Home, sweet home?

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

A master thesis by

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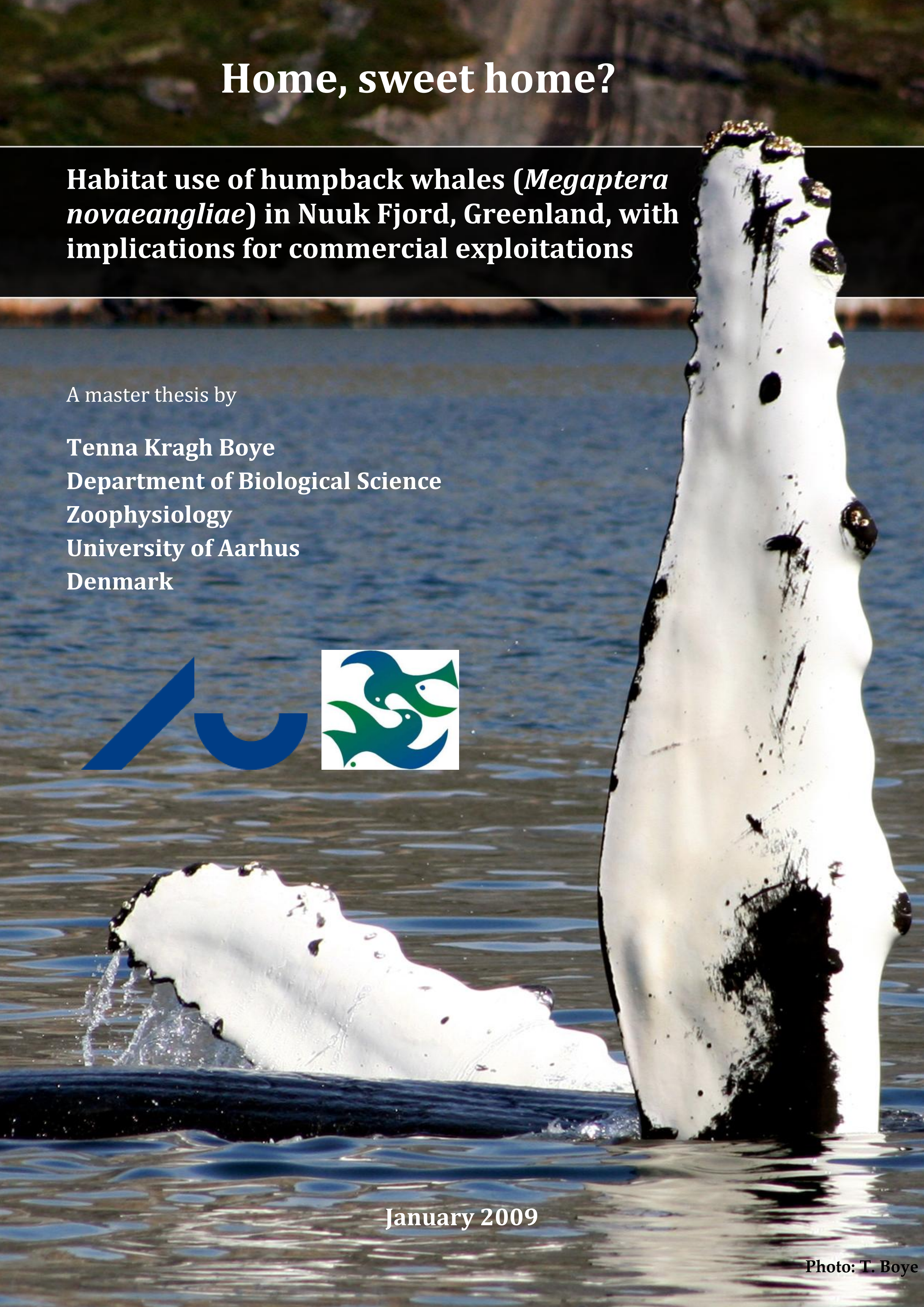

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AARHUS UNIVERSITY

GREENLAND INSTITUTE OF NATURAL RESOURCES

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Contents

Preface

This thesis describes a study of humpback whales in Nuuk fjord, West Greenland under the supervision of Peter Teglberg 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

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Tenna Kragh Boye

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Background

Introducing the humpback whales

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

Migration

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

Humpback whales migrate annually from low latitude breeding grounds to high latitude feeding grounds (Pomilla and Rosenbaum, 2005). They spend the summer months on their feeding grounds feeding on prey such as herring (*Clupea harengus*), sand lance (*Ammodytes dubius*), mackerel (*Scomber scombrus)*, capelin (*Mallotus villosus*) and euphausiids (Larsen and Hammond, 2004; Stevick *et al*., 2006); prey, which are characterized by having a patchy distribution and a variable patch size (Clapham, 1996). In late autumn, the whales migrate south/north to their breeding grounds to mate and give birth to calves and during the months there the whales rarely ingest food (Corkeron and Connor, 1999). Migration and division in habitat utilization allows the whales to benefit from different habitats that may not uphold optimal living conditions throughout an entire year. An explanation could be that the low latitude breeding areas offer warmer waters but the low productivity in these areas results in low food availability which probably would not support perennial populations of humpback whales. High latitude feeding grounds offer large food availability in the highly productive months from spring through autumn. However, when winter approaches food sources become scarce, the water becomes colder and in some places total ice coverage occurs, minimizing habitat suitability.

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

Whatever the reason for migration, it is well known that migration timing in humpback whales depends on their age, sex and reproductive status as shown by e.g. Craig *et al*. (2003). In their study, females in their early pregnancy and adult females were the first to leave the breeding areas followed by juveniles and adult males. The last to leave the breeding areas were females with new born calves. It should be noted that several studies have shown that not all females migrate to the winter breeding areas and Brown *et al*. (1995) confirmed a skew in the distribution of males and females in the winter breeding areas off Australia where more males are present. They estimated that up 50 % of the females remained in or near the Antarctic feeding area. One population of humpback whales does not undertake migration at all. Namely, the population in the Arabian Sea, that otherwise would have to travel great distances across equator to reach other high latitude feeding grounds (Mikhalev, 1997).

West Greenland humpback whales

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

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

In Nuuk fjord, West Greenland, the whales are present from late spring to late autumn (Boye *et al.* in prep., this thesis). The whales come to forage and during their stay in the fjord, the whales are likely to have a significant impact on the arctic food web in the fjord system. Although it has not been possible to find any literature describing the amount of food humpback whales ingest in the Nuuk area, Vilhjálmsson (2002) estimates the annual capelin removal by humpback whales in Icelandic annual capelin removal by humpback whales in Icelandic waters to be around 800.000 tons yr^{-1} (corresponding to 20.8% of the biological capelin removal and 16.4% of the total capelin removal) only exceeded by cod (900.000 tons yr^{-1}) and commercial landings (1 million tons yr^{-1}). This gives a good indication of the importance of the role that humpback whales might play in the arctic food web in Nuuk fjord. According to a survey conducted by Heide-Jørgensen *et al.* (2007) around 145 humpback whales forage in the Nuuk area. However, they make clear that this number is connected to great uncertainties due to uneven sampling and it surpasses by far the number of individuals identified in Nuuk fjord in our study (Boye *et al.*, in prep, this thesis).

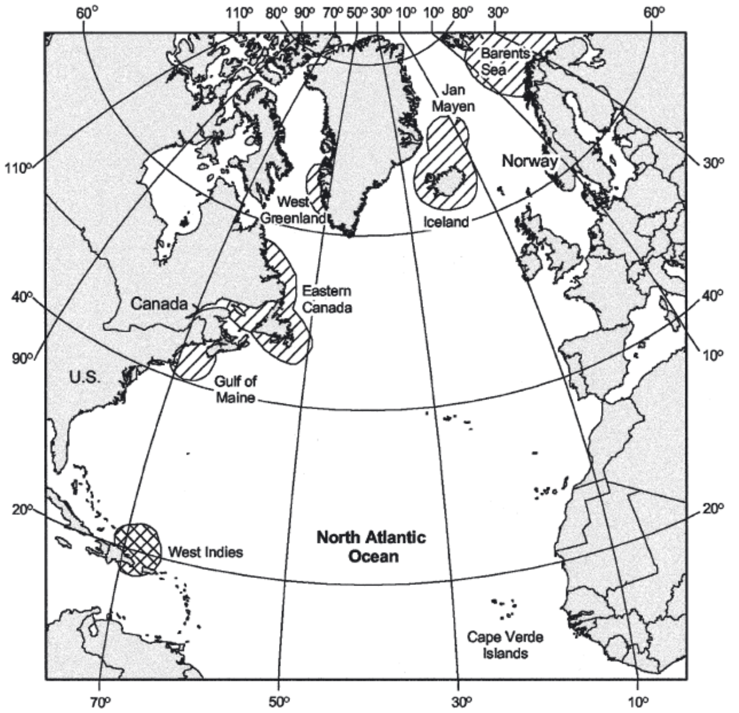

Fig 1. Primary breeding area (double crossed circle) and feeding areas (single stripped areas) for North Atlantic humpback whales (Stevick *et al*., 2003).

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

A note on Whaling

Since the mid-1800 and up until the early decades of the 1900, humpback whales were the target of extensive whaling which led to a rapid decline in population size (Stevick *et al*. 2003). To prevent extinction, a ban on commercial whaling (i.e. humpback whales) was initiated in the North Atlantic in 1955 and only local hunters in Greenland and the Lesser Antilles were allowed to catch a small number of humpback whales (Martin *et al*. 1984; Best, 1993). Roman and Palumbi (2003) have estimated that before commercial whaling set in, a population size of 240.000 humpback whales was found in the North Atlantic. In the period from 1979-1986 an estimated number of 5.502 humpback whales were living in the North Atlantic (Katona and Beard, 1990). In West Greenland about 800 humpback whales were caught in the period from 1886 to 1985 (Larsen and Hammond, 2004). However, in 1986 the IWC (International Whaling Commission) put a moratorium on whaling reducing the West Greenland quota of humpback whales to zero and this quota is still in place (IWC, 1986). Today the number of humpback whales is increasing and the IUCN (International Union for Conservation of Nature) recently moved this species from the category *Vulnerable* to the category of *Least Concern* (IUCN, 2008). This increase has led to intense debates on whether or not to reopen hunt on humpback whales, and in 2008 Denmark proposed an annual quota of 10 humpback whales on behalf of West Greenland. The scientific committee concluded that this would not harm the population. Nevertheless, the commission rejected the proposal and humpback whales are still protected from hunting (IWC, 2009)

The whale watching industry

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

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

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

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

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

Objectives of the study

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

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

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

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

Methods

Photo identification

The theory

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

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

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

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

In practice

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

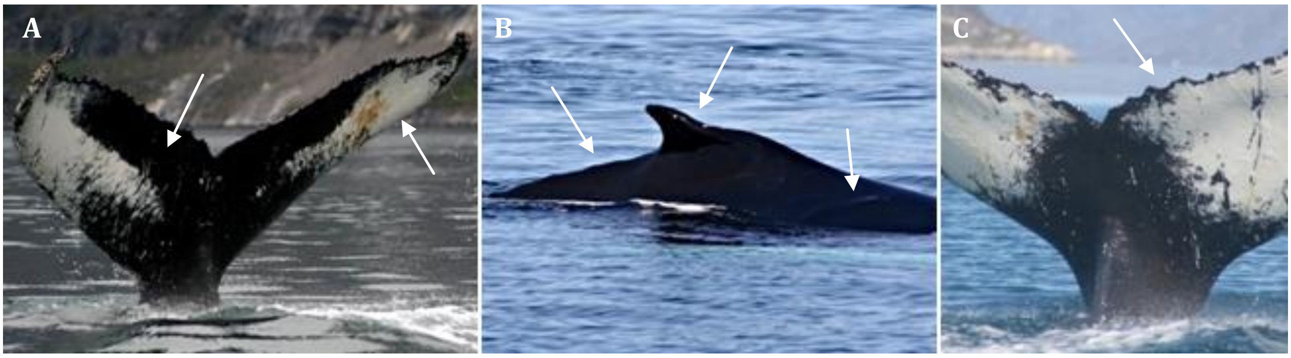

Fig. 3. Different characters used to identify humpback whale individuals. A) Fluke coloration patterns B) Caudal peduncle, dorsal fin shape and scarification C) serrated trailing edge.

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

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

Efficiency and reliability

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

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

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

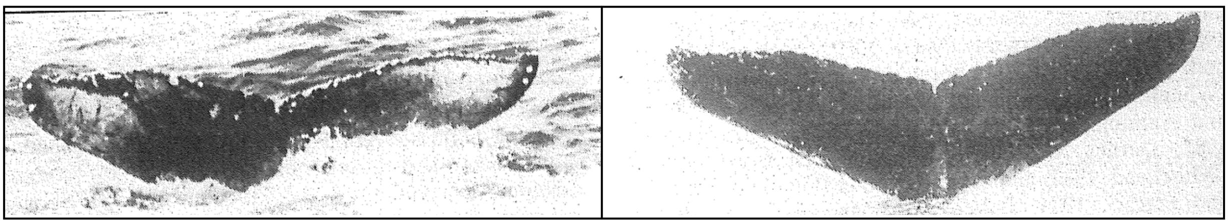

Fig. 4. Major changes in coloration patterns of calves within the first two years can occur (Carlson *et al.*, 1990).

Hence, identification solely through fluke coloration patterns is questionable in calf re-identification but appear to be reliable in older juveniles and adults.

Before the development of digital cameras, black and white film was used when obtaining ID-photos. One problem derives from this. Algae growth which is seen as yellow patches on the ventral side of the fluke is hard to distinguish in black and white photos, and can in some cases leave the scientist in doubt to whether or not the mark is in fact a mark. Furthermore, algae growth might present a problem to computer-assisted matching programs as they may not be able to differentiate algae from natural markings (Fig. 5).

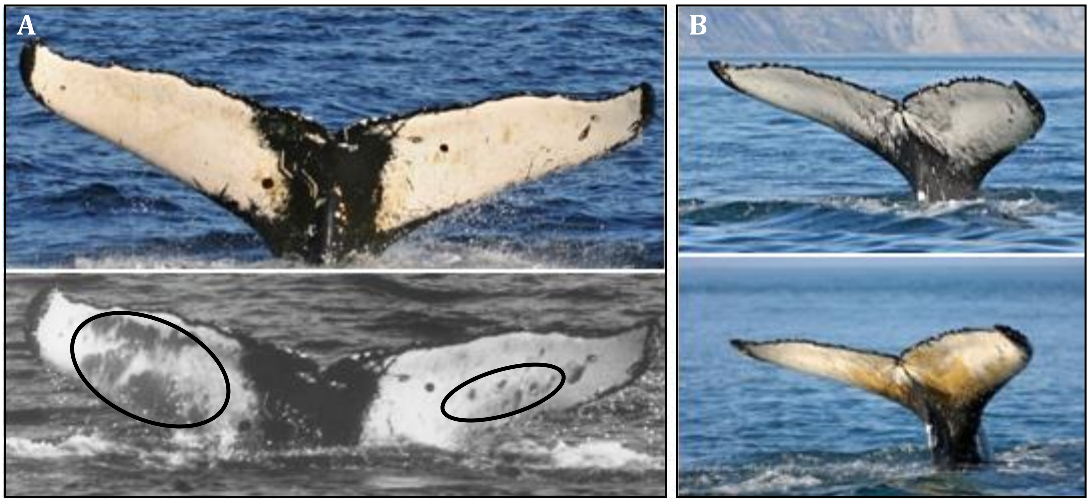

Fig. 5. A) Algae (circles) look like definitive markings in black and white photos. B) Algae on the fluke may confuse computer-assisted matching programs.

Mark-recapture techniques

Mark-recapture techniques are often used when answering different ecological questions in various biological subject areas. In population ecology classic usage of mark-recapture is calculating abundance estimates, population size and population vital rates (e.g. Bejder and Dawson, 2006; Heide-Jørgensen *et al*, 2008; Stevick, 2008). Due to its versatile usability many versions of the mark-recapture technique have been developed to overcome ecological problems following the different situations (i.e. is it a population in a small lake, a population stretching an entire coast-line, animals living in flocks, only the one sex that migrates etc). However, they are all based on the same principle. In practice, a number of individuals (n_1) in a population (N) are caught, marked (e.g. by conventional tags, toe clipping, banding or ID-photos) and released. Later, individuals from the same population are caught again (n_2). Of the individuals caught in round two, some of them are marked (m_1) and some of them are not. The basic theory behind mark-recapture is that the relationship between the recaptured individuals, m_1, and the total sample of n_2 is equal to the relationship between individuals marked in the first sample (*n_1*) and the total population size, N (Chao and Huggins, 2005). Hence, Population size, N, can be estimated from equation 1, Petersen estimator:

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

However certain assumptions must be made, for this relationship to be valid (Hammond, 1986; Chao and Huggins, 2005). First, it is important that animals do not lose their marks and that marks are noted correctly once retrieved. Second, if migration, birth or death of individuals occurs during the study, m_1 may change as the probability of recapturing a marked individual changes between the two sampling periods and the relation seen in equation 1 no longer exists. E.g. if marked individuals emigrate or die during the study period they will no longer have the chance of being recaptured. This will decrease the size of m_1 leading to an over estimate of population size. Contrary, death or emigration of unmarked animals will lead to an underestimate of population size, as the probability of recapturing a marked individual will increase. Hence, if this assumption of a fixed population is violated this will result in either over or under estimating population size. Therefore, it is necessary to assume that the population remains constant during the study period and that neither immigration/emigration nor birth/death occurs. Consequently, equation 1 is only employed when estimating abundance in what is referred to as closed populations and preferably over a short time period. An additional assumption to the closed population model is that all individuals must have an equal chance of being marked/recaptured. Therefore, it is important that marking does not affect the catchability of the animals. Some animals can become either trap shy or trap happy after marking leading to either a decrease or an increase in catchability. Trap shy animals will avoid being trapped the second time resulting in a decrease in the amount of recaptured individuals, m_1. Trap happy individuals on the other hand will result in a corresponding increase in m_1. As seen in equation 1, the population estimate will then again be either over or under estimated. However, death and recruitment take place in all animal populations and versions of closed population models, allowing for these components, have been generated or the sampling procedure can be modified to circumvent these assumption violations (e.g. by keeping the study period short hereby lowering the chance of death and recruitment or sampling a population outside its reproduction period (Hammond, 1986). Bejder and Dawson (2001) provide an example of a closed population in Hector's dolphins in Porpoise Bay, New Zealand. They argue that all individuals have been identified qualifying the population as closed, as no new individuals are photographed in the end of the study (their discovery curve levels off, see Figure 6 for example of discovery curve), no movement takes place between their study site and others and genetic differences are large over small geographical ranges indicating little migration. The authors disregard birth and death of individuals in the study period, thus relaxing this assumption, and due to the short sampling period, births/deaths will have little effect on the population estimates.

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

Case study in Nuuk fjord

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

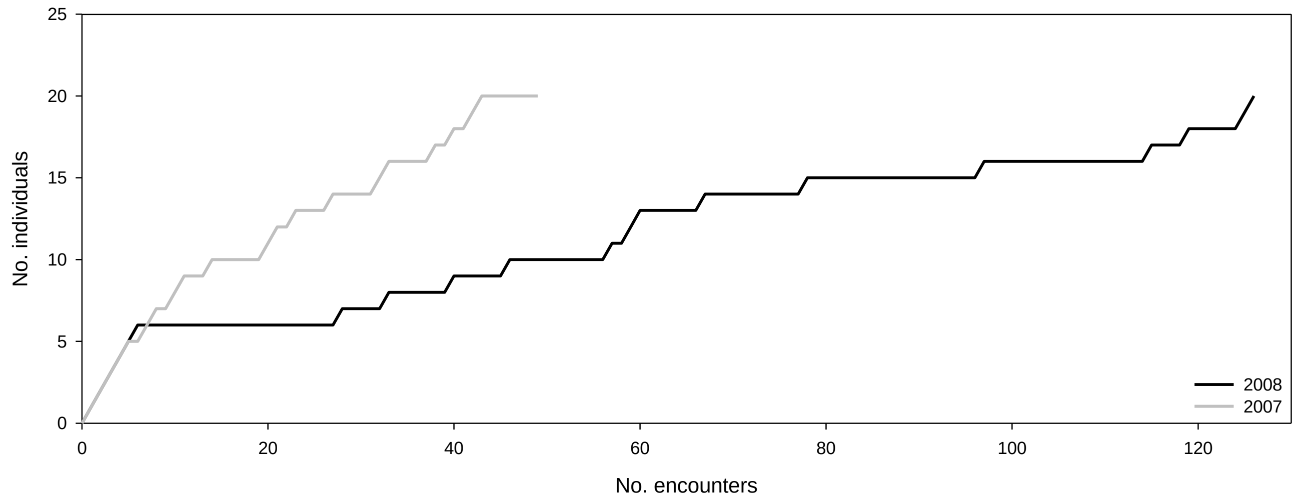

Fig 6. Humpback whales in Nuuk fjord constitute an open population as new individuals are encountered throughout the season (Boye *et al.*, in prep., this thesis)

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

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

Where,

N = no. of individuals in Nuuk fjord

Var (N) = the variance

n_1 = no. of individuals marked in 2007 in Nuuk fjord (20)

n_2 = no. of individuals marked in 2008 in Nuuk fjord (20)

m_2 = no. of individuals from 2007 recaptured in 2008 in Nuuk fjord (8)

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

By using the modified closed model we reach an abundance estimate of 48 ± 22 humpback whales in Nuuk fjord. This is considerably fewer than the number reached by Heide-Jørgensen *et al.* (2007). Although the estimate presented here is connected to several uncertainties (the use of closed population model on an open population) an estimate of 48 whales seems more realistic than 145 whales due to a longer sampling period and due the fact that only 20 individuals were indentified in the two consecutive years. It indicates that the assumption by Heide-Jørgensen *et al.* (2007) of a uniform density within the fjord is not correct. They accommodate this by giving a more conservative abundance estimate of 29 humpback whales, which is closer to the estimate calculated here.

Theodolite tracking of cetaceans

The theodolite

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

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

Calculating distances

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

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

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

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

where,

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

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

h = height of platform above sea level

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

β = the angle from the platform to the marine mammal (β = 180 – α)

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

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

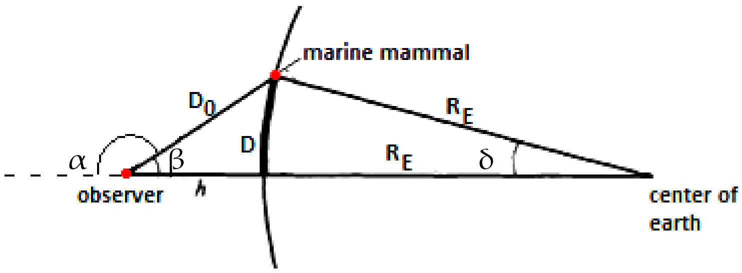

Fig. 7. R_E is the radius of the earth, D is the distance to the marine mammal along the surface of the earth, D_0 is the line of sight distance to the marine mammal, h is the height of the platform, δ is the central arc angle from the marine mammal to the platform, β is the angle from the platform to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

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

Computer-aid programs

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

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

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

6)

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

where,

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

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

Calibrating the theodolite

To determine inaccuracies linked to the individual researcher when tracking at different distances and directions the theodolite must be calibrated by each person using it. I did this by outlining a transect of GPS positions of known distances relative to the land based station. A boat served as the object being fixed and was positioned at the given positions in the transect. The theodolite, placed on a station with known position, fixed the boat in the waterline as if tracking a whale (Fig. 8). To estimate the RMS error, more fixes should be done on each position turning away the theodolite between each fix. As the boat might drift when laying on the position the crew on the boat noted the exact GPS positions corresponding to each fix made by the theodolite operator. It was then possible to calculate the RMS error (Root Mean Square) for both distance and horizontal displacement (eq. 7) (Fig. 9).

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

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

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

N = Number of fixes

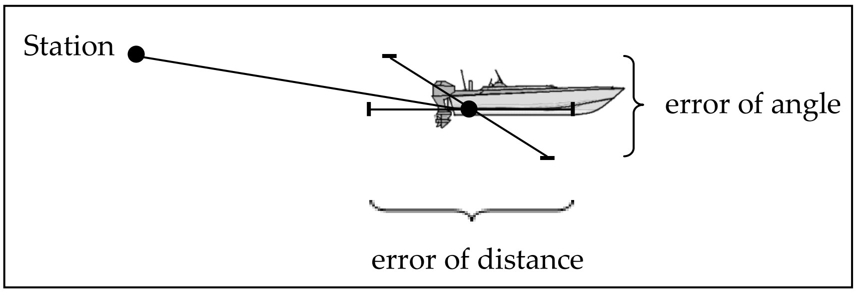

Fig. 8. Illustrates where to fix the boat during calibration and how the measurements of the objected tracked can be biased when tracked.

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

Example 1:

Position 1 in decimal degrees: 64.1861 N; 51.7325 W

Position 2 in decimal degrees: 64.1930 N; 51.7459 W

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

Where,

N = Latitudinal displacement

W = Longitudinal displacement

Distance between position 1 and 2:

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

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

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

In this example, the positions are limited to 4 decimals giving an accuracy of 11.1m. During analysis of the data in this thesis 7 decimals were used.

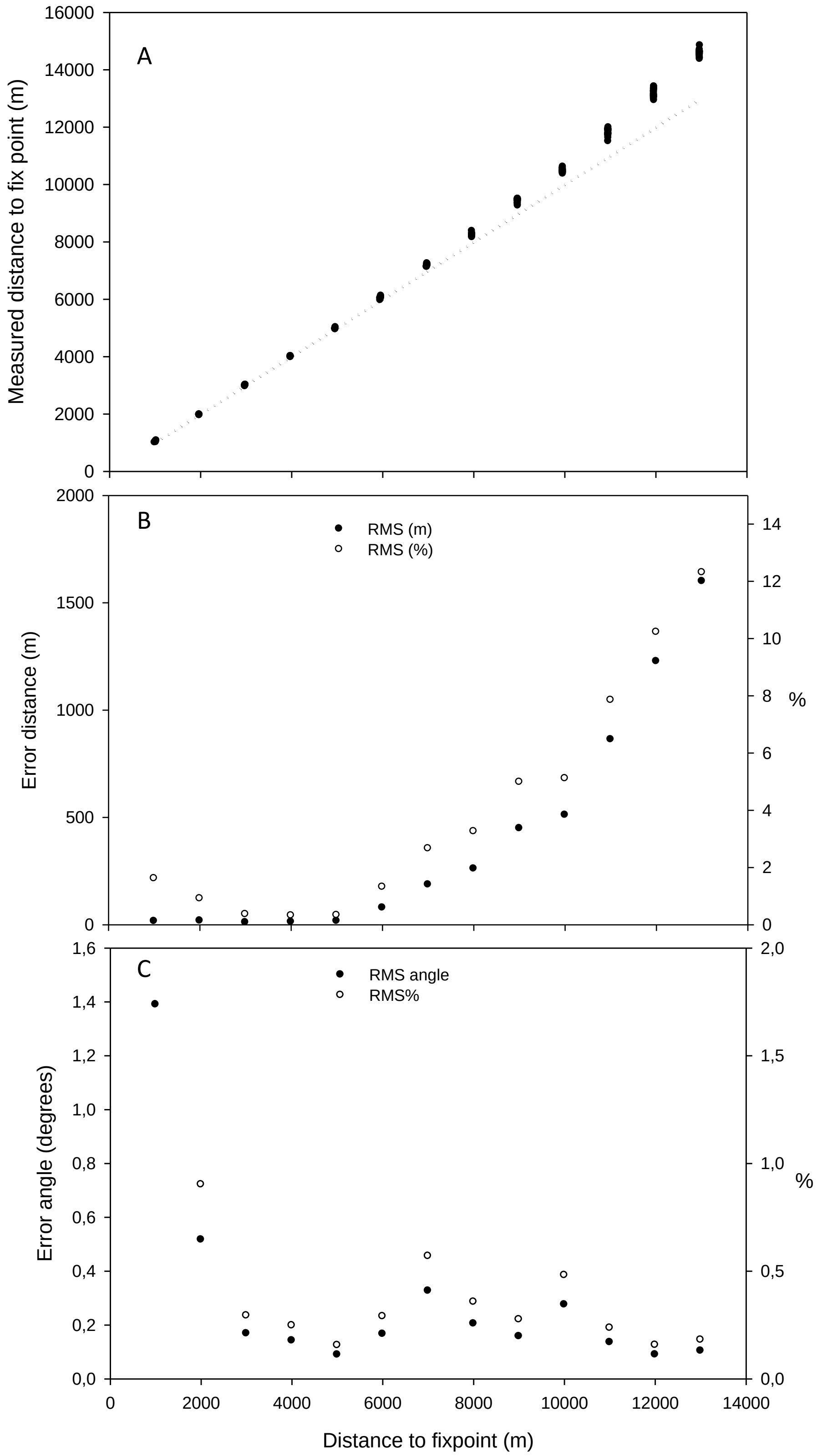

Fig. 9. Plots of the theodolite calibrations made in this study. A) The dashed line represents the actual distances to the fix point. As distance increases relative to the fix point the measured distance stray from the line B) The RMS error of distance increases with increasing distance relative to the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

Examples of tracks from Nuuk fjord

During the study I carried out surveys where whales were spotted from a lookout point at land. When spotted, the angles to the whale were measured with the theodolite and the angles were used to calculate the position. Afterwards the whale and potential whale watching boats were tracked. The positions of the whales and whale watching boats were then plotted in *MapInfo Professional vs. 9*.5 (Fig. 10).

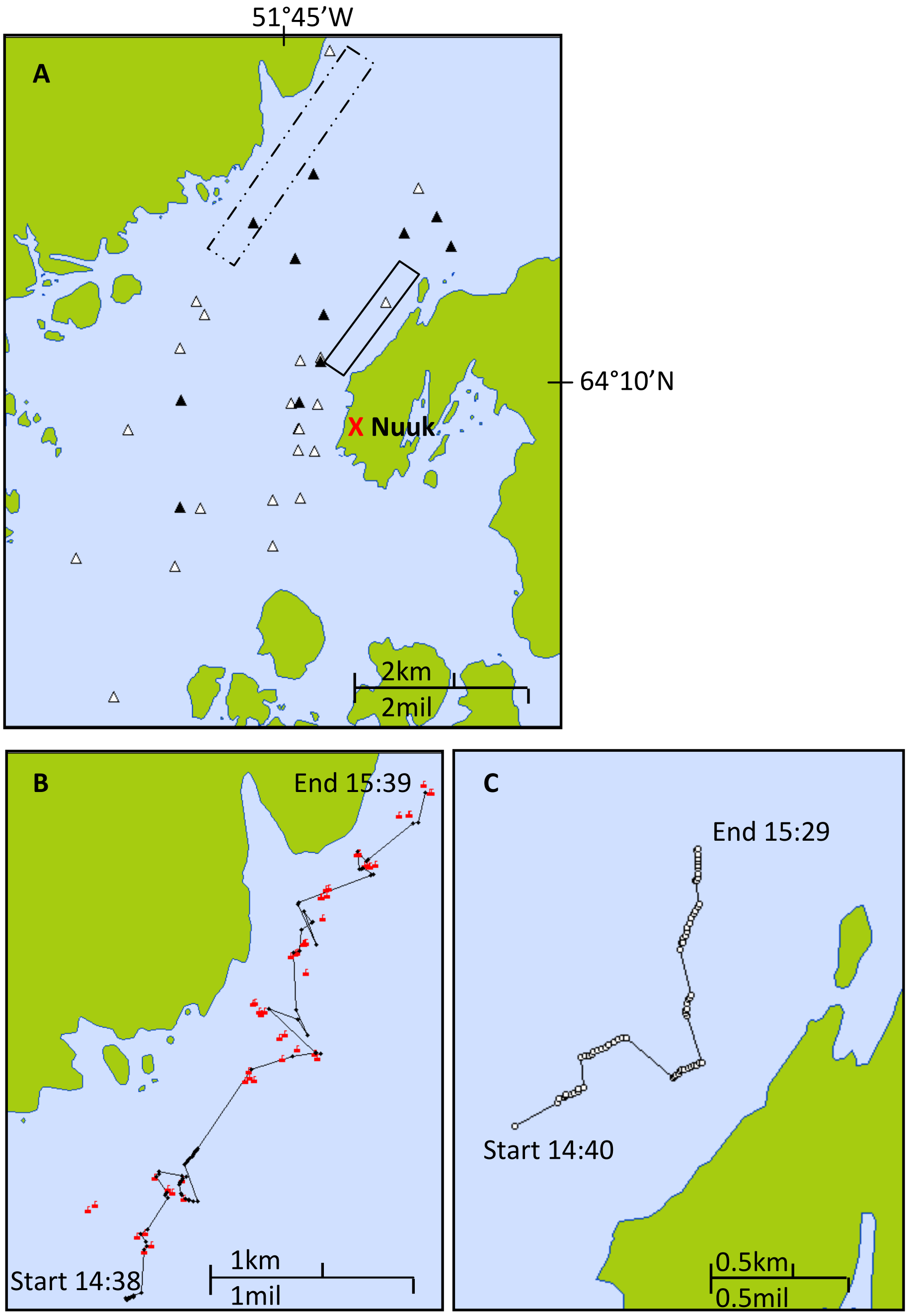

Fig. 10. A) Positions where whales were spotted during surveys in 2007 (Δ) and in 2008 (▲). Stripped square places the track with whale watching (B). Solid square places the track without whale watching (C) represents the boats present after each fluke up by the whale. • and ◦ are positions of the whales.

Problems in theodolite tracking of cetaceans

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

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

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

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

Perspectives

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

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

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

More profound studies should be done regarding whale watching. In this study we tracked whales under the influence of whale watching boats and whales not under the influence of whale watching boats. It would be ideal to track several individuals before, during and after whale watching to see under what circumstances behavior changes and to determine post-exposure behavior. Also, two different scenarios could be created. 1) Intense whale watching where boats come within few meters of the whales, the engine is turned on and the whale is continually observed. 2) Whale watching boats do not come within 100 m of the whales and the engine is turned off. This could profitably be done where individuals are tagged with non-invasive, archival tags (DTAG) (Johnson and Tyack, 2003) as described and incorporated in the following manuscript but not included in these introductory chapters. Dive profiles obtained from DTAGs will describe how whale watching before, during and after affect the foraging behavior of the whales and it would make it possible to determine if regulated whale watching methods have less effect on the whales' swimming and foraging behavior. Such a study could assist in the development of whale watching guidelines as found in other countries.

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

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

Abstract:

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

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

Introduction

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

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

Site fidelity is not only important from a basic science perspective but also in the context of potential commercial exploitation. Through time humpback whales have been considered a valuable resource in the Greenlandic society. Due to extensive commercial whaling up until the mid-1900, hunting of humpback whales was called off in 1966, and only aboriginal hunters off West Greenland and the Lesser Antilles were allowed to continue humpback whaling (Martin *et al*. 1984). In 1981, Whitehead *et al.* (1983) estimated the population size of West Greenland humpback whales to constitute of 85-200 animals. When it became evident that the West Greenland humpback whales constituted their own feeding aggregation or stock, for which a reliable abundance estimate was lacking, the International Whaling Commission (IWC) reduced the West Greenland quota on humpback whales to zero in 1986 (IWC, 1986) and this quota is still in place. During the IWC meeting in 2008, Denmark requested a quota of 10 humpback whales per year for West Greenland (IWC, 2009). The request was not granted and Denmark, on behalf of Greenland announced its intention of repeating the request in 2009. Today, the population of humpback whales in West Greenland is estimated to increase with approximately 9.4% yr.1 and currently an estimated 3000 (cv = 0.45) humpback whales comprise the West Greenland feeding aggregation stretching from Disko Bay to Arsuk (Heide-Jørgensen *et al*., 2008). During their stay in West Greenland humpback whales constitute a key species for a growing whale watching industry. The whale watching industry in Nuuk alone is expanding dramatically and in 2008 the industry turned over at least US$ 332,000 on whale watching only ([1]Skydsbjerg, pers. comm.). Around Nuuk whale watching is restricted to areas within Nuuk fjord, where the humpback whales are often approached closely by commercial and private whale watching boats. Hence, humpback whales play an important role both ecologically and economically in West Greenland, but the scientific basis for policy making around sustainable co-existence and commercial use of humpback whales is limited.

Here we used photo identification to investigate small scale site fidelity, residence time and habitat use of individual humpback whales foraging in Nuuk fjord. Furthermore we tracked humpback whales with a land based theodolite in the absence and presence of whale watching boats to test for possible impacts of the presently unregulated whale watching. Finally, we discuss these data in the context of the biological and economical role of humpback whales in western Greenland.

Materials and methods

Study area

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

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2100 km^2 and stretches *ca.* 100 km from the mouth of the fjord to the most inland parts.

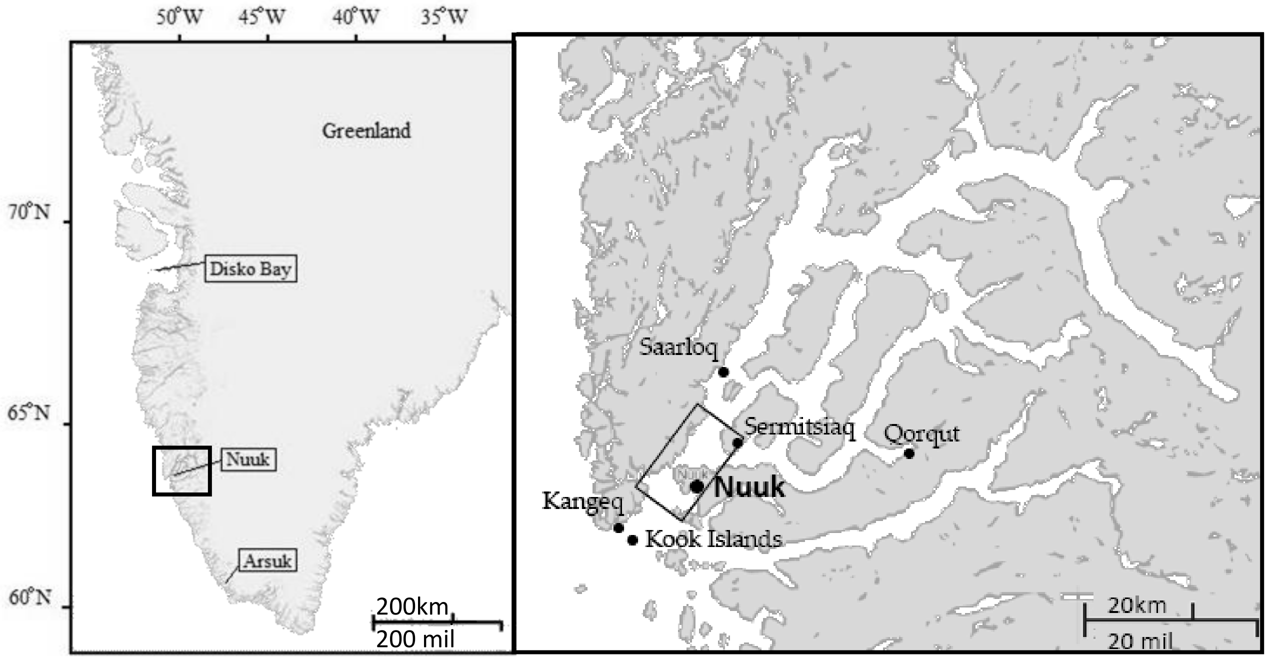


Fig. 1. Nuuk fjord. The square around Nuuk illustrates the area that can be covered during theodolite tracking

Photo identification

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

Analysis of photo- ID

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

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

Theodolite observations

Humpback whales were tracked with a land-based theodolite from June to October in 2007 and from May to September in 2008. The theodolite (Leica TC1103) was placed at an observation point (64°11,17N, 51°43,95W) 64.15 m relative to LAT (Lowest Astronomical Tide) overlooking the entrance of the fjord (Fig. 1). The position of the station was measured by ASIAQ (Greenland survey) using a high precision GPS (Leica 1200 with RTK). Height of the vantage point was calculated by calibrating the theodolite rendering a height above LAT with the lowest RMS error for distances up to 6000 m away from the land station. This resulted in a mean RMS distance error of 0.8% within 6000 m. The RMS error of the horizontal angle remained stable over all distances and did not exceed 0.3 degrees. Observations started with a half hour survey, carried out daily at 8 a.m., 14 p.m. and 19 p.m. The area was scanned for whales, and if a whale was present it was fixed by the theodolite, by measuring the horizontal and vertical angle to the whale relative to the land station. The survey then continued. When the half hour survey was done the whale was tracked with the theodolite for at least one hour if still present. Every surfacing of the whale was measured using focal sampling (Altmann, 1974). If more than one whale were present, one was chosen to be tracked for an hour and afterwards another whale would be tracked, if still present. If two whales were swimming together (within one body length of each other) they were considered a group and an attempt was made to track only one of the two individuals, based on characteristics such as size, shape of dorsal fin and color pattern of the fluke. If the two whales separated during tracking, one of the two was chosen for further tracking. The angles to the whale watching boats following the whales were measured subsequent to the fluke up of the whale. Surveys were restricted to sea state 4 or less and not carried out during reduced visibility from *e.g*. heavy fog or precipitation. From June 1st till June 20th 2007 surveys were carried out without theodolite due to technical problems.

Data from the theodolite were stored on a laptop and converted into geo-referenced x, y co-ordinates (latitude and longitude) using the equations of Gailey and Ortega-Ortiz (2000) implemented in Matlab 6.5 (*Mathworks*) and plotted in *MapInfo Professional vs. 9*.5. To determine the possible effect of whale watching boats on whale behaviour four parameters were analyzed using presence/absence of boats as a fixed factor. These parameters were the apparent surface speed (km/h) of the whales (calculated using the distance between each surfacing and the time taken to cover the distance), difference in duration of foraging dives (we defined foraging dives as dives exceeding 60 sec.), the ratio between foraging dives and short dives and difference in the degree of changes in heading (Williams *et al.,* 2002). All tests were preceded by tests for homoscedacity and normality, and when these were violated the data were either log transformed or non-parametric tests were applied. To test the difference in ratio between long and short dives each individual whale was considered as a sample unit while all other tests were performed on the individual data points. As some tracks were longer than others, the tracks were homogenized to ensure that all whales contributed equally to the performed tests. This was done by randomly selecting an equal number of data points from each track. Following this all data points were pooled in the two groups. Only tracks where whales were either constantly followed by a boat or no boat was present at all were included in analysis s of the effect of whale watching. Finally, to support theodolite data, data from a non-invasive, archival tag (DTAG) (Johnson and Tyack, 2003) were included. Of three whales tagged, a single whale was exposed to whale watching while tagged, and potential effects of exposure were investigated in the dive profile data. A two dimensional dive track was plotted and the dive behavior (time at surface and dive duration) without whale watching boats nearby was compared to the dive behavior with whale watching boats nearby as recorded in field notes and estimated from boat noise on the tag audio recordings.

Results

Photoidentification

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

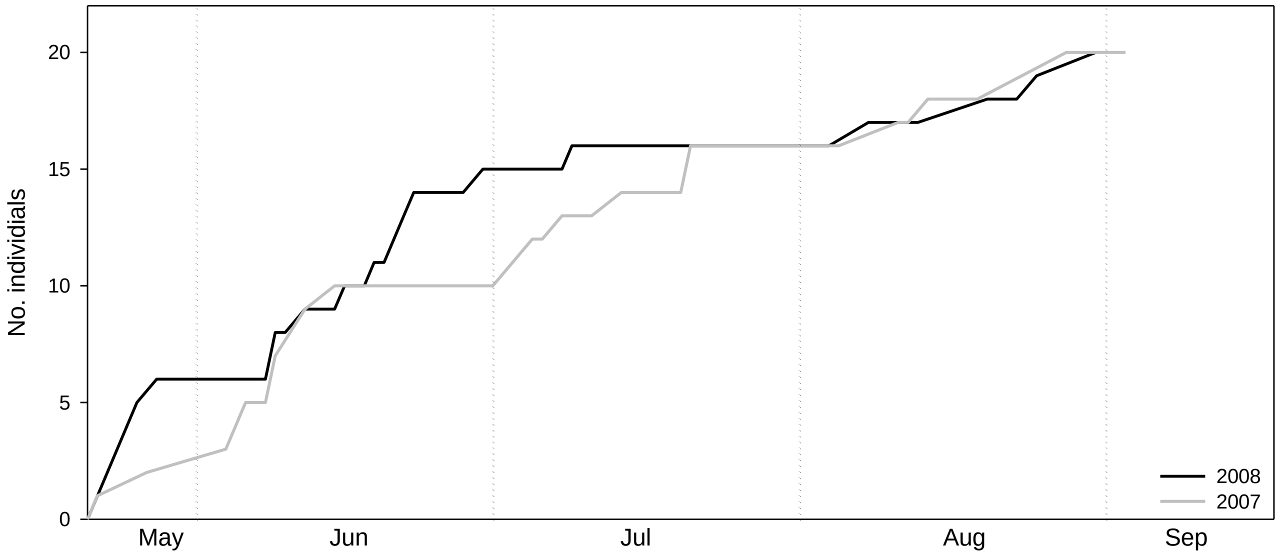
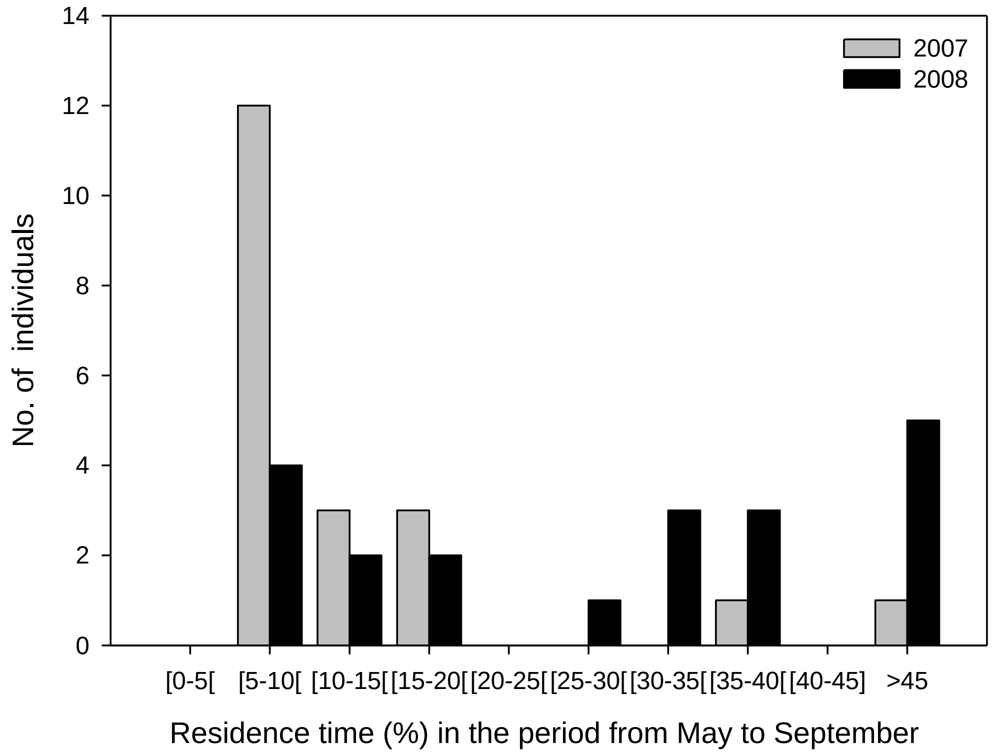


Fig. 2 Discovery curves of humpback whales in Nuuk Fjord. Number of new individuals identified during the field month (modified Julian days, where May 1st is day 1 to disregard leap year in 2008)

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

Residency

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



775 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.

		No. of whales seen in each subsequent year										
Year first seen	N	1992	1993	1996	1999	2003	2004	2005	2006	2007	2008	No. resighted in at least 1 year
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)
1996	1				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)	2 (66.7)
2003	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)	2 (40.0)
2005	1								-	0 (0.0)	0 (0.0)	0 (0.0)
2006	9									2 (22.2)	3 (33.3)	3 (33.3)
2007	15										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.

T*emporal and spatial distribution*

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

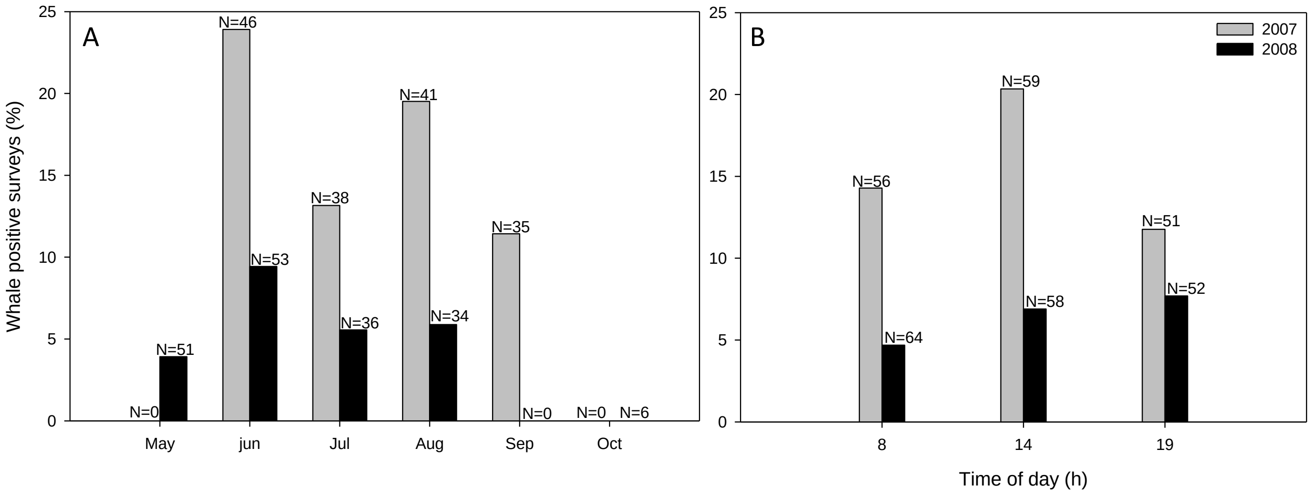


Fig 4. A) Number of surveys (%) in the months of both field seasons, where humpback whales were seen. N is the total number surveys conducted in the given month. B) Number of surveys (%) at the different time periods, where humpback whales were seen. N is the total number of surveys conducted at the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

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

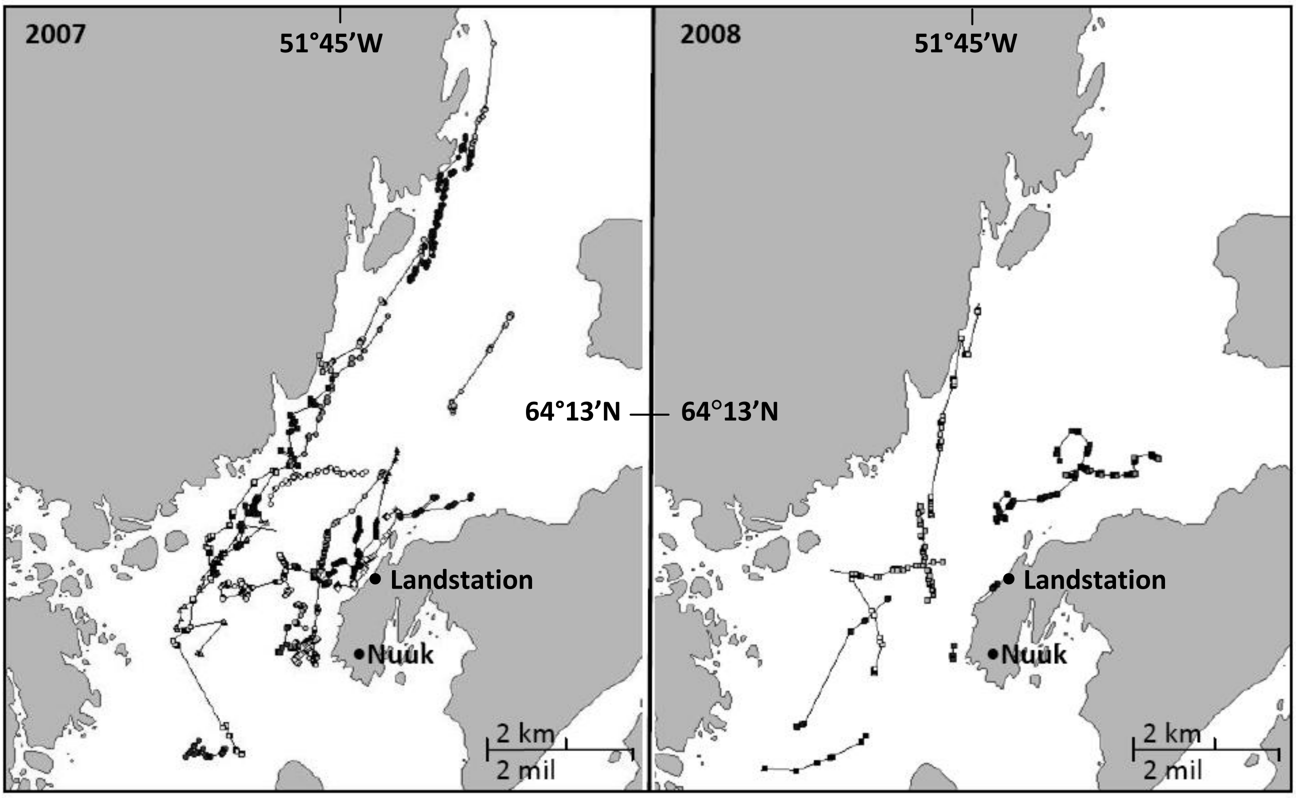


Fig. 5. Tracks of individual whales in 2007 and 2008. In 2007 they tended to migrate along the coast line while in 2008 they were seen crossing the fjord on several occasions

Effects of whale watching boats on whale behavior

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

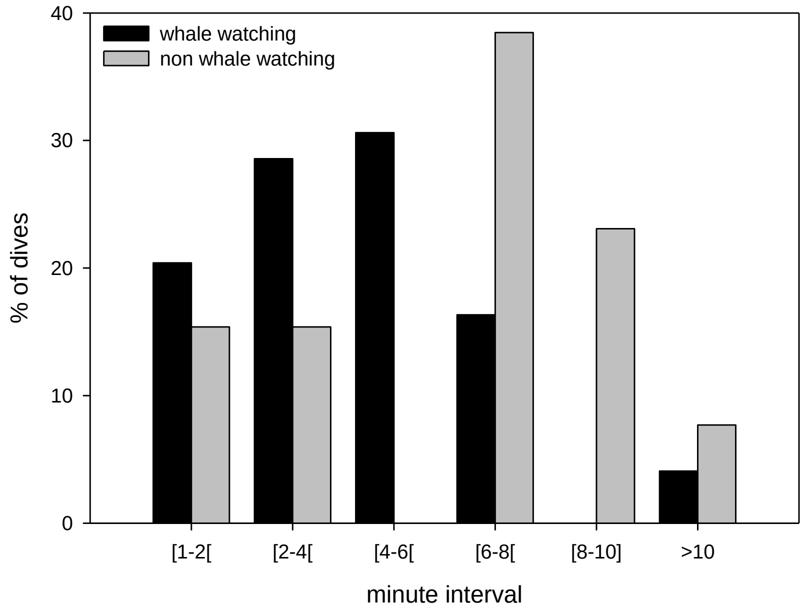


Fig 6. The duration of foraging dives (defined as dives exceeding 60 sec.) The whales carry out longer foraging dives when no whale watching boats are present. $N_{\text{whale watching}} = 49$, $N_{\text{non whale watching}} = 13$

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

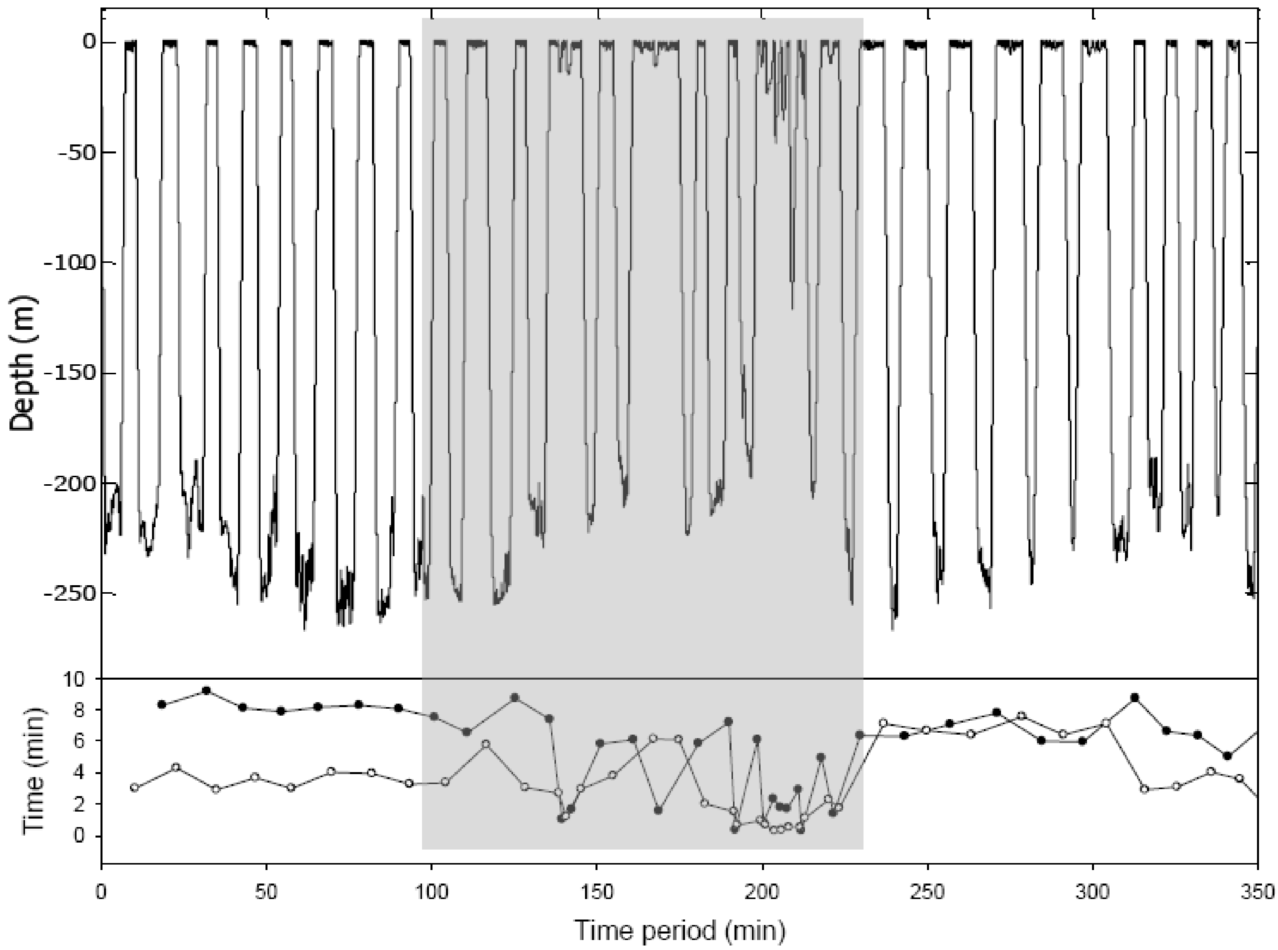


Fig. 7. Dive profile of humpback whale. The shadowed area illustrates the time period where the whale was exposed to whale watching and where high levels of engine noise was measured on and off. Top) Illustrates the diving pattern of the whale over time. Bottom) illustrates diving duration (●) and time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

Discussion

Residence patterns within years

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

Residence time amongst each individual was highly variable and the whales did not stay in the fjord the entire feeding season. Moreover, the amount of periods that each whale resided in the fjord varied between one, two and three periods of various lengths. Although this could merely reflect that the individual whales were not photographed within the fjord during consecutive weeks, we believe that if a whale was present in the study area of Nuuk fjord it was likely to have been photographed due to an almost daily effort on the water by either the whale watching boats or our crew. In addition, other studies have shown that humpback whales do migrate between different feeding areas within the foraging season (Heide-Jørgensen and Laidre, 2007). To define residence time and residence periods is, however, difficult and our definitions of the two terms are relatively broad. Therefore, we have not sought to calculate a mean residence time of the humpback whales in the fjord, as the estimate would be tied to large uncertainties. Because Nuuk fjord is open for migration there is a large probability of the whales migrating into the Davis Strait and we cannot assure that individuals were resident in the fjord between sightings. Yet, the fact that an individual is photographed several times in the fjord within a short time window does indicate that the individual has remained within the proximity of the fjord. Although humpback whales can move long distances within a relatively short time period (*e.g.* Della Rosa *et al.*, 2008), we believe that the time limit set in this study, does not allow the individuals to migrate far distances and reach Nuuk fjord in time to qualify for a single residence period. Hence, an individual that is photographed regularly over a longer temporal scale compared to another individual must necessarily be defined to have a longer residence time. Tagging with satellite transmitters would make it possible to determine the actual residence time of each individual , but that, on the other hand, is costly and invasive compared to photo-ID.

Number of humpback whales in Nuuk fjord

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

Site fidelity across years

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

Few studies on humpback whales have looked at site fidelity on a regional scale. However, Weinrich (1998) did a study on small scale site fidelity in calves in Gulf of Maine and found a strong degree of small scale site fidelity for calves (79.4%) returning to a regional area where they had been observed the year before. He argued that calves are introduced to the feeding areas during their year of maternal dependence and this introduction appears essential to their future choice of feeding ground on a regional scale. We also sighted young calves in the company of adult animals. It seems unlikely that the high rate of re-sightings found in both 2008 and in the period from 1992 to 2008 is a mere coincidence. First, the coast of West Greenland from Disko Bay to Arsuk, where foraging by humpback whales is known to take place, stretches more than 1000 km (Heide-Jørgensen and Laidre, 2007) and with a highly convoluted coastline with numerous fjords. Secondly, 3000 humpback whales are estimated to comprise the West Greenland feeding aggregation and could in theory enter the open fjord system, therefore the likelihood of at least 40% out of some 20 individuals from a 3000 animal population entering the fjord two years in a row by coincidence is very low. Our findings here thus support the conclusion on small scale site fidelity by Weinrich (1998), and demonstrate strong small scale site fidelity where individual humpback whales not only return to the same general feeding areas within hundreds of kilometers but also within few kilometers, illustrating strong navigational skills, and long term memory of the spatial and temporal distribution of food resources, likely introduced to them by their mothers.

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

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

Seasonal patterns and habitat use

As seen in fig. 4A the highest numbers of whales were observed from the land station in June. In July fewer whales were present during surveys but in August more whales were yet again spotted during the survey hours. This was the case in both 2007 and 2008 although more characteristically in 2007. This pattern is consistent with the number of individuals identified during the field seasons with photo-id. In both years, we identified most whales in June but in July the number of new individuals seemed to level off. In August new individuals continued to be identified. This suggests that most whales are present in the early summer month but during midsummer some individuals migrate elsewhere while new individuals arrive. This notion is supported by a single id-photo taken by locals in Aasiaat (app. 550 km north of Nuuk in Disko Bay) in July 2008 which we matched to an individual photographed in Nuuk fjord in June the same year. The first whales arrive to Nuuk fjord in May. In the same month capelin migrate from the depth of the banks and into the shallow waters of the fjord to spawn. Capelin spawning is separated temporally along the West coast of Greenland and begins in April at the southern tip of Greenland (Friis-Rødel and Kanneworf, 2002). Spawning starts in Nuuk fjord in mid-May in the innermost part of the fjord and ends in June in the outermost parts ([2]Hedeholm, pers. comm.). In the North from Disko Bay to Uummannaq spawning occurs from mid-June to mid-July. It seems likely that some whales time their arrival to coincide with capelin spawning in Nuuk fjord. It is possible that some of them migrate northwards during the foraging season to benefit from the staggered spawning behavior of capelin.

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

In other areas humpback whales have been shown to alter their distribution regionally subsequent to changes in the distribution of their prey species between years (Payne *et al.*, 1990; Weinrich *et al.*, 1997). Prey, of which most is characterized by having a patchy distribution and a variable patch size (Clapham, 1996). In this study a change in the distribution of humpback whales was also found between our consecutive field seasons as indicated in several ways. During the collection of ID-photos, whales where mostly present in the main course of the fjord from Saarloq to Kangeq in 2007. In 2008 the whales were more often spotted in the transversal waters running from Qorqut to southwest of Sermitsiaq (Fig. 1). Consequently, during our land based surveys fewer observations of whales were made in 2008 compared to 2007. This may stem from the fact, that the land station covered the main course of the fjord and as the whales in 2008 did not spend as much time in the area in front of the land station, they were not sighted as frequently from land. We do not have data on the distribution of humpback whale prey species in Nuuk fjord in either

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field seasons and we are therefore not able to investigate if a shift in prey distribution between field seasons caused this difference in whale distribution between seasons or the shorter residence time of humpback whales in 2007. Yet, the tracks from our consecutive field season do indicate a difference in habitat use between the two years. The whales often migrated along the coast line outside the land station in 2007 maybe foraging along the edges. In 2008 they were more often seen crossing the fjord and only few whales migrated along the coast line. This could be an indication of the whales simply passing through in the area in front of the land station in 2008.

The fact that more whales were seen moving than staying suggests that the survey area (i.e. between Nuuk and Nordland) is used for transit, rather than as a feeding area. This was especially true for 2008.

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

At the 2008 annual IWC meeting Denmark requested a quota of 10 humpback whales annually on behalf of Greenland that was declined by the commission (IWC, 2009). When considering reopening a hunt on humpback whales in Greenland the small scale site fidelity displayed by the whales in this study along with the limited number of individuals identified in the fjord in both field seasons should be taken into account. The small scale site fidelity and the fact that not many humpback whales make use of Nuuk fjord demonstrated in this study imply that, if individuals are hunted within the fjord, the number of whales in the fjord may decrease. The whale watching boats in Nuuk depend on the whales that stay within the fjord as whale watching is only carried out in the vicinity of Nuuk city and not in Davis Strait. Thus, a debate on a quota on West Greenland humpback whales should consider the high site fidelity in the light of the high economical interests in non-lethal exploitation through whale watching.

Whale watching in Nuuk fjord

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

Whale watching in Greenland is not regulated and on most occasions we observed boats at high speeds within few meters of the whales. On several incidents more than one boat was present and we counted up to 15 boats on a single occasion. If the relatively small number of humpback whales, identified in this study, to some degree reflects the abundance in Nuuk fjord, and given that they are not all present at the same time, it is likely that the same individuals are being repeatedly targeted by whale watching boats during their stay in the fjord.

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

In most countries where commercial whale watching takes place, regulations and codes of conduct have been developed to deal with negative effects on the targeted animals. In New Zealand the *Marine Mammal Protection Regulations 1992* are established (MMPR, New Zealand

Government, 2008) to provide guidelines on how to interact with whales in a least intrusive manner. A study by Lusseau (2003) in New Zealand showed that bottlenose dolphin, *Tursiops spp.*, behaved differently according to boats either respecting or ignoring the MMPR guidelines. He found, that a research vessel, which in an 8 year period had respected the MMPR guidelines, did not seem to affect the behavior of the dolphins. On the contrary, boats with an intrusive approach caused the dolphins to increase their dive intervals.

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

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

Concluding remarks

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

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Appendix A

ID-catalogue

Each picture represents an individual photographed in Nuuk fjord. Numbers in parentheses are the number already given to an individual by the Yonah project.

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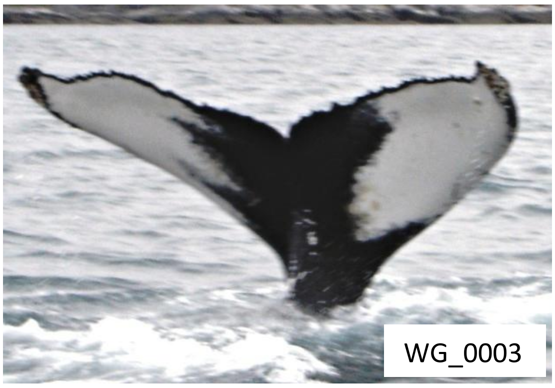

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WG_0005

WG_0006

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WG_0010


WG_0011


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WG_0020


WG_0021


WG_0022

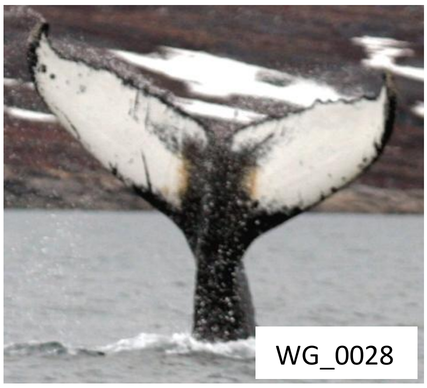

WG_0023


WG_0024


WG_0025


WG_0026


WG_0027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WG_0030


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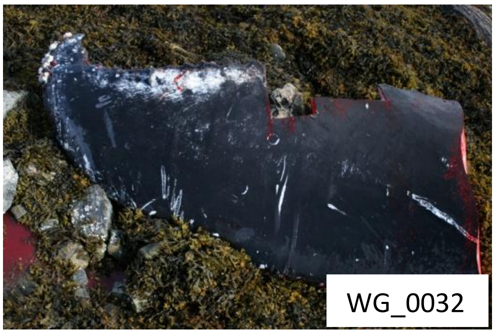
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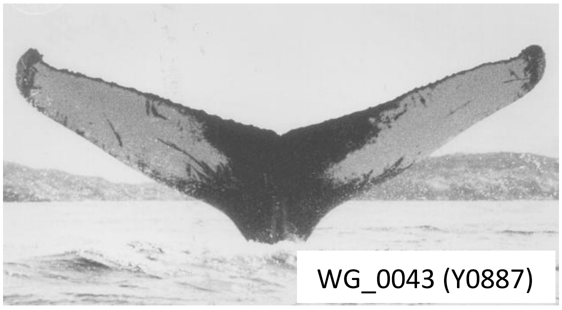
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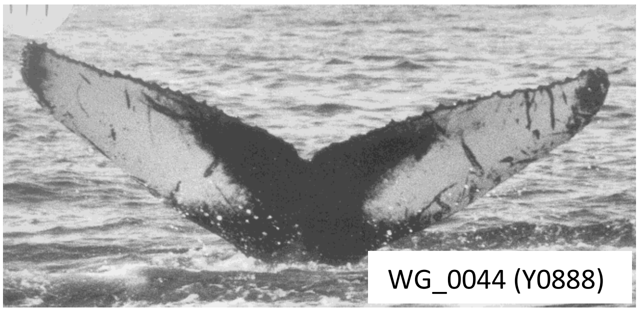
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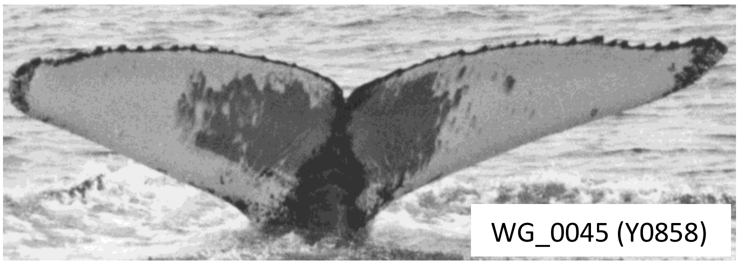
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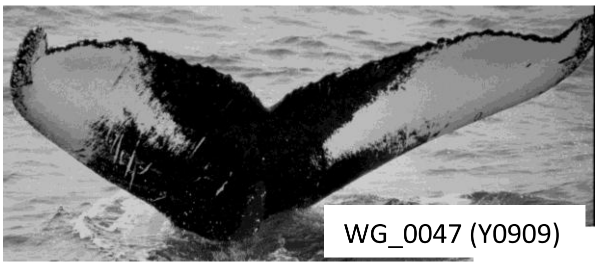
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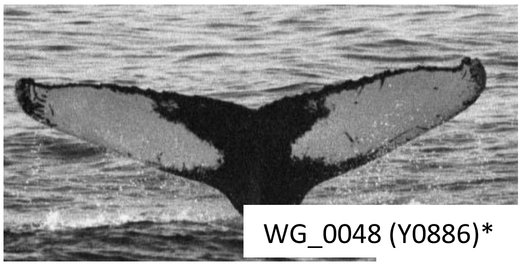
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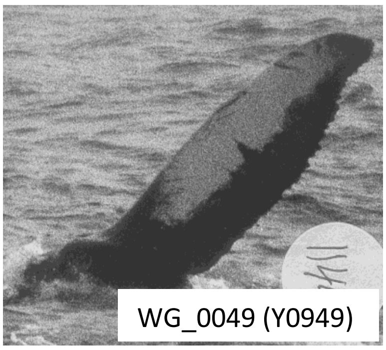
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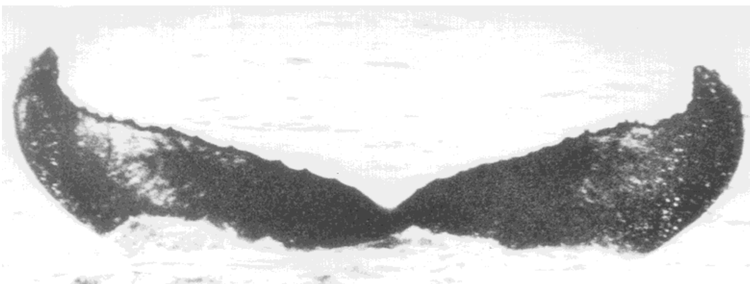
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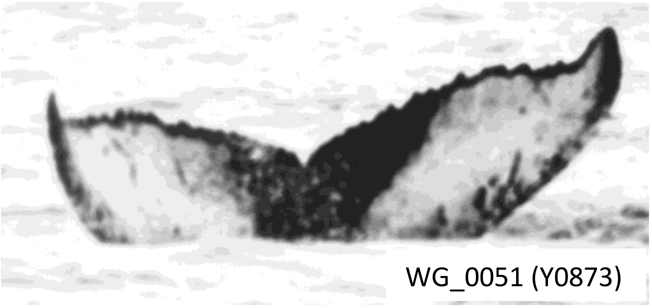

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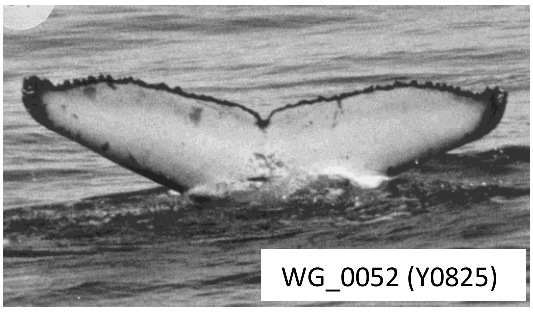


WG_0052 (Y0825)

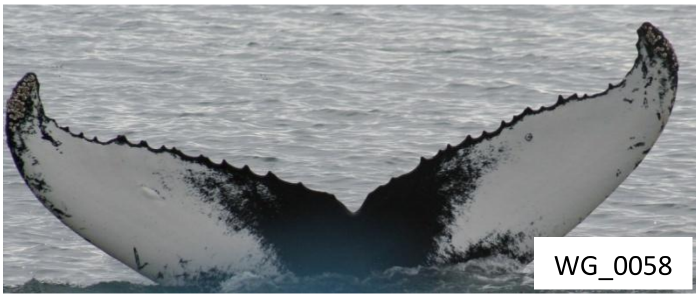
WG_0053 (Y0938)

WG_0054 (Y0886)*

WG_0055

WG_0056

WG_0057



WG_0058

* WG_0048 and WG_0054 have been given the same ID number (Y0886) by the Yonah project.