Calls recorded from North Pacific right whales (*Eubalaena japonica*) in the eastern Bering Sea

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ABSTRACT

Calls from North Pacific right whales (*Eubalaena japonica*) were recorded in the eastern Bering Sea during a visual and acoustic survey aboard the US Coast Guard buoy tender *Sweetbrier*, in July 1999. Calls were commonly detected to 20km, and in one case approximately 30km, via deployment of arrays of directional sonobuoys. Acoustic detections (clusters of right whale calls separated by time and location) numbered 26, but only five right whales were seen. Only one right whale produced calls while under visual observation. The types of calls recorded from North Pacific right whales were similar in duration and frequency to calls recorded from right whales in the South Atlantic. The predominant call type (85%; 436 of 511 calls) was the 'up' call, a signal sweeping from about 90Hz to 150Hz in 0.7s. Two call types are described as 'down' and 'constant' calls, based upon nomenclature established for southern right whales (*Eubalaena australis*). One call type, the 'down-up' was unique to the North Pacific repertoire. Right whales commonly produced calls in series lasting several minutes and then became silent for an hour or more, with some animals not calling for periods of at least four hours. Other cetaceans detected acoustically by 'random' sonobuoy deployments during the cruise included fin whales (19 times), killer whales (3 times) and sperm whales (once).

KEYWORDS: NORTH PACIFIC RIGHT WHALE; ACOUSTICS; ACOUSTIC-SURVEY; MONITORING

INTRODUCTION

A two-week cruise was conducted in July 1999 in association with aerial surveys to find and photograph North Pacific right whales (*Eubalaena japonica*) in the eastern Bering Sea, where they have been seen each July since 1996 (Goddard and Rugh, 1998; Tynan, 1998; 1999; Moore *et al.*, 2000; LeDuc *et al.*, 2001; Tynan *et al.*, 2001). The overall goal of the cruise was to biopsy right whales, collect aerial photographs and, if possible, detect and locate whales via localisation of acoustic calls (LeDuc *et al.*, 2000). Although calls of southern right whales (*Eubalaena australis*) are well documented (e.g. Clark, 1982; 1983), there are only a few descriptions of calls for the North Atlantic species (*Eubalaena glacialis*; e.g. Gillespie and Leaper, 2001; Matthews *et al.*, 2001) and none for North Pacific right whales. A goal of the acoustics work was to acquire baseline recordings of North Pacific right whale calls and to evaluate the potential for long term acoustic monitoring of the eastern Bering Sea using autonomous seafloor-moored recorders. Autonomous recorders can now record continuously for a year or more and will provide a means to ascertain seasonal occurrence and estimate minimum population size of this critically endangered species in the eastern Bering Sea.

METHODS

The vessels used in this study were the United States Coast Guard buoy tender, *Sweetbriar* and a Rigid Hull Inflatable Boat (RHIB) launched from the *Sweetbriar*. The science team consisted of five personnel, four visual observers and one acoustics observer. DIFAR (DIrectional Frequency Analysis and Recording) sonobuoys were deployed when whales were seen, and at intervals when they were not, to detect right whale calls and direct the ship towards the whales. When right whales were seen, an array of four or more sonobuoys was deployed to localise the source of any calls. Each array was deployed with the best practical geometry, which meant spacing sonobuoys a minimum of about 2km apart. Actual array geometry was limited by radio reception range and the track of the ship and RHIB relative to the whales. The ship's track was determined by the cruise objectives, which were to: (1) biopsy right whales; (2) collect aerial photographs for photo-identification; (3) record right whale calls; and (4) conduct a visual line transect survey.

All of the sonobuoys used for right whale recording were type 53 DIFAR, which transmit three multiplexed signals on a VHF radio carrier providing direction finding capability accurate to about 2°SD. Systematic errors of about 2°SD are also associated with each sonobuoy, but these were corrected using the ship as a sound source at a known location. Sonobuoy hydrophones were set to a depth of 28m (90ft) and secured with duct tape to prevent accidental release of additional hydrophone wire. Buoy life was set to eight hours, although the actual recording period was typically determined by the radio reception range. The frequency response of these sonobuoys increases by roughly 6dB per octave from 10Hz to 1kHz, flat from 1kHz to 2.4kHz and a 30dB/octave roll off from 2.4kHz to 4kHz, the effective upper limit of the recording capability. The spectrograms shown have not had this frequency response removed.

The radio receiving and recordings system had a flat frequency response across the band of interest. Radio signals were received on a *Ringo Ranger* omni-directional antenna, mounted at 19m (61ft) on a mast cross tree, and connected via a mast pre-amp and RG-8 cable to the receivers. The five radio receivers used were specially constructed and calibrated by *GreeneRidge Sciences Inc*[1]. Sonobuoy radio reception was typically strong to 18km (10 n.miles), and at times extended to roughly twice that distance. Radio reception distance did not appear to be effected by sea state,

[1] *Use of company or trade names does not imply endorsement.*

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suggesting that atmospheric conditions (temperature and humidity stratification) were the dominant cause of range variability. Data were recorded on *Sony* model TCD-D8[1] and model PCM-M1[1] digital audio tape (DAT) recorders, sampling at 48kHz and 44.1kHz respectively. Call localisation was performed using de-multiplexer software provided by *GreeneRidge Sciences Inc*[1] and direction finding software written by the lead author, based on the methods of D'Spain (1994). Scrolling spectrograms were monitored at sea using *SpectraPlus*[1] commercially available software.

All tapes were re-analysed post-cruise by the lead author to detect and classify calls. Call identification and classification was carried out using scrolling spectrograms combined with listening and localisation of all calls. Scrolling spectrograms are particularly helpful for detection of the lowest frequency calls where listening alone may be inadequate. Call localisation was achieved primarily by plotting multiple DIFAR sonobuoy bearings to each call, complimented by arrival time localisation, comparison of call amplitudes, and dispersive mode propagation.

Listening and call localisation were helpful in separating fin whale (*Balaenoptera physalus*) and humpback whale (*Megaptera novaeangliae*) calls from right whale calls. All fin whale calls that were recorded in the Bering Sea sweep down in frequency, while the most common right whale call in this region sweeps up, making them easy to separate. Humpback whales typically produced higher frequency calls than right whales. If a call was of a type similar to that known from both humpback and right whales, it was classified to species according to its geographic location and the presence of calls more clearly identifiable as belonging to one species or the other. The start and end points of each call were picked visually with a computer cursor on a spectrogram display and durations rounded to the nearest 0.1 second. On a few occasions, there were detections of single calls or just a few indistinct calls which could not readily be associated with any species. When these could not be localised to the known location of any species, no detection was scored in any category.

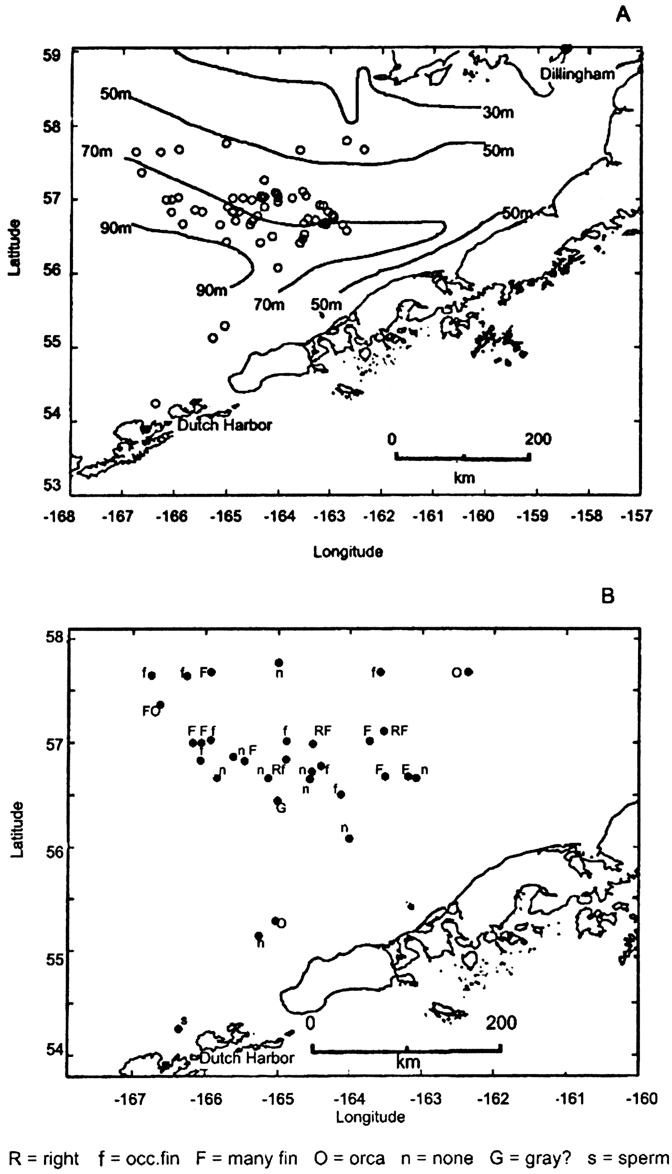

Fig. 1. Locations of 66 sonobuoys deployed during the cruise in relation to bathymetry (a); and locations for the 32 sonobuoys deployed 'at random' when no whales were seen, with symbols denoting the whale species detected, or none (b).

RESULTS

Sonobuoy deployments

Sixty-six sonobuoys were deployed during the cruise (Fig. 1a); 34 were set out during times when a whale/whales of any species had been recently seen or a right whale had been acoustically detected; 32 buoys were launched 'at random', when no whales had been recently observed. Of the 34 buoys deployed near the time of a whale sighting, 23 were deployed as right whale localisation arrays, while 11 buoys were deployed near the time of visual sightings of fin, humpback or killer whales (*Orcinus orca*). Except for the first buoy launched as the ship was leaving Dutch Harbour, all were deployed in shallow inner (<50m) and middle shelf (50-100m) water in the eastern Bering Sea.

Recordings from the 32 sonobuoys deployed 'at random' (Fig 1b), resulted in detections of right whales (3 times); fin whales (19 times); killer whales (3 times); sperm whales (once); and calls from an unknown biological source, possibly a gray whale (once). Humpback whales were acoustically detected on six occasions, although only on sonobuoys deployed after a whale sighting. Fin whale calls were frequency downswept pulses of about 0.8s duration as commonly recorded elsewhere in the world (e.g. Moore *et al.*, 1998), although many were at higher frequencies (sweeping from 120Hz to 90Hz) than is typical for fin whale pulses (Edds, 1988). The killer whale calls were similar to those reported for resident-type animals recorded elsewhere (Ford, 1991; Deeke *et al.*, 1999). The single deep-water buoy near Dutch Harbour recorded a sperm whale producing 'slow' clicks as is typical of a male (Whitehead and Weilgart, 1990). No calls were recorded from nine (28%) of the deployments. These random deployments give an indication of likely detection rates for different species, given that each buoy was recorded for about one hour.

Right whale detections

There were 26 occasions when right whales were detected acoustically including both the random sonobuoy deployments (3 encounters) and during the deployment of four arrays (23 encounters), where an acoustic 'encounter' is defined as a call or series of calls at a new location. Right whales were seen on four occasions (total of five animals), sometimes while following acoustic bearings to calls. Of note, post-cruise analyses of the acoustic data always revealed the presence of multiple right whales in the vicinity of each sighting. While acoustic detections resulted in re-directing the ship to the general search area where right whales were present, it was unclear if any of the whales seen were the same animals that produced the calls which caused the ship search to be re-directed. Only on one occasion (11 July) was a right whale calling while under direct visual observation. Calls from this whale were readily detected at a range of 19km and appear to have been detected out to at least 30km, as estimated by propagation mode dispersion.

Post-cruise analysis of the acoustics data during each right whale sighting revealed widely separated acoustic localisations over periods too short to allow for a single animal to have moved to each of the acoustic call locations (Fig. 2). It was not possible to definitively correlate the locations of the call clusters as a swim track. Some of the 26 encounters are likely multiple call series from the same whale on the same day, but this cannot be determined. The acoustic right whale locations observed on 17 July require a minimum of five right whales assuming typical right whale travel speeds.

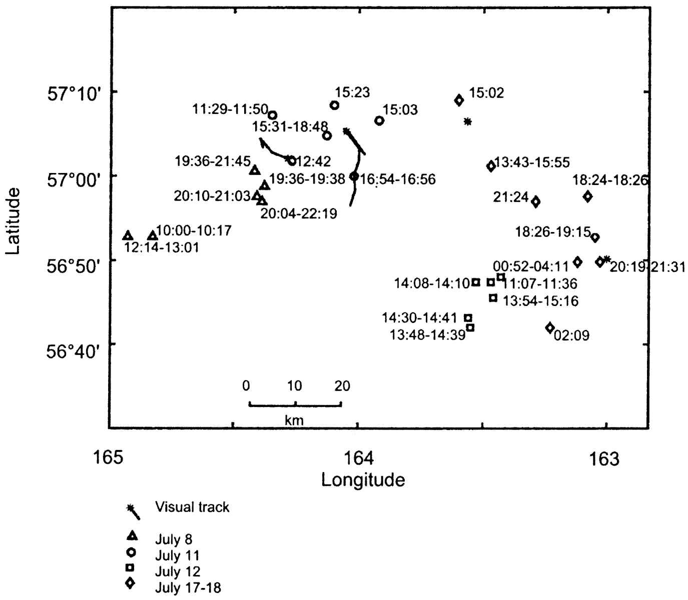

Fig. 2. The 26 North Pacific right whale acoustic detections are shown with a symbol corresponding to each array, with local times posted for each encounter. The acoustic encounter locations were determined by crossing bearings from a directional sonobuoy array. The visual right whale tracks are shown with an asterisk at the four initial locations and visual track lines are shown when available. The only match between visual and acoustic locations occurred at 16:54-16:56 on July 11. Tracks are shown for both of the two animals seen on this occasion although the animals were widely separated at the time of the acoustic calls.

Calls were usually produced in series at rates of several calls per minute, thus calls which were not of the most common 'up-type' were identified as being produced by right whales only if the call source was localised from the same location as the 'up' call. For example, 'high', 'hybrid' or 'pulsive' calls (as described in Clark, 1983) could have been missed if produced without the typical 'up' call in the same call series. Similarly, atypical sounds, such as a broadband 'slap' or 'gunshot' sounds (Clark, 1983), were commonly recorded during this cruise, but were typically associated with humpback whales and were not found to occur at the same location as typical 'up' calls. If right whales did produce such sounds, but not in association with right whale 'up' calls, they may not have been attributed to right whales. The one call series produced while the calling whale was under direct visual observation on 11 July, contained only 'up' calls.

Call types

The 511 calls considered to be from right whales were classified into five categories: (1) up; (2) down-up; (3) down; (4) constant; and (5) unclassified (Fig. 3). The 'up' call was the predominant type, comprising 85% ($n =$ 436) of all calls recorded. 'Up' calls were typically produced in a series of 10-15 calls (Fig. 4), followed by silence lasting an hour or more. A very similar call type, the 'down-up', differed in that it sweeps down in frequency for 10-20Hz before becoming a typical 'up' call (Fig. 3b). 'Down-up' calls comprised 5% ($n = 26$) of the call sample and most ($n = 20$) were recorded during only two of the 26 acoustic encounters, these two call series possibly being from the same animal. The 'down' calls ($n = 18$; 3.5% of all calls) were usually interspersed with up calls (see Fig. 4), as were 'constant' calls ($n = 27$; 5% of all calls). The constant frequency calls could be further sub-divided into those consisting of a single frequency tonal (2%) and those where the frequency wavers up and down by about 10Hz (3%; Fig. 4a). The remaining 1.5% of calls did not readily fit into any of the above categories.

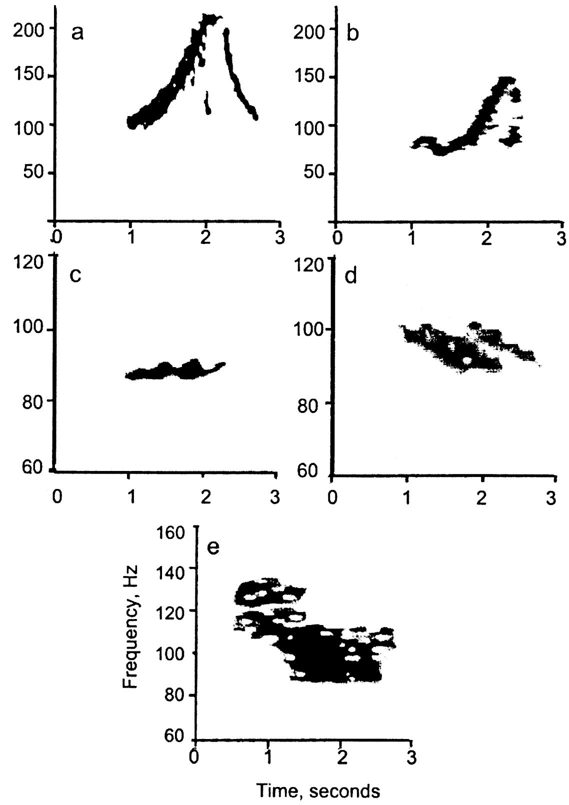

Fig. 3. Spectrograms illustrate representative examples of the call type classifications used in this study. The call types are (a) up; (b) down-up; (c) constant-tonal; (d) constant-waver; (e) down. All spectrograms use a 0.5 second FFT length with 87.5% overlap; note the different frequency scales. Dispersive propagation mode artifacts are visible in all but (c).

Descriptive statistics of the 'up' calls are provided in Figs 5 and 6. Typically, 'up' calls sweep from about 90Hz to 150Hz in 0.7s. Sweep rates ranged from 35 to 150Hz/s (median = 63). The 'down' and 'constant' calls are somewhat lower in frequency than the 'up', the average start frequency for the 'down' call being 118Hz (SD = 13), the

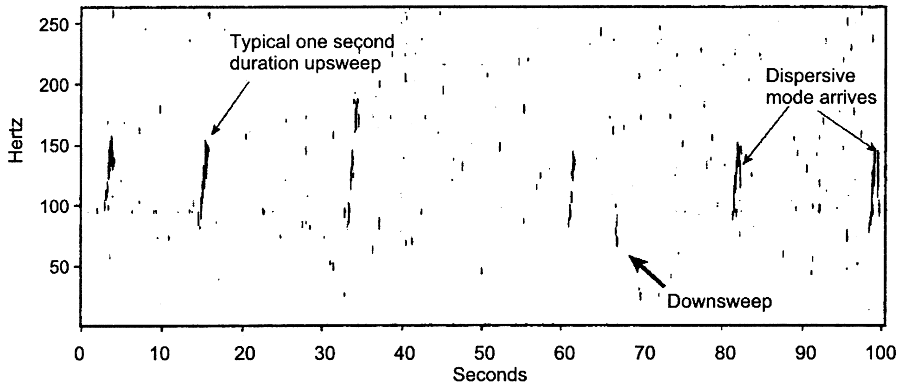

Fig. 4. This call series shows North Pacific right whale ‘up’ calls, with a ‘down’ call and examples of dispersive propagation mode arrivals of ‘up’ calls.

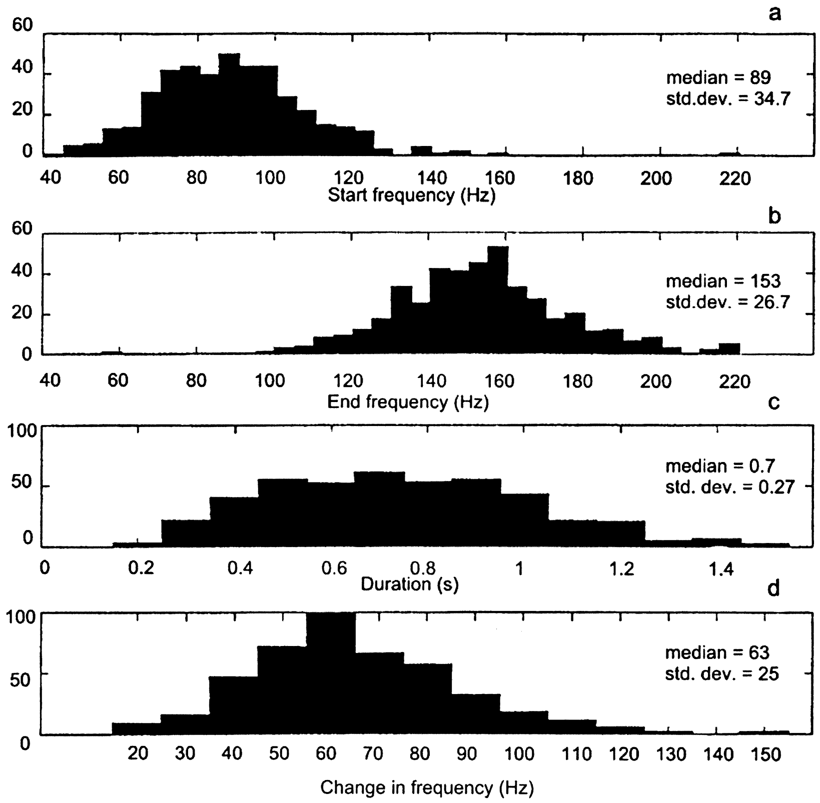

Fig. 5. Descriptive statistics for the 436 ‘up’ calls: start frequency (A) end frequency (B) duration (C) and change in frequency over the course of the call (D).

end frequency 86Hz (SD = 15) and duration 0.8 seconds (SD = 0.3). The ‘constant’ calls have an average frequency of 94Hz (SD = 22) and an average duration of 1.6 seconds (SD = 0.8). The durations of the constant calls appear to be longer than that of the ‘up’ calls, but this may be an artifact caused by the acoustic propagation modes rather than a longer sound source duration.

DISCUSSION

Call types

This study provides the first description of North Pacific right whale calls as well as a measure of their calling activity level in the eastern Bering Sea. Nearly all previous descriptions of right whale calls are from recordings at a breeding and nursery area in Argentina (Clark, 1982; 1983). Three of the call types reported here are described using the same nomenclature as Clark (1983), the down-up call being the exception. In the Argentine study, male and female right whales had similar call repertoires and whale surface-activity level, group size and sexual composition were correlated with the types of calls recorded. Description of calls for North Atlantic right whales are sparse, including a short summary on a phonograph record (Schevill and Watkins, 1962) and a report where calls were classified only as moans (> 100Hz), low frequency (LF ~ 70Hz), or ‘gunshots’ (Matthews *et al.*, 2001). In the latter study, moans were associated with larger whale groups and were more frequently recorded at night.

Acoustic versus visual detection

Passive acoustics techniques are now commonly used to detect and assess cetaceans. Comparatively long-term deployments of autonomous recorders are often used to detect and sometimes track mysticete whales (e.g. McDonald *et al.*, 1995; Stafford *et al.*, 2001), while towed

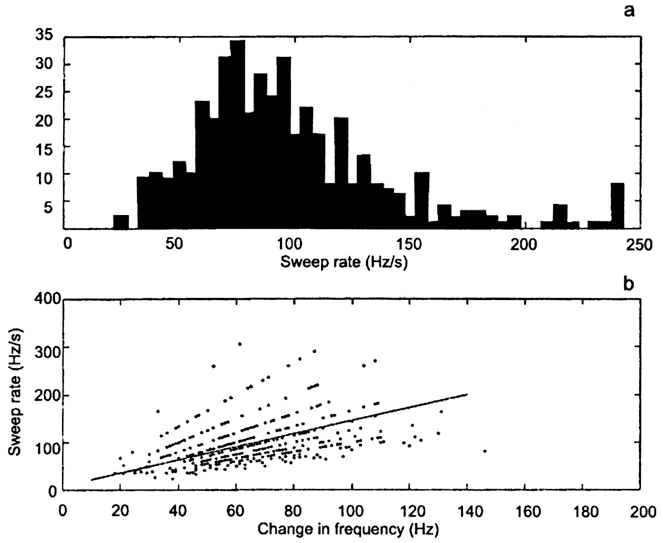

Fig. 6. The sweep rate for the 436 'up' calls is depicted. The apparent alignments in the scatter plot are caused by the rounding of the call duration to the nearest 0.1 second. The sweep rate is greater for those calls sweeping a greater frequency range, resulting in calls nearly the same length regardless of the change in frequency.

arrays are commonly used for odontocete detection (e.g. Gordon *et al.*, 2000; Leaper *et al.*, 2000). Studies that incorporate passive acoustics always benefit from the extended temporal and spatial range of sampling, as summarised over 15 years ago by Thomas *et al.* (1986).

Right whales were routinely detected to about 20km, roughly twice the furthest distance of visual detections. Given the longer detection ranges of acoustic methods, it is perhaps not surprising that more right whales were detected acoustically than visually during the *Sweetbrier* cruise. In addition, given the brief period (9.5 hours) during which right whales were kept under both acoustic and visual observation it is not surprising that only one of the 26 acoustic encounters occurred with the calling animal under direct visual observation (Table 1). Even if visual observations had been maintained for longer periods, approaches by the ship for biopsy sampling likely altered whale behaviour and thus the result of one acoustic encounter in 9.5 hours of observation is not necessarily typical of undisturbed animals. Finally, while as few as five whales could have been responsible for all 26 of the acoustic encounters, it is our belief that more than five whales were present because it is unlikely each animal within acoustic range produced calls during the sampling periods.

Table 1

Summary of acoustic and visual monitoring, after a North Pacific right whale was detected either visually or acoustically. Only one call series (on July 11th) was recorded from a visually monitored whale during a total of 9.5 hours of direct visual observation on all whales. The 56 hours of acoustic monitoring in the presence of one or more right whales resulted in the 26 acoustic encounters shown in Figure 2.

Date	Acoustic contacts (no.)	Visual contacts (no.)	Acoustic monitoring (hrs)	Visual observation (hrs)
8 July	6	1	14	2
11 July	6	2 (together initially)	15	3
12 July	6	1	8	4
17 July	8	0	16	0
18 July	0	1	3	0.5
Total	26	5	56	9.5

Calling activity, detection range and estimation of number of calling whales

Right whales in the eastern Bering Sea nearly always called in bouts ranging in duration from a few minutes to over an hour. Overall, calling activity was low, usually a series of 'up' calls lasting 5-10 minutes followed by an hour or more of silence. This calling pattern is similar to the 'moan cluster' reported in Matthews *et al.* (2001), but different from that described for Southern right whales (Clark, 1983). In the Argentine breeding area, right whale calling activity was correlated with group size and composition. Furthermore, several additional and more complex call types were described. These differences in calling activity could be attributable to species differences, but are more likely a function of behaviour. In the breeding and calving areas offshore Argentina, right whales are involved in a suite of social behaviours (Payne, 1986), with 'the complexity of the social context directly related to the complexity of the sounds made' (Clark, 1983). In the eastern Bering Sea, right whales are more typically focused on feeding (Tynan, 1999), although mating activity has been witnessed there (SEM). Thus, a simple series of 'up' or 'contact' (Clark, 1983) calls is likely sufficient to keep whales in acoustic contact. Indeed, the graded series signalling paradigm of Morton (1982) predicts this relationship between signalling complexity and call types.

Dispersive propagation modes

The relatively shallow and nearly constant water depth in the eastern Bering Sea provides a wave-guide for the low frequency acoustic energy of the right whale calls. The interaction of reflected energy travelling in the horizontal direction results in energy pulses called modes each travelling with a different velocity (Urick, 1983). Mode propagation is dispersive, which means lower frequencies travel more slowly than higher frequencies under these propagation conditions. Thus, while the mode 1 arrival of a right whale call may appear as an upsweep, the mode 2 arrival may appear as a downsweep due to this dispersive propagation phenomena.

The differential arrival times of the first two propagation modes and the dispersive nature of the mode 2 arrival are seen in spectrograms (Fig. 7). The increasing separation between mode 1 and mode 2 with increasing propagation distance is apparent. Four mode arrivals is the maximum number observed with the right and fin whale calls recorded during this cruise and it should be noted that not all calls show clear mode arrivals. Mathematical models of acoustic mode propagation have become routine to the extent that the models themselves are scarcely mentioned in papers which use such techniques to estimate seafloor geo-acoustic parameters and water column sound speed profiles (i.e. Potty *et al.*, 2000). Knowledge of the bathymetry is the single most important parameter and a relatively flat seafloor simplifies modelling accuracy (Medwin and Clay, 1998).

The likely reason why some calls show mode arrivals more clearly than others is the depth of the whale when the call was produced and the depth of the receiver, rather than simply the range from the calling whale. Further analyses of these propagation modes should allow calculation of the range to the call with accuracy on the order of 1km. While it will remain a difficult problem to estimate abundance of whales from acoustic data alone, knowledge of detection range and change in detection range with changes in ambient noise will be an important step towards the goal of better estimating the relative abundance of whales with autonomous seafloor recorder data.

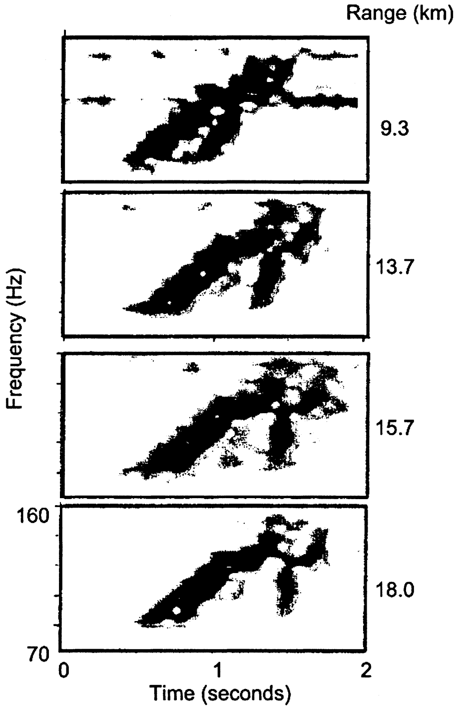

Fig. 7. A right whale call as recorded on four sonobuoys while under visual observation on 11 July at 16:54; water depth = 70-73m. The increasing separation between mode 1 and mode 2 with increasing propagation distance is apparent and dispersion of mode 2 is clearly seen where the lower frequency energy travels more slowly.

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