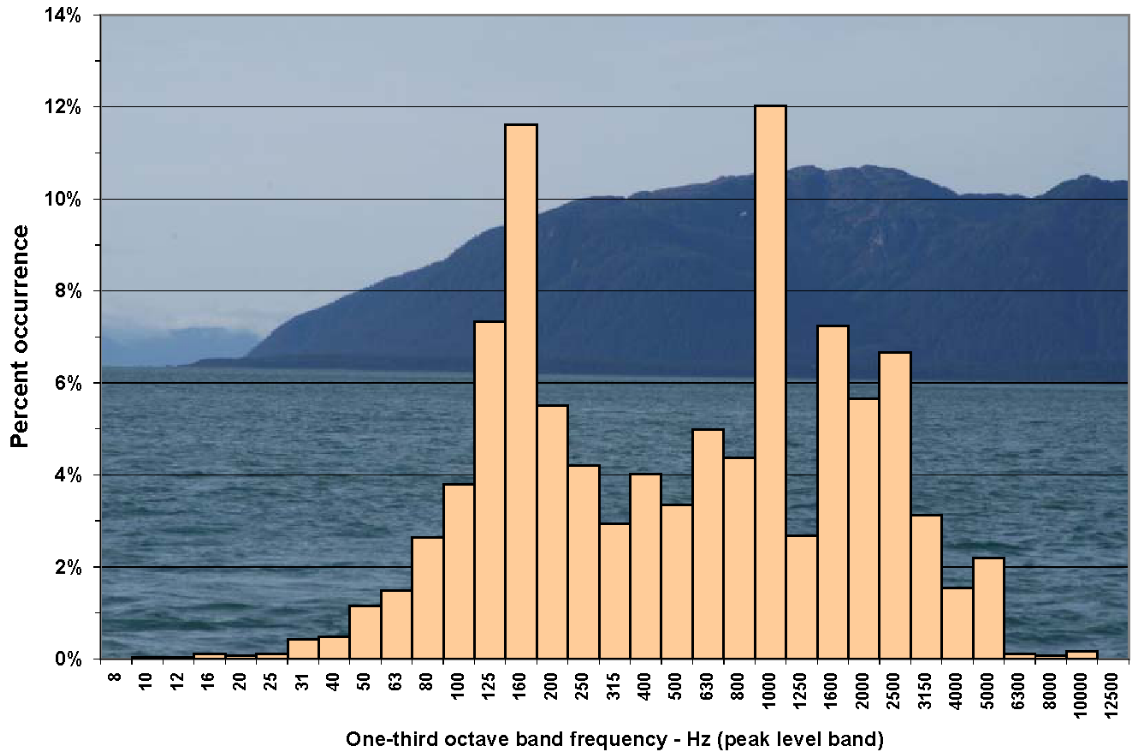


Fig. 29 Distribution of Vessel Noise Peak Frequencies

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. 30 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 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. 30 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

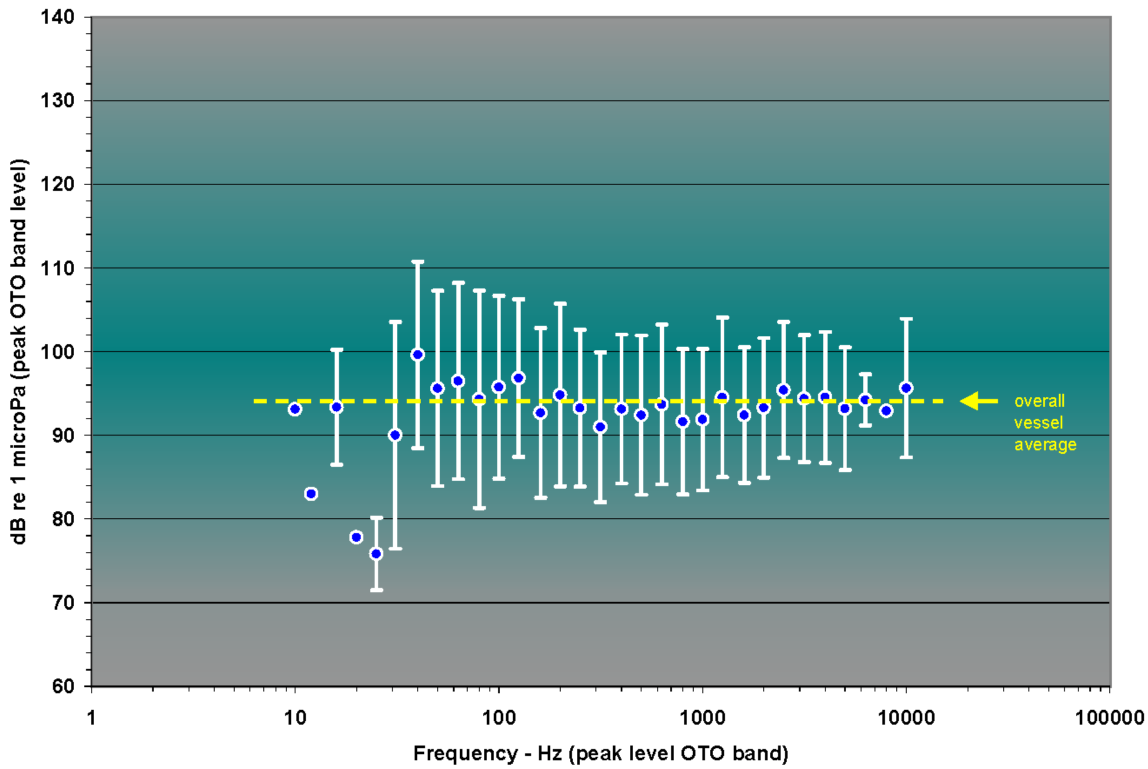


Fig. 30 Peak Vessel Noise Level vs. Peak Frequency

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 at 25 Hz and below. Here levels were consistently lower than average, except at 16 Hz. 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 10 data points at frequencies of 25 Hz and below). Also, levels from 40 to 125 Hz were consistently higher than average, perhaps due to levels from large vessels in this frequency range.

<u>Noise by Vessel Type</u>

The number of samples containing marine vessel noise was also established according to vessel type: small, medium, and large. Figure 31 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 68% of all vessels observed, while large and small vessels accounted for 15% and 12%, respectively.

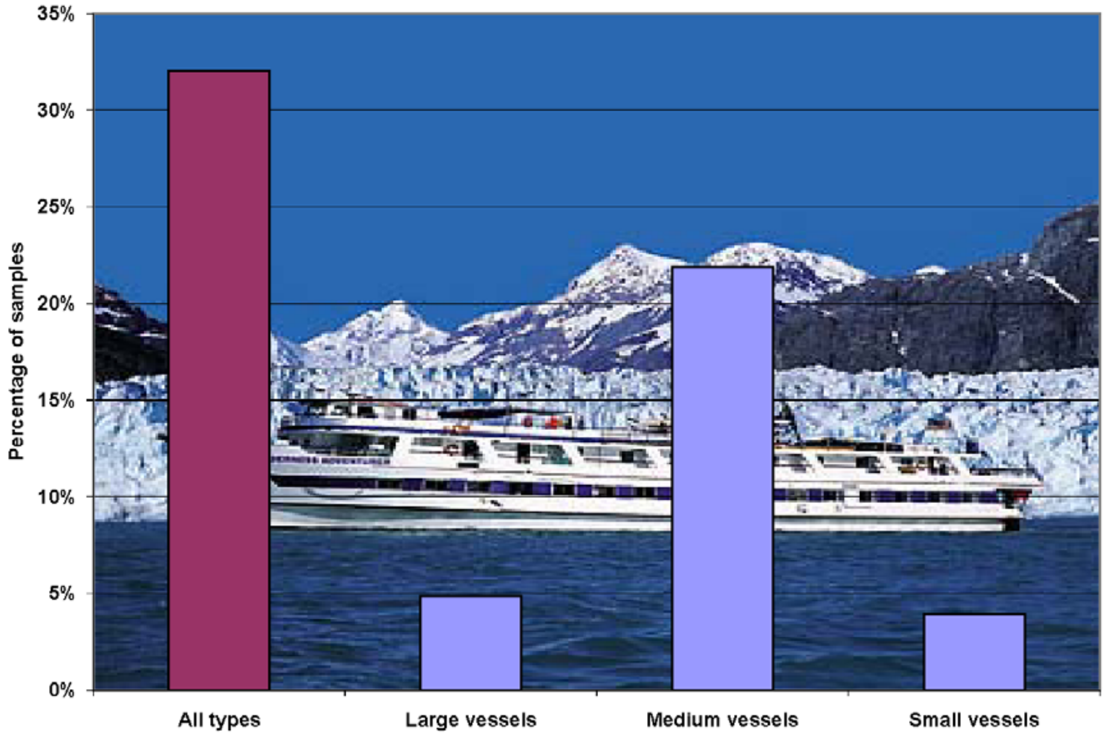


Fig. 31 Samples Containing Vessel Noise by Type

The number of samples per "day" that contained vessel noise was also plotted by type on a monthly basis. Figure 32 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. 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.

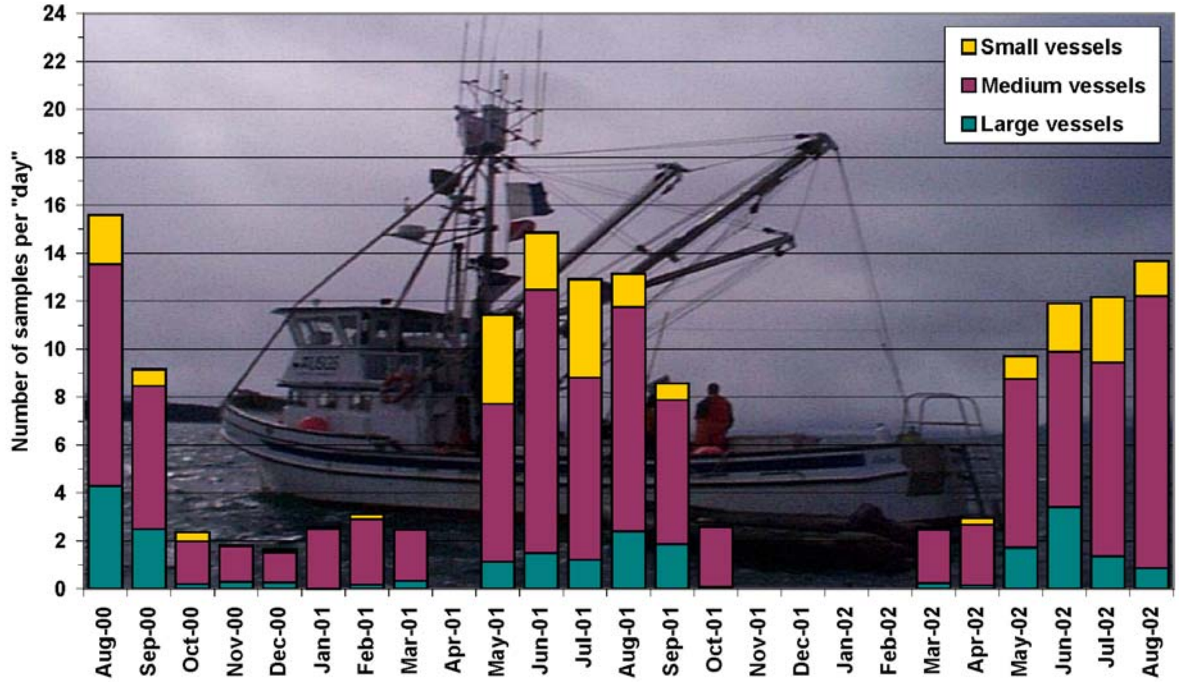


Fig. 32 Samples per Day Containing Vessel Noise

Vessel noise levels were also tracked according to vessel type. Figure 33 shows that large vessels were, on average, louder at the hydrophone than medium and small vessels. The average large vessel level (average peak one-third octave level for each sample) was 99 dB, versus 97 and 92 dB for small and medium vessels, respectively. Large vessels also logged the highest peak level (at the hydrophone) 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 12, 13, and 14. Note that, because of the hydrophone location in lower Glacier Bay, large vessels, particularly large cruise ships, do not operate close to the hydrophone. Based on the normal path of large cruise ships, their closest distance to the hydrophone would normally be about 1.2 miles. On the other hand, medium and small vessels operate throughout lower Glacier Bay and often pass close to 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.

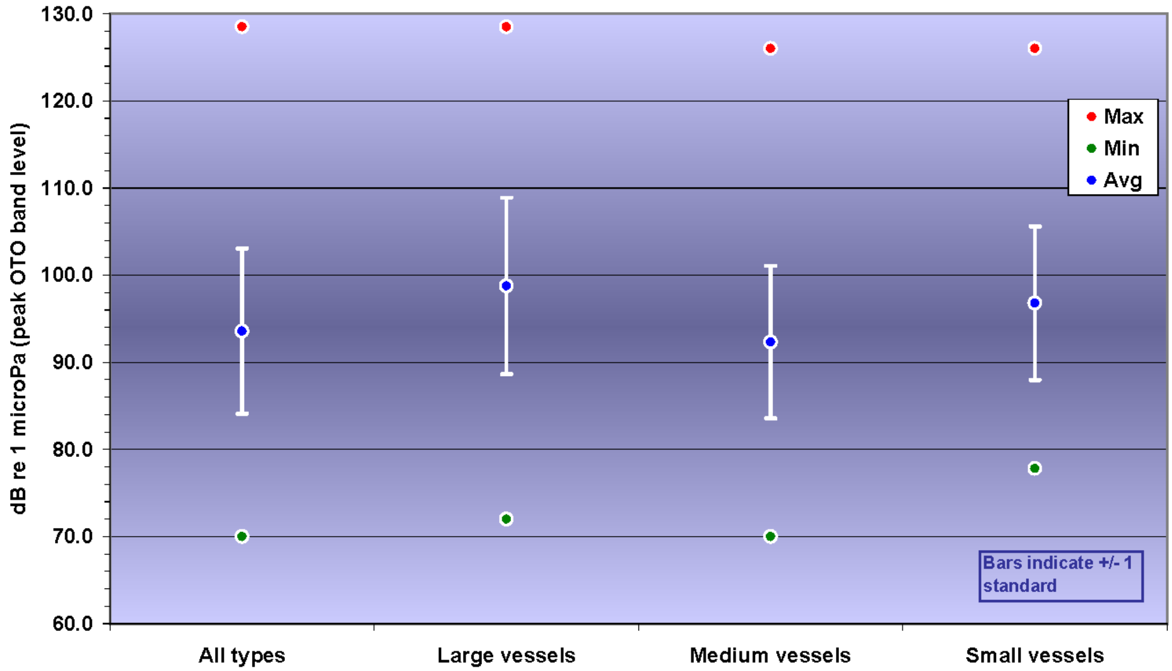


Fig. 33 Noise Statistics by Vessel Type

Table 12 Large Marine Vessel Noise Statistics

	Min (dB)	Avg (dB)	Max (dB)	Std Dev (dB)	Count
Overall	72	99	129	10.1	477
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
Jan-01					0
Feb-01	76	87	101	11.9	4
Mar-01	89	92	95	4.1	2
May-01	105	111	118	5.8	4
Jun-01	95	106	116	6.7	14
Jul-01	86	105	121	8.8	26
Aug-01	75	98	129	11.0	70
Sep-01	84	99	114	7.3	53
Oct-01	85	100	114		2
Mar-02	78	86	102	8.0	7
Apr-02	87	104	119	15.4	4
May-02	83	105	123	9.0	46
Jun-02	78	97	121	9.9	68
Jul-02	95	103	112	5.5	8
Aug-02	89	104	123	8.0	26

Table 13 Medium Marine Vessel Noise Statistics

	Min (dB)	Avg (dB)	Max (dB)	Std Dev (dB)	Count
Overall	70	92	126	8.7	2147
Aug-00	74	92	115	9.1	157
Sep-00	72	91	123	9.3	129
Oct-00	79	92	111	8.2	37
Nov-00	74	89	104	7.5	40
Dec-00	74	90	118	10.6	23
Jan-01	75	86	99	5.8	41
Feb-01	73	90	107	7.7	66
Mar-01	75	86	110	10.2	13
May-01	83	94	106	7.8	23
Jun-01	78	96	117	8.2	102
Jul-01	79	95	121	8.1	161
Aug-01	74	93	126	8.9	273
Sep-01	74	92	114	8.3	172
Oct-01	73	89	121	8.4	65
Mar-02	70	87	114	9.7	65
Apr-02	71	88	111	9.5	73
May-02	75	93	118	8.8	188
Jun-02	74	95	122	8.3	129
Jul-02	78	97	114	7.9	47
Aug-02	78	93	117	7.3	334

Table 14 Small Vessel Noise Statistics

	Min (dB)	Avg (dB)	Max (dB)	Std Dev (dB)	Count
Overall	78	97	126	8.8	384
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
Jan-01	88	88	88		1
Feb-01	83	91	103	7.3	5
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
Sep-01	85	98	117	8.7	20
Oct-01	103	103	103		1
Mar-02	83	92	101		2
Apr-02	87	95	100	5.3	8
May-02	84	103	121	9.8	25
Jun-02	80	98	121	9.9	40
Jul-02	86	97	110	7.9	16
Aug-02	81	95	121	9.1	43

The histogram in Fig. 26 showed the distribution of marine vessel noise for all vessels and Fig. 33 showed that received levels for large vessels were, on average, 2 to 7 dB 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. 34 along with the histogram for all vessels from Fig. 26. This comparison shows that the distribution of large vessel noise levels was weighted slightly towards higher levels than the distribution containing all vessel types. It also demonstrates that a minority of samples contained large vessel noise, as previously shown in Fig. 32.

Similar histograms were generated for medium and small vessel noise levels. These plots are also included in Fig. 34. 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 vessels that were observed (as previously shown in Fig. 32).

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 35 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, and most peak levels occurred in the 125 to 3150 Hz range. This wide distribution was probably 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.

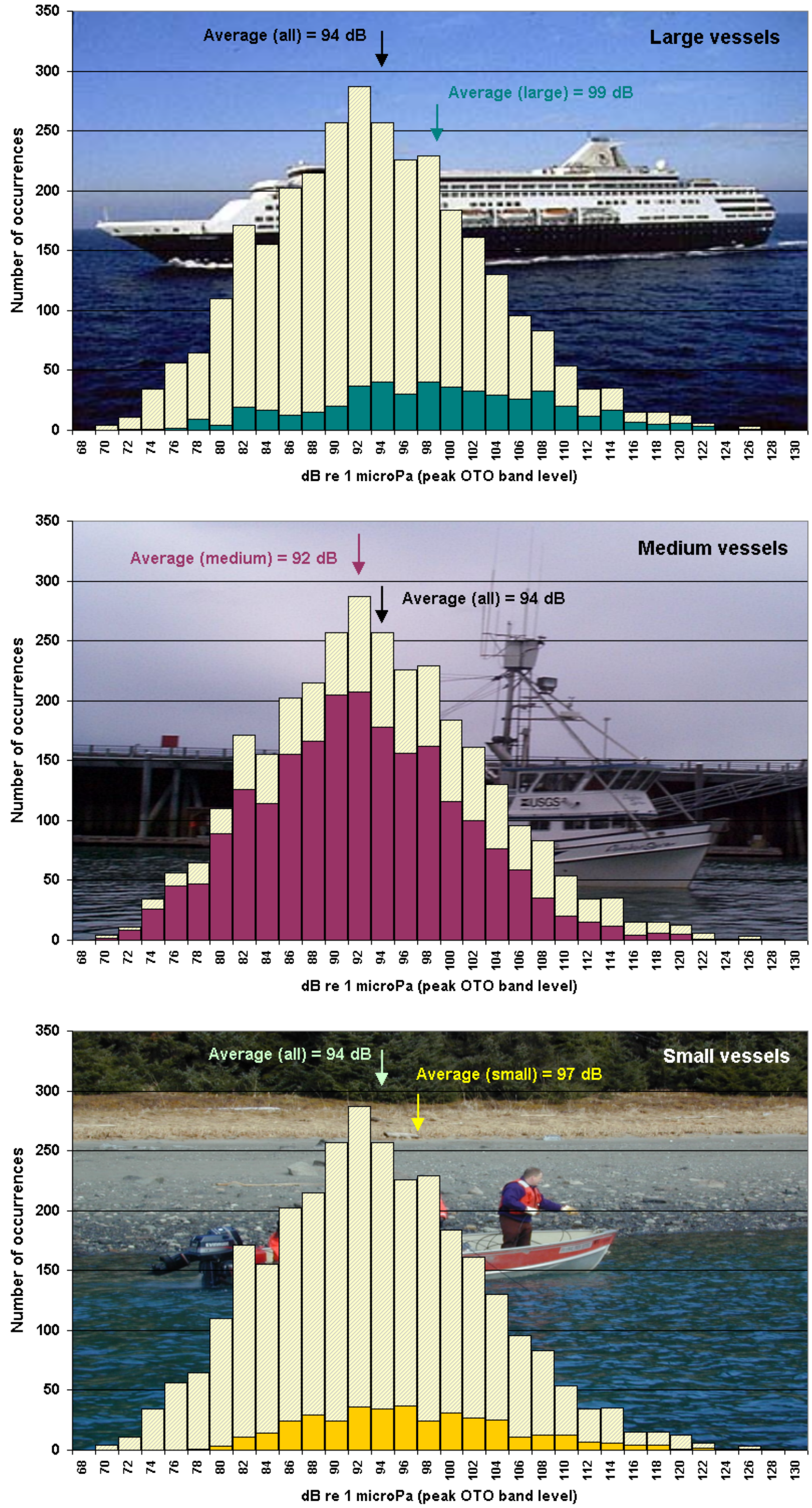


Fig. 34 Distribution of Vessel Noise Levels by Type

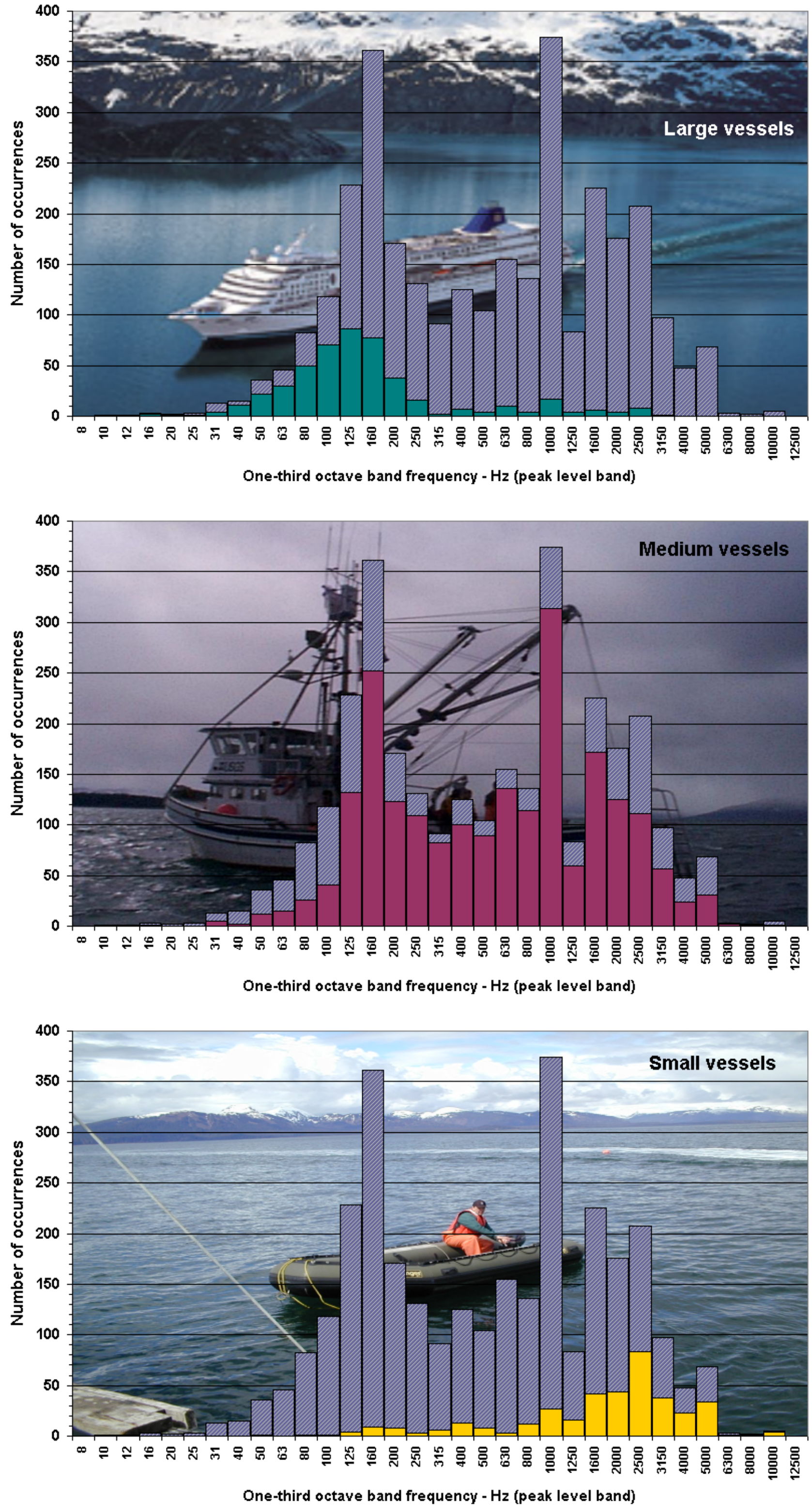


Fig. 35 Distribution of Vessel Noise Peak Frequencies by Type

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. 10:

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

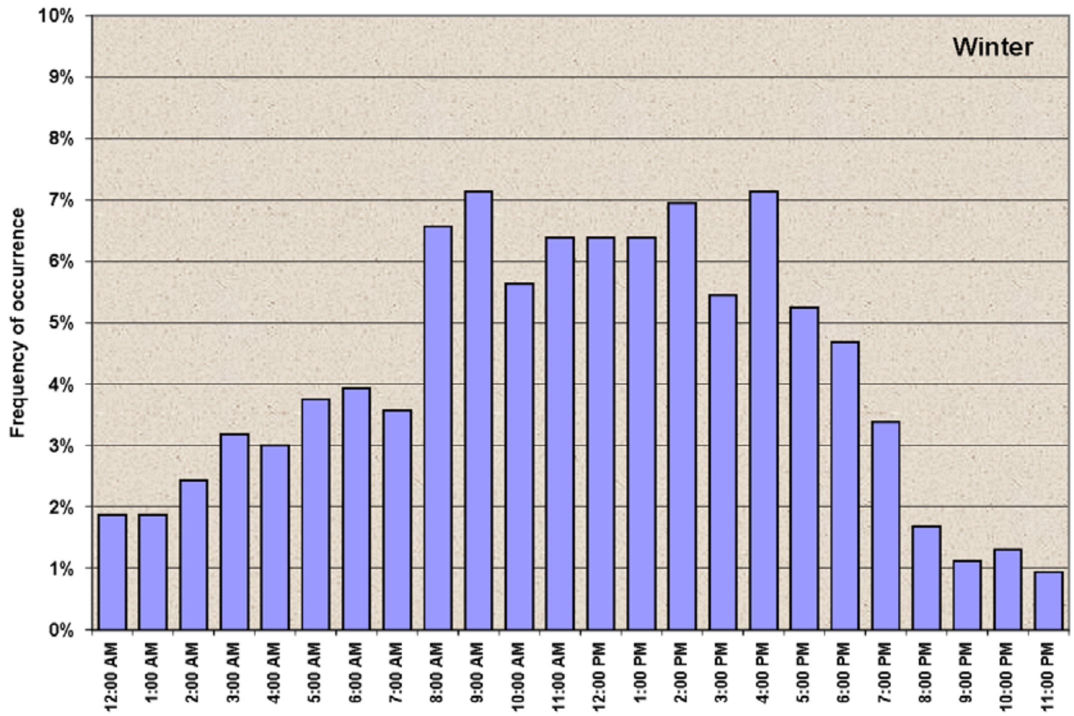
Figure 36 shows that late night and early morning noise samples were less likely to contain vessel noise compared to samples collected at other times-of-day. In any given season, 87-90% of the samples containing vessel noise occurred between 5 A.M. and 9 P.M. The graphs also show that vessel noise occurrence 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. During the period covered by this report, the 10-knot speed limit was in effect for

a) 2000 - 13 June to 20 September
b) 2001 - 31 August to 28 September
c) 2002 – 1 to 16 August.

To examine the effect of the speed limit on vessel noise levels, data from 10-knot periods were compared with levels from 20-knot periods. Table 15 identifies the 10 and 20-knot periods that were used for this comparison. All of the data collected in the periods identified in (a) through (c) above were not used for the comparison. September data were not used because they were in the fall season category, as per Fig. 10. June and July 2000 data were not used because these data were not fully analyzed for content, as per Table 1.



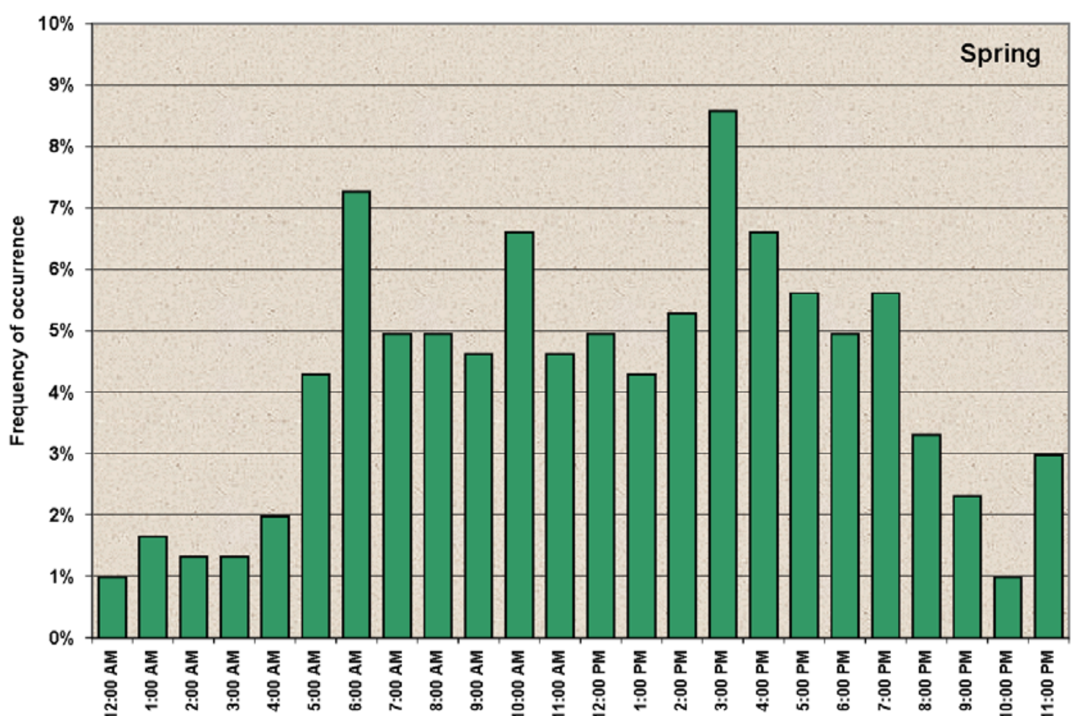
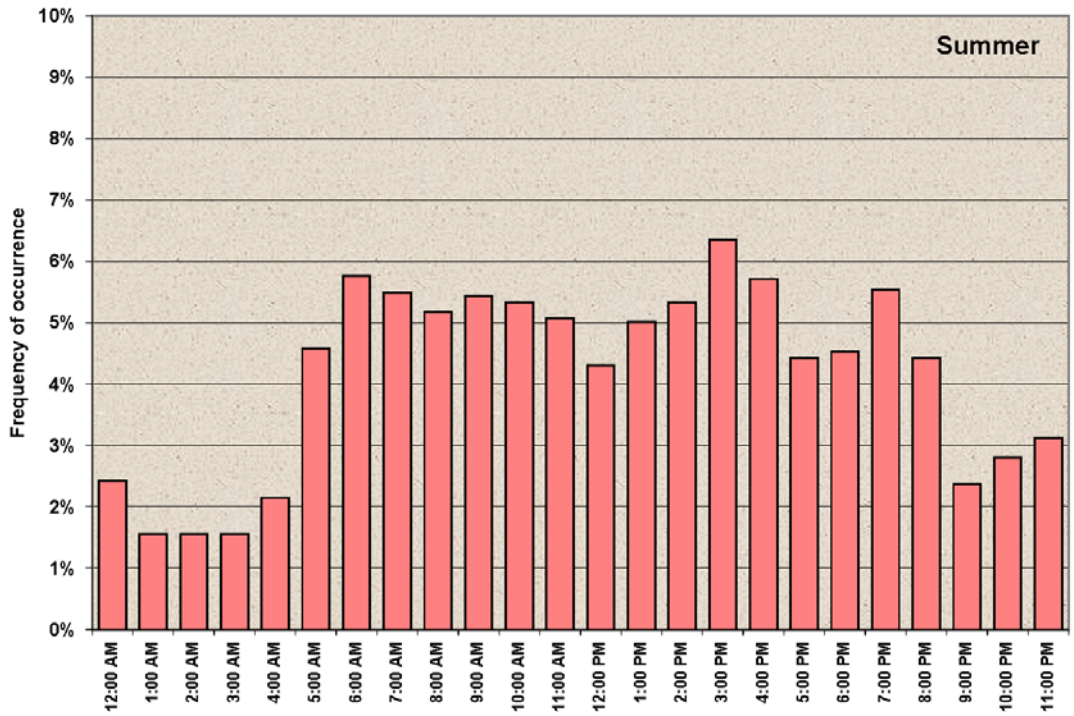


Fig. 36a Vessel Noise Frequency of Occurrence – Hourly – By Season



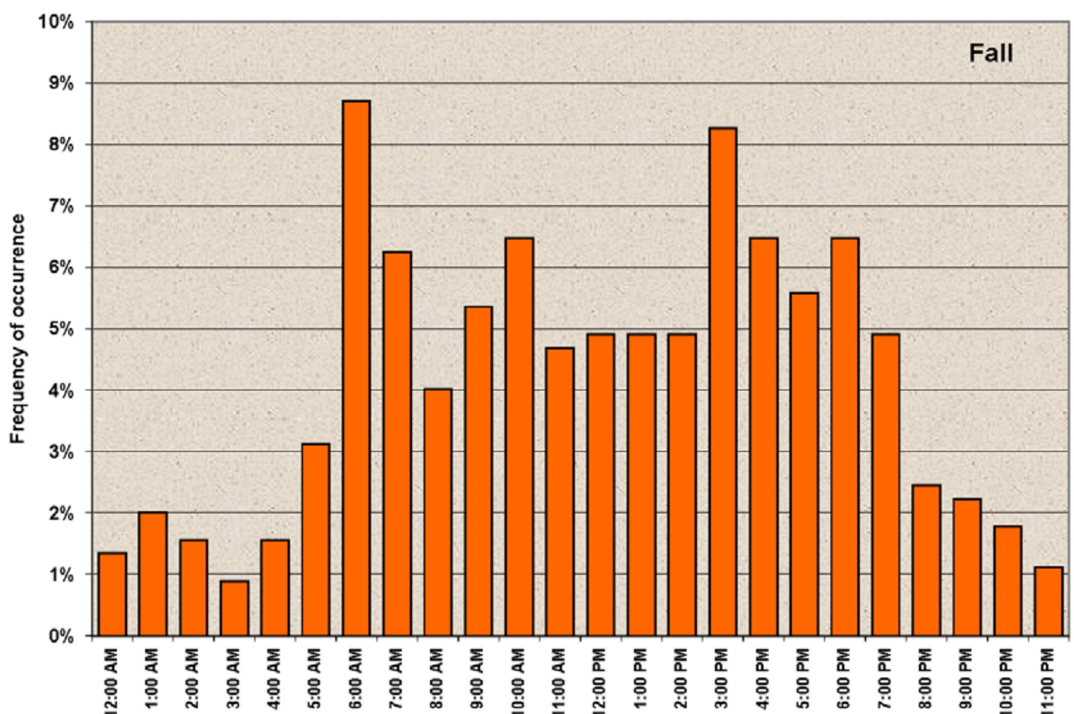


Fig. 36b Vessel Noise Frequency of Occurrence – Hourly – By Season

Table 15 Periods Used to Compare 10 and 20-knot Speed Limit Noise Levels

Time Period	Speed Limit (knots)
Aug 1-30 2000	10
Aug 1-16 2002	10
Aug 1-30 2001	20
Aug 17-30 2002	20

Figure 37 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 16, along with the number of samples for each category.

Table 16 10-knot versus 20-knot Vessel Noise Levels

Speed Limit	Vessel Type	Min (dB)	Avg (dB)	Max (dB)	Std Dev (dB)	Sample Count
10	Overall	72	93	123	8.6	498
20	Overall	74	94	129	9.3	568
10	Large	72	97	123	9.5	83
20	Large	75	99	129	10.7	83
10	Med	74	93	117	8.1	343
20	Med	74	93	126	8.5	406
10	Small	81	94	121	8.5	52
20	Small	81	98	126	9.3	64

The speed limit comparison shows that the maximum vessel noise levels for all categories were lower, by 5 to 9 dB, when the 10-knot speed limit was in effect compared to the 20-knot speed limit periods. For large and small vessels, the average noise levels were up to 4 dB lower during the 10-knot speed limit period. The average levels for medium vessels at 10 and 20 knots were equivalent. Also, the minimum vessel noise levels for small and medium vessels were unchanged between the 10 and 20-knot periods.

Unidentified Noise

A total of 2171 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,*

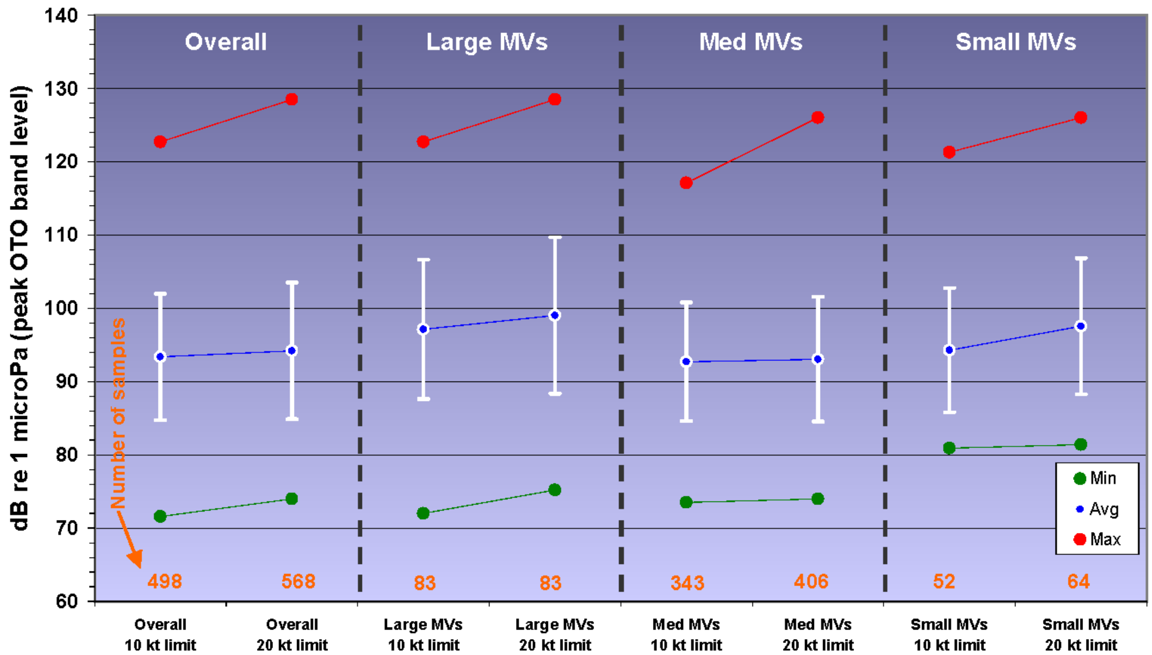


Fig. 37 10-Knot vs. 20-Knot Speed Limit Noise Levels

clank, clunk, pop, splash, and *gurgle*. Some of these sounds may be attributable to fish. 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 an oceanographic survey sonar.

Of the 2171 samples that contained unidentified noise, 1381 samples (or 64%) 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 38 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, and in July of 2002. 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.

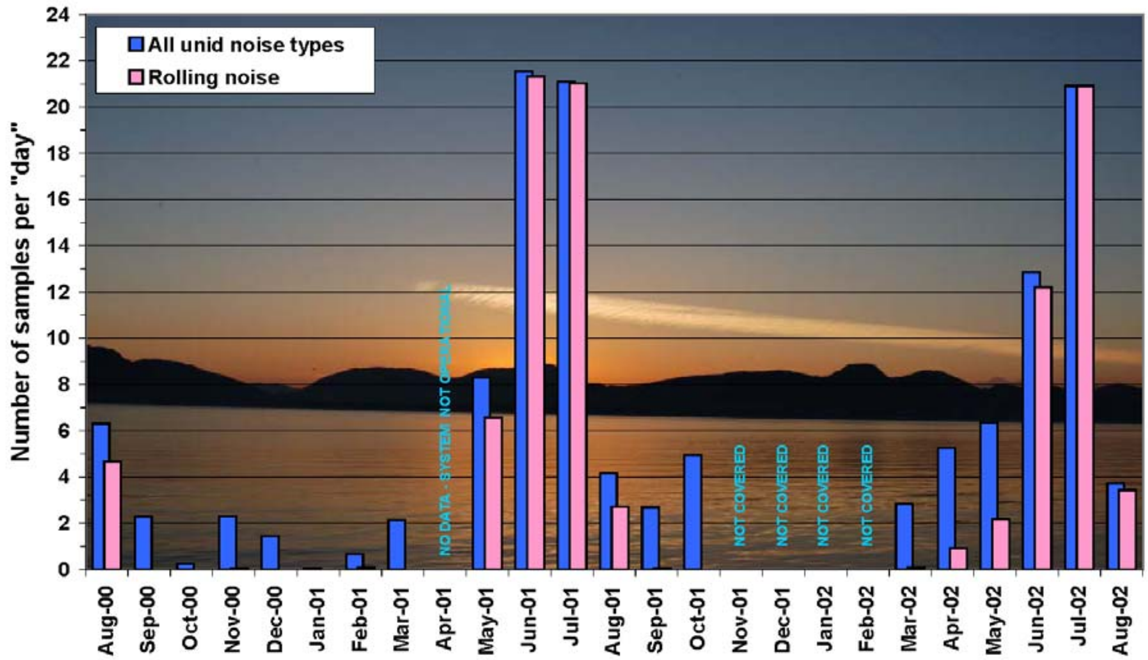


Fig. 38 Samples per Day Containing Unidentified Noise

SUMMARY AND CONCLUSIONS

Almost 10,000 underwater noise samples collected during 20 months between August 2000 and August 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, was 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 established.

As is typical for most areas, the dominant natural source of underwater noise was wind generated surface noise. In 64% 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 84 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 102 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 84 dB.

Forty percent of the 1 kHz wind noise levels were logged in the 84 to 90 dB range and 27% occurred within a 6 dB range centered about the mean. Fifty-two percent of wind noise levels occurred above the mean level and 47% were below the mean.

Glacier Bay wind noise levels were compared to observed sea-state levels for a two-month period. The correlation between sea-state and measured 1 kHz wind noise corresponded well with published wind noise levels for shallow water. Contrasted with published deep water wind noise spectra which peak near 1 kHz, the peak in the Glacier Bay one-third octave wind noise spectra occurred at 2 to 2.5 kHz. This result is in agreement with NSWC's experience with wind noise characteristics in Behm Canal, near Ketchikan, Alaska.

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 91 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, and September 2001. Over the entire period covered by the database, the number of samples per day containing rain noise averaged 2.1.

Forty-two percent of the 16 kHz rain noise levels were logged within a 6 dB range centered about the mean rain noise level. Fifty-five percent of wind noise levels occurred above the mean and 42% were below the mean.

Correlation of rain noise presence with daily rainfall statistics compiled by USGS showed good agreement for the one-month period that was examined. On all days where USGS logged rainfall, rain noise was also observed except where rainfall amounts were very low or where acoustic coverage was limited.

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 313 samples, and 28 samples contained humpback whale song sounds. Ninety-seven samples contained sounds from other biologic sources such as killer whales. Humpback whale sounds were most common in the August through November time period. Sixty-one 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 occurrence of humpback whale noise correlated well with humpback whale survey data collected by NPS, especially in the August to September 2000 period. Months where humpback whale noise was frequently logged corresponded to periods where NPS personnel observed whales in lower Glacier Bay and also when the 10-knot whale waters speed limit was in effect. Also, particularly in 2000, whale noise was frequently observed in October and November, after the NPS whale-surveying season concluded.

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, 7.7 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.

Examination of the hourly occurrence of vessel noise for each season of the year showed that the majority of vessel traffic was typically logged between 5 A.M. and 9 P.M. In summer there was a greater chance that vessel traffic might be observed outside of this period, but independent of season, 87 to 90% of the samples containing vessel noise occurred within this time period.

Vessel noise levels were tracked by logging the peak one-third octave band level that was 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, 10 dB greater than the average wind noise.

No vessel noise levels exceeded 130 dB at the hydrophone and less than 1% of the samples containing vessel noise had levels above 120 dB. Twenty-five percent of the peak vessel noise levels occurred in a 6 dB range centered about the mean. Forty-seven percent of the peak vessel noise levels were logged at levels above the mean and 52% occurred at levels below the mean vessel level.

Vessel noise character was used to categorize marine craft according to small, medium, and large types. Medium sized vessels comprised 68% of all the vessels observed. Large vessels and small craft were present in 15% and 12% 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 99 dB, while the average noise levels for medium and small vessel were 92 and 97 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 and August 2002 were examined. Average noise levels for large and small vessels were 2 to 4 dB lower during the 10-knot period compared to the 20-knot period. The average 10 and 20-knot medium vessel noise levels were comparable. Maximum vessel levels for a given vessel category were as much as 9 dB lower when the 10-knot speed limit was in effect.

Correlation of acoustic vessel detections with visual observations of vessels in lower Glacier Bay over two half-month periods showed that acoustic detections always occurred when motorized vessels were visually present. In cases where more than one vessel was present simultaneously, typically only one vessel type was identified, probably due to noise masking by the most prominent or closest vessel. Also, in a small number of cases small craft were improperly identified as medium vessels.

Over 2100 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, and July 2002. Additional investigation will be required to identify the source of this common summer noise.

This report was preceded by an *interim* report published in December 2002 which addressed a subset of the data covered in this report. The findings of the interim report were comparable to those in this report. Wind, rain, vessel, and unidentified noise statistics were only slightly different from those published in the interim report, but a more extensive time period was covered and almost twice the number of data samples was included in this study. As an example, the mean wind and rain noise levels only changed by 1 and 2 dB, respectively, and the mean vessel noise level remained the same.

As a result, it is expected that the wind and rain noise statistics given in this report will generally be applicable to lower Glacier Bay in the long term. Obviously monthly statistics, particularly with regard to frequency of rain noise, may change somewhat depending on weather patterns, but it is unlikely that mean rain noise levels will change significantly. Also, vessel noise statistics are not expected to change significantly unless significant changes in vessel traffic occur.

However, humpback whale acoustic activity was variable from year-to-year depending on changes in whale presence in lower Glacier Bay. Because of this variability, it is recommended that acoustic monitoring and noise trend investigation continue for fall 2002 data and for August to November 2003 and perhaps beyond, to determine if typical humpback whale acoustic patterns can be established.

Other recommendations include:

1) Initiate an effort to identify the source of the low frequency rolling noise that occurs frequently in June and July. If it is determined that it is related to biologic activity, it could lead to significant new knowledge.
2) If, at some point, significant changes in vessel traffic are anticipated, perform acoustic monitoring and establish vessel noise statistics to assess potential underwater acoustic impact.
3) Perform an assessment to establish typical noise durations for vessels transiting the length of lower Glacier Bay. This information will be useful to determine the duration of vessel noise influences in the lower bay.
4) Establish a capability to acquire a series of short duration (e.g. 1 second) noise samples so transient noise events can be captured. This capability will enable humpback whale noise levels to be more precisely determined.

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Appendix A

Data Acquisition and Processing Parameters

The Glacier Bay underwater acoustic data acquisition and processing system was set up according to the following parameters.

1) Sample record length: 30 seconds.
2) Analog-to-digital sample rate: 88.2 kHz.
3) Fast Fourier transform sampling window: Hanning with 1.5 Hz bandwidth correction factor.
4) Two processed frequency ranges:
   a) 0 – 1076.66 Hz, 1.346 Hz resolution.
   b) 0 – 39965.625 Hz, 43.066 Hz resolution.
5) One-third octave spectrum derived from the narrowband spectra.

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