

Report on blood testosterone and progesterone concentrations of the North Atlantic minke whale (*Balaenoptera acutorostrata*) during the feeding season in Icelandic waters from research catches 2003-2006

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ABSTRACT

Sex hormone measurements from the North Atlantic minke whale (common minke whale, *Balaenoptera acutorostrata*) in Icelandic coastal waters were obtained from frozen blood samples collected fresh postmortem from 23 females and 47 males caught during June–September 2003–2007 as a part of the Icelandic Research Program of Common Minke Whales. Respectively serum progesterone (P) and testosterone (T) concentrations were measured and compared with anatomical data. The frequency distribution of female serum P measurements in Norwegian catches has been shown to have two clusters, one consisting mainly of immature animals and the second of pregnant ones, with mean serum values of about 0.49 ± 0.04 (SE) and 44.2 ± 2.84 nmol·L⁻¹, respectively. Therefore only females that had no observed foetus and in some cases one or both ovaries missing were measured to provide information on the reproductive status. The Norwegian frequency distribution of male serum T did not show any group-specific distribution during the hunting season. Only males longer than 5.70 m were measured here. Contrary to earlier reports on the Antarctic minke whale (*Balaenoptera bonaerensis*), serum T values rose during the hunting season in the mature males as also observed in the Norwegian sample. This increase agrees with the predominantly annual reproduction cycle of minke whales. However the rise in the T measurements in the Icelandic sample happens during the days 215–243 of the year while the rise in the Norwegian measurements appears during days 180–220 of the year or earlier. As no genetic divergence has been observed between these areas and low diversity in the North Atlantic in general this may be due to segregation by reproductive status as has been observed by sex and age, generally north-south. Alternatively, this might also reflect potential local adaptation to these two areas while too recent to show up in the genetics.

INTRODUCTION

The common minke whale (*Balaenoptera acutorostrata*) species is the smallest in size of the genus *Balaenoptera*, which belongs to the Balaenopteridae family. As reviewed recently (Lockyer 1984, 1999; Horwood 1990), a considerable body of knowledge has been gathered by pioneering studies mainly during the last 40–50 years on the reproduction of the common minke whale. Contrary to other baleen whales, which generally reproduce every second year or even less frequently, the evidence available at present indicates that the common minke whale has mostly a yearly reproductive cycle (Horwood, 1990; Sigurjónsson *et al.*, 1990, SC/F13/SP12). Apparent pregnancy rates (proportion of sexually mature females with foetuses, females with calves not included) have persistently been reported between 90% and 100% in the common minke whale catches ((Christensen, 1981; Sigurjónsson *et al.*, 1990, SC/F13/SP12). This is about 50% higher than in the northern fin whale (*Balaenoptera physalus*) (Martin 1982; Lockyer and Sigurjónsson 1991) and sei whale (*Balaenoptera borealis*) (Lockyer and Martin 1983), which normally reproduce every other year. Likewise, the ovulation rates (number of corpora counted in ovaries per year by age) have generally been reported to be about 90% and higher, which is roughly two times greater than those for fin and sei whales (Horwood 1990; Lockyer 1999).

The common minke whale, like most other baleen whales, has an annual migration cycle of feeding, which should be in step with its breeding cycle. The animals breed at lower and warmer latitudes (SC/F13/SP18) but go to colder areas in the north during the summer for feeding. Gestation period is 10 months, a month or two shorter than for the other baleen whales, and the suckling period is thought to be less than 6 months (Lockyer 1999). Many lactating female minke whales have been found to be ovulating as evidenced by corpora lutea in their ovaries (International Whaling Commission 1979), and it seems probable that they do conceive while being suckled. If conception occurred mainly before the middle of the suckling period, the minke whale cows could maintain an annual reproduction cycle that fitted into their yearly migration. The postpartum inhibition of ovulation during suckling is variable in different animals but seems to be mainly controlled by the suckling

frequency of the offspring (McNeilly 1994), which causes suppression of the pulsatile secretion of gonadotropin-releasing hormone. Progesterone (P) and the endogenous opioid system are probably involved (Soaje *et al.* 2002), but the exact mechanism at the hypothalamic level is not yet clear.

Kjeld *et al.* (2004) confirmed that the yearly reproductive cycle of common minke whales with higher ovulation and pregnancy rates, i.e., increased ovarian activity, is reflected in different serum P concentrations when compared with other rorquals with a 2-year cycle. This comparison applies to the North Atlantic fin whale (Kjeld *et al.* 1992) and sei whale (Kjeld *et al.* 2003) in both of which serum P concentrations have been measured.

Antarctic minke whales caught off Durban, South Africa, during the winter months were reported to have higher mean testicular weights per length than those taken in the Antarctic during the summer months (Best 1982). However, no definite seasonal variation in serum testosterone (T) or P concentrations has so far been found in either sex of the Antarctic minke whale during the months of December–March (Yoshioka and Fujise 1992; Iga *et al.* 1996; Mogoe *et al.* 2000). Using heterologous antisera, Suzuki *et al.* (2001) also studied the concentrations of gonadotropins in the pituitary of the Antarctic minke whale during the months of December–March and found no rise in luteinizing hormone values and a significant rise in follicle stimulating hormone values only from February to March. However, serum T and P concentrations were mostly undetectable in immature males as well as mature males and immature females, respectively. This is contrary to findings of Kjeld *et al.* (2004) in a study on the common minke whale who found a clear rise of serum T levels during the feeding season in the sexually mature males and a weaker, but still significant, rise of serum P levels in the immature females, as well as for two other species of the same genus, the northern fin whale (Kjeld and Árnason 1990; Kjeld *et al.* 1992) and the sei whale (Kjeld *et al.* 2003), both of which showed significant increases of serum T concentrations during the hunting season. The Minke whale study was based on Norwegian catches off North Norway and the Kola Peninsula, Bear Island and Spitsbergen May–September 1992–1995.

Here, using relatively sensitive radioimmunoassays, we report the serum T and P measurements on samples available from the common minke whale. The serum T and P values are related to the time of the season, the length of the animals, and their anatomically assessed sexual status.

MATERIAL AND METHODS

Collection and storage of samples

The whales were caught as a part of the Icelandic Research Program of Common Minke Whales, during the period May–September 2003–2007, 23 females and 47 males (Marine Research Institute, 2003). The catches were distributed in the coastal Icelandic water according to densities observed in sightings surveys. Blood samples were collected by cutting into the jugular vein immediately after the animals had been taken aboard the vessel, generally less than 40 minutes *post-mortem*. Blood was left to coagulate in the vacutainers for 40–50 min and then centrifuged, the serum separated and kept at -20 °C. Extended storage was at -80 °C. These samples were also used in an earlier paper on urine production and salt balance (Kjeld and Ólafsson 2004, SC/F13/SP9).

Selection of samples for laboratory measurement

Of the 90 caught males only those above 5.70 m (n=83) were considered and useful T measurements obtained for 45. Of the 94 caught females only those where no foetus had been observed were considered (n=40) and useful P measurements obtained for 23.

Assays

Serum P and T was measured at the National University Hospital, Reykjavik, Iceland, Dept. of Clinical Biochemistry, Endocrine section, by an electrochemiluminescence immunoassay “ECLIA II” on Elecsys and cobas e analyzers. This is a competitive assay using electrochemiluminescence detection. The detection limit is < 0.1 nmol/L and CV < 5% on human serum. Specimen, biotinylated monoclonal hormone-specific antibody, and same hormone derivative labeled with ruthenium complex are incubated with Danazol to release the hormone. Hormone from the sample competes with the labeled hormone derivative for the antibody binding site. After addition of streptavidin-coated microparticles, the complex becomes bound to the solid phase via interaction of biotin and streptavidin. The amount of the labeled hormone derivative bound to the solid phase is inversely proportional to the hormone content of the sample. This reaction mixture is aspirated into measuring cell where the bound microparticles are captured onto the electrode surface and unbound substances are removed. Voltage is applied to the electrode inducing a chemiluminescent emission, which is then measured against a calibration curve to determine the amount of hormone in the specimen (Haymond and Gronowski 2006). (Package insert: Roche Cobas. Roche Diagnostics, Indianapolis, IN 09/2007)

Gross anatomical studies

The reproductive status of the females (immature, mature resting, pregnant, ovulating) was evaluated by studying the anatomy of the internal sex organs. In most cases this was accomplished by the observation of a fetus. In females with no observed fetus either corpora lutea or corpora albicantia or both in the ovaries indicate sexual maturity. Due to the harpooning or handling, a few ovaries were not sampled and some fetuses may not have been observed. Based on a previous study (Christensen 1981) of body length related to anatomic measures of the genital organs of both sexes of the whales, their reproductive status could also be estimated. This study showed that 50% of the females and males were sexually mature when they had reached a length of 7.15 and 6.75 m, respectively, and that approximately 70% of either sex became mature within a body length interval ranging 0.35 m above and below the respective means cited above (Christensen 1981). This was used as an indicator of sexual maturity in the males, separating the mature from the immature bulls in the Norwegian study (Kjeld *et al.* 2004).

RESULTS

Of the 45 T measured males 3 were in the size range 5.7-6.75 m and all had T values below the detection limit (Table 1a). These are not considered further for comparability with the Norwegian study (Kjeld *et al.* 2004). The $\log_{10}(T)$ values for the 42 males longer than 6.75 m (all classified as sexually mature except 3 pubertal from testis analysis) are given in Fig. 1 by day of year. T measurements were below the detection limit of $0.1 \text{ nmol}\cdot\text{L}^{-1}$ in 21 males (shown on the plot with a y-axis value -1). All 12 whales caught prior to day 115 (including one pubertal) had T measurements below 0.15 and all 8 measurements after day 243 are above 0.3. The median length of the plotted whales is 7.6 and out of the 9 high T values (>1.0) 7 are from median or longer whales (one pubertal), while all the 5 lower values after day 235 are from shorter than median males (one pubertal).

Of the 23 P measurements two were around $45 \text{ nmol}\cdot\text{L}^{-1}$ (Table 1b). These animals were over 8.4 m in length and one had a corpus luteum while the ovaries were not available from the other. For the closely related fin whale, it has been shown that for the months of June and July, almost all of the corpora lutea found indicated pregnancy (Lockyer and Sigurjónsson 1991). Although P itself may have a role in initiating ovulation (Zalányi 2001), as a rise in peripheral P levels precedes the luteinizing hormone surge of ovulation, in many terrestrial mammal species (Niswender and Nett 1994), as well as in the captive killer whale (*Orcinus orca*) (Robeck *et al.* 1993) and bottlenose dolphin (*Tursiops truncatus*) (Kirby 1990), P concentrations are considerably higher in pregnancy than after ovulation, so these two animals were most likely pregnant. All other measurements were below 1 and the two highest values (0.8 and 0.3) are from the only two of these animals that were caught in September (late), the first one only 5.3 m in length (the other 7.7 m). The length at which 50% of female common minke whales are sexually mature was estimated to be 7.50 m for minke whales off West Greenland during 1979–1981 (Larsen 1984) and 7.15 m for minke whales in the Barents Sea during 1972–1977 (Christensen 1981). With values lower but above the detection limit (0.1) were 4 and three of these likely anestrus, while of the 15 values at or below the detection limit two of the female ovaries looked anestrus.

DISCUSSION AND CONCLUSION

The clear rise of serum T levels during the feeding season in the males considered sexually mature and the weaker, but still significant, rise of serum P levels in the immature females reported in the Norwegian catches (Kjeld *et al.* 2004) are supported here. The 3 pubertal whales above the size limit of the sample (6.75 m) do not suggest they differ from the mature whales when size is factored in. These hormonal changes have not been found in the Antarctic minke whale, the species most extensively studied in this respect so far (Yoshioka *et al.* 1990; Yoshioka and Fujise 1992; Iga *et al.* 1996). Mogue *et al.* (2000) even found a decrease in the weight of the testes in the Antarctic minke whale during the December–February period. No similar studies have been done before on the common minke whale, but a rise of T levels during the feeding season has been described in the northern fin whale (Kjeld *et al.* 1992) and sei whale (Kjeld *et al.* 2003). The reasons for the above discrepancy seem most likely that the North Atlantic serum assays have had three to five times lower detection limits than those used by the above cited Japanese scientists. Secondly, the Antarctic minke whale may have lower hormonal levels in its peripheral blood than the common minke whale, thus adding one more characteristic to several already known to differ between the two whale species. The Antarctic whale is, for instance, larger (Lockyer 1999), has a white band on its flippers, and has different genetic constitution (Árnason and Gullberg 1994). The mean P levels for pregnant females found in Norwegian study are, about two times higher than those reported for the Antarctic minke whale in recent papers ($13.7\text{--}21.3 \text{ nmol}\cdot\text{L}^{-1}$) (Iga *et al.* 1996; Suzuki *et al.* 2001).

Although the sample is restricted to mature males the rise in the T measurements is still to some degree size related, as also observed in the Norwegian sample. The rise in the Icelandic sample happens during the days

215–243 of the year (3.-31.August) while in the Norwegian measurements it appears before or during days 180–220 (29. June -8. August) of the year (no measurement below 0.3 there after). As no genetic divergence has been observed between these areas and low diversity in the North Atlantic in general this may be due to segregation by reproductive status that is particularly pronounced in minke whales (Laidre et al., 2009, SC/F13/SP14). However, this might also reflect some sort of local adaptation to these two areas while too recent to show up in the genetics. Further investigations with large sample sizes are needed to further elucidate this.

In captive bottlenose dolphins (Schroeder and Keller 1989) and seasonally breeding terrestrial herbivores (Bronson and Heideman 1994), serum T concentrations generally reach a peak or an elevated plateau before the rutting period starts and then the levels begin to fall during the rut. The T levels of the mature minke males appear to be still rising at the end of the feeding season.

Not duplicated in the these Icelandic samples was the relatively high serum P levels in the immature and resting females ($0.49 \pm 0.04 \text{ nmol}\cdot\text{L}^{-1}$) observed in the Norwegian samples (Kjeld et al. 2004), which were at least five times higher than those ($\leq 0.1 \text{ nmol}\cdot\text{L}^{-1}$) reported for the fin whale (Kjeld et al. 1992) and sei whale (Kjeld et al. 2003) during the same time of the year and higher than the undetectable levels of the Antarctic minke whale (Yoshioka and Fujise 1992; Iga et al. 1996; Suzuki et al. 2001) where also no changes in level with time were reported. The low ratio of resting cows among the female minke whales in the North Atlantic studies is in agreement with the results (Iga et al. 1996; Suzuki et al. 2001) on the Antarctic minke.

Mansour et al. (2002) studied postmortem P levels in common minke whale blubber and found a very decisive difference in levels between pregnant (range 72.5–1441 nmol·g blubber⁻¹) and nonpregnant females (4.5–10.8 nmol·g blubber⁻¹). Kellar et al. (2009) studied blubber T values of short-beaked common dolphins (*Delphinus delphis*) and found significantly higher values in mature than immature or pubertal males and higher during the summer months. Although the levels in the dorsal fin were significantly lower, with care, this suggest the possibility of correlating sex hormone levels in serum and blubber and using blubber biopsies of free-ranging whales to predict their reproductive status.

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Table 1 a) and b). Hormone levels (Conc.) in common minke whale caught during the 2003-2007 research program, with length (cm) and sexual condition.

a) Testosterone in males.

ID	Date	Length	Condition	Conc.
A0306	2003-08-29	739	Mature	0.32
A0308	2003-08-31	697	Pubert	0.14
A0502	2005-07-07	764	Pubert	<0.10
B0302	2003-08-24	693	Mature	0.13
B0303	2003-08-27	845	Mature	1.79
B0307	2003-09-15	775	Mature	1.76
B0308	2003-09-22	603	Pubert	<0.10
B0309	2003-09-25	718	Mature	0.94
B0310	2003-09-26	750	Mature	0.39
B0311	2003-09-28	772	Mature	3.43
B0312	2003-09-28	771	Mature	6.47
B0501	2005-07-06	777	Mature	0.12
B0502	2005-07-19	802	Mature	<0.10
B0503	2005-07-19	727	Mature	<0.10
B0511	2005-08-15	788	Mature	0.30
B0609	2006-07-22	770	Mature	<0.10
B0612	2006-08-12	699	Mature	<0.10
B0613	2006-08-13	748	Mature	<0.10
B0614	2006-08-17	783	Mature	<0.10
B0615	2006-08-21	759	Mature	<0.10
B0617	2006-08-25	647	Mature	<0.10
C0301	2003-08-21	776	Mature	<0.10
C0302	2003-08-22	770	Mature	0.47
C0311	2003-09-19	762	Mature	2.07
C0312	2003-09-24	809	Mature	4.72
C0501	2005-07-06	705	Mature	<0.10
C0504	2005-07-22	797	Mature	<0.10
C0507	2005-07-28	766	Mature	0.11
C0508	2005-08-02	720	Mature	<0.10
C0510	2005-08-03	704	Mature	<0.10
C0511	2005-08-09	760	Mature	1.26
C0512	2005-08-10	790	Mature	<0.10
C0514	2005-08-14	790	Mature	<0.10
C0615	2006-08-09	692	Pubert	1.31
C0616	2006-08-12	857	Mature	0.29
D0603	2006-07-22	740	Mature	<0.10
D0604	2006-07-26	750	Mature	<0.10
D0605	2006-08-02	700	Mature	<0.10
D0606	2006-08-03	795	Mature	0.45
D0607	2006-08-14	730	Mature	<0.10
D0608	2006-08-14	836	Mature	<0.10
D0609	2006-08-18	789	Mature	<0.10
D0610	2006-08-20	740	Mature	0.51
D0613	2006-08-24	662	Pubert	<0.10
D0708	2007-09-02	731	Mature	4.30

b) Progesterone in females.

ID	Date	Length	Condition	Conc.
A0305	2003-08-28	542	Immat	<0.1
A0311	2003-09-16	526	Immat	0.8
A0312	2003-09-25	774	Immat	0.3
A0406	2004-07-04	819	Mature	<0.1
A0504	2005-07-13	599	Immat	<0.1
A0506	2005-07-21	730	Immat	<0.1
A0507	2005-07-22	682	Immat	<0.1
A0508	2005-08-08	725	Immat	0.2
A0606	2006-07-18	803	NA	0.2
A0608	2006-07-20	761	Anoes	0.3
A0611	2006-08-11	606	Immat	<0.1
A0701	2007-05-15	622	Immat	<0.1
B0408	2004-06-28	684	Immat	<0.1
B0505	2005-07-24	737	Immat	<0.1
B0510	2005-08-13	762	Anoest	<0.1
C0309	2003-09-16	840	NA	44.9
C0403	2004-06-13	712	Immat	<0.1
C0407	2004-07-04	634	NA	<0.1
C0602	2006-06-22	603	Immat	0.1
C0609	2006-07-15	781	Anoest	0.2
C0610	2006-07-20	858	Pregn	<0.1
C0613	2006-07-23	780	Anoest	<0.1
C0709	2007-07-14	871	Pregn	45.4

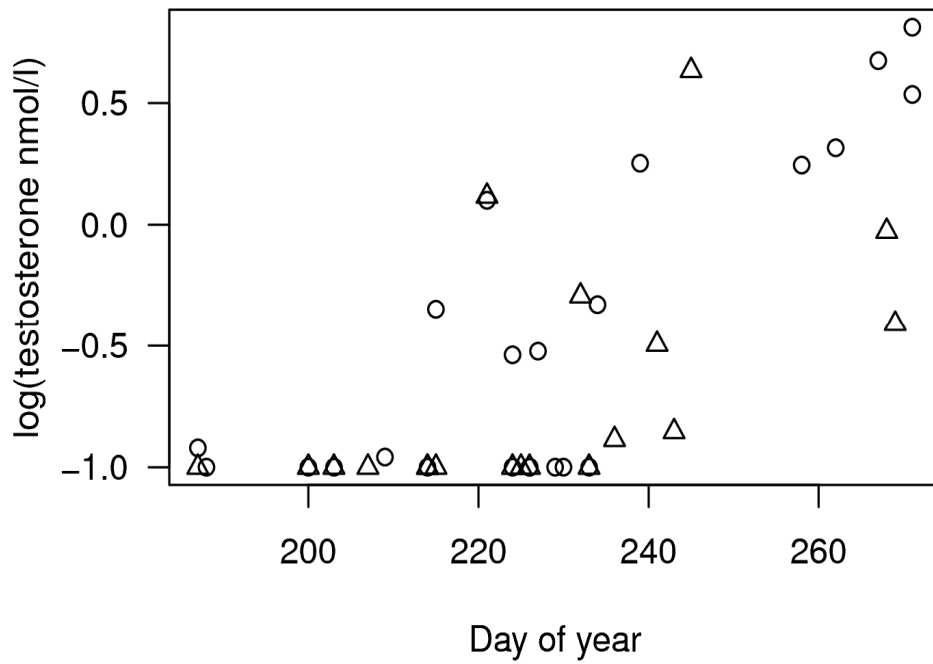


Fig. 1 Logarithm of Serum Testosterone measurements $\text{nmol}\cdot\text{L}^{-1}$ in Icelandic minke whale research catch 2003–2007, males >6.75 m, by day of year. Triangles where length <7.6 m (sample median length). The value -1.0 on the y-axis shows measurements at or below the detection limit of $0.1 \text{ nmol}\cdot\text{L}^{-1}$.