Recreational boating traffic: A chronic source of anthropogenic noise in the Wilmington, North Carolina Intracoastal Waterway

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The majority of attention on the impact of anthropogenic noise on marine mammals has focused on low-frequency episodic activities. Persistent sources of mid-frequency noise pollution are less well studied. To address this data gap, the contribution of 25 physical, biological and anthropogenic factors to the ambient noise levels in the Wilmington, North Carolina Intracoastal Waterway were analyzed using a principal components analysis and least squares regression. The total number of recreational vessels passing through the waterway per hour is the factor that had the single greatest influence on environmental noise levels. During times of high boat traffic, anthropogenic noise is continuous rather than episodic, and occurs at frequencies that are biologically relevant to bottlenose dolphins. As a daily part of resident bottlenose dolphins' acoustic environment, recreational boating traffic may represent a chronic source of acoustic harassment. © *2007 Acoustical Society of America.* [DOI: 10.1121/1.2717766]

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I. INTRODUCTION

As concern grows in both the scientific community and the public arena regarding the impact of anthropogenic noise on marine mammals, attention has focused on activities such as military sonar exercises (Frantzis, 1998; Tyack, 1998; Miller *et al.*, 2000; United States Department of the Navy, 1998), oil drilling, dredging and icebreaking activities (Richardson *et al.*, 1990, 1995; Erbe and Farmer, 1998) and acoustic thermometry (Munk *et al.*, 1994; Au *et al.*, 1997; Frankel and Clark, 1998, 2000, 2002). Such events generally occur at low frequencies over relatively short time periods, but can produce signals of high intensity and thus have a seemingly great potential to cause physiological damage and/or behavioral disruptions to marine mammals.

Although the U.S. Navy's peacetime use of low-frequency active sonar was heavily restricted after the mass Bahamian *Ziphius* strandings of March, 2000, it was mid-frequency sonar that was actually implicated in that event (Evans and England, 2001). In May 2003, researchers videotaped the reactions of resident *Orcinus orca* in Juan De Fuca and Haro Straits while simultaneously recording the *USS Shoup*, a Navy ship conducting mid-frequency (≈ 3 kHz) sonar exercises. The whales stopped feeding and gathered close together at the surface of the water for the duration of the exercise (Balcomb, 2004). An abnormally high number of harbor porpoises were later stranded, and although necropsies performed by NMFS did not find evidence of acoustically mediated damage, over 70% of specimens were in moderate to advanced stages of decomposition (NOAA/NMFS Final Report, 2004).

There is a clear need to understand the extent to which marine mammals may be affected by mid-frequency noise. Sound intensity, duration and frequency are all critical parameters of noise and different combinations of these parameters result in noise occurring at "biologically relevant" levels to various species; levels that have the potential to interfere with behaviors essential to life and reproduction (National Research Council, 2000). Loud sounds and/or sounds lasting over long time periods can only be relevant if they are occurring in a frequency range that the receiver can perceive. This report presents the results of a study designed to quantify the total environmental noise of a section of the Wilmington, NC Intracoastal Waterway (ICW), and to identify the dominant components of that noise. This area of the ICW supports a relatively closed population of bottlenose dolphins sighted year round (Koster, 2002); thus, particular attention was given to noise within the range of bottlenose dolphin hearing.

II. MATERIALS AND METHODS

A. Data collection

Audio data were collected continuously from 21 Jun 01–9 Sep 01 with a calibrated HTI 94-SSQ hydrophone (with a sensitivity of -170.1 dB re 1 V/μPa) mounted approximately 1 m off the bottom of the ICW and 1 m off the University of North Carolina Wilmington's Center for Marine Science (CMS) pier. The pier extends into the ICW, which at this location is roughly 100 m wide, with an approximately 30-m-wide channel ranging in depth from

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TABLE I. Potential factors influencing received sound pressure levels in the Wilmington ICW (P=physical, A=anthropogenic, T=temporal).

Factor	Type	Description
Mean hourly wind speed	P	Meters / second
Total hourly precipitation	P	Millimeters / hour
Tidal state	P	% of time per hour high tide
Total number of boats per hour	A	Number passing per hour
Small outboard motorboat	A	Length ≤6 m; outboard engine clearly visible at back of vessel
Small inboard motorboat	A	Length ≤6 m; flat aft panel of boat clearly visible
Small motorboat, engine unknown	A	Length ≤6 m; no engine visible at back, no clear view of aft panel
Medium outboard motorboat	A	Length 6–12 m; outboard engine clearly visible at back of vessel
Medium inboard motorboat	A	Length 6–12 m; flat aft panel of boat clearly visible
Medium motorboat, engine unknown	A	Length 6–12 m; no engine visible at back, no clear view of aft panel
Medium twin engine outboard boat	A	Length 6–12 m; two distinct engines visible at back of vessel
Large inboard vessel	A	Length ≥12 m; flat aft panel of boat clearly visible
Medium sailboat, under sail	A	Length ≤9 m with at least one sail hoisted
Medium sailboat, under motor	A	Length ≤9 m with at no sails hoisted
Large sailboat, under sail	A	Length >9 m with at least one sail hoisted
Large sailboat, under motor	A	Length >9 m with no sail hoisted
Canoes/kayaks	A	Small vessels under manual power
Industrial	A	Tugboats, barges, dredge ships
Jet skis	A	Personal watercraft
Unidentifiable	A	Any vessel that could not be placed into any of the above categories
R/V Cape Fear	A	Percentage of time per hour present
Seawater pumping	A	Percentage of time per hour on
Hour of the day	T	0600–2000; 0100–0300
Day of the week	T	1–8; 8=holidays
Day of the year	T	1–365

3 to 7 m (depending on tidal state). The hydrophone output was amplified by a Shure FP11 preamplifier, low-pass filtered at 30 kHz using a Frequency Devices filter (model 900-C9L8B), and then digitized at a sampling rate of 75 kHz by the field computer, a Dell Optiplex desktop equipped with a 12 bit National Instruments PCI-MIO 16E-4 analog-to-digital converter and a SCB-68 shielded input/output connector block. The field computer, preamplifier, filter, and analog-to-digital shielded input/output connector block were secured in a weatherproof container at the end of the Center for Marine Science pier. A data acquisition program on the field computer recorded audio data continuously and saved the wave forms as 30 s AIFF files on the field computer. Data were then transmitted to the CMS lab by fiber optic cable, processed and archived. Mean received sound pressure levels (RLs) were calculated for each second of raw wave form data in each of 13 variable width frequency bands. Hourly mean RLs were calculated and the hourly means were used for further analysis.

Potential factors affecting environmental noise in this area were recorded throughout the study period (Table I). Physical noise sources included wind, precipitation and tidal state. The North Carolina National Estuarine Research Reserve provided mean hourly wind speed and precipitation data which were collected from a site on Masonboro Island, approximately 2 km north of the Center for Marine Science (Fig. 1). High tide was considered to be ±3 h of the high tide time at Masonboro Inlet, a channel located approximately 4 km north of the study site. Tidal state was recorded as a percentage of time per hour during which it was high tide.

The number of vessels passing through the study area was measured from video data recorded from 0630–2030. Recordings were made with a surveillance camera mounted in a weatherproof housing to a light fixture at the end of the pier. Time stamps in the video and audio filenames were used to synchronize data files.

Video data of the ICW were annotated by recording the total number of boats passing per hour and then classifying those boats into one of 17 categories based on size and engine type. Small vessels were boats less than approximately 6 m, medium vessels ranged from 6 to 12 m and large vessels were longer than 12 m. Engine types included inboard, outboard and "engine unknown" (when the size of a boat could be determined, but not the engine type). Temporal factors were also tracked in order to determine if time of day,

FIG. 1. (Color online) Map of study area (image from Google Earth, ©2007 Europa Technologies, Image ©2007 New Hanover County, NC).

day of the week, or day of the year had any effect on mean received sound pressure levels; these factors were likely to be highly correlated with boat traffic.

Also noted was the percentage of time per hour seawater pumps were on, which were located in close proximity to the hydrophone. These pumps transferred seawater from the ICW to the CMS building. The presence or absence of the R/V Cape Fear, a 21 m research vessel that docked at the CMS pier, was also noted in terms of the percentage of time each hour this vessel was present. This vessel's proximity to the hydrophone meant it could have added to overall noise levels when its engines were turned on or decreased levels when its engines were turned off by shielding the hydrophone from noise sources offshore of the vessel.

Finally, while no independent confirmation of the presence of fish, shrimp, or other biological sound sources was possible, nighttime (0100–0300) audio data were considered to be representative of base line biological noise in this area. This time period was chosen to maximize the likelihood that no boats would be passing and no anthropogenic factors other than the presence of the R/V Cape Fear would be affecting noise levels. Each nighttime hour was randomly spot checked for boat noise before being added to the data set.

B. Statistical procedures

Outliers were first removed from the data set; these were defined as those hours in which the mean RLs recorded were outside four standard deviations of the overall mean. This resulted in the removal of 47 h of data, eight of which were greater than the mean and 39 of which were less than the mean. In each case when the RL recorded was higher than four standard deviations of the mean, unusual biological noise was responsible; a single fish or group of fish was vocalizing very near the hydrophone during those instances. A specific cause could not be determined for RLs lower than four standard deviations of the mean, despite spot checking those hours for equipment failure. Neither the extremely high nor low sound levels were considered representative samples of the population, however, and were therefore discarded (Zar, 1999).

Mean RLs were calculated from pressure values (μPa) and were then converted to decibels for statistical testing. In order to determine if mean broadband (0–37.5 kHz) RLs were higher during the day than at night, a Kruskal-Wallis test was used because of differences in sample sizes between day and night (Zar, 1999).

To determine if daytime mean RLs were higher than nighttime mean RLs within each of the 13 frequency bands, a multivariate analysis of variance (MANOVA) was used. With a large daytime sample size, this test was appropriate because it is a single test that reduces Type I error (Zar, 1999). Although Bonferroni corrections can also be employed to reduce Type I error associated with multiple testing of the same data set, Type II error can increase unchecked when variables are correlated (Perneger, 1998). Therefore a single parametric test, which is robust to deviations from normality (Zar, 1999), was used for this particular data set. Differences between frequency bands were determined using *post hoc* ANOVA tests.

For the remainder of the analyses, daytime and nighttime hours were tested separately. To determine if mean RLs differed between individual hours of the day or individual hours of the night, ANOVA testing followed by *post hoc* Tukey-Kramer tests were used. Finally, the effect that day of the week had on daytime and nighttime mean RLs was analyzed using an ANOVA test, followed by *post hoc* Tukey-Kramer tests when necessary.

Once the characteristics of mean received sound pressure level in this area had been described, analyses were constructed to determine which factors contributed most highly to those patterns. Twenty-five factors that could potentially contribute to ambient were examined. This large set of interrelated variables was linearly transformed into a set of 25 statistically uncorrelated linear combinations of variables, or principal components (PCs). The PCs were ranked according to the amount of variation each explained in the original data set. Those explaining approximately 85% of the variability in the original data set (in this case, the first 15) were used for further testing.

A least squares regression model using these 15 PCs as independent variables and daytime mean RLs the dependent variable was run to determine which PCs predict mean RLs. The PCs that were significantly related to mean RLs were then combined, weighted by how much of the overall model each one explained. These weights were determined from the regression model; the sum of the squares for each principal component was divided by the sum of the squares for the whole model. Each eigenvector of each of the significant principal components was multiplied by its corresponding percentage. Thus, the first principal component's eigenvectors were multiplied by the largest percentage, since the first principal component explained the most variation. This process allowed each weighted principal component to have eigenvectors that could be compared to each other directly. Finally, the weighted eigenvectors from each principal component with a significant relationship to RL were summed for each of the 25 factors.

This process yielded a single vector, termed the Noise Index, which summarized the combined results of these tests. The principal components created, not the individual factors that potentially affected ambient noise, were statistically compared directly to mean RLs. The Noise Index helped to determine which factors were the strongest contributors to mean RLs, which were then subjected to additional tests.

Descriptive statistics were used to summarize the total number of boats passing on any given day, and the total number of boats passing during each hour of any given day. Analysis of variance was used to determine if the total number of boats recorded per hour (log transformed) varied significantly with respect to hour of the day and/or day of the week. *Post hoc* Tukey-Kramer testing identified the hours and/or days that had significantly more or less boat traffic than others.

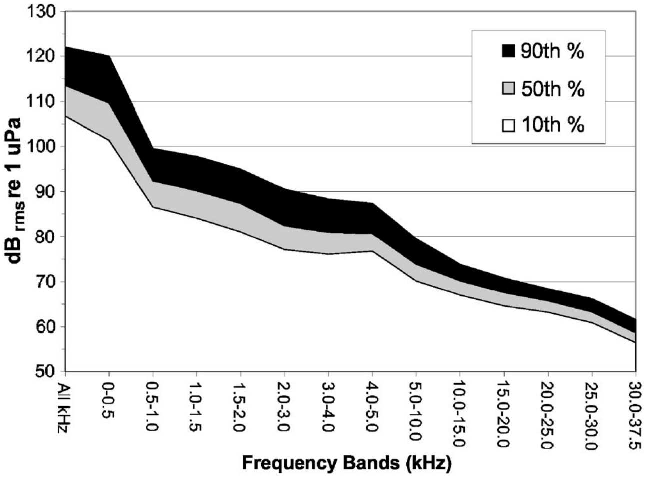

FIG. 2. Environmental daytime noise level profile for the Wilmington, North Carolina ICW (June–September 2001).

Additionally, hourly totals of environmental noise levels, wind speed and boat traffic were compared with ANOVAs during times when fishing tournaments were being held in Wilmington waters to those times when no fishing tournaments were taking place.

The spectral characteristics and received sound pressure levels of some vessel types were examined by generating composite power spectra [fast Fourier transform (FFT) $=4096$, no overlap, Hanning window]. These spectra were preferentially generated from times when only a single boat was passing the hydrophone, the R/V Cape Fear was absent, seawater pumps were off, the mean hourly wind speed was <3 m/s, and it was high tide (as previously defined). These were the times that had the highest signal-to-noise ratio, but these criteria were not met for all vessel types. For each vessel type that did meet these criteria the spectral values from each sample ($n=2-7$) were averaged to form that vessel type's composite spectrum.

To address the potential impact of recreational boating traffic on bottlenose dolphins, data from photoidentification survey efforts at the University of North Carolina at Wilmington were analyzed. Chi-square tests were used to compare the observed and expected total number of dolphins in the ICW on weekends versus weekdays for the time period of the present study. Expected values were determined by dividing the number of weekday/weekend days surveyed by the total number of days surveyed and then multiplying this value by the total number of dolphins seen. Thus, if dolphins were observed in the ICW equally on weekends and weekdays, it was expected that the number of dolphins seen would closely mirror the amount of survey effort on weekends versus weekdays.

III. RESULTS

A. Daytime environmental noise profile

Quantile daytime RLs averaged across the entire data set were plotted to form a profile of daytime noise levels over the time period of this study (Fig. 2). When averaged hourly across all summed frequency bands, the mean RL for the

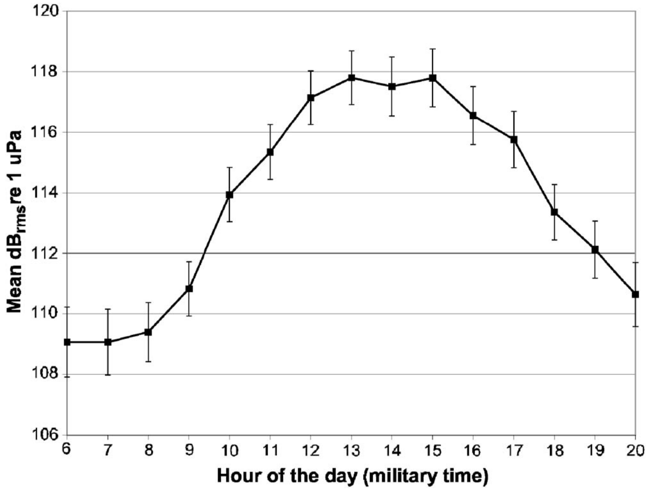

FIG. 3. Mean received sound pressure levels by hour of the day; standard error bars are shown for each data point.

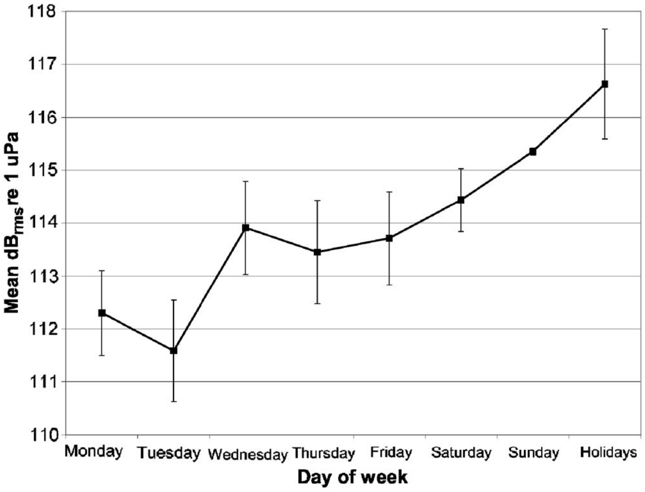

FIG. 4. Mean received sound pressure level by day of the week; standard error bars are shown for each data point.

study area was 116 dB$_{rms}$ re 1 μPa (SE=87.5 dB). Ninety percent of RL values were between 107 and 122 dB$_{rms}$ re 1 μPa and the maximum value for any given hour was 127 dB$_{rms}$ re 1 μPa.

The mean value of 116 dB$_{rms}$ re 1 μPa was exceeded during 129 h, or 34.4% of the total time surveyed. Of that time, mean RLs were between 120 and 127 dB$_{rms}$ re 1 μPa during a total of 63 h, or 16.8% of the total survey time. Hourly mean RLs exceeded 116 dB$_{rms}$ re 1 μPa for some portion of 27 out of 30 days surveyed, and occurred during two or more consecutive hours on 19 of those 27 days. Ten consecutive hours of hourly RLs exceeding 116 dB$_{rms}$ re 1 μPa were recorded on 1 Jul 01, which was the maximum for any 14 h survey day.

B. Temporal characteristics of the acoustic environment in the ICW

Daytime (0630–2030) mean RLs were higher than nighttime (0100–0300) mean RLs when averaged over 0–37.5 kHz ($\chi^2=101.90$, $df=1$, $p<0.0001$), and within each frequency band except the two highest: 25.0–30.0 kHz and 30.0–37.5 kHz. This relationship was further confirmed by parametric MANOVA testing ($F=18.21$, $df=12$, error $df=404$, $p<0.0001$), which showed significantly higher noise levels during daytime hours (mean=115.9 dB$_{rms}$ re 1 μPa, SE±87.5, $n=375$ h) than nighttime hours (mean =102.0 dB$_{rms}$ re 1 μPa, SE±80.8, $n=42$ h).

Nighttime mean RLs did not vary significantly with hour of the day or day of the week, however, daytime mean RLs varied with both. In general, total environmental noise increased steadily through the day, peaking around 1300–1500 h and then falling off in the evening hours ($F=11.46$, $df=14$, error $df=360$, $p<0.0001$, Fig. 3). Further, total environmental noise tended to increase from relatively low values during the beginning of the week to significantly higher values on the weekends and the holidays of 4 Jul 01 and 3 Sep 01 ($F=3.20$, $df=7$, error $df=367$, $p=0.0026$, Fig. 4).

C. Major sources of environmental noise

The relative effects of anthropogenic, temporal and physical sound sources on environmental noise levels in the ICW at this location were determined using a principal components analysis, as previously described. The first 15 principal components accounted for 86.8% of the variability. The overall regression model was statistically significant ($r^2=0.5313$, $F=27.13$, $df=15$, error $df=359$, $p<0.0001$). Nine principal components were significantly related to mean RLs at $p<0.01$, however principal components 1, 12 and 13 were found to predict mean received sound pressure levels at $p<0.0001$ and thus were used to calculate the Noise Index (Table II).

The resulting Noise Index, with factors influencing noise on the x axis and summed, weighted eigenvectors on the y axis, is plotted in Fig. 5. Total number of boats recorded per hour was the factor with the highest magnitude, meaning this factor was the largest contributor to the three principal components most significantly related to daytime mean RLs. Of the 11 factors with the highest magnitudes, all but one were anthropogenic noise specific to recreational boating traffic; the exception was mean hourly wind speed.

Despite the complex interactions occurring between factors contributing to overall noise levels, linear fit regressions revealed that the log of total boats observed per hour was significantly related to RLs averaged across 0–37.5 kHz ($r^2=0.37$, $F=216.62$, $df=1$, error $df=371$, $p<0.0001$), as was mean hourly wind speed ($r^2=0.35$, $F=221.23$, $df=1$, error $df=415$, $p<0.0001$).

A total of 12,562 boats passed the CMS pier during 36 14 h days during June–September 2001, with the maximum for any given day being 847 (4 Jul 01). Boat traffic varied significantly with hour of the day ($F=17.66$, $df=14$, error $df=358$, $p<0.0001$). Relatively few boats were observed during the early morning hours; boat activity generally increased throughout the day, peaked between 1400 and 1600 h and declined in the late afternoon (Fig. 6). Boat traffic also varied significantly with day of the week, with significantly more boat traffic on Saturdays, Sundays and holi-

TABLE II. Generating the Noise Index (all values rounded): (A) Regression results and weighting calculations; (B) eigenvector chart (prime values indicate weighted principal components).

(A)

	SS	*F* Ratio	*p*	% of model
Whole model	4.17E+13	27.1273	<0.0001	100.00%
Prin. Comp. 1	2.94E+13	286.6537	<0.0001	70.45%
Prin. Comp. 12	1.83E+12	17.8163	<0.0001	4.38%
Prin. Comp. 13	3.31E+12	32.2919	<0.0001	7.94%

(B)

Factors	1	1′	12	12′	13	13′	Summed
Hour of the day	0.0879	0.0619	0.3003	0.0131	−0.2852	−0.0226	0.0525
Day of the year	0.0092	0.0065	−0.0411	−0.0018	0.5640	0.0448	0.0495
Boat totals per hour	0.3866	0.2723	−0.0667	−0.0029	0.0022	0.0002	0.2696
Small outboard motorboat	0.3254	0.2292	−0.0145	−0.0006	−0.0781	−0.0062	0.2224
Small inboard motorboat	0.2847	0.2006	0.0545	0.0024	−0.0258	−0.0020	0.2009
Small motorboat, eng. unk.	0.2748	0.1936	−0.1135	−0.0050	0.0527	0.0042	0.1928
Medium outboard motorboat	0.3035	0.2138	−0.1066	−0.0047	−0.0082	−0.0007	0.2085
Medium inboard motorboat	0.3083	0.2172	0.0290	0.0013	−0.0252	−0.0020	0.2165
Medium motorboat, eng. unk.	0.2618	0.1844	−0.1453	−0.0064	0.0679	0.0054	0.1835
Large inboard motorboat	0.2550	0.1797	0.0529	0.0023	0.1336	0.0106	0.1926
Medium twin outboard	0.2540	0.1789	−0.1808	−0.0079	−0.0013	−0.0001	0.1709
Medium sailboat (motor)	0.0560	0.0395	0.1640	0.0072	0.3430	0.0272	0.0739
Medium sailboat (sail)	0.1365	0.0961	−0.1034	−0.0045	−0.2259	−0.0179	0.0737
Large sailboat (motor)	0.0600	0.0422	0.0947	0.0041	−0.1980	−0.0157	0.0307
Large sailboat (sail)	0.0802	0.0565	0.1354	0.0059	−0.1402	−0.0111	0.0513
Canoes /kayaks	0.0439	0.0309	0.4644	0.0203	−0.0177	−0.0014	0.0499
Industrial	0.0383	0.0270	0.1127	0.0049	0.1209	0.0096	0.0415
Jet skis	0.3128	0.2204	−0.0943	−0.0041	−0.0261	−0.0021	0.2142
Unidentifiable	0.1420	0.1000	−0.1402	−0.0061	0.0601	0.0048	0.0987
% hour seawater pumps on	−0.0033	−0.0023	−0.0090	−0.0004	−0.1052	−0.0084	−0.0111
% hour Cape Fear present	0.0628	0.0442	0.0738	0.0032	0.4670	0.0371	0.0845
Day of the week	0.0567	0.0399	−0.0604	−0.0026	−0.2496	−0.0198	0.0175
% hour±3 h high tide	−0.0615	−0.0433	−0.2180	−0.0095	0.1075	0.0085	−0.0443
Total hourly precipitation	−0.0335	−0.0236	−0.2890	−0.0127	0.0687	0.0055	−0.0308
Mean hourly wind speed	0.1722	0.1213	0.5972	0.0261	0.1157	0.0092	0.1566

days (4 Jul 01, and 3 Sep 01) than on other days of the week ($F=17.09$, $df=7$, error $df=365$, $p<0.0001$, Fig. 7).

In the Wilmington area during the summer months, wind tends to peak in velocity during the afternoon hours and fall off at night ($F=11.26$, $df=17$, error $df=399$, $p<0.0001$). Mean hourly wind speeds also varied significantly with day of the week ($F=7.93$, $df=7$, error $df=409$, $p<0.0001$) with holidays having significantly more wind than Mondays, Tuesdays or Thursdays. Sundays also had significantly more wind than Tuesdays.

Two fishing tournaments were held in Wilmington waters over three days used in this study: 30 June 01, 1 July 01, and 14 July 01. Mean RLs were significantly higher on fishing tournament days ($F=6.67$, $df=1$, error $df=373$, $p=0.0102$). The log of total boats recorded per hour was also significantly higher on days with fishing tournaments ($F=18.59$, $df=1$, error $df=371$, $p<0.0001$) while mean hourly wind speed was not ($F=0.10$, $df=1$, error $df=373$, $p=0.7520$).

D. Power spectra for boat types

Composite power spectra (FFT=4096, no overlap, Hanning window) for six boat types were used to calculate the maximum $\mathrm{dB_{rms}}$ re 1 μPa received sound levels for those vessel types. These values were plotted along with the percentage of total traffic comprised by each vessel type (Fig. 8). Small outboard motorboats have the highest maximum received $\mathrm{dB_{rms}}$ re 1 μPa levels and comprise the highest percentage traffic in this area.

E. Bottlenose dolphin use of the ICW

A total of 113 dolphins were sighted in the ICW between Carolina Beach Inlet and Masonboro Inlet from June through September of 2001 (the time period of the current study). There was a significant difference between the number of dolphins observed and expected on weekends versus weekdays ($\chi^2=6.28$, $df=1$, $p=0.0122$, $n=85$, Fig. 9). Fewer dolphins were observed in the ICW than expected on weekends while more dolphins were observed than expected during weekdays.

IV. CONCLUSION

A. Factors affecting environmental noise

Total number of boats, and nine other boat-related factors were identified as the most important contributors to

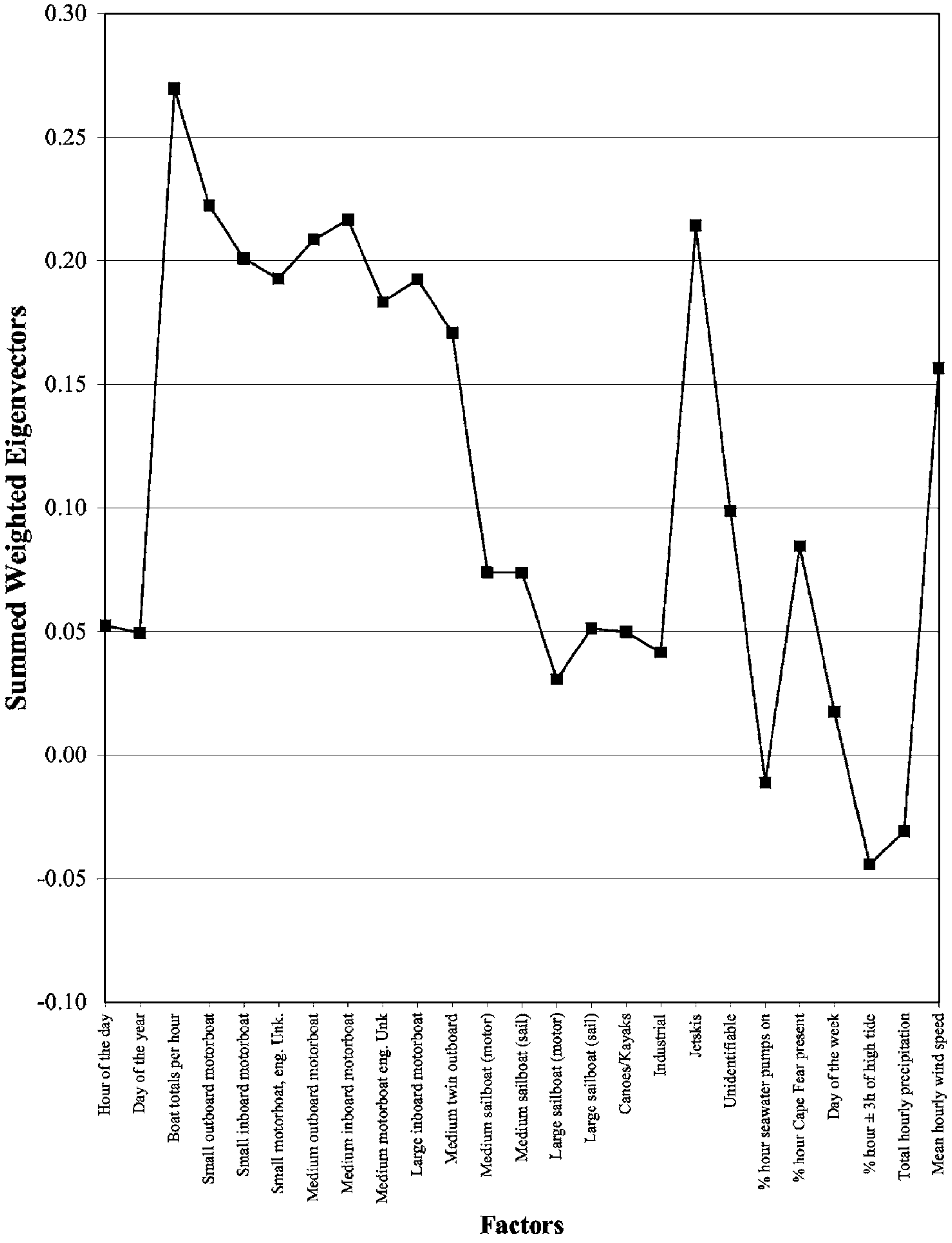

FIG. 5. Noise Index plot.

mean RLs. Daytime mean RLs measured on an hourly basis closely matched the hourly boat total trend, which peaked between 1200 and 1600 h. A combined principal components analysis and linear regression confirmed this strong relationship; total number of boats observed per hour had a significant relationship to received sound pressure levels averaged per hour, despite the complex interactions between number of boats and other potential factors influencing sound. The log of total number of boats observed per hour accounted for 36.9% of the overall variability in received sound levels.

The most important natural source of noise was mean hourly wind speed; however, principal components analysis ranked total number of boats and several boat categories as more influential than mean hourly wind speed. Mean RLs were nearly 2.5 dB higher on fishing tournament days, meaning those days had sound levels 70% higher than days without fishing tournaments. During fishing tournaments, boat traffic was significantly higher than on days without fishing tournaments, but mean hourly wind speed was not. Further, linear regressions showed that the amount of boat traffic explained slightly more variability in daytime mean RLs (36.9%) than did mean hourly wind speed (34.8%). Therefore, data from the present study suggest that anthropogenic noise from recreational boating traffic is the greatest contributor to environmental noise levels in this area.

B. Recreational boating traffic in the ICW

Boat traffic was quantified continuously on a daily basis over a period of several months to provide an accurate representation of this anthropogenic noise source in an environment utilized by bottlenose dolphins. The Atlantic Intracoastal Waterway is an important component of the habitat of bottlenose dolphins in the Wilmington area (Koster, 2002).

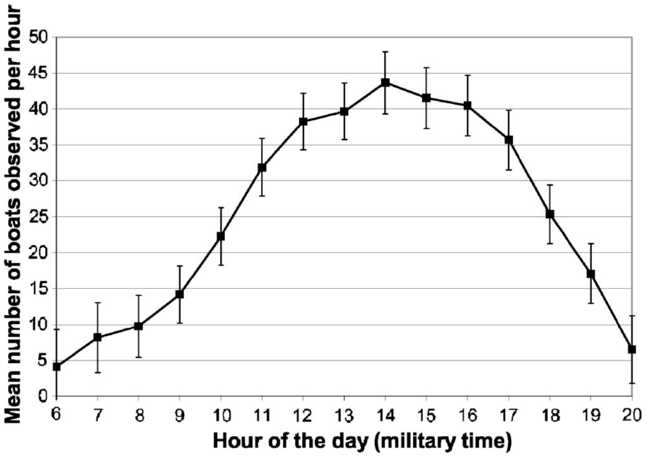

FIG. 6. Mean number of boats observed averaged per daytime hour; standard error bars are shown for each data point.

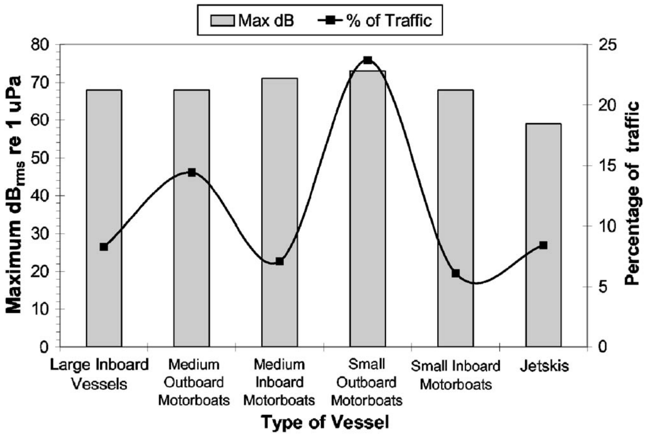

FIG. 8. Percent occurrence of various vessel types and maximum received sound levels of each type.

The amount of vessel traffic seen during this study was unexpected. The maximum amount of vessel traffic for any given day (847 boats) was recorded on 4 Jul 01, however, this number is a conservative estimate of the true number of vessels out that day. All daytime recordings stopped at 2030, but waterfront fireworks were scheduled to begin at 2100; thus, it is likely that a great deal more traffic was actually present than was recorded.

Large amounts of vessel traffic also occurred on days other than the 4th of July holiday. The maximum number of boats recorded per hour (118) occurred on 14 Jul 2001. In fact, hourly means exceeded 60 boats (one boat per minute) on 56 different occasions, often over consecutive hours. At this frequency, boat traffic essentially stops being an incidental occurrence in the ICW and becomes a continuous presence.

Although some traffic could be attributed to seasonal visitors transiting craft through the area, the predominance of small outboard motorboats suggests the ICW is being utilized most often by area residents or weekend visitors to Wilmington. Not surprisingly, boat traffic was heavier on weekends than on weekdays and peaked in the mid-to-late afternoon hours each day. Boat traffic in the ICW was also higher when fishing tournaments were taking place.

Van Parijs and Corkeron (2001) found that acoustic communication in Pacific humpback dolphins (*Sousa chinensis*) was significantly affected by boat traffic averaging only one boat per hour. With boat traffic averaging 36 boats per hour during weekends in the Wilmington ICW, it seems likely that vessel traffic may affect bottlenose dolphin behavior and acoustic communication in this area as well. Moreover, since these recordings were made at the edge of the ICW, the values reported here may be lower than dolphins may actually hear, since dolphins could be in closer proximity to the boats. Given that the ICW is only about 30 m wide in this area, it is highly likely that dolphins were often closer to boats than to the hydrophone.

C. Potential for harassment of bottlenose dolphins

Daytime sound levels were higher than nighttime, or natural ambient noise levels, and above dolphin auditory threshold levels from 1 to 25 kHz (Fig. 10). Of particular concern are the levels recorded during the daytime hours between 5 and 25 kHz, where the primary energy of social

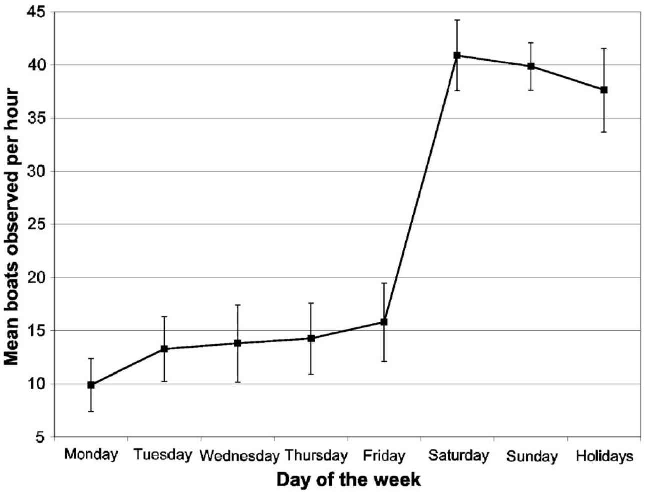

FIG. 7. Mean number of hourly boat totals observed, averaged per day of the week; standard error bars are shown for each data point.

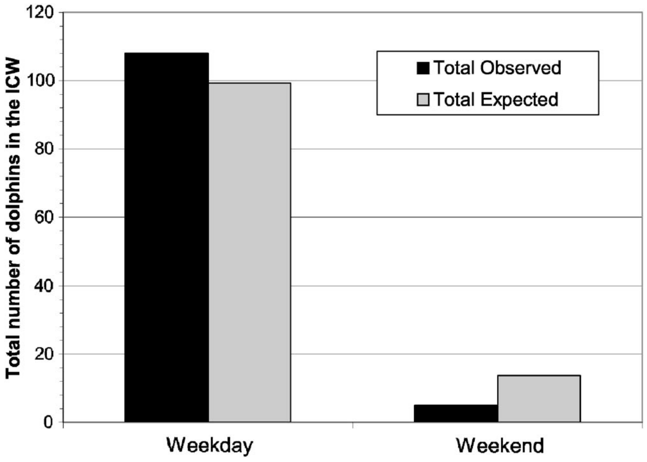

FIG. 9. Total number of dolphins observed and expected on weekdays versus weekends (based on survey effort) in the Wilmington ICW between Masonboro Inlet and Carolina Beach Inlet from June 2001 to September 2001 ($\chi^2=6.28$, $p=0.0122$).

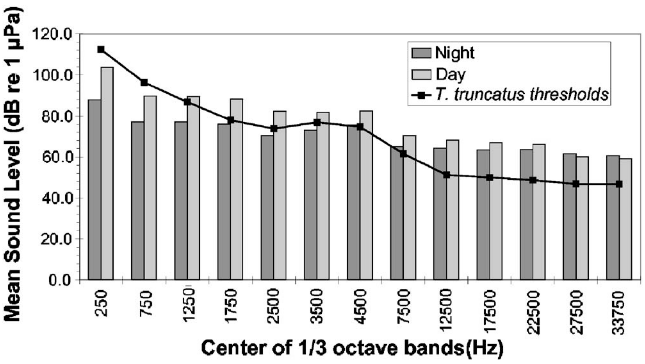

FIG. 10. Mean RLs for daytime and nighttime, 0–37.5 kHz, and *Tursiops truncatus* auditory threshold levels (extracted from Johnson (1967) as presented in Richardson *et al.* (1995).

whistles occurs. Anthropogenic noise is thus occurring at frequencies that are biologically relevant to bottlenose dolphins and may have the potential to cause harassment as it has been broadly defined under the Marine Mammal Protection Act.

Additionally, mean hourly RLs exceeded 116 dB_{rms} re 1 μPa nearly every day surveyed, indicating bottlenose dolphins in the ICW near Wilmington, North Carolina could be at risk for noise exposure on a daily basis. High mean RLs were often recorded over consecutive hours, making high sound levels the rule in this area during the summer, not the exception.

Thus, bottlenose dolphins utilizing the ICW during times of heavy boat traffic may have a more difficult time communicating than when the ICW is relatively free of anthropogenic noise inputs. Additionally, anthropogenic noise could pose an impediment to feeding by obscuring fish vocalizations. Gut content analysis indicates that Atlantic bottlenose dolphins feed mainly on soniferous fishes (Barros and Wells, 1998) and a recent study by Gannon *et al.* (2005) confirmed that dolphins use passive listening during foraging. Noise from recreational boats could make the passive localization of prey more difficult, as our observations from this study indicate the primary energy of most fish vocalizations falls below 1 kHz.

Preliminary data suggest that dolphins may be avoiding the ICW during times of increased boat traffic. After adjusting for survey effort, bottlenose dolphins were seen less often than expected on weekends (times of heavy boat traffic) than on weekdays throughout the study period. However, it is not known if boat traffic was responsible for this change in dolphin distribution.

D. Future research

The present study showed that an area regularly utilized by bottlenose dolphins was subject to large amounts of boat traffic on a nearly continuous basis during the summer months. This raises questions regarding both the potential short and long-term impacts of such traffic. Future research is needed to determine if bottlenose dolphins are exhibiting avoidance behavior patterns in response to boat traffic, and if so, whether or not that those behaviors are influenced by the accompanying increased noise levels. In order to investigate matters of this nature, there is a need to adequately define what may constitute acoustic harassment of marine mammals, in terms of frequency ranges, sound levels, and length of exposure to sounds of varying intensity.

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