J. Mar. Biol. Ass. U.K. (2001), **81**, 189–190
Printed in the United Kingdom

Effects of diel and seasonal cycles on the dive duration of the minke whale (*Balaenoptera acutorostrata*)

K.A. Stockin*[†§], R.S. Fairbairns[‡], E.C.M. Parsons* and D.W. Sims[†∫]

*The Hebridean Whale and Dolphin Trust, Main Street, Tobermory, Isle of Mull, Argyll. [†]Department of Zoology, University of Aberdeen, Tillydrone Avenue, Aberdeen, AB24 2TZ. [‡]Sea Life Surveys, Torrbreac, Dervaig, Isle of Mull, Argyll. [∫]Current address: Marine Biological Association of the United Kingdom, Citadel Hill, Plymouth, Devon, PL1 2PB. [§]E-mail: hwdt@sol.co.uk.

Minke whale (*Balaenoptera acutorostrata*) surfacing intervals were recorded over a period of three years in the coastal waters of Mull, Coll and the Small Isles, in the north-west of Scotland. Significant differences in surfacing intervals were noted both throughout the day and throughout the year. Surfacing intervals were shortest at noon and in the months of June and July. Surfacing intervals were longest both mid-morning and mid-afternoon and during May and August. Differences in surfacing intervals were interpreted to be the result of ecological changes such as different foraging strategies. Consequently, the results of this study have an impact on the methodologies and designs of minke whale sightings surveys.

Despite being the most common baleen whale species occurring in UK waters (Evans, 1991), information on the behaviour of the minke whale (*Balaenoptera acutorostrata*) is limited. Observations of minke whale surfacing rates and patterns have become an integral part of the research on this species. An understanding of whale surfacing behaviour is clearly necessary in order to correct survey sighting data, where the probability of detecting a whale on the trackline is not equal to one.

To collect baseline information on the behaviour of this species, data on minke whale dive times were gathered over a 3-y period (1992–1994), from an area of high minke whale abundance in western Scotland (Leaper et al., 1997). The survey area extended from the Isle of Mull and Ardnamurchan in the east to the Isles of Coll and Tiree in the west, and northwards to the Small Isles (Canna, Rum, Eigg and Muck), an area of approximately 450 km^2. Minke whales are resident in this region throughout the summer (mid April–October), with identifiable individuals returning to the area in subsequent years (Gill & Fairbairns, 1995).

Data was collected from a 10.5-m motor yacht equipped with a flying bridge 2 m above sea level and a global positioning system. A minimum of six observers was present at any one time on the bridge, arranged equally to achieve full observer coverage of the surrounding waters. The intervals between minke whale surfacings were recorded by one observer using a digital stopwatch. An additional sub-set of dives times (N=163) were recorded simultaneously using both the stopwatch method and a Psion Series 2a datalogger to compare the accuracy of recording methods. The data sets were found to be statistically comparable (F-test, $P=0.99$) and hence the method by which dive times were measured had no effect in this current study.

Dive sequences were recorded for 30 min (see Gunnlaugsson, 1989). Dive sequences of less than 30 min duration were discarded from the data set. Only dive sequences recorded during optimal sightings conditions (sea state <2) were used in this study. During the study period, 67% of encountered whales were solitary animals (292 encounters). Dive times of whales encountered in groups were discarded as, in these cases, the identity of the surfacing whale could not be determined in the field. This left a remainder of 1,367 dive sequences to be analysed in this study.

To analyse diel differences in surfacing rates the daily study period (09:00–18:00) was divided into eight equal periods. An equal number of dives sequences (N=93) were randomly taken from each period, using random number tables, and analysed. There were highly significant differences between the lengths of surfacing intervals during different parts of the day (ANOVA on log transformed data: $F=5.89$; $P<0.0001$; Figure 1A). Significantly longer dive durations were recorded between 10:00 and 11:00 and between 13:00 and 16:00, and significantly shorter dive durations between 12:00 and 13:00 (Table 1).

Significant differences in surfacing intervals were also recorded between months (ANOVA on log transformed data: $F=6.35$; $P<0.0001$; Figure 1B) which are summarised in Table 1.

The mean surfacing interval recorded in this current study for north-west Scotland was 66.1 sec (SD=96.7; range 1–806 sec), which is comparable to the surfacing rate of Icelandic minke whales (Gunnlaugsson, 1989; Joyce et al., 1990). Surfacing intervals of minke whales off the coast of Norway have been recorded with longer surfacing intervals of 85.7 (Øien et al., 1990), 80.6 (surfacing interval during daytime; Øen, 1990 (unpublished data)) and 74.6 sec (surfacing interval during daytime; Folkow & Blix, 1993). This suggests a great variability in surfacing intervals for minke whales between different geographic regions. However, many of the above studies based their surfacing rates

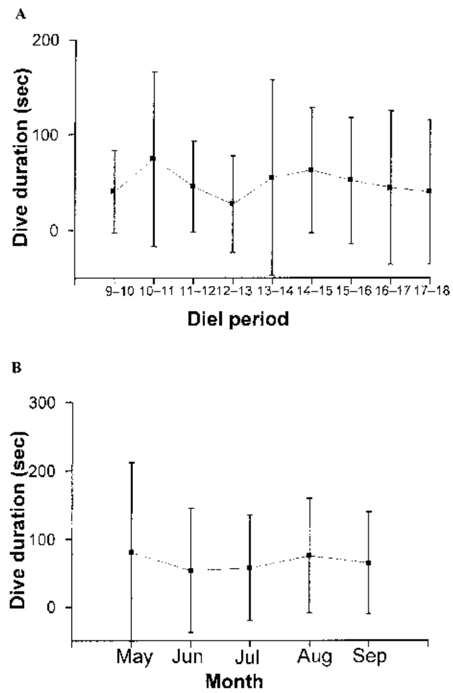

Figure 1. Mean minke whale surfacing intervals between different (A) diel periods and (B) months (showing standard deviation range).

Table 1. *Summary results of Tukey multiple comparisons between log transformed surfacing interval data over different diel periods*

Diel period	09:00–10:00	10:00–11:00	11:00–12:00	12:00–13:00	13:00–14:00	14:00–15:00	15:00–16:00	16:00–17:00
17:00–18:00	ns	$P<0.01$	ns	ns	ns	$P<0.001$	$P<0.01$	ns
16:00–17:00	ns	ns	ns	ns	ns	ns	ns	
15:00–16:00	ns	ns	ns	$P<0.001$	ns	ns		
14:00–15:00	ns	ns	ns	$P<0.001$	ns			
13:00–14:00	ns	ns	ns	$P<0.05$				
12:00–13:00	ns	$P<0.01$	$P<0.05$					
11:00–12:00	ns	ns						
10:00–11:00	ns							

ns, not significant.

on only one or two animals over a short period of time (Øen, 1990; Joyce et al., 1990; Folkow & Blix, 1993) and the above-mentioned geographical variations may be due to individual differences or seasonal changes in surfacing rates.

Attempts to investigate diel patterns in surfacing rates have previously failed to find any significant patterns. Joyce (1982) compared surfacing rates for Antarctic minke whales in the morning, at midday and in the afternoon (0.72, 0.53 and 0.66 surfacings min^{-1}, respectively), but these differences were not significant. Stern (1992) also compared surfacing rates in the morning with rates in the afternoon for Californian minke whales (0.61 and 0.66 surfacings min^{-1}, respectively), but again no significant difference was observed. However, Joyce et al. (1990) and Folkow & Blix (1993) did observe differences between mean daytime and night-time surfacing intervals for Icelandic and Norwegian minke whales respectively (day: 59.0, night: 48.1, Joyce et al., 1990; day: 74.6, night: 89.4, Folkow & Blix, 1993). This current paper is, therefore, the first study to record fine-scale diel and seasonal differences in minke whale surfacing behaviour.

The geographical, seasonal and diel differences in minke whale surfacing intervals are probably due to changing patterns in the foraging behaviour and habitat utilisation of minke whales. Prey species targeted by minke whales may have changed throughout the year as the availability of prey changed. Thus, the diving behaviour of minke whales would be expected to change as they adopted different foraging behaviours for different species.

The results of this study have implications for minke whale survey design. Minke whales do not display much aerial behaviour and 'blows' are typically the most conspicuous visual cue for sighting individuals. Variations in blow behaviour greatly affect the sightability of whales during visual surveys. Therefore, the significant differences between surfacing intervals, both throughout the day and during different parts of the year, imply that the ability to sight minke whales will also change.

The studies which have estimated minke whale numbers in the north-east Atlantic based on line-transect surveys, have used data collected exclusively in July (e.g. Schweder et al., 1997). This report suggests that as minke whale surfacing rates vary throughout the year, estimates based exclusively from one part of the year may misrepresent actual minke whale population sizes. This study demonstrated that July is a period when the minke whales have shorter surfacing intervals than later in the year and, hence, an estimate calculated from data collected during this month may over-estimate minke whale population size.

Norwegian whaling operations currently kill an annual quota of minke whales which is based upon population estimates produced by line-transect surveys, which may currently be inaccurate and over-estimated due to the reasons stated above. This paper illustrates that a comprehensive assessment of the abundance of minke whales through surveys should consider changes in minke whale behaviour and its underlying ecological cause.

The authors wish to thank Alison Gill and Jonathan Gordon for their help and advice during this study and Russell Leaper, Justin Cooke, Caroline Warburton, Simon Berrow and an anonymous reviewer for their constructive comments on draft versions of this paper. We also thank the staff at Sealife Surveys and the Hebridean Whale and Dolphin Trust who helped with logistics and the collection of data for this project.

REFERENCES

Evans, P.G.H., 1991. Whales, dolphins and porpoises: order cetacea. In *The Handbook of British Mammals. 3rd edition* (ed. G.B. Corbet and S. Harris), pp. 299–350. Oxford: Blackwell Science.

Folkow, L.P. & Blix, A.S., 1993. Daily changes in surfacing rates of minke whales (*Balaenoptera acutorostrata*) in Norwegian waters. *Reports of the International Whaling Commission*, **43**, 311–314.

Gill, A. & Fairbairns, R., 1995. Photo-Identification of the minke whale *Balaenoptera acutorostrata* off the Isle of Mull, Scotland. In *Whales, seals, fish and Man* (ed. A.S. Blix et al.), pp. 129–132. Amsterdam: Elsevier Science.

Gunnlaugsson, T., 1989. Report of Icelandic minke surfacing rate experiments in 1987. *Reports of the International Whaling Commission*, **39**, 435–436.

Joyce, G.G., 1982. Blow patterns as sightings cues for censusing minke whales in Antarctic waters. *Reports of the International Whaling Commission*, **32**, 787–790.

Joyce, G.G., Sigurjónsson, J. & Vikingsson, G., 1990. Radio tracking a minke whale *Balaenoptera acutorostrata* in Icelandic waters for examination of dive-time patterns. *Reports of the International Whaling Commission*, **40**, 357–361.

Leaper, R., Fairbairns, R., Gordon, J., Hiby, A., Lovell, P. & Papastavrou, V., 1997. Analysis of data collected from a whalewatching operation to assess relative abundance and distribution of the minke whale (*Balaenoptera acutorostrata*) around the Isle of Mull, Scotland. *Reports of the International Whaling Commission*, **47**, 505–511.

Øen, E.O., 1990. A new VHF-dart radiotransmitter for minke whales. Paper SC/42/NHMi17 presented to the IWC Scientific Committee, June 1990 (unpublished). 9 pp. [Available from iwc@iwcoffice.org]

Øien, N., Folkow, L. & Lydersen, C., 1990. Dive time experiments on minke whales in Norwegian waters during the 1988 season. *Reports of the International Whaling Commission*, **40**, 337–341.

Schweder, T., Skaug, H.J., Dimakos, X.K., Langaas, M. & Øien, N., 1997. Abundance of north-eastern Atlantic minke whales, estimates for 1989 and 1995. *Reports of the International Whaling Commission*, **47**, 453–483.

Stern, S.J., 1992. Surfacing rates and surfacing patterns of minke whales (*Balaenoptera acutorostrata*) off Central California and the probability of a whale surfacing within visual range. *Reports of the International Whaling Commission*, **42**, 379–385.

Submitted 25 July 2000. Accepted 20 October 2000.