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ORIGINAL PAPER

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Summer vocalisations of adult male white whales (*Delphinapterus leucas*) in Svalbard, Norway

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Abstract The principal aim of this study was to describe the vocalisations produced by the largely unstudied white-whale population in Svalbard, Norway. It was found that Svalbard's white whales produced most of the vocalisations that have been documented in other populations, but they also displayed minor vocal novelties and differences. A subjective classification suggested 21 call types, which were dominated by a variety of whistles. A statistical classification (cluster analyses) produced 11 groupings (after exclusion of general pulsed call types), which contained fairly logical grouping of the subjectively determined call types. However, neither method of classification employed was considered ideal for classifying white-whale vocalisations because of the highly graded nature of the calls. The white whales in this study were most vocal during milling and joining behaviours. A surprising result in this study was how little time white whales in this area spent vocalising. Their relative silence could possibly be: (1) an anti-predator strategy in response to killer whales (*Orcinus orca*); (2) a result of the type of schools encountered during this study (all-male grouping); (3) a by-product of the presence of the research boat in an area where whales are not accustomed to boat traffic; or (4) a result of the limited behavioural repertoire covered in this study. More extensive studies of acoustic behaviour of this population, which include various age and sex classes, with broader seasonal coverage that includes more potential behavioural contexts, are required before firm conclusions can be made regarding geographic trends in white-whale acoustic behaviour.

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Introduction

The white whale, or beluga (*Delphinapterus leucas*), is one of the most vociferous cetacean species (Jefferson et al. 1993); early whalers called them "canaries of the sea". It is a gregarious, odontocete whose distribution is largely confined to the Arctic. The species appears to have a relatively fluid social structure. Some white-whale populations migrate long distances and form very large aggregations during some parts of the year, while other populations tend to reside in more restricted areas and are generally found in smaller groupings (e.g. Lønø and Øynes 1961; Smith et al. 1994; Michaud 1999; Lydersen et al. 2001; Richard et al. 2001). The vocal behaviour of this species has been studied in the Canadian Arctic (Sjare and Smith 1986a, b), the St Lawrence River Estuary (Faucher 1988), Bristol Bay, Alaska (Angiel 1997), and in the White Sea in Russia (Belkovich and Shchekotov 1993). These studies report that white-whale vocalisations are known to vary with the behavioural context of the calls, and school size and structure are thought to have an influence on the types of signals used, and the suggestion has been made that geographic differences occur among populations. The purpose of the present study was to document the vocalisations of the largely unstudied white-whale population in Svalbard, Norway, and to attempt to classify the sounds they produce in an objective manner.

Materials and methods

Fieldwork was conducted during the period 1–19 August 1997 in Van Keulenfjorden in Svalbard, Norway (77°34′N, 15°30′E). The

Svalbard white-whale population has been protected since the termination of the fishery for this species in 1960 (Wiig and Gjertz 1992). This specific fjord was chosen because of the relatively predictable occurrence of white whales in the area during the summer months. During favourable weather conditions, observations were conducted from the roof of the research hut on the south shore of Van Keulenfjorden. When whales were spotted, they were cautiously approached in a Zodiac. At a distance of 50–200 m from the whales, the engine was stopped. The boat drifted while recordings were being made. A recording session was terminated when contact with the whales was lost, either because they moved very close to glacier fronts where it is unsafe to follow, due to rough sea conditions, or because they moved out of the area.

All recordings were made with a Brüel and Kjær 8106 hydrophone (0.1–180 kHz re 1 V/μPa) and a Sony TCD-D10 PROII DAT-recorder (20 Hz–22 kHz re 1 V/μPa, 48 kHz sampling rate). The hydrophone was placed approximately mid-way between the bottom and the water surface (the bottom depth was measured using a cable that was lowered to the bottom; the hydrophone was subsequently lowered to half the depth measured). Surface behaviour of the white whales was sampled ad libitum in parallel with acoustic recordings (Altmann 1974; Mann 1999). Three classes of behaviour were defined: (1) travelling was recorded when all the whales in a group swam in a consistent direction and the location of the group changed geographically (Sjare and Smith 1986b; Baird and Dill 1995); (2) milling was recorded when individuals in a group were moving in a non-synchronous manner, with animals oriented in different directions (Shane et al. 1986; Belkovich and Shchekotov 1993); little change in actual location occurred during this activity (3) joining was documented when small groups of whales came together to form a larger group. Joining terminated when all individuals in the consolidated group started to travel.

Recording sessions, where whale behaviour was clearly identified, were split into 10-s sequences, and calls in each sequence were counted using a scrolling spectrogram in Spectra Plus 3.0a (Pioneer Hill Software) to compare vocal activity within and between behaviour classes. Calls were divided into three categories based on their physical structure displayed by a spectrogram: (1) whistles were identified as narrow-band calls which had little or no harmonic structure; (2) pulsed calls included broad-band click series and "other" pulsed calls. Broad-band click series were brief bursts of sounds that often extended over most of the audible frequency range and beyond; these sounds were assumed to be associated with echolocation (Au 1993) and were not included in further analysis unless they were associated with other call elements, where they were referred to as echoclicks. Pulsed calls in which neither harmonic structures nor individual pulses were distinguishable were categorised as noisy calls (Sjare and Smith 1986a; Beeman 1998). (3) Combined calls consisted of both a whistle and a pulsed component. Measurements were taken from call components according to methods described in Watkins (1967), Sjare and Smith (1986a), Faucher (1988) and Angiel (1997).

A simple subjective classification method and a more objective multivariate statistical approach, employing cluster analyses, were used to classify the whistles, pulsed and combined calls into more detailed sound categories. In the subjective classification, similar calls were classified into mutually exclusive call types (CTs) based on call structure (e.g. whistle, pulsed), call contour shape given by the frequency modulation of the fundamental frequency, and aural impression (e.g. Sjare and Smith 1986a; Rendell and Gordon 1999). Calls could have similar frequency modulations or pulse repetition rates but still vary in contour shape. These were defined as general CTs (Sjare and Smith 1986a). In contrast, discrete CTs were easily recognisable, distinct calls that varied little in the shape of their contours (Ford 1989). Whenever possible, whistles were classified into the CTs defined by Sjare and Smith (1986a) in their analysis of white-whale calls, e.g. CT-6ab in this study included signals corresponding to both CT-6a and CT-6b in Sjare and Smith (1986a). New whistle CTs recorded in Svalbard were numbered alphanumerically where the letter S indicated geographical area (Svalbard). Pulsed calls, including trills, were given Roman numerals. Combined calls were named using letters.

General pulsed CTs were not included in the cluster analysis because many of the variables measured for the other CTs could not be obtained for these calls. In order to reduce auto-correlation among the variables, a correlation analysis using Spearman Rank Correlation Coefficient was carried out (Hair et al. 1998), and one variable from each group of highly correlated variables (i.e. correlation coefficient ≥0.70; Fowler et al. 1998) was randomly chosen to be included in cluster analyses. The following eight variables were used as input in subsequent analysis: maximum frequency; call duration; number of inflection points; duration of first component; presence of harmonic structure; number of consecutive repetitions; presence of both whistle and pulsed components; frequency range. All input variables were transformed and standardised to Z scores because cluster analysis is sensitive to variables of different scales, putting greater emphasis on variables with higher absolute values (Zar 1996; Hair et al. 1998). Log_{10} transformations were performed because the data set included small values, and by adding 1 to all values before the transformation, log (zero) was avoided and zero-values were retained (van Tongeren 1995; Zar 1996). A combination of hierarchical and *k*-means cluster analysis was conducted (SAS 6.12, SAS Institution) (Hair et al. 1998). The sequential threshold method for assigning calls into clusters in the *k*-means cluster analysis was chosen since this method has been developed for large data sets. Because cluster analysis groups objects into relatively few classes (Fowler et al. 1998), each of the clusters resulting from the *k*-means cluster analysis was used as new input and the whole clustering procedure was run a second time.

Results

During 115 h of active searching and listening for white whales, groups were observed at the surface only four times, and during only two of these encounters acoustic signals were produced and recorded. Only large white individuals were observed, suggesting that encounters in this study involved all-male schools. A total of 4 h and 25 min of recordings, containing more than 7,000 white-whale vocalisations, were documented. During 72% of the recording time, when whales were known to be in the immediate vicinity, the whales were silent. During 3 h of the recording time, whale behaviour was classified. The first recording session in which calls were successfully documented involved ~20 whales milling and travelling, while the second session included ~10–80 travelling and joining whales. Milling occurred 4 times (total 2,976 calls, 30 min); travelling occurred 6 times (total 1,038 calls, 117 min); joining occurred once (3,137 calls, 24 min) in the behavioural records. Vocal activity increased from 9 ± 16 calls/min to 99 ± 86 calls/min when the whales switched from travelling to milling during the first recording session, and to 131 ± 44 calls/min when the ~10 travelling whales joined with ~70 other whales. Vocal activity decreased when the ~80 whales started to travel after joining. Twenty CTs were recorded during milling and 20 CTs also occurred during travelling whereas only 11 CTs were recorded during joining. However, all general whistle and pulsed CTs were found in all behavioural contexts.

Subjective classification was performed on 1,694 vocalisations. Sixty-three percent of these were classified as whistles, 31% as pulsed calls, and 6% as combined calls. Whistles were grouped into ten different

CTs, pulsed calls into five CTs and the combined calls into six CTs (Figs. 1, 2, 3, Tables 1, 2, 3). One thousand and sixty vocalisations were classified as whistles; 98% were general whistle CTs and only 2% were discrete whistle CTs (Table 1). Each of the general whistle CTs was highly variable in its frequency and duration (Table 1). CT-1a constituted 32% of all analysed calls. The three discrete whistle CTs were less variable in

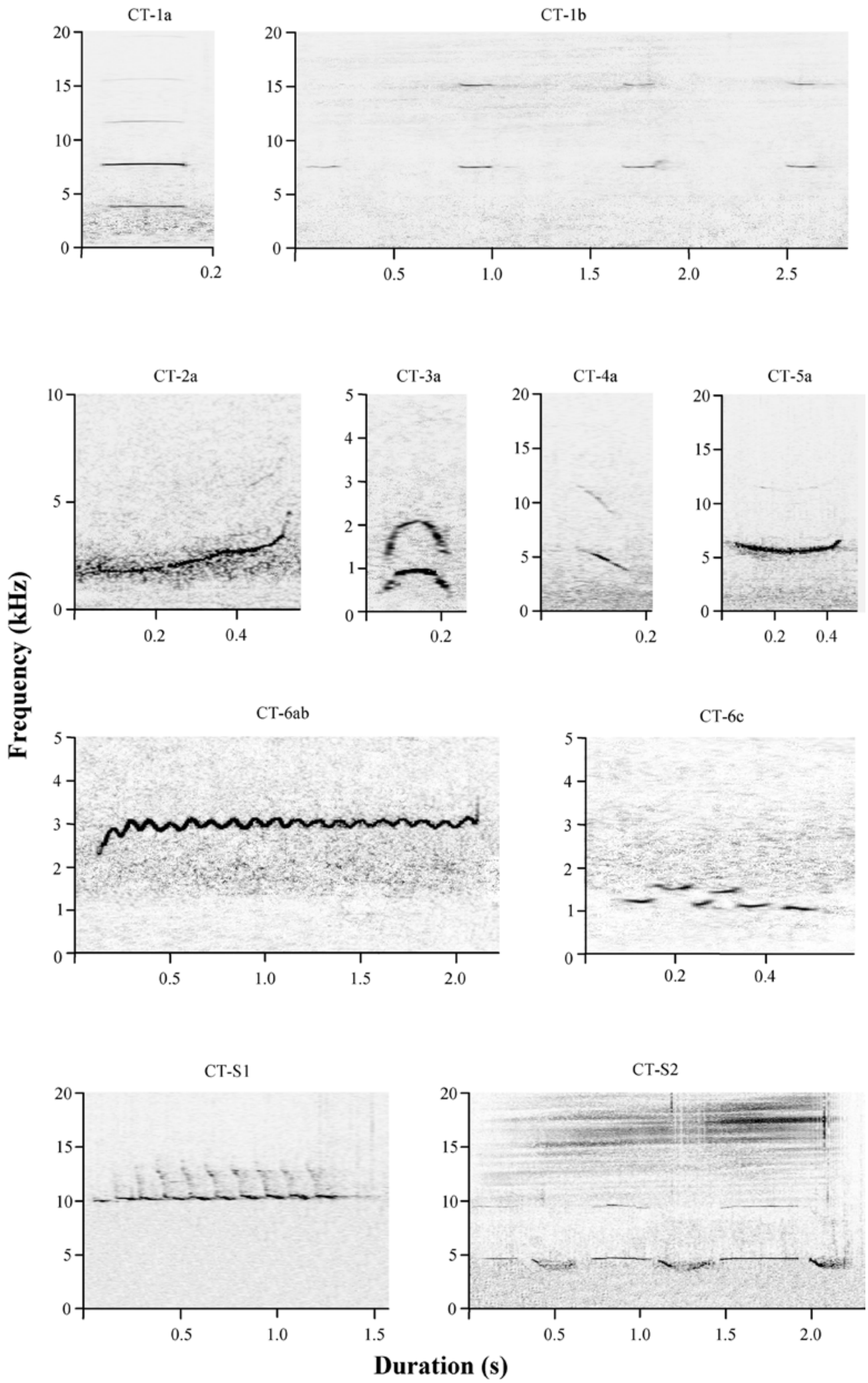


Fig. 1. Spectrograms of whistle call types (CTs) recorded in Van Keulenfjorden. CT-S2 (*S* Svalbard) has an overlapping echoclick series. Note the different time and frequency scales of the spectrograms. Frequency resolutions: CT-1a, CT-2a, CT-4a, CT-5a and CT-S2 = 46.88 Hz; other CTs = 23.44 Hz. Time resolutions: CT-1b and CT-6ab = 8.53 ms; CT-2a = 2.13 ms; CT-5a = 7.47 ms; CT-S1 = 6.40 ms; CT-S2 = 7.04 ms; and other CTs = 4.27 ms

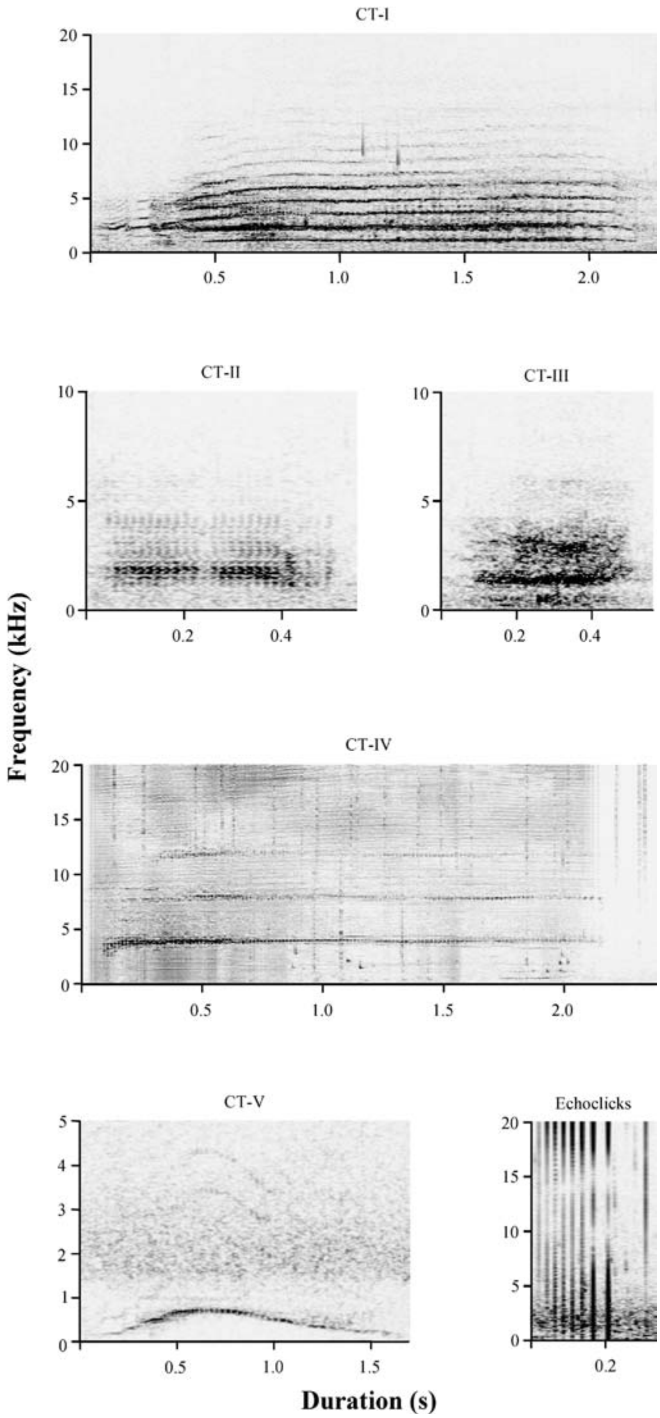


Fig. 2. Spectrograms of pulsed call types (CTs) recorded in Van Keulenfjorden. CT-IV, the trill, has an overlapping echoclick series. Note the different time and frequency scales of the spectrograms. Frequency resolutions: CT-V = 23.44 Hz; other CTs = 46.88 Hz. Time resolutions: CT-II = 2.13 ms; CT-III and echoclicks = 4.27 ms; CT-V = 8.53 ms; and other CTs = 7.47 ms

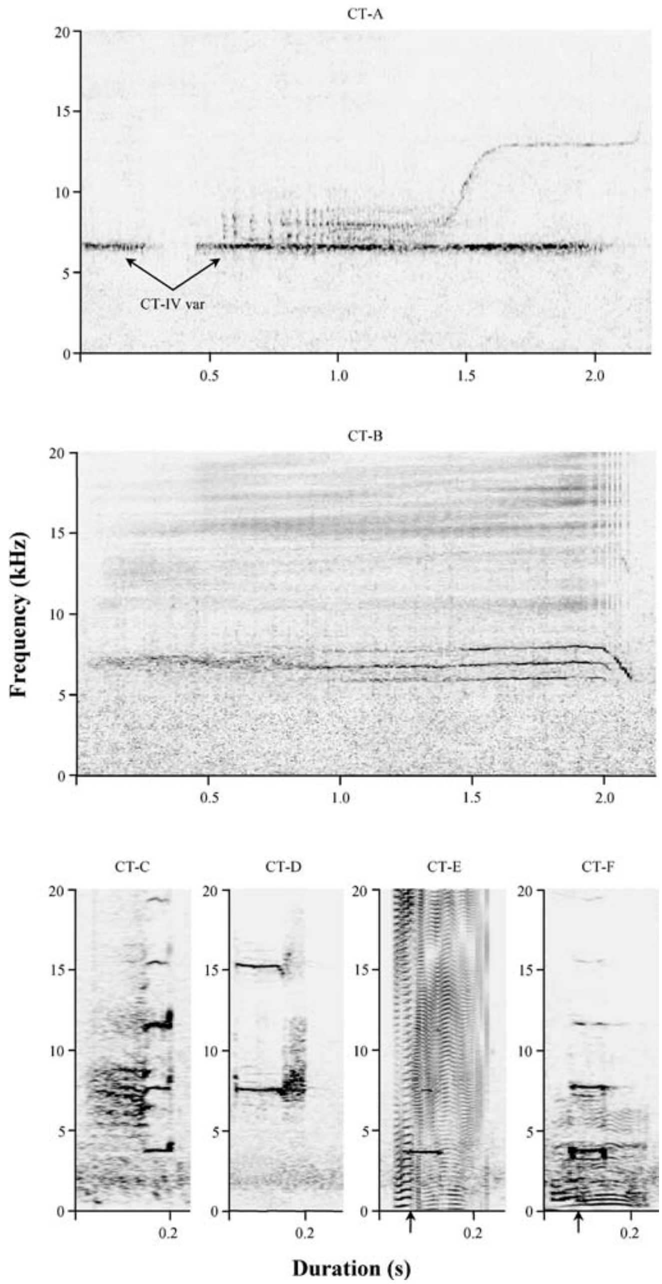


Fig. 3. Spectrograms of combined call types (CTs) composed of whistle and pulsed elements recorded in Van Keulenfjorden. The spectrogram of CT-A also shows a two-component variant trill (see CT-IV var). CT-B has an overlapping echoclick series. CT-E and CT-F show a rapid change in pulse repetition rate of the pulsed component (*arrows*). Note the different time scales of the spectrograms. Frequency resolutions: CT-A = 93.75 Hz; other CTs = 46.88 Hz. Time resolutions: CT-A = 6.93 ms; CT-B = 10.67 ms; CT-C = 3.20 ms; and other CTs = 4.27 ms

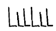
both frequency and duration (Table 1). The few CT-6c calls occurred at relatively low frequencies. CT-S1 had an L-shaped contour and was found only in the higher frequency range. CT-S2 occurred at intermediate frequencies. Most of the discrete CTs had long durations relative to the general CTs. Harmonics were found in 43% of all whistles and were predominately present in the general CTs. Five hundred and thirty-one of the analysed vocalisations were classified as pulsed calls; 89% of these were general pulsed CTs and 11% discrete pulsed CTs (Table 2). The general pulsed CTs were highly variable in frequency and duration

Table 1. Descriptive statistics of white-whale whistles recorded in Van Keulenfjorden. The *call contour column* shows stylised sketches of the frequency modulation patterns of the fundamental of each whistle call type [*M* milling; *T* travelling; *J* joining; *%VK* percentage calls of the total number of all calls analysed, including pulsed and combined calls (i.e. 1694)]. *a* General whistle call types; *b* discrete whistle call types

a)

Call	Call	Behavioural	Frequency (kHz)				Duration	n	%VK
type	**contour**	**context**	**Start**	**End**	**Minimum**	**Maximum**	**(s)**		
1a		M T J						546	32.2
Range			0.2-12.0	0.2-12.1	0.2-12.0	0.2-12.1	0.01-2.11		
Mean ± SD			4.2 ± 2.6	4.2 ± 2.6	4.2 ± 2.6	4.2 ± 2.6	0.16 ± 0.27		
1b		M T J						95	5.6
Range			0.6-12.7	0.6-12.8	0.6-12.6	0.6-12.9	0.04-3.80		
Mean ± SD			5.3 ± 3.0	5.3 ± 3.0	5.3 ± 3.0	5.4 ± 3.0	0.84 ± 0.71		
2a		M T J						114	6.7
Range			0.5-15.8	0.7-16.1	0.5-15.8	0.7-16.1	0.02-2.61		
Mean ± SD			4.3 ± 3.2	5.0 ± 3.3	4.3 ± 3.2	5.0 ± 3.3	0.38 ± 0.51		
3a		M T J						70	4.1
Range			0.5-15.6	0.2-15.6	0.2-15.6	1.0-15.8	0.03-1.79		
Mean ± SD			4.2 ± 3.3	4.0 ± 3.3	3.8 ± 3.3	5.5 ± 3.9	0.28 ± 0.30		
4a		M T J						131	7.7
Range			0.7-19.6	0.3-19.1	0.3-19.1	0.7-19.6	0.02-3.92		
Mean ± SD			6.1 ± 4.0	5.3 ± 3.9	5.3 ± 3.9	6.1 ± 4.0	0.37 ± 0.64		
5a		M T J						34	2.0
Range			1.2-11.5	1.3-11.2	1.1-11.0	1.3-11.5	0.02-3.05		
Mean ± SD			5.7 ± 3.0	5.7 ± 2.9	5.3 ± 2.9	5.8 ± 3.0	0.30 ± 0.54		
6ab		M T J						52	3.1
Range			0.7-17.6	0.9-18.1	0.5-17.6	1.2-18.1	0.12-3.25		
Mean ± SD			5.7 ± 4.5	6.0 ± 4.4	5.2 ± 4.3	6.8 ± 4.9	1.06 ± 0.80		
Sum								**1042**	**61.5**

b)

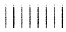
Call	Call	Behavioural	Frequency (kHz)				Duration	n	%VK
type	**contour**	**context**	**Start**	**End**	**Minimum**	**Maximum**	**(s)**		
6c		M						2	0.1
Range			1.3-1.4	0.9-1.2	0.9-1.2	1.4-1.7	0.42-0.58		
Mean ± SD			1.4 ± 0.1	1.1 ± 0.2	1.1 ± 0.2	1.6 ± 0.2	0.50 ± 0.11		
S1		M T						6	0.4
Range			9.7-14.6	10.3-10.6	9.4-10.6	13.3-16.0	0.29-1.55		
Mean ± SD			11.6 ± 2.3	10.5 ± 0.1	9.9 ± 0.4	14.6 ± 1.1	1.16 ± 0.44		
S2		M T						10	0.6
Range			3.9-4.9	3.7-4.9	3.6-4.1	4.0-4.9	0.85-2.78		
Mean ± SD			4.6 ± 0.4	4.3 ± 0.4	3.7 ± 0.2	4.8 ± 0.1	2.03 ± 0.53		
Sum								**18**	**1.1**

(Table 2). Many of these had frequency ranges that exceeded the audible range for humans. CT-I contained burst-pulsed calls with high repetition rates, which were mainly perceived as creak- and squeak-like sounds. CT-II included click series with low pulse repetition rates. CT-III consisted of noisy calls that resembled roars and screams. CT-IV (trills) and CT-V were the only discrete pulsed CTs recorded (Table 2). A trill variant had a characteristic gap that occurred about one-third way through the call (CT-IV var, Fig. 2). The remaining 103 vocalisations fell into the category of combined calls (Table 3). These were the most complex CTs (Fig. 3). CT-A consisted of S-shaped calls that started with pulses of low repetition rate and graded into whistles. CT-B was the most common combined CT. In these calls, sidebands occurred around the carrier frequency of the pulsed first component. Harmonic structures of both components were apparent in some calls. Fifteen of these calls were overlaid by an echoclick series. CT-C consisted of a noisy first component and a whistle second component. The least-frequent combined call type, CT-D, had a whistle first component and a noisy second component. CT-E had one pulsed component with an abrupt change in pulse repetition rate. This pulsed component was perceived as a buzz and overlapped a shorter unmodulated whistle. CT-F consisted of two components: a squeaky pulsed component in this call displayed a sharp change in pulse repetition rate that overlapped in time and frequency with one or two short-duration whistle components. Each of the combined CTs occurred infrequently in the recordings.

Thirty-four of the calls that were analysed in this study were overlaid by an echoclick series, where the echoclick series started and ended at the same time as the call (see CT-S2, Fig. 1). These calls were found in whistle CTs (CT-1a, CT-6ab, CT-S2), one pulsed CT (CT-IV, Fig. 2), and one combined CT (CT-B, Fig. 3).

Table 2. Descriptive statistics of white-whale pulsed calls recorded in Van Keulenfjorden. The *call contour column* shows stylised sketches of the pulsed call types (*M* milling, *T* travelling, *J* joining, *%VK* percentage calls of the total number of all calls analysed, including whistles and combined calls; *n.a.* not applicable). *a* General pulsed call types; *b* discrete pulsed call types

a)

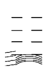
Call type	Call contour	Behavioural context	Freq. range (kHz)	Duration (s)	Start PRR (pulses/s)	n	%VK
I		M T J				220	13.0
Range			0.1->20.0	0.03-2.87	100-3600		
Mean ± SD			n.a.	0.33 ± 0.44	890 ± 840		
II		M T J				63	3.7
Range			0.2->20.0	0.07-3.12	23-240		
Mean ± SD			n.a.	0.55 ± 0.54	104 ± 64		
III		M T J				191	11.3
Range			0.2->20.0	0.01-2.51	n.a.		
Mean ± SD			n.a.	0.54 ± 0.60	n.a.		
Sum						**474**	**28.0**

b)

Call type	Call contour	Behavioural context[a]	Freq. range (kHz)	Duration (s)	Start PRR (pulses/s)	n	%VK[b]
IV		M T J				46	2.7
Range			1.5-11.4	0.20-3.94	26-1900		
Mean ± SD			6.4 ± 2.0	1.69 ± 0.75	94 ± 297		
V		M T				11	0.6
Range			0.1-1.4	0.38-2.46	24-80		
Mean ± SD			0.7 ± 0.4	1.25 ± 0.65	50 ± 18		
Sum						**57**	**3.4**

n.a. = not applicable

Table 3. Descriptive statistics of white-whale combined call types recorded in Van Keulenfjorden. The *call contour column* shows stylised sketches of each combined call type [*M* milling, *T* travelling, *J* joining (not observed for combined call types), *%VK* percentage of the total number of all calls analysed, including whistles and pulsed calls (i.e. 1694) n.a. = not applicable]

			Whistle part					*Pulsed part*			*Whole call*		
Call	Call	Behavioural	Frequency (kHz)				Duration	Freq. range	Duration	PRR	Total duration	n	%VK
type	contour	context	Start	End	Minimum	Maximum	(s)	(kHz)	(s)	(pulses/s)	(s)		
A		M T										13	0.8
Range			7.8-8.8	12.8-16.3	7.8-8.8	12.8-16.3	0.32-1.63	5.9-9.7	0.53-1.37	20-43	0.88-2.09		
Mean ± SD			8.2 ± 0.3	13.4 ± 1.0	8.2 ± 0.3	13.4 ± 1.0	0.77 ± 0.40	7.9 ± 1.2	0.81 ± 0.28	28 ± 8	1.53 ± 0.40		
B		M T										33	1.9
Range			6.8-9.1	5.0-7.2	5.0-7.2	6.8-9.1	0.04-1.46	5.4-16.1	0.77-3.53	300-1100	0.85-3.63		
Mean ± SD			8.0 ± 0.4	6.6 ± 0.4	6.6 ± 0.4	8.0 ± 0.4	0.19 ± 0.27	7.7 ± 2.5	1.82 ± 0.55	900 ± 200	1.93 ± 0.55		
C		M T										26	1.5
Range			3.7-7.9	3.8-7.9	3.7-7.9	3.8-8.3	0.03-0.13	3.0-17.1	0.09-0.91	100-1100	0.12-1.04		
Mean ± SD			4.3 ± 1.3	4.3 ± 1.3	4.3 ± 1.3	4.3 ± 1.4	0.05 ± 0.03	9.1 ± 4.4	0.19 ± 0.17	600 ± 700	0.25 ± 0.20		
D		M T										5	0.3
Range			3.9-7.8	3.9-7.8	3.9-7.8	3.9-7.8	0.07-0.13	4.2->20	0.03-0.09	n.a.	0.10-0.20		
Mean ± SD			6.9 ± 1.7	6.9 ± 1.7	6.9 ± 1.7	6.9 ± 1.7	0.12 ± 0.03	n.a.	0.05 ± 0.02	n.a.	0.17 ± 0.04		
E		M T										18	1.1
Range			3.7-8.7	3.7-9.0	3.7-8.7	3.7-9.0	0.02-0.27	0.2->20	0.05-1.05	200-700	0.12-1.19		
Mean ± SD			4.4 ± 1.6	4.4 ± 1.6	4.4 ± 1.6	4.4 ± 1.6	0.09 ± 0.06	n.a.	0.29 ± 0.28	500 ± 100	0.32 ± 0.31		
F		T										8	0.5
Range			3.7-4.9	3.8-5.1	3.7-4.6	3.8-5.1	0.03-0.13	0.3-10.3	0.19-0.36	100-700	0.19-0.36		
Mean ± SD			4.0 ± 0.3	4.0 ± 0.4	3.9 ± 0.2	4.0 ± 0.4	0.08 ± 0.03	3.9 ± 4.0	0.26 ± 0.06	400 ± 200	0.26 ± 0.06		
Sum												**103**	**6.1**

n.a. = not applicable

After excluding the general pulsed CTs, 1,251 vocalisations were subjected to cluster analyses (Table 4). Three primary clusters were identified: VK-1 contained relatively long duration calls with many inflection points (5% of all calls); VK-2 calls were shorter in duration than the calls in the two other clusters and had narrow frequency ranges (92% of all the calls); VK-3 calls had relative high mean frequencies and long durations and were composed of one long-duration component and one short-duration component (3% of all calls). Secondary cluster analysis conducted on each of the 3 clusters above, produced 11 clusters in total (Table 4).

Table 4. Descriptive statistics of the clusters resulting from the hierarchical and *k*-means cluster analysis of white-whale whistles, discrete pulsed calls and combined calls [*%VK* percentage calls in the cluster of the total number of all calls analysed by cluster analysis (i.e. 1251)]

Cluster	Frequency (kHz)				Duration (s)	*n*	%VK
	Start	End	Minimum	Maximum			
VK-1						63	5.0
Range	0.2–17.6	0.4–18.1	0.2–17.6	1.0–18.1	0.21–3.25		
Mean ± SD	5.4 ± 4.4	5.6 ± 4.3	4.9 ± 4.2	6.3 ± 4.7	1.39 ± 0.77		
VK-2						1148	9.18
Range	0.1–19.6	0.2–19.1	0.1–19.1	0.2–19.6	0.01–3.94		
Mean ± SD	4.6 ± 3.1	4.7 ± 3.2	4.4 ± 3.0	4.9 ± 3.3	0.36 ± 0.55		
VK-3						40	1.2
Range	4.2–11.4	3.8–11.3	3.7–11.2	4.8–11.4	0.20–3.63		
Mean ± SD	7.1 ± 0.9	6.7 ± 1.1	6.6 ± 1.1	7.9 ± 0.9	1.91 ± 0.60		
From cluster VK-1:							
VK-1a						3	0.2
Range	0.2–1.2	0.4–1.1	0.2–0.6	1.0–1.3	1.31–2.46		
Mean ± SD	0.8 ± 0.5	0.7 ± 0.4	0.4 ± 0.2	1.2 ± 0.2	1.77 ± 0.61		
VK-1b						17	1.4
Range	0.8–6.6	0.9–8.4	0.5–6.6	1.1–9.7	0.32–1.66		
Mean ± SD	2.7 ± 1.5	3.2 ± 2.1	2.4 ± 1.6	3.5 ± 2.2	0.96 ± 0.47		
VK-1c						10	0.8
Range	0.7–17.6	1.3–17.6	0.7–17.6	1.4–18.0	1.35–3.25		
Mean ± SD	4.1 ± 4.8	4.5 ± 4.7	4.1 ± 4.8	4.7 ± 4.7	2.31 ± 0.62		
VK-1d						4	0.3
Range	8.1–9.6	6.4–8.5	6.4–8.5	9.2–9.6	0.42–0.99		
Mean ± SD	8.9 ± 0.6	7.6 ± 0.9	7.6 ± 0.9	9.5 ± 0.2	0.68 ± 0.24		
VK-1e						11	0.9
Range	2.7–4.9	2.6–5.1	2.6–4.9	2.9–5.4	1.14–2.78		
Mean ± SD	4.5 ± 0.7	4.3 ± 0.7	3.8 ± 0.6	4.7 ± 0.6	1.88 ± 0.42		
VK-1f						18	1.4
Range	1.9–17.6	1.0–18.1	1.0–17.6	3.5–18.1	0.21–3.05		
Mean ± SD	9.3 ± 4.9	9.5 ± 4.9	8.4 ± 4.9	11.0 ± 4.8	1.08 ± 0.72		
From cluster VK-2:							
VK-2a						23	1.8
Range	0.3–11.2	0.4–10.9	0.3–10.9	0.6–11.2	0.05–1.10		
Mean ± SD	2.8 ± 3.1	3.7 ± 2.2	2.4 ± 2.6	4.2 ± 2.7	0.26 ± 0.27		
VK-2b						1125	89.9
Range	0.1–19.6	0.2–19.1	0.1–19.1	0.2–19.6	0.01–3.94		
Mean ± SD	4.7 ± 3.1	4.7 ± 3.2	4.5 ± 3.0	5.0 ± 3.3	0.36 ± 0.55		
From cluster VK-3:							
VL-3a						16	1.3
Range	6.9–7.4	3.8–7.1	3.7–6.8	7.7–8.9	0.20–2.05		
Mean ± SD	7.2 ± 0.2	6.4 ± 1.3	6.2 ± 1.2	8.1 ± 0.4	1.50 ± 0.72		
VK-3b						20	1.6
Range	6.6–7.6	5.0–7.2	5.0–7.2	6.8–3.1	0.99–3.63		
Mean ± SD	7.1 ± 0.3	6.7 ± 0.5	6.5 ± 0.4	7.9 ± 0.4	1.98 ± 0.55		
VK-3c						4	0.3
Range	4.2–11.4	4.0–11.3	4.1–11.2	4.8–11.4	0.67–2.50		
Mean ± SD	7.3 ± 2.2	7.2 ± 2.2	7.2 ± 2.1	7.4 ± 2.1	2.01 ± 0.63		

When these clusters were examined with respect to the CT they contained, it was found that one or two CTs dominated each cluster.

Discussion

Vocal activity of white whales varied according to the type of behaviour being performed during this study. Only sporadic bursts of calls were recorded during travelling, whereas call production was more common during milling and joining behaviours. The increase in the number of whales in a group explained, in part, the increase in vocal activity during joining. However, the number of individuals cannot explain the differences in vocal activity when the whales switched between travelling and milling. Milling in this study was probably associated with feeding activity because the movements of the whales were unsynchronised and vigorous (Kleinenberg et al. 1969; Shane et al. 1986; Belkovich and Shchekotov 1993; Lesage et al. 1999), and birds hovered above the whales during this behaviour and occasionally plunged into the sea surface, suggesting the presence of small fishes or other prey. The correlation between behaviour and levels and types of vocalisations observed here is consistent with findings for white whales from other areas, as well as for other odontocetes. Highly active whales, engaged in feeding or social interactions, tend to increase their vocalisation rates (Sjare and Smith 1986b; Faucher 1988; Weilgart and Whitehead 1990).

One surprising finding in the present study was that the white whales were silent so much of the time, including most of the recording time. White whales were known to be in the study fjord routinely during the study period (see Lydersen et al. 2001), but were not acoustically detected. This phenomenon has also been observed in the autumn with all-male groups, as well as mixed groups of females and immature animals from the Svalbard population (Van Parijs,, unpublished data). White whales have been reported to decrease and even cease vocalising when disturbed by engine noise or frightened by killer whales (Schevill 1964; Fish and Vania 1971; Morgan 1979; Finley et al. 1990; Lesage et al. 1999) and Lydersen et al. (2001) have suggested that the highly coastal movement patterns exhibited by this population could be anti-predator behaviour in response to the presence of sympatric killer whales (Øien 1988). This might also explain their relative quietness. However, although the presence of engine noise in this study was minimal, disturbance cannot be ruled out as a possible cause for the low incidence of vocalisation in this study.

The subjective classification method revealed 21 CTs in the vocal records, which is similar to the 21–24 CTs described for white-whale populations in other geographical areas where comparable classification techniques have been used (Sjare and Smith 1986a; Faucher 1988; Angiel 1997). All seven general whistle CTs have been documented in all areas where white-whale vocal behaviour has been studied, and unmodulated whistles have been the most frequent vocalisations in all studies undertaken to date on this species. Duration patterns of CTs were fairly consistent among the various locations, while mean call frequencies were somewhat more variable, but most of the values were in the range of 3–7 kHz. Fewer multi-component CTs were found in this study than in Cunningham Inlet and the St Lawrence Estuary, but this may be due to the small sample size achieved in the current investigation.

Pulsed calls from this study could only be compared to those from Cunningham Inlet and St Lawrence white whales (Sjare and Smith 1986a; Faucher 1988) because pulsed calls studied in white whales from Bristol Bay were analysed quite differently (Angiel 1997). Comparable pulse repetition rates and durations were found for CT-I and CT-III in all three studies, but these CTs were not found above 13 kHz in the two other areas. A narrower range of pulse repetition rate in CT-II was described in this study; but this is a sampling artefact resulting from the analysis of click series being limited to those that had restricted frequency ranges. Trills were commonly emitted in all three populations and were similar with respect to frequency and duration variables.

A few combined CTs have been described for white whales from other areas (mixed vocalisations in Faucher 1988; Recchia 1994; Angiel 1997), but four combined CTs recorded in this study appear to be novel.

Both discrete and variable call types occurred occasionally with a conspicuous, simultaneous echoclick series. The echoclick series started and ended at precisely the same time as a specific call and they were repeated numerous times in the same way, which suggests that one individual emitted these sounds simultaneously. The simultaneous production of two sound types has not previously been described for white whales, but this phenomenon is well documented for other species of captive and free-ranging odontocetes (e.g. Ford 1989; Markov and Ostrovskaya 1990; Murray et al. 1998). These sounds are probably made by two sound-producing systems working simultaneously in the nasal region of odontocetes (Cranford et al. 1996). However, the possibility that different individuals emitted the two sounds cannot be excluded because the sound-producing individual could not be identified during the recordings.

The vocal repertoire of white whales has been described previously as a graded system in which general CTs shift into each other (Sjare and Smith 1986a; Faucher 1988). They also exhibit gradation within a call, sliding from one call structure to another. Both features complicate classification of calls. In this study, cluster analyses supported the main conclusions from the subjective classification by creating fairly logical groupings of CTs distinguished from the spectrographic analysis. However, the cluster analysis did not consistently distinguish between discrete and general white-whale CTs, nor did it separate all previously distinguished CTs (also see Janik 1999). In the subjective classification, overall contour patterns are a primary cue used to categorise calls. However, only one frequency measurement could be included in the cluster analysis because of the high correlation between all frequency measurements. Thus, the ability to distinguish differences based on contour pattern is lost when performing clustering. Angiel (1997) used several frequency measurements when conducting hierarchical cluster analysis of white-whale vocalisations but still had only 39% similarity in classification relative to subjective classification of the same data. The best agreement with the subjective classification in the current study was achieved for some CTs after one clustering run, while for others two sequential cluster analyses seemed more appropriate. This makes it difficult to know how many sequential cluster analyses are actually appropriate for a data set (also see Janik 1999). Thus, neither of the two classification methods used during this study was considered ideal for categorising white-whale calls. Subjective classification schemes suffer from low inter-observer agreement when classifying call types that exhibit considerable variability (see Angiel 1997; Janik 1999), which are common in white-whale vocal repertoires. Increased standardisation between observers, and studies, may help reduce this variability and enhance our ability to do geographic comparisons that are more meaningful (see Janik 1999; Eltink et al. 2000). However, quantitative classification methods are preferable because they reduce observer biases; they may detect characteristics that simple observation might miss when classifying the sounds subjectively, and because they can handle large data sets in a time-efficient manner. However, cluster analysis has difficulties with auto-correlated variables and natural gradation that occurs between the types of signals produced by white whales. More work is needed regarding appropriate statistical treatments of odontocete vocalisations.

In summary, this study found that white whales in Svalbard produce most of the vocalisations documented in other populations, but even the small data set achieved in this study also displays minor vocal novelties and differences. A surprising result in this study was how little time white whales in this area spent vocalising. Their relative silence could possibly be: (1) an anti-predator strategy in response to killer whales (*Orcinus orca*); (2) a result of the type of schools encountered during this study (all-male grouping); (3) a by-product of the presence of the research boat in an area where whales are not accustomed to boat traffic; or (4) a bias in the type of schools documented, and the limited behavioural repertoire covered in this study. However, more extensive studies of the acoustic behaviour of this population, which include various age and sex classes, with broader seasonal coverage that includes more potential behavioural contexts, are required before firm conclusions can be made regarding geographic trends in white-whale acoustic behaviour.

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References

Altmann J (1974) Observational study of behavior: sampling methods. Behaviour 49:227–267

Angiel NM (1997) The vocal repertoire of the beluga whale in Bristol Bay, Alaska. MSc Thesis, University of Washington

Au WWL (1993) The sonar of dolphins. Springer, Berlin Heidelberg New York

Baird RW, Dill LM (1995) Occurrence and behaviour of transient killer whales: seasonal and pod-specific variability, foraging behaviour, and prey handling. Can J Zool 73:1300–1311

Beeman K (1998) Digital signal analysis, editing, and synthesis. In: Hopp SL, Owren MJ, Evans CS (eds) Animal acoustic communication: sound analysis and research methods. Springer, Berlin Heidelberg New York, pp 59–103

Belkovich VM, Shchekotov MN (1993) The belukha whale: natural behavior and bioacoustics (Belukha. Povedenie i bioakustika v prirode 1990). Woods Hole Oceanographic Institution, Woods Hole

Cranford TW, Amundin M, Norris KS (1996) Functional morphology and homology in the odontocete nasal complex: implications for sound generation. J Morphol 228:223–285

Eltink ATG, Newton AW, Morgado C, Santamaria MTG, Modin J (2000) EFAN Report 3–2000. http://www.efan.no/NewsAndReports/EFANReport32000.html

Faucher A (1988) The vocal repertoire of the St. Lawrence Estuary population of beluga whale (*Delphinapterus leucas*) and its behavioral, social and environmental contexts. MSc Thesis, Dalhousie University

Finley KJ, Miller GW, Davis RA, Greene CR (1990) Reactions of belugas, *Delphinapterus leucas*, and narwhals, *Monodon monoceros*, to ice-breaking ships in the Canadian high arctic. In: Smith TG, St. Aubin DJ, Geraci JR (eds) Advances in research on the beluga whale, *Delphinapterus leucas*. Can Bull Fish Aquat Sci 224:97–117

Fish JF, Vania JS (1971) Killer whale, *Orcinus orca*, sounds repel white whales, *Delphinapterus leucas*. Fish Bull 69:531–535

Ford JKB (1989) Acoustic behaviour of resident killer whales (*Orcinus orca*) off Vancouver Island, British Columbia. Can J Zool 67:727–745

Fowler J, Cohen L, Jarvis P (1998) Practical statistics for field biology. Wiley, Chichester

Hair JF Jr, Anderson RE, Tatham RL, Black WC (1998) Multivariate data analysis. Prentice-Hall, Englewood Cliffs, NJ

Janik VM (1999) Pitfalls in the categorization of behaviour: a comparison of dolphin whistle classification methods. Anim Behav 57:133–143

Jefferson TA, Leatherwood S, Webber MA (1993) FAO species identification guide: marine mammals of the world. FAO and UNEP, Rome

Kleinenberg SE, Yablokov AV, Belkovich BM, Tarasevich MN (1969) Beluga (*Delphinapterus leucas*): investigation of the species. Israel Program for Scientific Translations, Jerusalem

Lesage V, Barrette C, Kingsley MCS, Sjare B (1999) The effect of vessel noise on the vocal behavior of belugas in the St. Lawrence River estuary, Canada. Mar Mammal Sci 15:65–84

Lønø O, Øynes P (1961) White whale fishery at Spitzbergen. Norw Whaling Gaz 50:267–286

Lydersen C, Martin AR, Kovacs KM, Gjertz I (2001) Summer and autumn movements of white whales (*Delphinapterus leucas*) in Svalbard, Norway. Mar Ecol Prog Ser 219:265–274

Mann J (1999) Behavioral sampling methods for cetaceans: a review and critique. Mar Mammal Sci 15:102–122

Markov VI, Ostrovskaya VM (1990) Organization of communication system in *Tursiops truncatus* Montagu. NATO ASI Ser A 196:599–622

Michaud R (1999) Social organization of the St. Lawrence beluga whale. 13th Biennial Conference Biology Marine Mammals, Wailea, Maui, Hawaiii, 28 Nov–3 Dec 1999

Morgan DW (1979) The vocal and behavioral reactions of the beluga, *Delphinapterus leucas*, to playback of its sounds. In: Winn HE, Olla BL (eds) Behavior of marine animals. Plenum Press, New York, pp 311–343

Murray SO, Mercado E, Roitblat HL (1998) Characterizing the graded structure of false killer whale (*Pseudorca crassidens*) vocalizations. J Acoust Soc Am 104:1679–1688

Øien N (1988) The distribution of killer whales (*Orcinus orca*) in the north Atlantic based on Norwegian catches, 1938–1981, and incidental sightings, 1967–1987. Rit Fiskideildar 11:65–78

Recchia CA (1994) Social behaviour of captive belugas, *Delphinapterus leucas*. PhD Thesis, Woods Hole Oceanographic Institution/Massachusetts Institute of Technology

Rendell LE, Gordon JCD (1999) Vocal response of long-finned pilot whales (*Globicephala melas*) to military sonar in the Ligurian Sea. Mar Mammal Sci 15:198–204

Richard PR, Martin AR, Orr JR (2001) Summer and autumn movements of belugas of the Eastern Beaufort Sea stock. Arctic 54:223–236

Schevill WE (1964) Underwater sounds of cetaceans. In: Tavolga WN (ed) Marine bio-acoustics. Pergamon Press, London, pp 307–316

Shane SH, Wells RS, Würsig B (1986) Ecology, behavior and social organization of the bottlenose dolphin: a review. Mar Mammal Sci 2:34–63

Sjare BL, Smith TG (1986a) The vocal repertoire of white whales, *Delphinapterus leucas*, summering in Cunningham Inlet, Northwest Territories. Can J Zool 64:407–415

Sjare BL, Smith TG (1986b) The relationship between behavioral activity and underwater vocalizations of the white whale, *Delphinapterus leucas*. Can J Zool 64:2824–2831

Smith TG, Hammill MO, Martin AR (1994) Herd composition and behaviour of white whales (*Delphinapterus leucas*) in two Canadian arctic estuaries. In: Born EW, Dietz R, Reeves RR (eds) Studies of white whales (*Delphinapterus leucas*) and narwhals

(*Monodon monoceros*) in Greenland and adjacent waters. Medd Grøn Biosci 39:175–184

Tongeren OFR van (1995) Cluster analysis. In: Jongman RHG, Braak CJF ter, Tongeren OFR van (eds) Data analysis in community and landscape ecology. Cambridge University Press, Cambridge, pp 174–203

Watkins WA (1967) The harmonic interval: fact or artifact in spectral analysis of pulse trains. In: Tavolga WN (ed) Marine bio-acoustics. Pergamon Press, London, pp 15–44

Weilgart LS, Whitehead H (1990) Vocalizations of the north Atlantic pilot whale (*Globicephala melas*) as related to behavioral contexts. Behav Ecol Sociobiol 26:399–402

Wiig O, Gjertz I (1992) Review of the present management status and historical catches of white whales in Norway. Paper SC/44/SM 10 presented to the Scientific Committee of the International Whaling Commission 9–22 June 1992. IWC, Cambridge

Zar JH (1996) Biostatistical analysis. Prentice-Hall, Englewood Cliffs, NJ