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HOME, SWEET HOME?

Habitat use of humpback whales (*Megaptera novaeangliae*) in Nuuk fjord, Greenland, with implications for commercial exploitation

Master thesis

By

Tenna Kragh Boye

20020221

Zoophysiology

Department of biological Science

University of Aarhus, Denmark

Supervisors:

Peter Teglberg Madsen

Department of biological Science

University of Aarhus, Denmark

Malene Simon

Department of birds and mammals

Greenland Institute of Natural Resources, Greenland

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Preface

This thesis describes a study of humpback whales in Nuuk fjord, West Greenland under the supervision of Peter Teglbjerg Madsen and Malene Simon, Aarhus University, in collaboration with Greenland Institute of Natural Resources. It constitutes a part of the multidisciplinary monitoring and research project *NuukBasis* which describes the biotic and abiotic factors that affect marine ecosystem dynamics in the Arctic in the light of climate changes. Data analysis took place at the Department of Biological Science, Zoophysiology, University of Aarhus, Denmark.

The thesis consists of a general introduction describing in detail the background of the study and the methods used. Furthermore it includes a manuscript entitled “Habitat use of humpback whales (*Megaptera novaeangliae*) in Nuuk fjord, Greenland, with implications for commercial exploitation” drafted for submission to the journal *Marine Mammal Science*.

Aarhus, January 2009

Tenna Kragh Boye

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1 Background

2 ***Introducing the humpback whales***

3 The humpback whale, *Megaptera novaeangliae*, is a mysticete placed in the family of *Balaenopteridae*
4 (rorquals) due to the longitudinal throat pleats (Lambertsen, 1983). Their long pectoral fins of up to
5 5 m in length place them in their own genus *Megaptera* meaning exactly “large wings” (Frazer and
6 Mercado, 2000). The humpback whale is a cosmopolitan species found in the oceans in both the
7 Northern and Southern hemisphere (Clapham, 1996). To a large degree, the continents separate the
8 populations living in different oceans, and equator parts populations within an ocean due to the
9 migratory behavior of humpback whales (Baker *et al.* 1994; Clapham, 1996). This segregation has
10 resulted in 11 alleged stocks worldwide which are, to a greater or lesser extent, genetically distinct
11 despite the lack of oceanographic barriers (Best, 1993; Valsecchi *et al.*, 1997).

12 ***Migration***

13 Migrating between areas is costly in terms of energy and time. Nevertheless, many animal groups
14 (e.g. birds, fish and mammals) take up long-distance migrations which have evolved independent-
15 ly forced by different ecological factors. Although costly, the benefits gained from migration must
16 necessarily surpass the costs for a migrating behavior to evolve and these various benefits most
17 often manifest them-self through an increase in fitness. The reasons for migration are many and
18 Alerstam *et al.* (2003) have discussed some of the potential reasons on the basis of different animal
19 species and go through factors such as competition, parasites, seasonality and habitats. An exam-
20 ple of parasitism effecting migration is suggested by Folstad *et al.* (1991). They propose that warble
21 flies, *Hypoderma tarandi*, cause reindeer, *Rangifer tarandus tarandus*, in Norway to migrate to minim-
22 ize levels of parasitic infections. Mysterud (1999) found female roe deer, *Capreolus capreolus*, in Lier,
23 Norway, to migrate longer and to more unfavorable habitats than males during migration to their
24 summer habitats. He suggests that either dominance by males or risk of predation cause the ex-
25 tended migration in female roe deer.

26 Humpback whales migrate annually from low latitude breeding grounds to high latitude feeding
27 grounds (Pomilla and Rosenbaum, 2005). They spend the summer months on their feeding
28 grounds feeding on prey such as herring (*Clupea harengus*), sand lance (*Ammodytes dubius*), mack-
29 erel (*Scomber scombrus*), capelin (*Mallotus villosus*) and euphausiids (Larsen and Hammond, 2004;
30 Stevick *et al.*, 2006); prey, which are characterized by having a patchy distribution and a variable
31 patch size (Clapham, 1996). In late autumn, the whales migrate south/north to their breeding

32 grounds to mate and give birth to calves and during the months there the whales rarely ingest
33 food (Corkeron and Connor, 1999). Migration and division in habitat utilization allows the whales
34 to benefit from different habitats that may not uphold optimal living conditions throughout an
35 entire year. An explanation could be that the low latitude breeding areas offer warmer waters but
36 the low productivity in these areas results in low food availability which probably would not sup-
37 port perennial populations of humpback whales. High latitude feeding grounds offer large food
38 availability in the highly productive months from spring through autumn. However, when winter
39 approaches food sources become scarce, the water becomes colder and in some places total ice
40 coverage occurs, minimizing habitat suitability.

41 Still, the exact reason for migration to low latitude areas with poor productivity remains unex-
42 plained and is still discussed. Corkeron and Connor (1999) suggested that baleen whales migrate
43 to low latitude breeding grounds to protect them-self and their new born calves from killer whale
44 (*Orcinus orca*) attacks in high latitude areas. Further, they suggest that killer whales may be the
45 foundation of the selection pressure for migration in baleen whales. Clapham (2001) rejects this
46 hypothesis. He argues that killer whales also are found in humpback whale breeding waters and
47 that sightings of interaction between the two species are scarce, if existing. Additionally, he states
48 that killer whale attacks on humpback whales are rare, and that the threat which killer whales con-
49 stitute to humpback whales is inadequate to have evolutionary force. Clapham (2001), on the other
50 hand, speculate that calves born in warm waters may be able to devote more energy to growth,
51 where colder water would require additional energy for thermoregulation. According to Clapham
52 (2001) calves born in the tropics could lead to larger sized adults with larger reproductive success,
53 larger competitive ability and larger survival rates and these factors would entail an immense se-
54 lection for the evolution of migration. Yet, a study on blue whales (*Balaenoptera musculus*) by La-
55 vigne *et al.* (1990) showed that this species does not have problems maintaining homeothermy in
56 water temperatures as low as -2°C. It is therefore questionable if it is the warm water itself that is
57 the fundamental reason for migration to breeding areas.

58 Whatever the reason for migration, it is well known that migration timing in humpback whales
59 depends on their age, sex and reproductive status as shown by e.g. Craig *et al.* (2003). In their
60 study, females in their early pregnancy and adult females were the first to leave the breeding areas
61 followed by juveniles and adult males. The last to leave the breeding areas were females with new
62 born calves. It should be noted that several studies have shown that not all females migrate to the
63 winter breeding areas and Brown *et al.* (1995) confirmed a skew in the distribution of males and

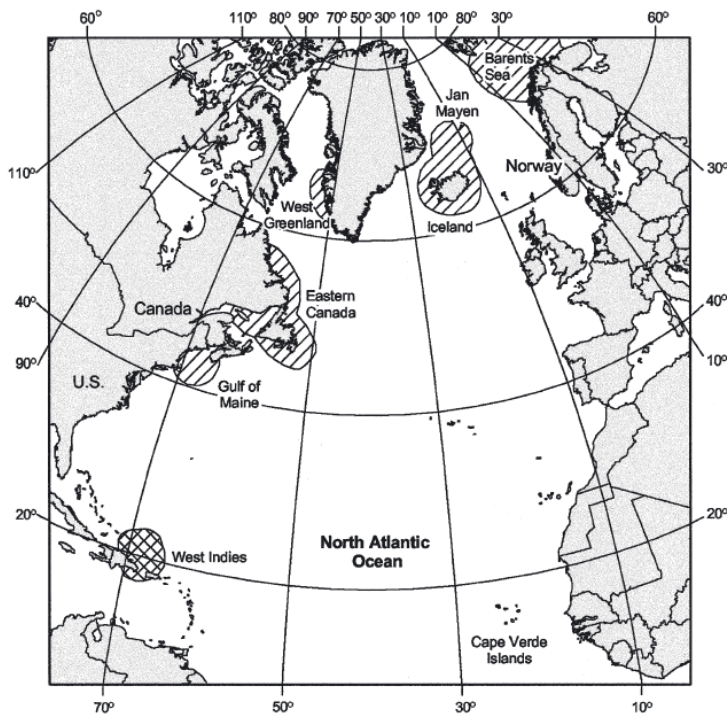
64 females in the winter breeding areas off Australia where more males are present. They estimated
65 that up 50 % of the females remained in or near the Antarctic feeding area. One population of
66 humpback whales does not undertake migration at all. Namely, the population in the Arabian Sea,
67 that otherwise would have to travel great distances across equator to reach other high latitude
68 feeding grounds (Mikhalev, 1997).

69 **West Greenland humpback whales**

70 Larsen and Hammond (2004) estimated the population of West Greenland humpback whales from
71 1988-1993 to constitute around 360 individuals. New estimates by Heide-Jørgensen *et al.* (2008)
72 state a West Greenland population of 3039 individuals with an annual increase of 9.4% yr⁻¹.

73 Humpback whales foraging alongside the West coast of Greenland breed in the West Indies along
74 with other North Atlantic humpback whale stocks (Stevick *et al.* 2003). Although breeding in the
75 same area, the humpback whales show great site fidelity towards their summer feeding grounds
76 and the North Atlantic population divides during their northern migration into four feeding ag-
77 gregations: The Gulf of Maine, Eastern Canada, West Greenland and the Northeast Atlantic (Fig. 1)
78 (Stevick *et al.* 2003). Some, but little exchange between the feeding aggregations have been docu-
79 mented (Heide-Jørgensen and Laidre, 2007) and this fidelity towards a specific feeding area is be-
80 lieved to be passed on maternally during the year of maternal dependence (Weinrich, 1998). Al-
81 though large scale site fidelity towards feeding areas is well investigated, few studies have de-
82 scribed the extent of small scale site fidelity in humpback whales.

83 In Nuuk fjord, West Greenland, the whales are present from late spring to late autumn (Boye *et al.*
84 in prep., this thesis). The whales come to forage and during their stay in the fjord, the whales are
85 likely to have a significant impact on the arctic food web in the fjord system. Although it has not
86 been possible to find any literature describing the amount of food humpback whales ingest in the
87 Nuuk area, Vilhjálmsson (2002) estimates the annual capelin removal by humpback whales in Ice-
88 landic waters to be around 800.000 tons yr⁻¹ (corresponding to 20.8% of the biological capelin re-
89 moval and 16.4% of the total capelin removal) only exceeded by cod (900.000 tons yr⁻¹) and com-
90 mercial landings (1 million tons yr⁻¹). This gives a good indication of the importance of the role that
91 humpback whales might play in the arctic food web in Nuuk fjord. According to a survey con-
92 ducted by Heide-Jørgensen *et al.* (2007) around 145 humpback whales forage in the Nuuk area.
93 However, they make clear that this number is connected to great uncertainties due to uneven sam-
94 pling and it surpasses by far the number of individuals identified in Nuuk fjord in our study
95 (Boye *et al.*, in prep, this thesis).



96 Fig 1. Primary breeding area (double crossed circle) and feeding areas (single stripped areas) for North At-
 97 lantic humpback whales (Stevick *et al.*, 2003).

98 If the population size of humpback whales in Nuuk fjord is known, knowledge on the average
 99 residence time and estimates on the amount of daily food consumption by the whales in the fjord
 100 would render possible an estimate of the biomass turnover for the whales in the fjord during their
 101 stay.

102 ***A note on Whaling***

103 Since the mid-1800 and up until the early decades of the 1900, humpback whales were the target of
 104 extensive whaling which led to a rapid decline in population size (Stevick *et al.* 2003). To prevent
 105 extinction, a ban on commercial whaling (i.e. humpback whales) was initiated in the North Atlan-
 106 tic in 1955 and only local hunters in Greenland and the Lesser Antilles were allowed to catch a
 107 small number of humpback whales (Martin *et al.* 1984; Best, 1993). Roman and Palumbi (2003) have
 108 estimated that before commercial whaling set in, a population size of 240.000 humpback whales
 109 was found in the North Atlantic. In the period from 1979-1986 an estimated number of 5.502
 110 humpback whales were living in the North Atlantic (Katona and Beard, 1990). In West Greenland
 111 about 800 humpback whales were caught in the period from 1886 to 1985 (Larsen and Hammond,
 112 2004). However, in 1986 the IWC (International Whaling Commission) put a moratorium on whal-
 113 ing reducing the West Greenland quota of humpback whales to zero and this quota is still in place
 114 (IWC, 1986). Today the number of humpback whales is increasing and the IUCN (International
 115 Union for Conservation of Nature) recently moved this species from the category *Vulnerable* to the

116 category of *Least Concern* (IUCN, 2008). This increase has led to intense debates on whether or not
117 to reopen hunt on humpback whales, and in 2008 Denmark proposed an annual quota of 10
118 humpback whales on behalf of West Greenland. The scientific committee concluded that this
119 would not harm the population. Nevertheless, the commission rejected the proposal and hump-
120 back whales are still protected from hunting (IWC, 2009)

121 ***The whale watching industry***

122 Most people who have seen whales in their natural environment can concur that it is a breath tak-
123 ing experience. Worldwide, whale watching popularity is increasing, and Hoyt (2001) has esti-
124 mated the industry to attract more than 9 million participants annually, primarily from Western
125 countries, and achieve an annual turnover of US\$ 1 billion. In many places whale watching has
126 replaced whaling and whaling it-self has become a subject of controversy between countries that
127 approve (e.g. Greenland, Norway, Japan) and disapprove (e.g. Australia, Germany, United States)
128 of whaling (Hamazaki and Tanno, 2001). In the study by Hamazaki and Tanno (2001) they found
129 that approval of whaling by the public was positively correlated with approval of consumption of
130 whale meat and not correlated with knowledge on whale abundance. This shows, that the opinion
131 on whaling basically is controlled by the public's own persuasions and feelings rather than what is
132 sustainable or not. In this case it can be a challenge to make whaling co-exist with whale watching
133 and this controversy has been approached in several studies. Higham and Lusseau (2007) express
134 the need for research in whaling and whale watching to clarify the opinions of whale watchers on
135 whaling and account for any possible conflicts between the industries. Obrams (2002) performed
136 such a study on the effects of potential resumption of whaling in Tonga. He concluded that the two
137 industries would not be able to coexist in this small island community where the majority of guests
138 were strongly opposed to whaling. Also, Parsons and Rawles (2003) concluded that resumption of
139 whaling in Iceland could result in great economical consequences, as 91.4% of the whale watchers
140 asked would not go whale watching in a country that hunted whales.

141 Since the early 1990s whale watching taken place in Greenland and as in other areas, it is increas-
142 ing rapidly here as well (Hoyt, 2001). In Nuuk, the industry depends on the whales that reside
143 within the fjord, which are primarily humpback whales. The new initiatives to reopen hunt on
144 humpback whales in West Greenland have already caused the whale watching industry in Nuuk
145 to voice their concern. Although not against whaling they request that whales are not hunted with-
146 in the fjord (¹Skydsbjerg, pers. comm.). Firstly, according to Hoyt (2001) 90% of the whale watching

¹Henrik Skydsbjerg, proprietor of Tupilak Travel, Imaneq 18, P.O. box 2291, 3900 Nuuk, Greenland, phone: +299 313218

147 tourists that visit Greenland are from western countries. This could, as shown in previous men-
148 tioned studies, lead to negative financial consequences due to boycott by the tourists. Secondly, as
149 shown in our study, the whales display a strong degree of small scale site fidelity. Hence, if indi-
150 viduals are killed within the fjord, there is a chance that these individuals are not replaced by new
151 individuals.

152 Seen in a conservation perspective whale watching is a good way to introduce people to whales
153 and create an interest in these species. However, where the majority of whale watchers are against
154 whaling and would not support whale watching in a country that carried out whaling, Scott and
155 Parsons (2005) showed in a study on the public opinion on cetacean conservation issues, that the
156 minority of the public (0.8%) regarded whale watching it-self as a potential threat. This is not the
157 case in many areas. As whale watching has increased and become more intense, several studies
158 have been carried out to determine if whales are affected over a short or long time scale. Many
159 short term effects have been documented in the form of increased swimming speed, change in dive
160 duration, change in swimming direction and groups that have become more compact when boats
161 approach (Bejder *et al.*, 1999; Williams *et al.* 2002; Lusseau, 2003). Long term effects have been
162 shown by Bejder *et al.* (2006). They discovered a decrease in the relative abundance of bottlenose
163 dolphins (*Tursiops truncatus*) in shark Bay, Australia, due to an increase in whale watching. Long
164 term effects are harder to detect as it requires years of studies. However, continuous disturbances
165 of foraging, breeding and resting could potentially have a negative effect on fecundity, health and
166 distribution. Some countries have decided to react on the potential implications of whale watching
167 and have introduced guidelines on sustainable whale watching (e.g. Australian Government, 2005;
168 New Zealand Government, 2008).

169 ***Objectives of the study***

170 Having gone through the background information on humpback whales both in general and in
171 specific and presented some of the topics that we address in our study, I will continue to introduce
172 the two methods used (i.e. photo-identification and theodolite tracking). Here, I will discuss their
173 applicability and drawbacks and present examples from our study which have not been included
174 in the final manuscript.

175 The results of the study are presented in the drafted manuscript where I have sought to answer the
176 following questions:

- 177 I. Do the same individuals return to Nuuk fjord every year (small scale site fidelity)?
- 178 II. What is the seasonality in the presence of humpback whales in Nuuk fjord and how
179 long do individual whales reside in the fjord?
- 180 III. Does whale watching in Nuuk fjord have an impact on the swimming behavior of
181 the humpback whales that reside in the fjord in the presence of boats?
- 182 IV. Build an ID-catalogue of individuals in Nuuk fjord

183 The results have led to a discussion on small scale site fidelity, habitat use and whale watching in
184 Nuuk fjord but also what the consequences of a potential quota on humpback whales in Greenland
185 may be.

187 **Photo identification**

188 *The theory*

189 When studying animal ecology it can be useful to be able to distinguish conspecifics within a
190 group or a population. This gives the researcher the opportunity to do detailed studies of popula-
191 tion changes, movement patterns and interrelations within a population (Gilkinson *et al.* 2006).

192 Different methods have been developed for the purpose of individual recognition of animals. Tag-
193 ging, where animals are caught and marked with either satellite tags, radio transmitters or conven-
194 tional tags (for instance banding of birds or plastic labels shot into the skin of fish) are some of the
195 methods developed (e.g. Storr-Paulsen *et al.* 2004; Heide-Jørgensen *et al.* 2006). Genetic marking,
196 where samples of sloughed skin, blood, fur or blubber are collected is a technique that gives the
197 scientist the ability to not only differentiate between individuals but also to determine the sex of
198 the animal (Palsbøll *et al.*, 1997). However, in tagging and genetic marking physical contact with
199 the animals is required when placing and retrieving tags from the animals or when the genetic
200 samples are obtained and this can have a negative effect on animal survival (Hammond, 1986; Pol-
201 lock K. H. and Alpizar-Jara, 2005). Additionally, when studying tagged animals it is hard to take
202 into account how a given tag may affect behavior and survival of the animals. Finally, tags can be
203 lost or destroyed during the study period and excluded from the dataset. Yet, tags like satellite
204 transmitters make it possible to follow individual animals for month long periods and is the only
205 tool for continuous studies of overall diving behavior, migrations, habitat use and distribution of
206 marine mammals (Born *et al.*, 2004; Heide-Jørgensen and Laidre, 2007).

207 Photo-identification of wild animals uses natural long term markings such as fin shape, scars,
208 nicks and coloration patterns to identify individuals within a species, and photographs of the phe-
209 notypic variations are collected without physically handling the animals. It is a good non-invasive
210 alternative to tagging and genetic marking and the method has been used for the past 20 years on a
211 variety of animal species, especially marine mammals (Gilkinson *et al.* 2006). "Tags", such as mor-
212 phological features and permanent coloration patterns, are not lost or worn off through time, un-
213 less the natural mark changes or new marks overlap. Photo-identification is employed when ad-
214 dressing questions of residency and site fidelity (Bejder and Dawson, 2001), migration routes
215 (Rasmussen *et al.*, 2007), social associations (Grellier *et al.*, 2003), habitat use (Craig and Herman,

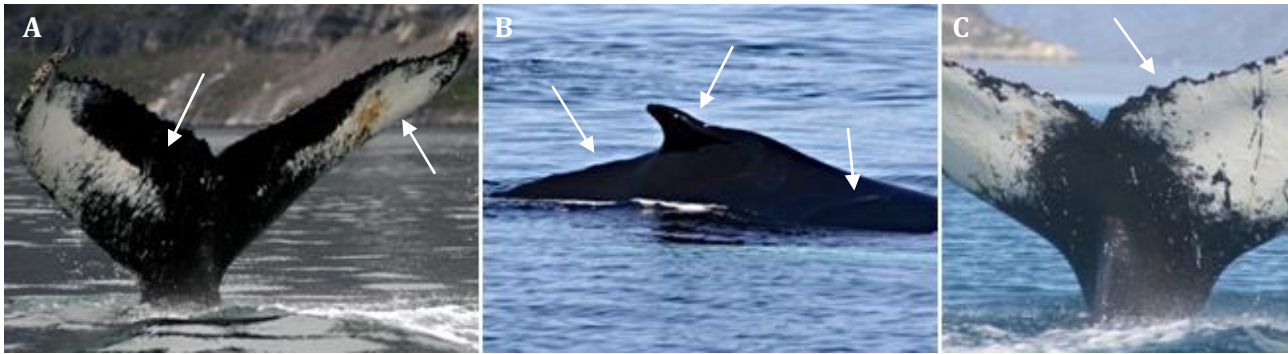
216 2000) and in combination with mark-recapture techniques for estimating abundance of marine
217 mammals in specific areas (e.g. Larsen and Hammond, 2004) (see later paragraph).

218 ***In practice***

219 Characters used in photo-identification vary with the animal species in question as the natural
220 marks used for identification are species specific (e.g. Langtimm *et al.*, 2004; Gilkinson *et al.*, 2006;
221 Graham and Roberts, 2007). When using photo-identification on killer whales, the grey saddle
222 patch along with the dorsal fin is used for identification (Baird and Stacey, 1988; Kuningas *et al.*,
223 2007). The shape of the saddle patch is unique to the individual as is the shape and nicks of the
224 dorsal fin. When identifying humpback whales various features can be used. The ventral side of
225 the fluke contains color patterns unique to the individual (Katona *et al.*, 1979) and these color pat-
226 terns are fairly persistent and can be used as identification through many years (Carlson *et al.* 1990)
227 (Fig. 2). This type of photo identification in humpback whales is often employed and is the most
228 described in the literature (e.g. Larsen and Hammond, 2004; Constantine *et al.*, 2007). It is also this
229 type of photo-ID which is used in humpback whale ID-catalogues worldwide and from which the
230 ID-catalogue in this study is build (Appendix A). Another option of photo-identification of hump-
231 back whales is the serrated trailing edge of the fluke but also the shape and scarification of the dor-
232 sal fin along with the caudal peduncle can be used for humpback whale identification (Blackmer *et*
233 *al.*, 2000) (Fig 3).



Fig. 2. The same whale photographed in 1992 (top photo) and again in 2008 (bottom photo) (Boye *et al.*, in prep., this thesis).



237 Fig. 3. Different characters used to identify humpback whale individuals. A) Fluke coloration patterns B)
 238 Caudal peduncle, dorsal fin shape and scarification C) serrated trailing edge.

239

240 There is a variety of methods developed for analyzing identification photos. In many studies the
 241 photographs are divided into categories depending on quality and are hereafter compared ma-
 242 nually (e.g. Larsen and Hammond, 2004), however , no objective definition of the different “quali-
 243 ty” classes have been described and varies therefore between studies. Perkins *et al.* (1984) did a
 244 study on abundance and distribution of West Greenland humpback whales using photo-
 245 identification. They divided the photographs into a quality gradient ranging from good (1) to poor
 246 (4). They took into account the image sharpness, resolution, contrast and distance at which the
 247 photo was taken and conducted a visual comparison of photos. Other studies divide the photos
 248 into either “usable” or “not usable” and discard ambiguous photos (Calambokidis *et al.*, 2000).

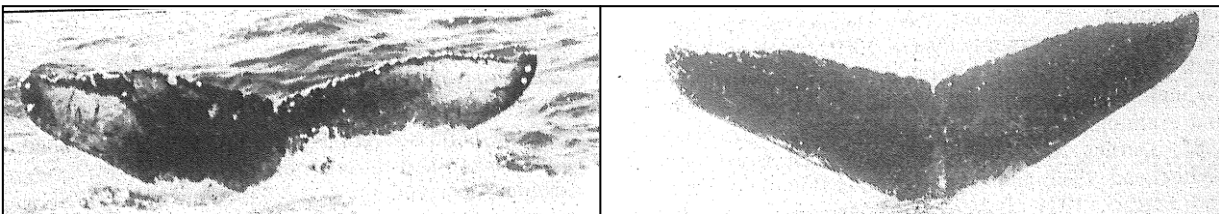
249 Because photo-identification is a commonly used method and because the amount of photographs
 250 has increased immensely since the development of digital cameras, the last couple of years have
 251 seen a progress in the development of various computer-assisted matching programs. *Europhlukes*
 252 is a program made for sperm whale identification, but may be useful for identification of other
 253 cetaceans. This program uses the trailing edge of the fluke for identification and matches it against
 254 the whole catalogue. Other programs developed are *Finscan* for bottlenosed dolphins (Gailey,
 255 2001) and *Highlight* for sperm whales (Whitehead, 1990). Computer-assisted matching programs
 256 can assist in identifying individuals that otherwise would not have been identified due to lack of
 257 distinctive markings. Such programs can compare ID-photographs to large ID-catalogues and nar-
 258 row down the amount of possible matches. Furthermore, it is a good way of double checking the
 259 identified individuals to prevent/decrease the number of mismatches. However, the final matching
 260 still relies on manual comparison.

261 ***Efficiency and reliability***

262 Photo identification is in many ways a good method to approach various scientific questions how-
263 ever some matters of dispute can occur and must be taken into account.

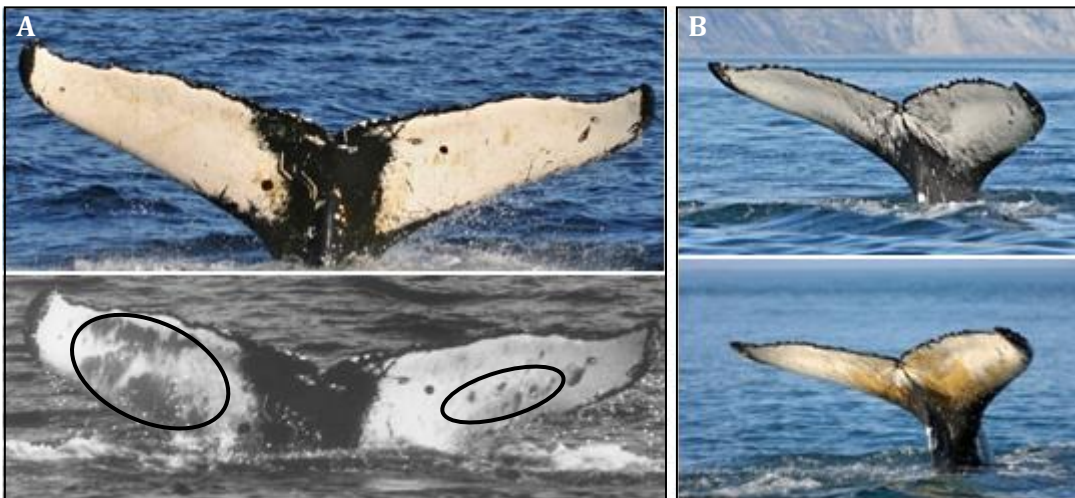
264 When manually matching photos, the scientists solely rely on their own judgment and the subjec-
265 tivity remains the main drawback. Due to poor quality photos (e.g. bad angle of the photos, over-
266 exposure of light, un-sharp) or lack of distinctive markings there is a risk of falsely matching dif-
267 ferent individuals or mistaking the same animal as two different individuals. In combination with
268 mark-recapture methods to estimate abundance this can be a problem as the individuals incorrect-
269 ly marked or recaptured will result in an inaccurate abundance estimate (Stevick *et al.*, 2001). To
270 lower the risk of misidentifying individuals the photos can, as already mentioned, be divided into
271 quality categories. However these categories can turn out biased as the photos placed in them are
272 personally judged (Friday *et al.*, 2000). This can result in ID-photos being placed in the wrong cate-
273 gory and subsequently either included or excluded from further analysis. The risk of this is lo-
274 wered by having several people matching independently and only including the ID-photos placed
275 in the same category by all.

276 Another problem when using natural markings for identification is the persistency of these marks.
277 When using scars for identification the possibility of the animals losing or gaining marks during
278 the field period must be considered. In humpback whales the patterns on the ventral side of the
279 fluke is believed to be quite persistent, still Blackmer *et al.* (2000) recommended the use of the dor-
280 sal fin in combination with the peduncle knobs (Fig. 3) in addition to fluke pattern coloration for
281 identification. They found young humpback whales to undergo substantial changes in their fluke
282 color patterns contrary to the shape of the caudal peduncle which did not change. Carlson *et al.*
283 (1990) also found changes in fluke patterns of calves within the first years (Fig. 4). Especially in
284 flukes with dark pigmentation. However after the second year there was little or no change
285 in the coloration patterns.



286 Fig. 4. Major changes in coloration patterns of calves within the first two years can occur (Carlson *et al.*,
287 1990).

288 Hence, identification solely through fluke coloration patterns is questionable in calf re-
289 identification but appear to be reliable in older juveniles and adults.
290 Before the development of digital cameras, black and white film was used when obtaining ID-
291 photos. One problem derives from this. Algae growth which is seen as yellow patches on the ven-
292 tral side of the fluke is hard to distinguish in black and white photos, and can in some cases leave
293 the scientist in doubt to whether or not the mark is in fact a mark. Furthermore, algae growth
294 might present a problem to computer-assisted matching programs as they may not be able to diffe-
295 rentiate algae from natural markings (Fig. 5).



296 Fig. 5. A) Algae (circles) look like definitive markings in black and white photos. B) Algae on the fluke may
297 confuse computer-assisted matching programs.

298 **Mark-recapture techniques**

299 Mark-recapture techniques are often used when answering different ecological questions in vari-
300 ous biological subject areas. In population ecology classic usage of mark-recapture is calculating
301 abundance estimates, population size and population vital rates (e.g. Bejder and Dawson, 2006;
302 Heide-Jørgensen *et al*, 2008; Stevick, 2008). Due to its versatile usability many versions of the mark-
303 recapture technique have been developed to overcome ecological problems following the different
304 situations (i.e. is it a population in a small lake, a population stretching an entire coast-line, ani-
305 mals living in flocks, only the one sex that migrates etc). However, they are all based on the same
306 principle. In practice, a number of individuals (n_1) in a population (N) are caught, marked (e.g. by
307 conventional tags, toe clipping, banding or ID-photos) and released. Later, individuals from the
308 same population are caught again (n_2). Of the individuals caught in round two, some of them are
309 marked (m_1) and some of them are not. The basic theory behind mark-recapture is that the rela-
310 tionship between the recaptured individuals, m_1 , and the total sample of n_2 is equal to the relation-

311 ship between individuals marked in the first sample (n_1) and the total population size, N (Chao
312 and Huggins, 2005). Hence, Population size, N , can be estimated from equation 1, Petersen estima-
313 tor:

314

315 1)
$$\frac{n_1}{N} = \frac{m_1}{n_2} \rightarrow N = \frac{n_1 \times n_2}{m_1}$$

316

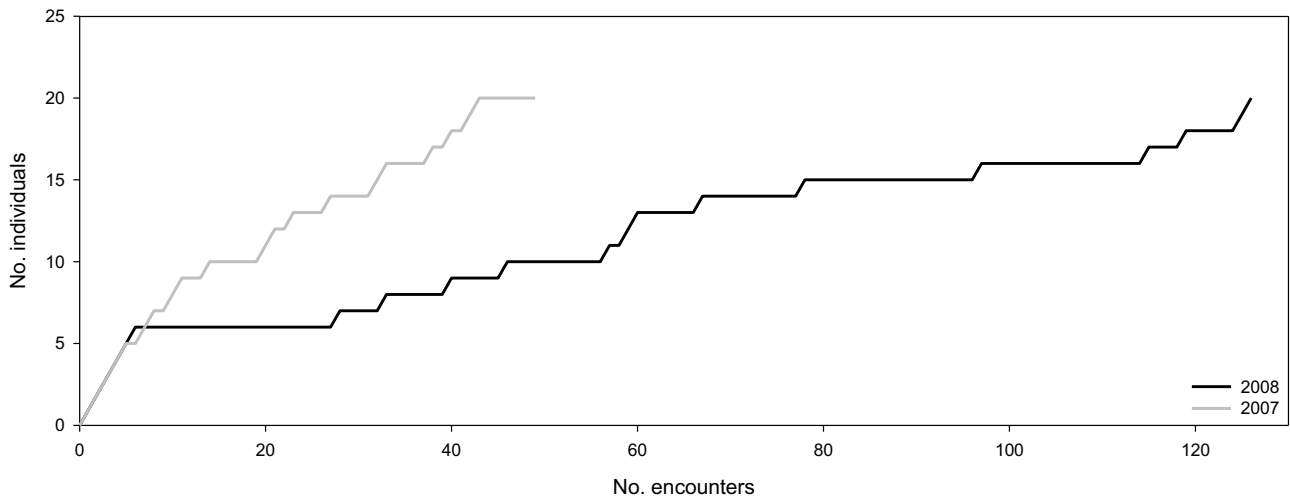
317 However certain assumptions must be made, for this relationship to be valid (Hammond, 1986;
318 Chao and Huggins, 2005). First, it is important that animals do not lose their marks and that marks
319 are noted correctly once retrieved. Second, if migration, birth or death of individuals occurs during
320 the study, m_1 may change as the probability of recapturing a marked individual changes between
321 the two sampling periods and the relation seen in equation 1 no longer exists. E.g. if marked indi-
322 viduals emigrate or die during the study period they will no longer have the chance of being re-
323 captured. This will decrease the size of m_1 leading to an over estimate of population size. Contrary,
324 death or emigration of unmarked animals will lead to an underestimate of population size, as the
325 probability of recapturing a marked individual will increase. Hence, if this assumption of a fixed
326 population is violated this will result in either over or under estimating population size. There-
327 fore, it is necessary to assume that the population remains constant during the study period and
328 that neither immigration/emigration nor birth/death occurs. Consequently, equation 1 is only em-
329 ployed when estimating abundance in what is referred to as closed populations and preferably
330 over a short time period. An additional assumption to the closed population model is that all indi-
331 viduals must have an equal chance of being marked/recaptured. Therefore, it is important that
332 marking does not affect the catchability of the animals. Some animals can become either trap shy
333 or trap happy after marking leading to either a decrease or an increase in catchability. Trap shy
334 animals will avoid being trapped the second time resulting in a decrease in the amount of recap-
335 tured individuals, m_1 . Trap happy individuals on the other hand will result in a corresponding
336 increase in m_1 . As seen in equation 1, the population estimate will then again be either over or un-
337 der estimated. However, death and recruitment take place in all animal populations and versions
338 of closed population models, allowing for these components, have been generated or the sampling
339 procedure can be modified to circumvent these assumption violations (e.g. by keeping the study
340 period short hereby lowering the chance of death and recruitment or sampling a population out-
341 side its reproduction period (Hammond, 1986). Bejder and Dawson (2001) provide an example of a
342 closed population in Hector's dolphins in Porpoise Bay, New Zealand. They argue that all indi-

343 individuals have been identified qualifying the population as closed, as no new individuals are photo-
344 graphed in the end of the study (their discovery curve levels off, see Figure 6 for example of dis-
345 covery curve), no movement takes place between their study site and others and genetic differenc-
346 es are large over small geographical ranges indicating little migration. The authors disregard birth
347 and death of individuals in the study period, thus relaxing this assumption, and due to the short
348 sampling period, births/deaths will have little effect on the population estimates.

349 Most marine populations do not meet the closed population criteria, allowing individuals to come
350 and go. Therefore open population versions of the mark recapture model are more applicable. It
351 allows migration, death and recruitment. Yet, it is restricted to certain assumptions as the closed
352 population model (Hammond, 1986; Pollock and Alpizar-Jara, 2005). Again marks must not be lost
353 and should be noted correctly once recovered. Sampling should be instantaneous (i.e. to avoid in-
354 dividuals to move from one sampling area to the other during sampling) and all animals should
355 have the same chance of being caught, given they are alive or in the population during sampling.
356 Hence all marked animals must have the same chance of being returned to the population after
357 capture and the same chance of survival between sampling periods. The most widely used model
358 is the Jolly-Seber model, which provides population estimates for all samples, except the first and
359 the last (Hammond, 1986). Hence, the model is only applicable when more than two samples are
360 available.

361 ***Case study in Nuuk fjord***

362 Nuuk fjord is an open fjord system and humpback whales along the west coast of Greenland have
363 the opportunity to migrate in and out. Humpback whales foraging in Nuuk fjord are therefore part
364 of a larger feeding aggregation stretching the entire west coast (Perkins *et al.* 1984). As found in the
365 present study they constitute an open population where new individuals are identified each year
366 and the discovery curve does not level off (Fig. 6). Yet our study also infers that the humpback
367 whales in Nuuk fjord express a strong degree of small scale site fidelity where many of the same
368 individuals return every summer. This makes it hard to do mark-recapture analysis on the Nuuk
369 fjord population. Due to migration and due to the fact that new individuals are identified
370 throughout the summer season an open population model seems preferable. But, because some
371 animals may show greater site fidelity than others, the humpback whales may not have the same



372 Fig 6. Humpback whales in Nuuk fjord constitute an open population as new individuals are encountered
 373 throughout the season (Boye *et al.*, in prep., this thesis)

374 chance of being marked/recaptured. Also, an open model analysis requires more than 2 sampling
 375 periods. In the present study we “marked” the animals in 2007 and “recaptured” them in 2008. It is
 376 therefore not possible to employ the open population model and instead we can employ the closed
 377 population model modified from the Petersen estimator (eq. 2) to calculate a debatable abundance
 378 estimate (Hammond, 1986). Chapman’s modified model reduces small sample bias and makes it
 379 possible for an estimate of variance to be calculated (Chao and Huggins, 2005):

380 2)
$$N = \frac{(n_1 + 1)(n_2 + 1)}{(m_2 + 1)} - 1 \quad \pm \quad \text{var}(N) = \frac{(n_1 + 1)(n_2 + 1)(n_1 - m_2)(n_2 - m_2)}{(m_2 + 1)^2(m_2 + 2)}$$

381 Where,

382 N = no. of individuals in Nuuk fjord

383 Var (N) = the variance

384 n₁ = no. of individuals marked in 2007 in Nuuk fjord (20)

385 n₂ = no. of individuals marked in 2008 in Nuuk fjord (20)

386 m₂ = no. of individuals from 2007 recaptured in 2008 in Nuuk fjord (8)

387 then, N = 48 and Var(N) = 22

388 By using the modified closed model we reach an abundance estimate of 48 ± 22 humpback whales
 389 in Nuuk fjord. This is considerably fewer than the number reached by Heide-Jørgensen *et al.*
 390 (2007). Although the estimate presented here is connected to several uncertainties (the use of
 391 closed population model on an open population) an estimate of 48 whales seems more realistic

392 than 145 whales due to a longer sampling period and due the fact that only 20 individuals were
393 indentified in the two consecutive years. It indicates that the assumption by Heide-Jørgensen *et al.*
394 (2007) of a uniform density within the fjord is not correct. They accommodate this by giving a
395 more conservative abundance estimate of 29 humpback whales, which is closer to the estimate
396 calculated here.

397 **Theodolite tracking of cetaceans**

398 ***The theodolite***

399 A theodolite is a tracking device used for surveys. It measures vertical and horizontal angles with
400 an accuracy better than 0.001° , making it possible to calculate position of an object with respect to
401 the theodolite (Lerczak and Hobbs, 1998). Theodolites can be used to track animal movement and
402 in cetacean studies it can provide information on habitat utilization (Bejder and Dawson, 2001),
403 movement patterns (Würsig *et al.*, 1991) and anthropogenic impact on marine mammals (Bejder *et*
404 *al.*, 1999). Again, these surveys are performed in a non-invasive way, as theodolite tracking takes
405 place from land. The theodolite is dependent on a stable platform where it can be leveled of pre-
406 cisely to achieve accurate angle measurements and thereby accurate coordinate calculations.
407 Hence, it is not possible to do theodolite trackings at sea.

408 When doing theodolite tracking you must know the exact position of the point on which the theo-
409 dolite is placed. Also the height from sea level to the theodolite is needed and tidal height during
410 tracking must be taken into account. Würsig *et al* (1991) point out the importance of the height of
411 the station relative to the animal being tracked and suggest a platform height of at least 20 m if
412 tracking animals within 5 km. During a survey the object of relevance is tracked through a tele-
413 scope which can move 360° vertically and horizontally and the angles are stored for further calcu-
414 lations. The vertical angle is measured relative to a fixed reference point of either straight up or
415 down whereas the horizontal angle is measured relative to a self-selected reference point of known
416 position (Bailey and Lusseau, 2004).

417 ***Calculating distances***

418 Lerczak and Hobbs (1998) present formulae for distance approximations of marine mammals us-
419 ing theodolites, which in turn can be used when tracking any object at sea. These formulae take
420 into account the curvature of the earth and are described below (eq. 3-5). They assume the earth to
421 be spherical, which is a suitable assumption at sea but not for terrestrial uneven terrains (Fig. 7).

422 3)
$$D_0 = (R_E + h) \cos(\beta) - \sqrt{(R_E + h)^2 \cos(\beta^2) - (2hR_E + h^2)}$$

423 4)
$$\delta = \sin^{-1}\left(\sin(\beta) \frac{D_0}{R_E}\right)$$

424 5)
$$D = \delta R_E \cong \sqrt{D_0^2 - h^2}$$

425 where,

426 D_0 = line-of-sight distance from platform to the marine mammal

427 R_E = radius of the earth (6.371×10^6 m)

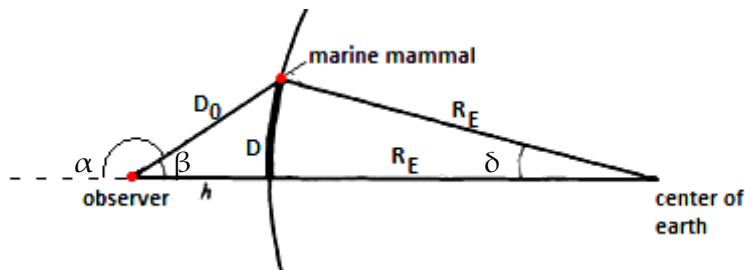
428 h = height of platform above sea level

429 α = the vertical angle given by theodolite between the vertical angle reference point (0) to the
430 marine mammal.

431 β = the angle from the platform to the marine mammal ($\beta = 180 - \alpha$)

432 δ = the central arc angle from the marine mammal to the platform

433 D = distance to marine mammal from the platform along the surface of the earth



434 Fig. 7. R_E is the radius of the earth, D is the distance to the marine mammal along the surface of the earth, D_0
435 is the line of sight distance to the marine mammal, h is the height of the platform, δ is the central arc angle
436 from the marine mammal to the platform, β is the angle from the platform to the marine mammal, α is the
437 angle given by theodolite between the vertical angle reference point (0) to the marine mammal. Modified
438 from Lerczak and Hobbs (1998).

439

440 When calculating the distances, all angles must be expressed in radians corresponding to radians =
441 $\pi/180 \times$ degrees (Lerczak and Hobbs, 1998). If the theodolite works in grads this must also be taken
442 into account before converting degrees into radians (grads = $400/360 \times$ degrees).

443

444 **Computer-aid programs**

445 Few theodolite computer-aid programs exist for managing theodolite data. Bejder and Dawson
446 (2001) used a theodolite to track Hector's dolphins in Porpoise Bay, New Zealand. They deter-
447 mined the positions of the animals using the program *T-trak*. *Pythagoras* is a program developed by
448 Gailey and Ortega-Ortiz (2000), to assist researchers in data managing and calculations, and the
449 formula presented by Lerczak and Hobbs (1998) is implemented in *Pythagoras* (Gailey and Ortega-

450 Ortiz, 2000). *Pythagoras* is designed to communicate with digital theodolites. It stores information
 451 on platform details (e.g. height, geographical position, reference azimuth) and take tidal values
 452 into account (Gailey and Ortega-Ortiz, 2002). The vertical and horizontal angles measured by the
 453 theodolite in degrees, minutes and seconds are converted into positions (lat, lon) of the object be-
 454 ing tracked and the track of the animal is shown in a 'track window'. *Pythagoras* uses the great cir-
 455 cle equation (eq. 6) to determine positions of the object being tracked (Gailey and Ortega-Ortiz,
 456 2002):

$$457 \quad Lat_F = \sin^{-1}(\cos(\tau) \times \sin(D/60/1852) \times \cos(Lat_P) + (\sin(Lat_P) \cos(D/60/1852)))$$

$$458 \quad 6) \quad Lon_F = \cos^{-1} \left(\frac{\cos(D/60/1852) - (\sin(Lat_P) \times \sin(Lat_F))}{\cos(Lat_P) \times \cos(Lat_F)} \right) \times Lon_P$$

459

460 where,

- 461 η = Horizontal angle measured with theodolite relative to the reference azimuth
 462 ρ = Reference azimuth (bearing from reference point to platform relative to geographical
 463 north)
 464 τ = Bearing from platform to object ($\tau = \eta - \rho$)
 465 D = distance to marine mammal from the platform along the surface of the earth (eq. 5)
 466 Lat_P = Latitude of platform
 467 Lon_P = Longitude of platform
 468 Lat_F = Latitude of object being fixed
 469 Lon_F = Longitude of object being fixed

470 Theodolite computer-assisting programs constitute a good way of managing theodolite data. The
 471 calculations would be time consuming but here they are handled during the on-going survey and
 472 the tracks plotted immediately. However *Pythagoras* requires more than one person when tracking,
 473 and I therefore opted for a custom implementation. In the present study, the above mentioned eq-
 474 uations were implemented in Matlab (*mathworks*) by P.T. Madsen in an automated routine that
 475 computed distance, bearing and estimated geo-referenced location of the tracked whale or boat

476 ***Calibrating the theodolite***

477 To determine inaccuracies linked to the individual researcher when tracking at different distances
 478 and directions the theodolite must be calibrated by each person using it. I did this by outlining a
 479 transect of GPS positions of known distances relative to the land based station. A boat served as

480 the object being fixed and was positioned at the given positions in the transect. The theodolite,
 481 placed on a station with known position, fixed the boat in the waterline as if tracking a whale (Fig.
 482 8). To estimate the RMS error, more fixes should be done on each position turning away the theo-
 483 dolite between each fix. As the boat might drift when laying on the position the crew on the boat
 484 noted the exact GPS positions corresponding to each fix made by the theodolite operator. It was
 485 then possible to calculate the RMS error (Root Mean Square) for both distance and horizontal dis-
 486 placement (eq. 7) (Fig. 9).

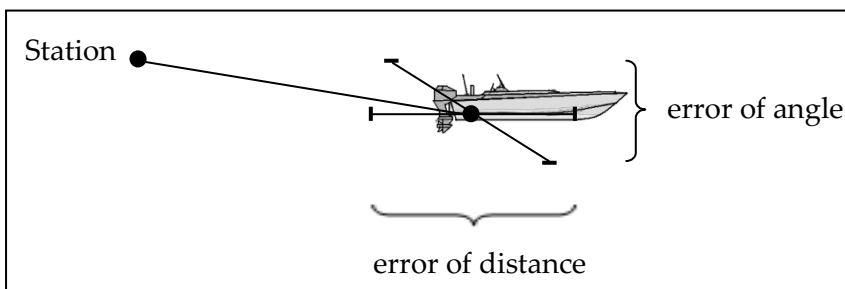
487 7)
$$RMS_{error} = \sqrt{\frac{\sum(a_i - m)^2}{N}}$$

488

489 a_i = The distance or angle between the station and the position calculated from theodolite angles

490 m = The exact distance or angle between the position and the station

491 N = Number of fixes



492 Fig. 8. Illustrates where to fix the boat during calibration and how the
 493 measurements of the object tracked can be biased when tracked.

494

495 The positions of each fix determined from the horizontal and vertical angles given by the theodo-
 496 lite is calculated using the great circle equation mentioned above (eq. 6). The exact distance (m)
 497 between positions is calculated as in example 1 below. The latitudinal displacement benefits from
 498 the almost invariable distance of 60 nautical miles (nmi) between latitudes. To corrugate for the
 499 decreasing distance between longitudes moving north and south of equator cosines is included in
 500 calculations of distance between longitudes.

501 Example 1:

502 Position 1 in decimal degrees: 64.1861 N; 51.7325 W

503 Position 2 in decimal degrees: 64.1930 N; 51.7459 W

504

505 Distance (m) between positions = $\sqrt{N^2 + W^2}$

506 Where,

507 N = Latitudinal displacement

508 W = Longitudinal displacement

509 Distance between position 1 and 2:

510 N: $(64.1930 - 64.1861) \times 60nmi \times \frac{1.852km}{nmi} \times 1000m/km \cong 767m$

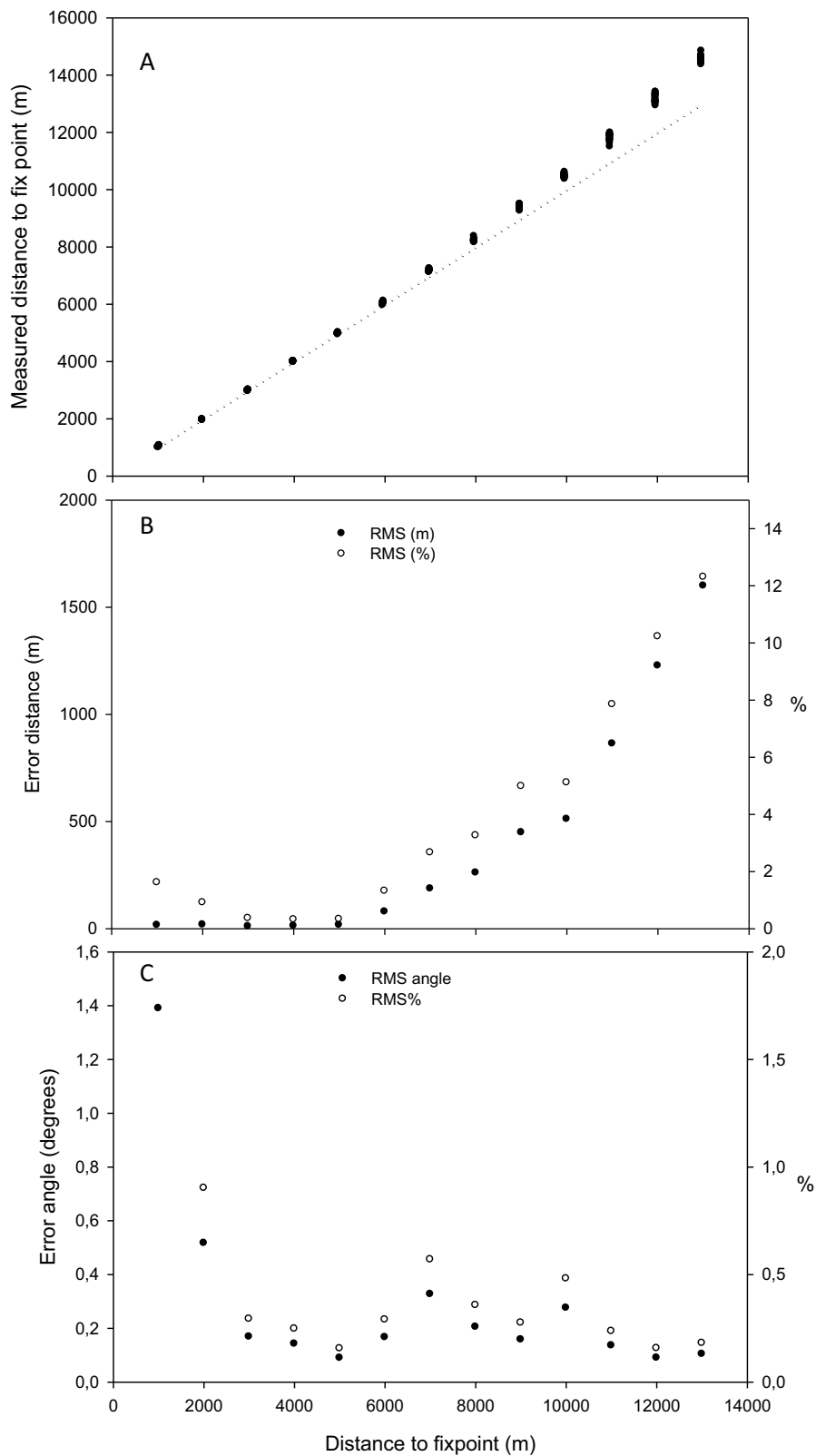
511 W) $(51.7459 - 51.7325) \times \cos(64.1930) \times 60nmi \times \frac{1.852km}{nmi} \times 1000m/km \cong 648m$

512 $m = \sqrt{766.73^2 + 648.23^2} \cong 1004m$

513

514 In this example, the positions are limited to 4 decimals giving an accuracy of 11.1m. During analy-

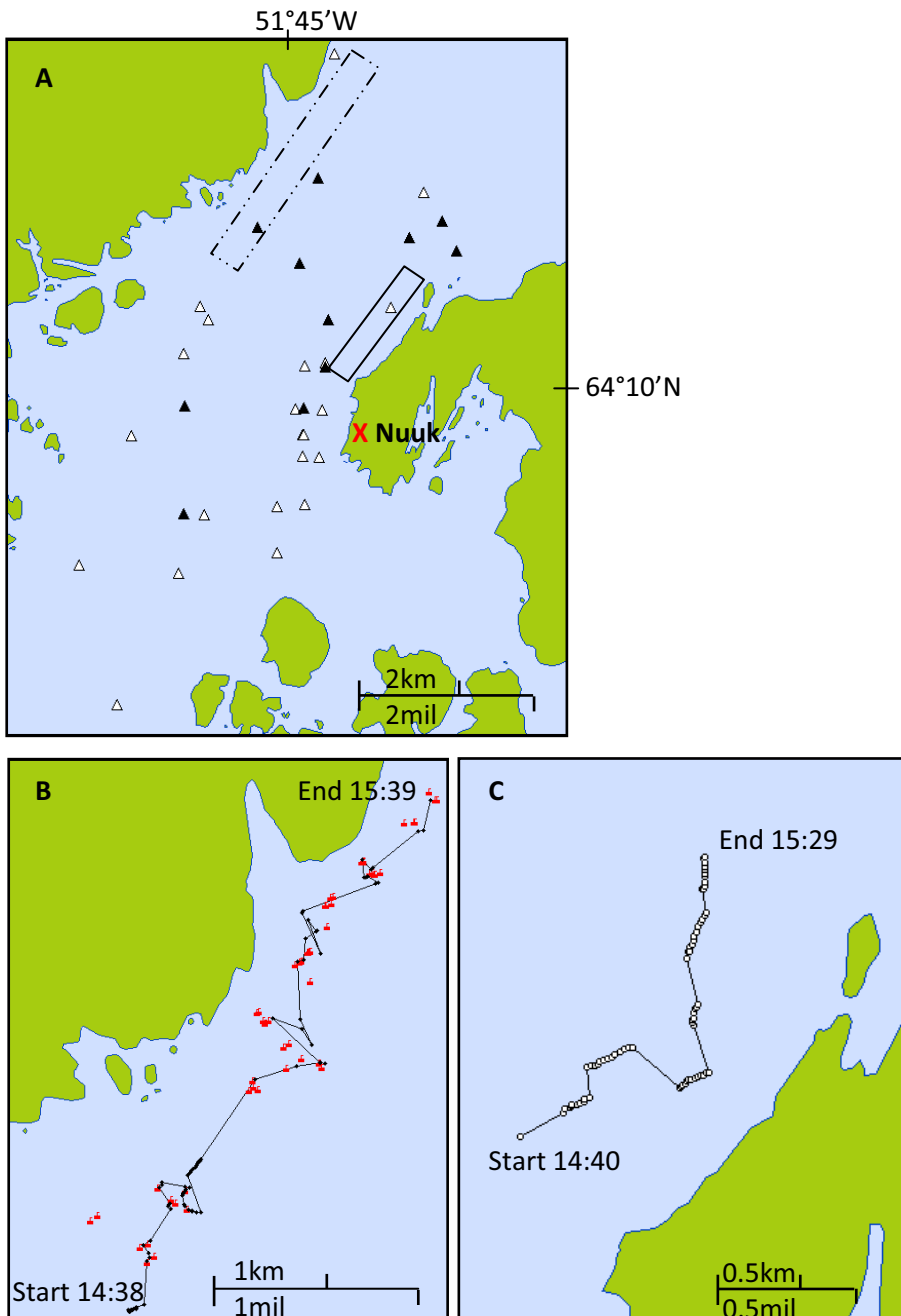
515 sis of the data in this thesis 7 decimals were used.



516 Fig. 9. Plots of the theodolite calibrations made in this study. A) The dashed line represents the actual dis-
 517 tances to the fix point. As distance increases relative to the fix point the measured distance stray from the
 518 line B) The RMS error of distance increases with increasing distance relative to the fix point. C) The RMS
 519 error of the angle varies less with distance and remains more stabile, however the high error level at short
 520 distances are due to incorrect measurements.

521 **Examples of tracks from Nuuk fjord**

522 During the study I carried out surveys where whales were spotted from a lookout point at land.
523 When spotted, the angles to the whale were measured with the theodolite and the angles were
524 used to calculate the position. Afterwards the whale and potential whale watching boats were
525 tracked. The positions of the whales and whale watching boats were then plotted in *MapInfo Pro-*
526 *fessional vs. 9.5* (Fig. 10).



527 Fig. 10. A) Positions where whales were spotted during surveys in 2007 (Δ) and in 2008 (\blacktriangle). Stripped square
528 places the track with whale watching (B). Solid square places the track without whale watching (C)
529 \blacksquare represents the boats present after each fluke up by the whale. \bullet and \circ are positions of the whales.

530 ***Problems in theodolite tracking of cetaceans***

531 Theodolite tracking can provide good data on cetacean movements and habitat use. However, li-
532 mited sighting distance from shore based platforms restricts the operating radius within which
533 theodolites can be applied. Consequently, theodolite tracking is only possible on cetacean species
534 moving close to shore. Here, the height of the platform has great influence on the operating dis-
535 tance (e.g. Gailey *et al.*, 2007). The higher the platform the longer the sighting distance. If the plat-
536 form is too low there is a chance that the observer will miss possible cetaceans, and if doing a
537 study on e.g. habitat utilization the results may falsely conclude that the animals are operating in a
538 smaller area.

539 Tracking animals at long distances is difficult as accuracy drops. A small theodolite adjustment on
540 both the horizontal and the vertical angle will in long distances result in large adjustments and it is
541 therefore important to calibrate the theodolite to estimate the error of measurements when track-
542 ing. Although the calibration estimates the error of measurement linked to the person performing
543 the tracking, there is also an error linked to the GPS which gives the position of the boat. In addi-
544 tion tidal values vary a lot in Nuuk fjord (3-4m difference from low tide to high tide) and might
545 also constitute a bias if they are not taken into account.

546 The weather has large effects on theodolite tracking. Glare can make tracking difficult as the blows
547 become hard to see. This can result in blows being missed thus apparently reducing whale surfac-
548 ing frequency. Likewise, precipitation and fog make it difficult to spot and track animals. Also
549 strong winds resulting in waves hamper theodolite surveys making it hard to spot animals but
550 also hard to keep the theodolite leveled off. Therefore, theodolite tracking is restricted to relatively
551 calm weather and in studies by Bejder *et al.* (1999) and by Bejder and Dawson (2001) they restricted
552 their observations to sea state 2 or less. Gailey *et al.* (2007) restricted their surveys to sea state 4 or
553 less, which was also employed in this study.

554 Lastly, tracking a single individual within a group can be difficult. Although morphological fea-
555 tures often make it possible to distinguish individuals, whales for instance are only at the surface
556 for a few seconds at the time when travelling, making it difficult to track a specific individual.

Perspectives

558 In the following, the manuscript will present the results of this study on small scale site fidelity,
559 residence time and consequences of intense whale watching. Due to the small scale site fidelity
560 found in this study and due to the effect of whale watching boats on the swimming behavior of
561 humpback whales it may be necessary to enforce guidelines regarding whale watching in Green-
562 land or at least in the Nuuk area. Also, if hunting on humpback whales is resumed, there is a
563 chance that whales harvested within the fjord will not be replaced by new individuals, which in
564 the end will affect the population size of the whales in the Nuuk fjord.

565 However, further studies are needed as a supplement to this study. Photo-identification of the
566 humpback whales in Nuuk fjord should be continued to proceed building the ID-catalogue of in-
567 dividuals in Nuuk fjord. I recommend that the ID-catalogue is expanded to include dorsal fin pho-
568 tos of each individual as well because of the risk of coloration patterns changing in calves. Fur-
569 thermore, if photo-identification is continued over a period of years, it will then, through mark-
570 recapture techniques, be possible to apply the Jolly-Seber open model (Hammond, 1986) to calcu-
571 late a more accurate abundance estimate than presented here.

572 Photo-identification could potentially widen to other areas of West Greenland (e.g. Disko Bay) to
573 investigate small scale site fidelity in other areas as well and elucidate if individuals from Nuuk
574 fjord show small scale site fidelity to more than one area. To clarify the extent of small scale site
575 fidelity in Nuuk fjord, I suggest that genetic samples of individual humpback whales within the
576 fjord are collected from existing and new individuals over time. Genetic sampling will provide
577 information on sex and interrelation of the whales in the fjord. This may potentially show that the
578 degree of small scale site fidelity found in this study is underestimated, as new identified individ-
579 uals could be the off spring of old individuals already tied to Nuuk fjord

580 More profound studies should be done regarding whale watching. In this study we tracked whales
581 under the influence of whale watching boats and whales not under the influence of whale watch-
582 ing boats. It would be ideal to track several individuals before, during and after whale watching to
583 see under what circumstances behavior changes and to determine post-exposure behavior. Also,
584 two different scenarios could be created. 1) Intense whale watching where boats come within few
585 meters of the whales, the engine is turned on and the whale is continually observed. 2) Whale
586 watching boats do not come within 100 m of the whales and the engine is turned off. This could
587 profitably be done where individuals are tagged with non-invasive, archival tags (DTAG) (Johnson

588 and Tyack, 2003) as described and incorporated in the following manuscript but not included in
589 these introductory chapters. Dive profiles obtained from DTAGs will describe how whale watch-
590 ing before, during and after affect the foraging behavior of the whales and it would make it possi-
591 ble to determine if regulated whale watching methods have less effect on the whales' swimming
592 and foraging behavior. Such a study could assist in the development of whale watching guidelines
593 as found in other countries.

594 Another interesting study would be an anthropological study similar to the study by Parsons and
595 Rawles (2003) on the potential negative impact on whale watching in relation to resumption of
596 commercial whaling. As described by Tillman (2008) international managers of aboriginal whaling
597 have been willing to take conservational risks through time by allowing aboriginal hunting to con-
598 tinue on depleted stocks where commercial hunting was no longer allowed. He continues to say
599 that it arises from a shared belief of aboriginal hunt being self-limiting and only takes what is ne-
600 cessary for human needs. As mentioned previously, the majority of whale watchers is against
601 commercial whaling and would not go whale watching in a country that practices it. However, if
602 there is a general belief of aboriginal hunting being self-limiting and an understanding of a culture
603 that has been practicing whaling for centuries, would this have any effect on the attitude of whale
604 watchers in Greenland and would whaling and whale watching be able to co-exist here?

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Habitat use of humpback whales (*Megaptera novaeangliae*) in Nuuk fjord, Greenland, with implications for commercial exploitation

Tenna Kragh Boye¹, Malene Simon^{1,2} and Peter Teglberg Madsen¹

¹Zoophysiology, Department of Biological Sciences, University of Aarhus, C. F. Møllers Allé, Build. 1131, 8000 Aarhus C, Denmark; tenna.kragh.boye@post.au.dk

²Department of Birds and Mammals, Greenland Institute of Natural Resources, P.O. box 570, 3900 Nuuk, Greenland

In agreement with my supervisors I have imbedded figures and tables in the text to improve readability

1 **Abstract:**

2 North Atlantic humpback whales migrate from low latitude breeding grounds to four different
3 high latitude feeding areas to which individuals display large scale site fidelity. In Nuuk fjord,
4 West Greenland, humpback whales are present from early spring to late autumn. To study small
5 scale site fidelity and residence time in this habitat, ID-photos were collected from May to Septem-
6 ber 2007 and 2008 and compared with an older catalogue. Individual humpback whales in the
7 presence and absence of boats were tracked from land using a theodolite to test if whale watching
8 had an effect on whale behavior. We found a strong degree of small scale site fidelity where 40% of
9 the whales present in 2007 were resighted in 2008. The resight rate from 1992 to 2008 was 24.1%.
10 Individuals did not stay in the fjord the entire season and residence time was highly variable
11 amongst individuals varying between 6.7-60% of the time from May to September. Whale watch-
12 ing was shown to significantly increase swimming speed, cause abbreviated foraging dives and
13 diminish the ratio between surfacings and foraging dives. In conclusion the same foraging whales
14 use this fjord system year after year, which calls for regulation of whale watching and for consid-
15 eration when discussing the reopening hunt of humpback whales in West Greenland.

16

17 *Key words: Humpback whales, photo-ID, site fidelity, residence time, theodolite tracking, whale watching*

18 Introduction

19 Humpback whales (*Megaptera novaeangliae*) migrate annually from low latitude breeding grounds
20 to high latitude feeding areas (Pomilla and Rosenbaum, 2005). They mate and give birth during
21 winter in low productive areas close to the equator with little or no food availability. The whales
22 therefore rely on their fat reserves during winter (Scheidat *et al.* 2004). As spring approaches the
23 humpback whales migrate to high productive areas at high latitudes and through the summer they
24 restore their fat reserves to be used at the breeding grounds in the winter. In the North Atlantic
25 four main feeding areas have been identified; Gulf of Maine, Eastern Canada, West Greenland and
26 the Northeast Atlantic (Stevick *et al.* 2003) and genetic tagging and photo-ID studies support that
27 humpback whales display strong degree of large scale site fidelity towards these areas with little
28 migration between them (Palsbøll *et al.*, 1997; Stevick *et al.*, 2006). However, little is known about
29 small scale site fidelity in humpback whales, where the same individuals may return yearly to the
30 same area within few kilometers.

31 In Nuuk fjord, West Greenland, humpback whales are present from late spring to late
32 autumn (Heide-Jørgensen and Laidre, 2007) but it is not clear to what degree it is the same whales
33 targeting food resources in this fjord ecosystem. They come to feed on prey such as sand lance
34 (*Ammodytes dubius*), capelin (*Mallotus villosus*) and euphausiids (Larsen and Hammond, 2004; Ste-
35 vick *et al.*, 2006). In Icelandic waters humpback whales have been estimated to eat 800,000 tons of
36 capelin yr-1 exceeded only by cod (900,000 tons yr-1) and commercial landings (1 million tons yr-1)
37 (Vilhjálmsson, 2002). Thus, during their stay in Nuuk fjord the whales likely consume a large bio-
38 mass and will as such have a large impact on this ecosystem. To investigate the ecological impact
39 of humpback whales in the Nuuk fjord ecosystem, data on residence time of individual whales,
40 abundance and the amount of food individual whales consume is needed. Heide-Jørgensen *et al.*
41 (2007) estimated, with very large confidence intervals, the abundance of humpback whales in
42 Nuuk fjord to be 145 (cv=0.38) individuals in September 2005, but next to nothing is known about
43 residence time, biomass turnover and site fidelity.

44 Site fidelity is not only important from a basic science perspective but also in the context of poten-
45 tial commercial exploitation. Through time humpback whales have been considered a valuable
46 resource in the Greenlandic society. Due to extensive commercial whaling up until the mid-1900,
47 hunting of humpback whales was called off in 1966, and only aboriginal hunters off West Green-

48 land and the Lesser Antilles were allowed to continue humpback whaling (Martin *et al.* 1984). In
49 1981, Whitehead *et al.* (1983) estimated the population size of West Greenland humpback whales to
50 constitute of 85-200 animals. When it became evident that the West Greenland humpback whales
51 constituted their own feeding aggregation or stock, for which a reliable abundance estimate was
52 lacking, the International Whaling Commission (IWC) reduced the West Greenland quota on
53 humpback whales to zero in 1986 (IWC, 1986) and this quota is still in place. During the IWC meet-
54 ing in 2008, Denmark requested a quota of 10 humpback whales per year for West Greenland
55 (IWC, 2009). The request was not granted and Denmark, on behalf of Greenland announced its
56 intention of repeating the request in 2009. Today, the population of humpback whales in West
57 Greenland is estimated to increase with approximately 9.4% yr.¹ and currently an estimated 3000
58 (cv = 0.45) humpback whales comprise the West Greenland feeding aggregation stretching from
59 Disko Bay to Arsuk (Heide-Jørgensen *et al.*, 2008). During their stay in West Greenland humpback
60 whales constitute a key species for a growing whale watching industry. The whale watching in-
61 dustry in Nuuk alone is expanding dramatically and in 2008 the industry turned over at least US\$
62 332,000 on whale watching only (¹Skydsbjerg, pers. comm.). Around Nuuk whale watching is re-
63 stricted to areas within Nuuk fjord, where the humpback whales are often approached closely by
64 commercial and private whale watching boats. Hence, humpback whales play an important role
65 both ecologically and economically in West Greenland, but the scientific basis for policy making
66 around sustainable co-existence and commercial use of humpback whales is limited.
67 Here we used photo identification to investigate small scale site fidelity, residence time and habitat
68 use of individual humpback whales foraging in Nuuk fjord. Furthermore we tracked humpback
69 whales with a land based theodolite in the absence and presence of whale watching boats to test
70 for possible impacts of the presently unregulated whale watching. Finally, we discuss these data in
71 the context of the biological and economical role of humpback whales in western Greenland.

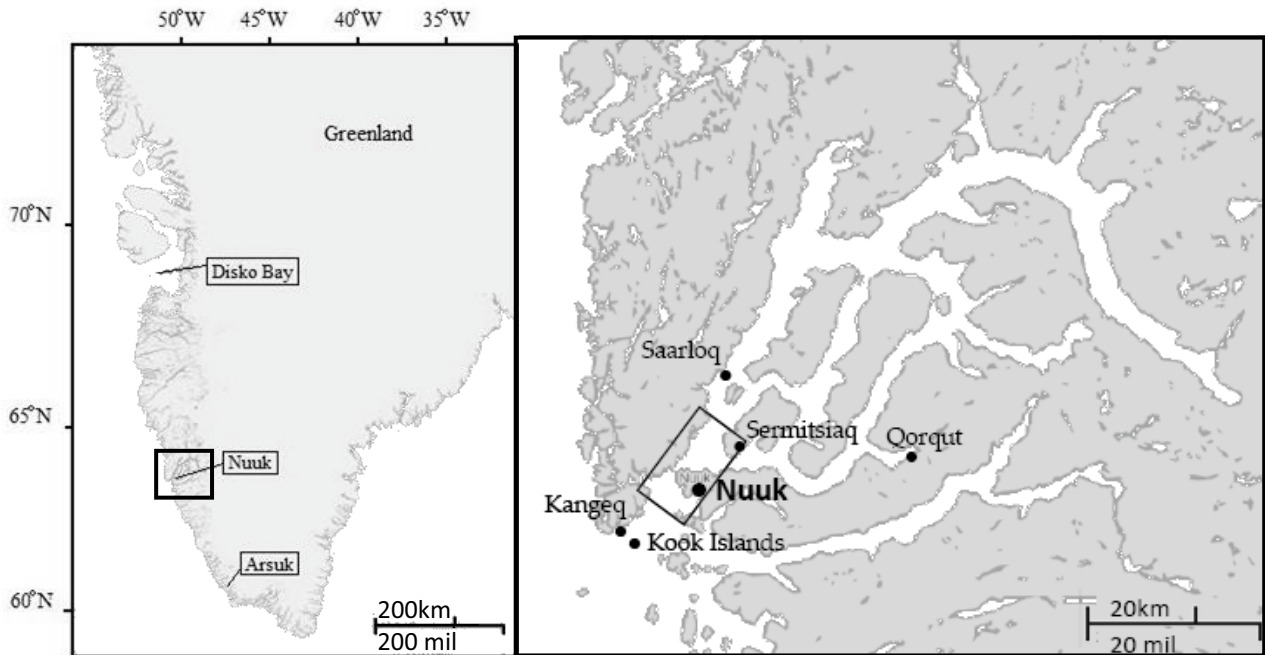
72 **Materials and methods**

73 *Study area*

74 The study was conducted in Nuuk fjord, West Greenland (Fig. 1), covering the field seasons of
75 May to October 2007 and May to September 2008. Nuuk fjord covers an area of approximately

¹Henrik Skydsbjerg, proprietor of Tupilak Travel, Imaneq 18, P.O. box 2291, 3900 Nuuk, Greenland, phone: +299 313218, December 2008

76 2100 km² and stretches *ca.* 100 km from the mouth of the fjord to the most inland parts.



77 Fig. 1. Nuuk fjord. The square around Nuuk illustrates the area that can be covered during theodolite tracking
78 ing

79 *Photo identification*

80 ID-photos of the ventral side of the fluke were taken of humpback whales along with photos of the
81 dorsal fin (Katona *et al.* 1979). Searches of whales were conducted from a 5 m boat. When a whale
82 was encountered the boat slowed down to idling and photos were taken with an EOS 350D Canon
83 digital camera equipped with a Canon EF 75-300mm f/4-5.6 III USM lens. Shutter speed was
84 >1/1000. Upon an encounter, GPS position, time, date and number of whales were noted. Photos
85 were also taken from a local whale watching boat aiming at areas likely to see whales. Finally, pho-
86 tos of humpback whale flukes from Nuuk fjord along with information on date, time and place if
87 possible were provided by the public.

88 *Analysis of photo-ID*

89 Photos judged to be of suitable quality (Calambokidis *et al.*, 2000) were compared visually and
90 sorted into individual whales by two independent observers with identification experience. An ID-
91 catalogue of whales in Nuuk fjord was build from the photos collected in both field seasons along
92 with photos from Kook Islands found in an ID-catalogue of humpback whales from the west coast
93 of Greenland (GINR and YONAH projects) ranging from 1988-1993 (Larsen and Hammond, 2004).

94 To investigate site fidelity of the individual humpback whales, ID-photos of the same individuals
95 in Nuuk fjord were divided into the years they were taken. Residence time was determined from
96 the photos taken of each individual from day to day throughout the entire field season. All photos
97 were divided into the week number they were taken in. If two ID-photos of the same individual
98 were separated by one week number, the whale was assumed to have been present in the fjord
99 during the week, without having been photographed. Residence periods, indicating levels of mi-
100 gration in and out of the fjord were determined by counting how many periods each individual
101 was observed in the fjord. A period was defined by the first and last ID photos of the same indi-
102 vidual taken in consecutive weeks. A new period was counted if two week numbers or more sepa-
103 rated ID-photos of the same individual.

104 *Theodolite observations*

105 Humpback whales were tracked with a land-based theodolite from June to October in 2007 and
106 from May to September in 2008. The theodolite (Leica TC1103) was placed at an observation point
107 ($64^{\circ}11,17\text{N}$, $51^{\circ}43,95\text{W}$) 64.15 m relative to LAT (Lowest Astronomical Tide) overlooking the en-
108 trance of the fjord (Fig. 1). The position of the station was measured by ASIAQ (Greenland survey)
109 using a high precision GPS (Leica 1200 with RTK). Height of the vantage point was calculated by
110 calibrating the theodolite rendering a height above LAT with the lowest RMS error for distances
111 up to 6000 m away from the land station. This resulted in a mean RMS distance error of 0.8% with-
112 in 6000 m. The RMS error of the horizontal angle remained stable over all distances and did not
113 exceed 0.3 degrees. Observations started with a half hour survey, carried out daily at 8 a.m., 14
114 p.m. and 19 p.m. The area was scanned for whales, and if a whale was present it was fixed by the
115 theodolite, by measuring the horizontal and vertical angle to the whale relative to the land station.
116 The survey then continued. When the half hour survey was done the whale was tracked with the
117 theodolite for at least one hour if still present. Every surfacing of the whale was measured using
118 focal sampling (Altmann, 1974). If more than one whale were present, one was chosen to be
119 tracked for an hour and afterwards another whale would be tracked, if still present. If two whales
120 were swimming together (within one body length of each other) they were considered a group and
121 an attempt was made to track only one of the two individuals, based on characteristics such as
122 size, shape of dorsal fin and color pattern of the fluke. If the two whales separated during tracking,
123 one of the two was chosen for further tracking. The angles to the whale watching boats following

124 the whales were measured subsequent to the fluke up of the whale. Surveys were restricted to sea
125 state 4 or less and not carried out during reduced visibility from *e.g.* heavy fog or precipitation.
126 From June 1st till June 20th 2007 surveys were carried out without theodolite due to technical prob-
127 lems.

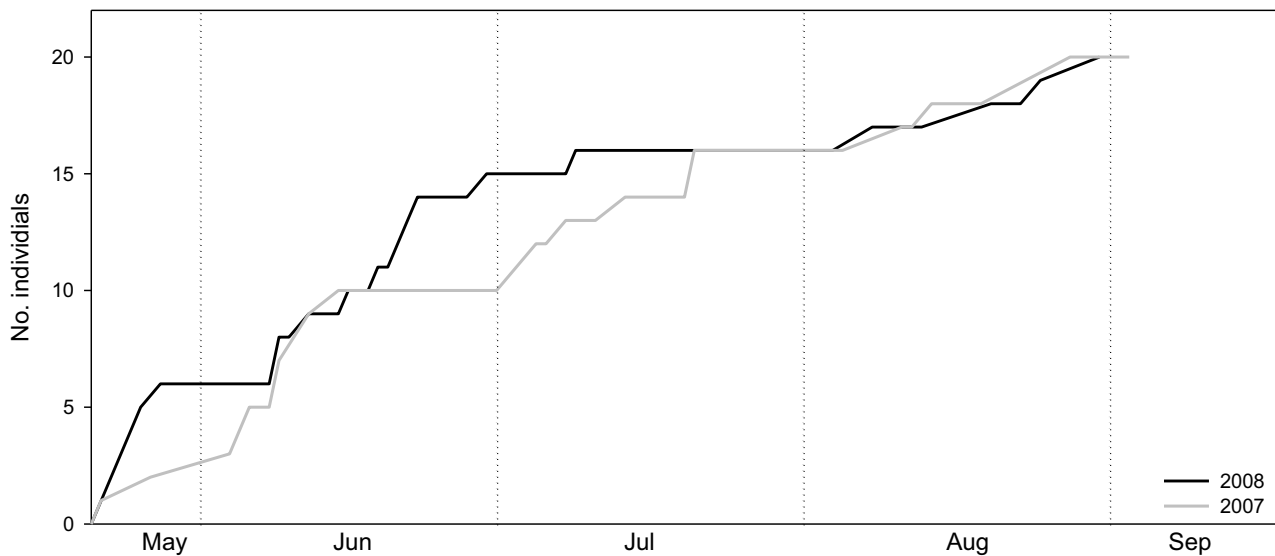
128 Data from the theodolite were stored on a laptop and converted into geo-referenced
129 x, y co-ordinates (latitude and longitude) using the equations of Gailey and Ortega-Ortiz (2000)
130 implemented in Matlab 6.5 (*Mathworks*) and plotted in *MapInfo Professional vs. 9.5*. To determine the
131 possible effect of whale watching boats on whale behaviour four parameters were analyzed using
132 presence/absence of boats as a fixed factor. These parameters were the apparent surface speed
133 (km/h) of the whales (calculated using the distance between each surfacing and the time taken to
134 cover the distance), difference in duration of foraging dives (we defined foraging dives as dives
135 exceeding 60 sec.), the ratio between foraging dives and short dives and difference in the degree of
136 changes in heading (Williams *et al.*, 2002). All tests were preceded by tests for homoscedacity and
137 normality, and when these were violated the data were either log transformed or non-parametric
138 tests were applied. To test the difference in ratio between foraging dives and short dives each indi-
139 vidual whale was considered as a sample unit while all other tests were performed on the individ-
140 ual data points. As some tracks were longer than others, the tracks were homogenized to ensure
141 that all whales contributed equally to the performed tests. This was done by randomly selecting an
142 equal number of data points from each track. Following this all data points were pooled in the two
143 groups. Only tracks where whales were either constantly followed by a boat or no boat was
144 present at all were included in analysis s of the effect of whale watching. Finally, to support theo-
145 dolite data, data from a non-invasive, archival tag (DTAG) (Johnson and Tyack, 2003) were in-
146 cluded. Of three whales tagged, a single whale was exposed to whale watching while tagged, and
147 potential effects of exposure were investigated in the dive profile data. A two dimensional dive
148 track was plotted and the dive behavior (time at surface and dive duration) without whale watch-
149 ing boats nearby was compared to the dive behavior with whale watching boats nearby as record-
150 ed in field notes and estimated from boat noise on the tag audio recordings.

151

152 **Results**

153 *Photoidentification*

154 A total of 47 and 126 ID-photos were collected during the two field seasons in 2007 and 2008, re-
155 spectively. From the photos collected, 20 individuals were identified in 2007 and 20 individuals
156 were identified in 2008 (Fig. 2). Most individuals had been identified by the beginning of July but
157 new individuals were identified throughout both field seasons (Fig. 2).

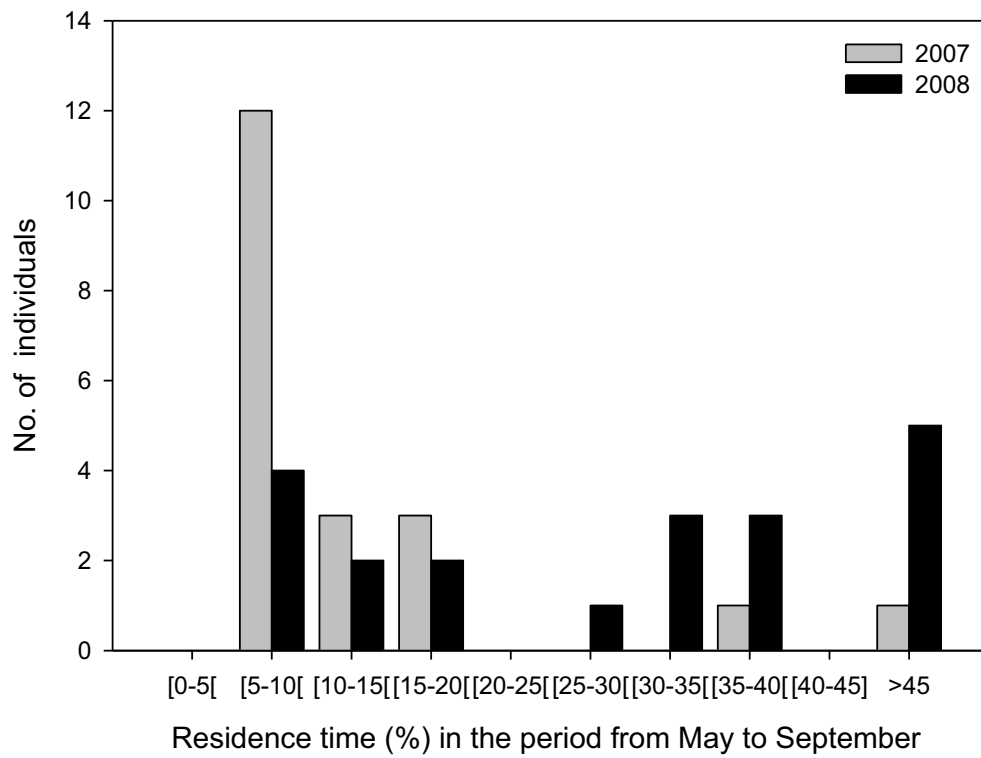


158 Fig. 2 Discovery curves of humpback whales in Nuuk Fjord. Number of new individuals identified during
159 the field month (modified Julian days, where May 1st is day 1 to disregard leap year in 2008)

160
161 Of the 20 individuals identified in 2007, a total of 8 (40.0%) were re-identified in 2008. 58 individu-
162 als visited Nuuk fjord in the time period from 1992 to 2008 (table 1). Of these, 14 (24.1%) have been
163 re-identified in the fjord during the 16 year period. One individual photographed in Nuuk fjord in
164 1992 was re-sighted again in 2008 and at least in 7 other different years within the 16 year period
165 (Table 1).

166 *Residency*

167 Residence time during the field season varied in both years among individuals ranging between
168 6.7% and 60.0% (Fig 3). In both years, the majority of the whales (80%) were photographed during
169 a single period within a year. 7 whales were photographed in two different periods in the same
170 year and a single whale was photographed over three different periods.



171 Fig. 3. Residence time in both field periods for humpback whales in 2007 and 2008.

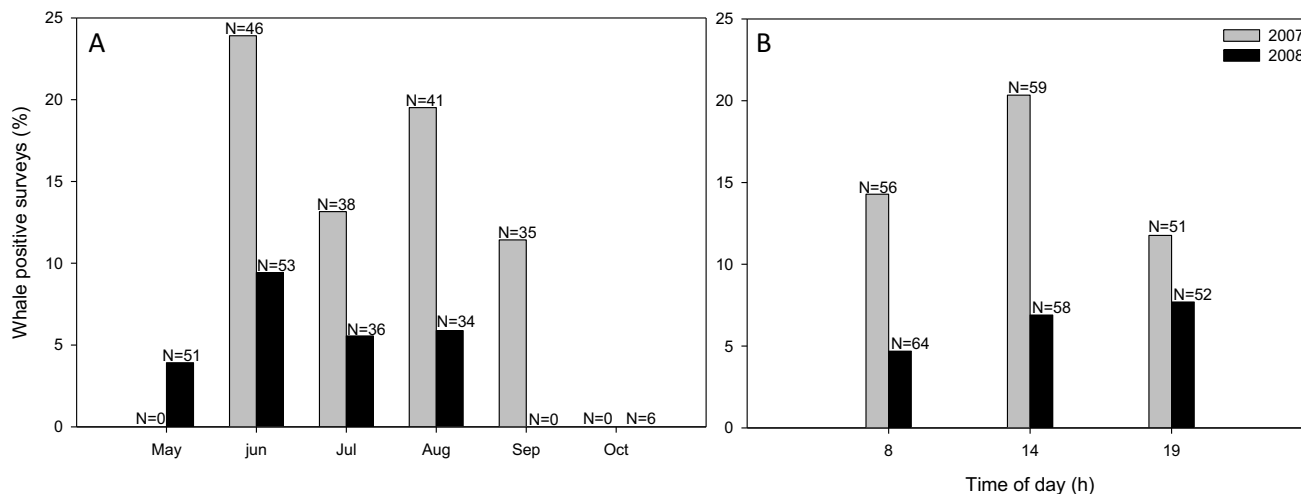
Table 1. Number of whales resighted in the period from 1992 to 2008 in Nuuk fjord.

Year first seen	N	No. of whales seen in each subsequent year											No. resighted in at least 1 year
		1992	1993	1996	1999	2003	2004	2005	2006	2007	2008		
1992	13		2 (15.4)	1 (7.7)	1 (7.7)	1 (7.7)	1 (7.7)	-	1 (7.7)	0	1 (7.7)	2 (15.4)	
1993	0			0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0	0 (0.0)	0 (0.0)	0 (0.0)	
1996	1			0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (100.0)	0 (0.0)	0 (0.0)	1 (100.0)	
1999	3				0 (0.0)	2 (66.7)	1 (33.3)	1 (33.3)	1 (33.3)	1 (33.3)	1 (33.3)	2 (66.7)	
2003	0					0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	
2004	5						1 (20.0)	1 (20.0)	1 (20.0)	1 (20.0)	1 (20.0)	2 (40.0)	
2005	1							-	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	
2006	9								2 (22.2)	3 (33.3)	3 (33.3)	3 (33.3)	
2007	15									4 (26.7)	4 (26.7)	4 (26.7)	
2008	11									-	-	-	
Total	58											14 (24.1)	

Note: N is the number of new identified individuals. The numbers in parentheses are percentages. No data available is indicated by missing numbers.

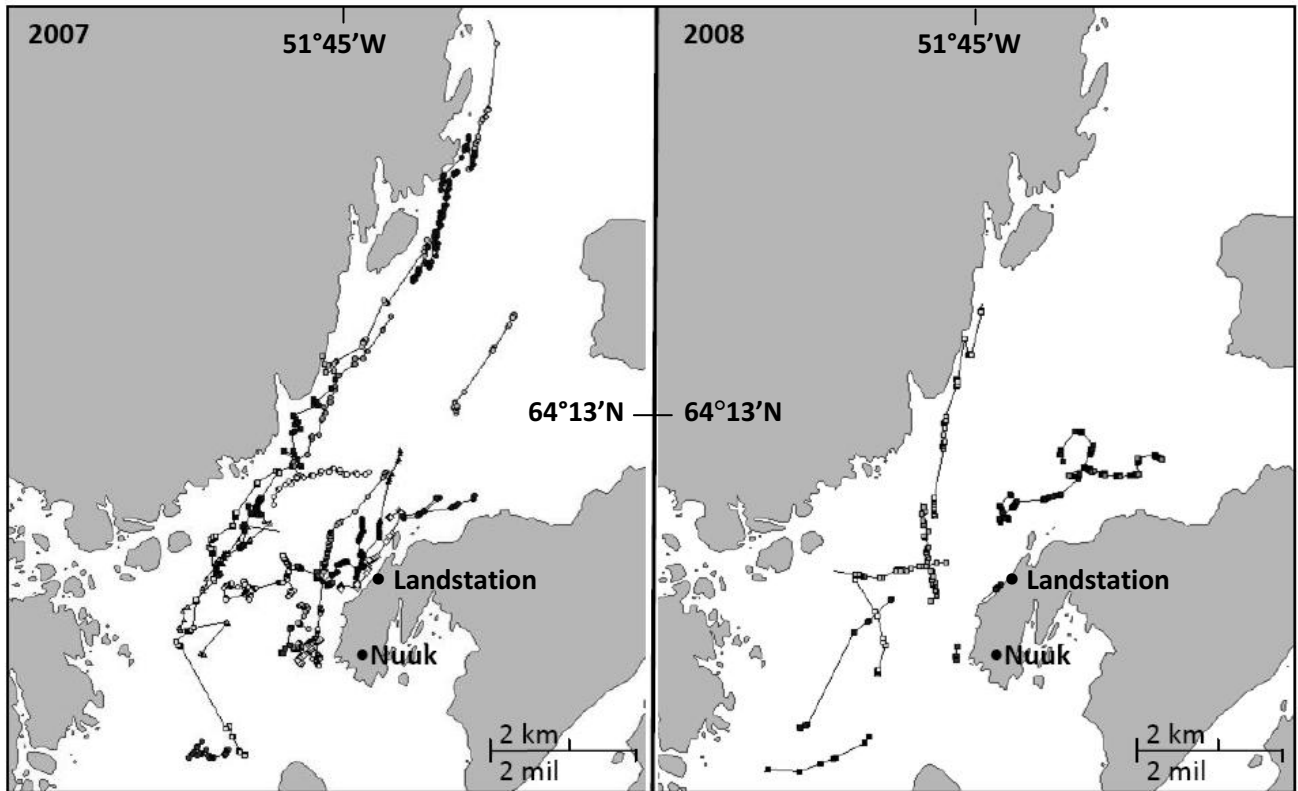
172 *Temporal and spatial distribution*

173 In 2007 and 2008, 166 and 174 theodolite surveys were carried out respectively. This corresponds
 174 to a total of 170 hours of surveys (Fig. 4A). In both 2007 and 2008 most whales were sighted during
 175 the summer months from June-August where June had the majority of whale positive surveys
 176 (23.9% and 9.4% respectively). In both years August tended to have a few more whale positive
 177 surveys than July (13.2% and 5.6% in July contrary to 17,1% and 5.9% in August of 2007 and 2008
 178 correspondingly). Least whales were spotted in May (in 2008) and October (in 2007). Mean effort
 179 between 2007 and 2008 by time of the day was 60, 58.5 and 51.5 hours at 0800, 1400 and 1900, re-
 180 spectively (Fig. 4B). When comparing the two field seasons, no specific pattern was found between
 181 time of day and the number of whale positive surveys.



182 Fig 4. A) Number of surveys (%) in the months of both field seasons, where humpback whales were seen. N
 183 is the total number surveys conducted in the given month. B) Number of surveys (%) at the different time
 184 periods, where humpback whales were seen. N is the total number of surveys conducted at the given time.

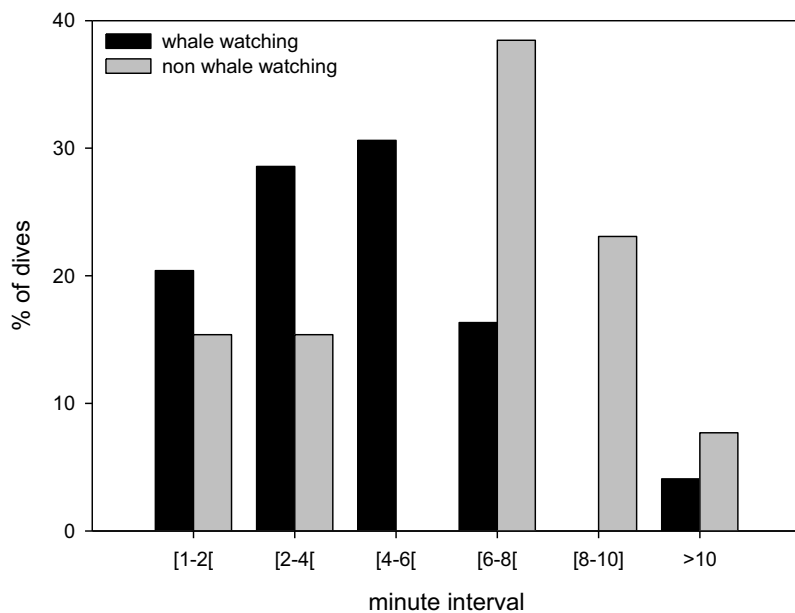
185 As seen in figure 4 more whales were sighted in 2007 during the theodolite surveys compared to
 186 2008 (16.9% whale positive surveys in 2007 compared to 6.3% whales positive surveys in 2008). A
 187 total of 27 and 10 tracks of humpback whales movement were conducted in the season of 2007 and
 188 2008, respectively. In 2007 the whales tended to migrate along the coast line and little movements
 189 were seen across the fjord (Fig. 5). No such tendency was seen in 2008, where the whales were seen
 190 crossing the fjord on several occasions.



191 Fig. 5. Tracks of individual whales in 2007 and 2008. In 2007 they tended to migrate along the coast line
 192 while in 2008 they were seen crossing the fjord on several occasions

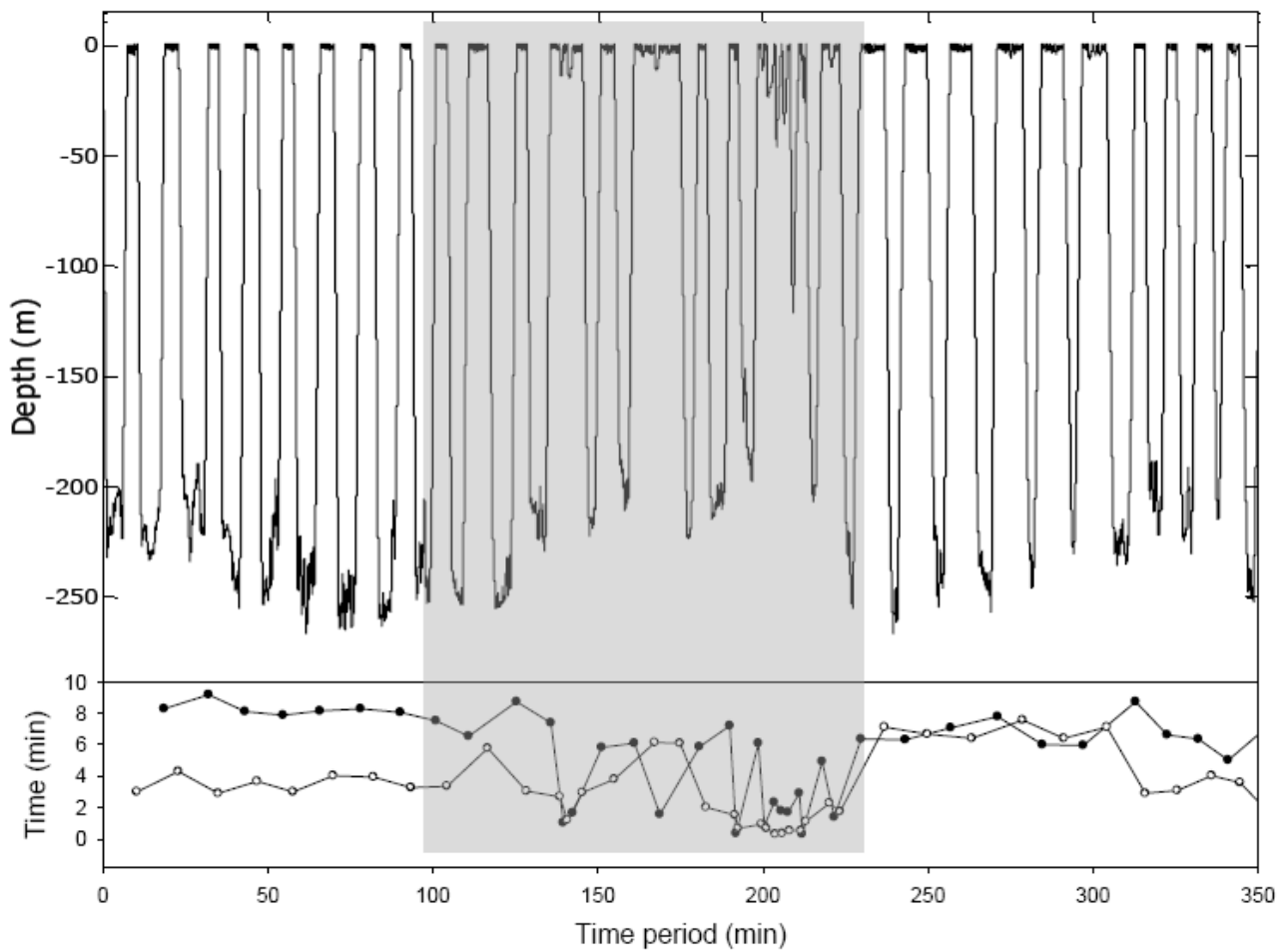
193 *Effects of whale watching boats on whale behavior*

194 Sufficient data for analysis of the effect of whale watching was obtained only in 2007. When a
 195 whale watching boat was present the apparent speed of the whales increased significantly contrary
 196 to when no boats were present (Mann-Whitney, $P = 0.001$). Furthermore, undisturbed whales car-
 197 ried out foraging dives of longer duration than whales followed by whale watching boats (Fig 6).
 198 Foraging dives of whales followed by boats were on average 117 seconds shorter than foraging
 199 dives carried out by whales not influenced by whale watching boats (Mann-Whitney, $P = 0.031$).
 200 The whales performed less than half the amount of surfacing between foraging dives when whale
 201 watching boats were present contrary to non-whale watching (Student's t -test, $t_{15} = -2.393$, $P = 0.03$).
 202 On average only 4.3 surfacings were made contrary to 9.3 surfacings when left undisturbed. The
 203 degree of change in directionality seemed unaffected by whale watching boats as there was no
 204 difference with or without whale watching (Student's t -test, $t_{342} = 0.774$, $P = 0.439$).



214 Fig 6. The duration of foraging dives (defined as dives exceeding 60 sec.) The whales carry out longer foraging
 215 dives when no whale watching boats are present. $N_{\text{whale watching}} = 49$, $N_{\text{non whale watching}} = 13$

216 Fig 7 illustrates a dive profile recorded with a DTAG onboard a humpback whale exposed to
 217 whale watching. Before exposure (0-110 min) the whale made regular foraging dives between 7
 218 and 9 minutes of length. After some time in presence of a whale watching boat, driving fast to-
 219 wards the whale with closest distances of less than 30 meters, foraging dives became shorter, of
 220 decreased depth, and the whale surfaced fewer times before foraging dives (130-230 min) (Fig. 7).
 221 At certain times foraging ceased completely (195-215 min). After exposure (230-350 min) regular
 222 foraging was resumed, however within the first hour (230-300 min) the whale had longer surface
 223 times before foraging dives.



224 Fig. 7. Dive profile of humpback whale. The shadowed area illustrates the time period where the whale was
 225 exposed to whale watching and where high levels of engine noise was measured on and off. Top) Illustrates
 226 the diving pattern of the whale over time. Bottom) illustrates diving duration (●) and time spent at the sur-
 227 face (○) over time.

228 **Discussion**

229 *Residence patterns within years*

230 If the population of humpback whales in Nuuk fjord constituted a closed population,
231 the discovery curve (Fig. 2) would gradually level off as no new individuals would enter the fjord
232 and the same individuals would be observed during subsequent encounters. Our discovery curves
233 did not level off in either year. This strongly indicates that the humpback whales foraging in Nuuk
234 fjord is an open population where some individuals from the West Greenland feeding aggregation
235 migrate in and out of the fjord during the summer months. This is not unexpected as Nuuk fjord is
236 an open fjord system which allows the whales to migrate in and out easily, making it accessible to
237 all whales travelling along the coast of West Greenland. An interesting feature of the discovery
238 curves for both years is that there are plateaus where no new individuals are added to the cata-
239 logue during several days. These plateaus could be due to periods when few whales are leaving or
240 entering the fjord system (i.e. the same individuals remain inside the fjord for a number of days).

241 Residence time amongst each individual was highly variable and the whales did not
242 stay in the fjord the entire feeding season. Moreover, the amount of periods that each whale re-
243 sided in the fjord varied between one, two and three periods of various lengths. Although this
244 could merely reflect that the individual whales were not photographed within the fjord during
245 consecutive weeks, we believe that if a whale was present in the study area of Nuuk fjord it was
246 likely to have been photographed due to an almost daily effort on the water by either the whale
247 watching boats or our crew. In addition, other studies have shown that humpback whales do mi-
248 grate between different feeding areas within the foraging season (Heide-Jørgensen and Laidre,
249 2007). To define residence time and residence periods is, however, difficult and our definitions of
250 the two terms are relatively broad. Therefore, we have not sought to calculate a mean residence
251 time of the humpback whales in the fjord, as the estimate would be tied to large uncertainties. Be-
252 cause Nuuk fjord is open for migration there is a large probability of the whales migrating into the
253 Davis Strait and we cannot assure that individuals were resident in the fjord between sightings.
254 Yet, the fact that an individual is photographed several times in the fjord within a short time win-
255 dow does indicate that the individual has remained within the proximity of the fjord. Although
256 humpback whales can move long distances within a relatively short time period (*e.g.* Della Rosa *et*
257 *al.*, 2008), we believe that the time limit set in this study, does not allow the individuals to migrate

258 far distances and reach Nuuk fjord in time to qualify for a single residence period. Hence, an indi-
259 vidual that is photographed regularly over a longer temporal scale compared to another individu-
260 al must necessarily be defined to have a longer residence time. Tagging with satellite transmitters
261 would make it possible to determine the actual residence time of each individual , but that, on the
262 other hand, is costly and invasive compared to photo-ID.

263

264 *Number of humpback whales in Nuuk fjord*

265 Though it is not possible for us to estimate the population size of humpback whales in Nuuk fjord
266 through mark/recapture analysis due to the open population structure of the whales in the fjord
267 and only two seasons of sampling, the only 20 identified individuals make it clear that the same,
268 very limited number of whales seem to use the fjord year after year. Furthermore, the 20 individu-
269 als were not present at the same time and few encounters were made on days when collecting ID-
270 photos. The highest number of individuals encountered in one day was 10, in the beginning of
271 June 2008. The number dropped to 2 from the end of June and throughout the season. This points
272 to the fact that not many whales make use of the fjord despite the ability to migrate in and out, and
273 that the abundance estimate of 145 individuals by Heide-Jørgensen *et al.* (2007) hence appear sig-
274 nificantly overestimated.

275

276 *Site fidelity across years*

277 Of the 20 whales identified in Nuuk fjord in 2007, 40% were resighted in the fjord in 2008. Fur-
278 thermore, of the individuals identified from the ID-photos available from Nuuk fjord in the time
279 period from 1992 to 2008, we found a return rate of 24.1%. These high resight rates are despite the
280 small sample size (table 1) and effort over that entire period and the number thus represents the
281 minimum rates of return during the 16 year period.

282 Few studies on humpback whales have looked at site fidelity on a regional scale.
283 However, Weinrich (1998) did a study on small scale site fidelity in calves in Gulf of Maine and
284 found a strong degree of small scale site fidelity for calves (79.4%) returning to a regional area
285 where they had been observed the year before. He argued that calves are introduced to the feeding
286 areas during their year of maternal dependence and this introduction appears essential to their
287 future choice of feeding ground on a regional scale. We also sighted young calves in the company

288 of adult animals. It seems unlikely that the high rate of re-sightings found in both 2008 and in the
289 period from 1992 to 2008 is a mere coincidence. First, the coast of West Greenland from Disko Bay
290 to Arsuk, where foraging by humpback whales is known to take place, stretches more than 1000
291 km (Heide-Jørgensen and Laidre, 2007) and with a highly convoluted coastline with numerous
292 fjords. Secondly, 3000 humpback whales are estimated to comprise the West Greenland feeding
293 aggregation and could in theory enter the open fjord system, therefore the likelihood of at least
294 40% out of some 20 individuals from a 3000 animal population entering the fjord two years in a
295 row by coincidence is very low. Our findings here thus support the conclusion on small scale site
296 fidelity by Weinrich (1998), and demonstrate strong small scale site fidelity where individual
297 humpback whales not only return to the same general feeding areas within hundreds of kilometers
298 but also within few kilometers, illustrating strong navigational skills, and long term memory of the
299 spatial and temporal distribution of food resources, likely introduced to them by their mothers.

300 Small scale site fidelity has been documented in other migrating cetacean species as
301 well. Ciano and Heule (2001) found individual sperm whales (*Physeter macrocephalus*) returning to
302 Bleik Canyon, Norway, over years. One individual in their study was resighted during 10 consecu-
303 tive years. We also confirmed an individual to return to Nuuk fjord through several years in the
304 period from 1992 to 2008.

305 As the coloration patterns of humpback whale calves can change dramatically within
306 the first two years (Carlson *et al.*, 1990), there is a chance that some of the new identifications in
307 2008 are individuals identified in 2007 that have undergone large changes in fluke coloration. This
308 would lead to an underestimation of the degree of small scale site fidelity. Collection of genetic
309 samples would establish if new individuals are offspring of the individual humpback whales that
310 already show a strong degree of small scale site fidelity towards Nuuk fjord.

311

312 *Seasonal patterns and habitat use*

313 As seen in fig. 4A the highest numbers of whales were observed from the land station
314 in June. In July fewer whales were present during surveys but in August more whales were yet
315 again spotted during the survey hours. This was the case in both 2007 and 2008 although more
316 characteristically in 2007. This pattern is consistent with the number of individuals identified dur-
317 ing the field seasons with photo-id. In both years, we identified most whales in June but in July the

318 number of new individuals seemed to level off. In August new individuals continued to be identi-
319 fied. This suggests that most whales are present in the early summer month but during mid-
320 summer some individuals migrate elsewhere while new individuals arrive. This notion is sup-
321 ported by a single id-photo taken by locals in Aasiaat (app. 550 km north of Nuuk in Disko Bay) in
322 July 2008 which we matched to an individual photographed in Nuuk fjord in June the same year.
323 The first whales arrive to Nuuk fjord in May. In the same month capelin migrate from the depth of
324 the banks and into the shallow waters of the fjord to spawn. Capelin spawning is separated tempo-
325 rally along the West coast of Greenland and begins in April at the southern tip of Greenland (Friis-
326 Rødel and Kanneworf, 2002). Spawning starts in Nuuk fjord in mid-May in the innermost part of
327 the fjord and ends in June in the outermost parts (²Hedeholm, pers. comm.). In the North from
328 Disko Bay to Uummannaq spawning occurs from mid-June to mid-July. It seems likely that some
329 whales time their arrival to coincide with capelin spawning in Nuuk fjord. It is possible that some
330 of them migrate northwards during the foraging season to benefit from the staggered spawning
331 behavior of capelin.

332 Other whales may stay/arrive to take advantage of other food sources such as eu-
333 phausiids. Upwelling during the winter forms the basis of a spring and a late summer bloom in
334 Nuuk fjord due to the highly nutrient water (Larsen and Hammond, 2004). This creates favorable
335 conditions for the herbivorous euphausiids feeding on algae. Large amounts of euphausiids were
336 caught during the 2008 Dana cruise in Nuuk fjord in mid August (³Rysgaard, pers. comm.). Fur-
337 thermore, in late May 2008 we observed humpback whales lunge feeding in the surface in areas
338 with high densities of visual observable euphausiids, and on one occasion euphausiids were ob-
339 served inside the mouth of a feeding whale in June. Hence, it appears that the variable residence
340 time within our field seasons may reflect that the humpback whales employ different regional mi-
341 gratory patterns to match the availability of different food sources during the foraging season.

342 In other areas humpback whales have been shown to alter their distribution regional-
343 ly subsequent to changes in the distribution of their prey species between years (Payne *et al.*, 1990;
344 Weinrich *et al.*, 1997). Prey, of which most is characterized by having a patchy distribution and a

²Biologist Rasmus Berg Hedeholm, Department of Marine Ecology, University of Aarhus, Finlandsgade 14, 8200 Aarhus N, Denmark, phone: +45 89424376, November 2008

³Professor Søren Rysgaard, Centre of Marine Ecology and Climate Effects, Greenland Institute of Natural Resources, P.O. Box 570, 3900 Nuuk, Greenland, phone: +299 361246, August 2008

345 variable patch size (Clapham, 1996). In this study a change in the distribution of humpback whales
346 was also found between our consecutive field seasons as indicated in several ways. During the
347 collection of ID-photos, whales were mostly present in the main course of the fjord from Saarloq
348 to Kangeq in 2007. In 2008 the whales were more often spotted in the transversal waters running
349 from Qorqut to southwest of Sermitsiaq (Fig. 1). Consequently, during our land based surveys
350 fewer observations of whales were made in 2008 compared to 2007. This may stem from the fact,
351 that the land station covered the main course of the fjord and as the whales in 2008 did not spend
352 as much time in the area in front of the land station, they were not sighted as frequently from land.
353 We do not have data on the distribution of humpback whale prey species in Nuuk fjord in either
354 field seasons and we are therefore not able to investigate if a shift in prey distribution between
355 field seasons caused this difference in whale distribution between seasons or the shorter residence
356 time of humpback whales in 2007. Yet, the tracks from our consecutive field season do indicate a
357 difference in habitat use between the two years. The whales often migrated along the coast line
358 outside the land station in 2007 maybe foraging along the edges. In 2008 they were more often seen
359 crossing the fjord and only few whales migrated along the coast line. This could be an indication of
360 the whales simply passing through in the area in front of the land station in 2008.
361 The fact that more whales were seen moving than staying suggests that the survey area (i.e. be-
362 tween Nuuk and Nordland) is used for transit, rather than as a feeding area. This was especially
363 true for 2008.

364

365 *Management implications of small-scale site fidelity and low local-population size*

366 At the 2008 annual IWC meeting Denmark requested a quota of 10 humpback whales annually on
367 behalf of Greenland that was declined by the commission (IWC, 2009). When considering reopen-
368 ing a hunt on humpback whales in Greenland the small scale site fidelity displayed by the whales
369 in this study along with the limited number of individuals identified in the fjord in both field sea-
370 sons should be taken into account. The small scale site fidelity and the fact that not many hump-
371 back whales make use of Nuuk fjord demonstrated in this study imply that, if individuals are
372 hunted within the fjord, the number of whales in the fjord may decrease. The whale watching
373 boats in Nuuk depend on the whales that stay within the fjord as whale watching is only carried
374 out in the vicinity of Nuuk city and not in Davis Strait. Thus, a debate on a quota on West Green-

375 land humpback whales should consider the high site fidelity in the light of the high economical
376 interests in non-lethal exploitation through whale watching.

377 *Whale watching in Nuuk fjord*

378 Whale watching is estimated to turn over US \$ 1 billion a year attracting more than 9 million
379 guests (Hoyt, 2001). Several studies on whale watching have shown that disturbances from vessels
380 or swimmers cause a significant change in behavior in many cetacean species (*e.g.* Bejder *et al.*,
381 1999). From our results it is clear that the humpback whales in Nuuk fjord can be disturbed by the
382 intense whale watching, as testified by a significant change in diving behavior when foraging. In-
383 creased apparent swimming speed in the presence of boats is a sign of avoidance along with the
384 fact that the whales are surfacing fewer times before a foraging dive when boats are present
385 (Scheidat *et al.*, 2004). The fewer surfacing periods apparently result in truncated foraging dives
386 due to a decrease in the time to replenish oxygen stores when at the surface. Among the parame-
387 ters measured, only the degree of change in directionality was not different between the two situa-
388 tions. A similar situation was observed by Williams *et al.* (2006), where killer whales approached
389 by boats responded by decreasing their dive times and increasing the change in direction. Also,
390 Scheidat *et al.* (2004) observed that humpback whales in Ecuador reacted to whale watching boats
391 by significantly increasing their swimming speeds and through more erratic swimming paths. Be-
392 cause our data was homogenized to avoid problems of tracks of different length, our tracks may
393 have become too short to be able to distinguish between whale watching and non-whale watching
394 situations with respect to change of headings. Yet, our results could also reflect that humpback
395 whales display different avoidance techniques in the presence of boats. The increase of the whale
396 watching industry and the many private boats that exercise whale watching in Nuuk fjord have
397 the potential to cause significant disturbance of individual humpback whales in Nuuk fjord. Those
398 with long residence times are particularly vulnerable.

399 Whale watching in Greenland is not regulated and on most occasions we observed
400 boats at high speeds within few meters of the whales. On several incidents more than one boat was
401 present and we counted up to 15 boats on a single occasion. If the relatively small number of
402 humpback whales, identified in this study, to some degree reflects the abundance in Nuuk fjord,

403 and given that they are not all present at the same time, it is likely that the same individuals are
404 being repeatedly targeted by whale watching boats during their stay in the fjord.

405 As the summer season provides the only chance for the whales to restore their fat re-
406 serves, repeated disturbance may likely reduce the food intake over the season along with the ad-
407 ditional energetic costs of avoidance. Fig. 7 shows shorter dive duration when foraging, most like-
408 ly as a result of the shorter time period spent at the surface before diving. The profile also indicates
409 a post-exposure reaction as the whale spends additional time at the surface in consecutive foraging
410 dives an hour after the boat had left. Thus the whales seem affected almost equally long during
411 exposure and post exposure. This could indicate an oxygen debt incurred during the exposure and
412 the need for additional ventilation due to increased speed and less time spent at the surface in the
413 vicinity of the boat. However, more dive profiles of whales both exposed to whale watching and
414 whales unexposed would be needed to make general conclusions.

415 In most countries where commercial whale watching takes place, regulations and
416 codes of conduct have been developed to deal with negative effects on the targeted animals. In
417 New Zealand the *Marine Mammal Protection Regulations 1992* are established (MMPR, New Zealand
418 Government, 2008) to provide guidelines on how to interact with whales in a least intrusive man-
419 ner. A study by Lusseau (2003) in New Zealand showed that bottlenose dolphin, *Tursiops spp.*, be-
420 haved differently according to boats either respecting or ignoring the MMPR guidelines. He found,
421 that a research vessel, which in an 8 year period had respected the MMPR guidelines, did not seem
422 to affect the behavior of the dolphins. On the contrary, boats with an intrusive approach caused
423 the dolphins to increase their dive intervals.

424 If the presently unregulated whale watching in Nuuk continues to grow, it may have
425 an indirect effect on fitness of individual humpback whales as the energy needed for *e.g.* migration
426 and calving is reduced if the food intake is reduced through vessel induced disturbances of normal
427 foraging behaviour. Even a relatively small reduction in food intake of *e.g.* 5-10% over the season
428 may cause some whales to skip a breeding season, hereby avoiding migration due to insufficient
429 energy reserves. This will result in fewer calves being born overall. Furthermore, intense whale
430 watching could result in females having decreased energetic resources to produce or nurse their
431 offspring which will have a direct effect on survival of the calves.

432 So while whale watching is often considered an economically important and non-
433 invasive use of whales, our findings indicate that intense, unregulated whale watching may cause
434 fitness reductions for some individuals in the West Greenland stock this in turn calls for guidelines
435 if such effects are to be mitigated.

436 *Concluding remarks*

437 Although the humpback whales in Nuuk fjord do not reside in this area for the entire foraging
438 season but migrate between foraging areas, these humpback whales display a strong degree of
439 small scale site fidelity where the same individuals return to Nuuk fjord between and within years.
440 Thus if humpback whales are hunted within the fjord it is questionable if such individuals will be
441 replaced. This will affect the still growing whale watching industry in Nuuk which rely on the
442 whales within the fjord system. However, intense and unregulated whale watching can have more
443 subtle negative effects on the humpback whales foraging in Nuuk fjord, causing a change in both
444 swimming and foraging behavior. To ensure a sustainable whale watching industry we suggest
445 that guidelines similar to the MMPR are enforced in Greenland.

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