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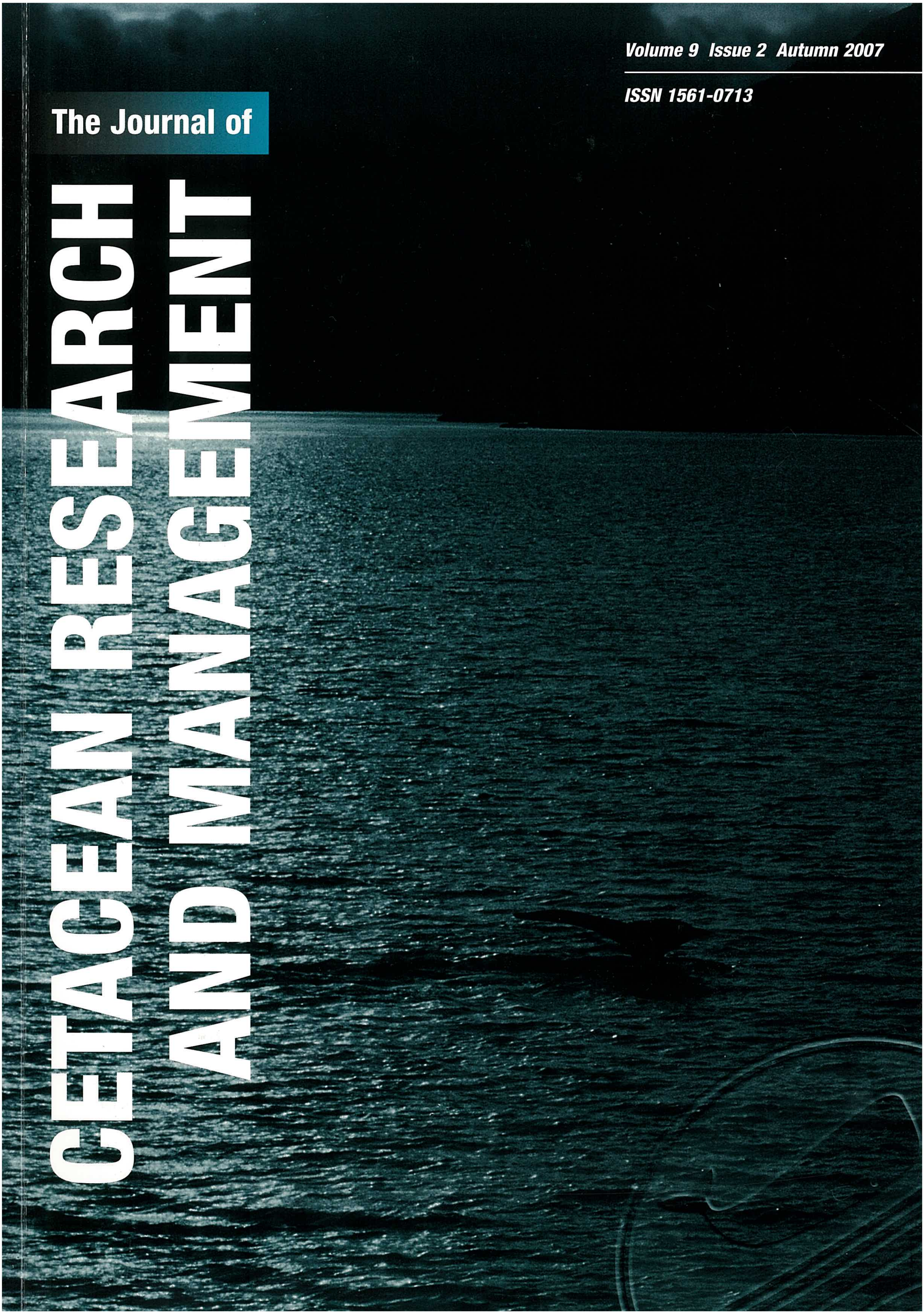

Contents

Editorial

This summary of the work of the Scientific Committee at the recent annual meeting follows the 2007 meeting of the International Whaling Commission held in Anchorage, Alaska. Details of the Commission meeting will be published in the next *Annual Report of the International Whaling Commission*. The full report of the Scientific Committee will be published in spring 2007 as *J. Cetacean Res. Manage.* 10 (Suppl.).

REVISED MANAGEMENT PROCEDURE

After the adoption of the moratorium on commercial whaling in 1982, the Committee spent over eight years developing the Revised Management Procedure (RMP) for baleen whales. In brief, the RMP is a generic management procedure designed to estimate safe catch limits for commercial whaling of baleen whales. This was adopted some time ago by the Commission, at the 1992 meeting. However, the Commission has stated that it will not set catch limits for commercial whaling for any stocks until it has agreed and adopted a complete Revised Management Scheme (RMS) which will include a number of non-scientific matters, including inspection and enforcement. The RMS has been the subject of a considerable amount of discussion within the Commission. The Commission had received a proposal by the Chair of the Commission for an RMS package of measures that he believed was a fair and balanced approach to move to the rapid completion of the RMS (IWC, 2005a). However, this was not accepted as a package by the Commission, and despite further work, the Commission agreed that it was at an impasse at the 2006 meeting in St Kitts and Nevis. Whilst no progress was made at the Anchorage meeting on this issue it was agreed that an intersessional meeting of the Commission on the future of the IWC would be held.

Process for revision of the *CLA*

The *CLA* (*Catch Limit Algorithm)* is used to determine safe removal limits under the RMP and was agreed in 1992. As a result of a request by Norway (IWC, 2006b), the Committee reviewed the process for considering revisions to the *CLA* agreed in 1992 and clarified some issues. The result of the review was to:

(1) agree that comparison of any proposed revision will be for a 100 year time period;
(2) agree an appropriate range of maximum sustainable yield rates for trials;
(3) agree requirements for an appropriate set of trials including additional trials to model environmental degradation;
(4) agree requirements for an appropriate set of performance statistics.

This year, the Committee agreed to hold an intersessional Workshop on (2) with a view to making a decision on this at the 2008 Annual Meeting

Implementation Simulation Trials

Implementation Simulation Trials are trials that are carried out before using the RMP to calculate a catch limit; they involve investigating the full range of plausible hypotheses related to a specific species and geographic area, particularly with respect to issues of stock structure.

The process of developing *Implementation Simulation Trials* is not the same as identifying the 'best' assessment for the species/region, but involves considering a set of alternative models to examine a broad range of uncertainties with a view to excluding variants of the RMP that show performance that is not sufficiently robust across the trials. Account needs to be taken of the plausibility of the various trial scenarios when evaluating RMP variants.

In the light of difficulties experienced in recent years, particularly with respect to the North Pacific region (common minke whales and Bryde's whales), the Committee has spent some time discussing the general question of how best to ensure that the process of carrying out *Implementations* (or *Implementation Reviews*) is efficient and prompt, whilst taking into account the available information. To achieve this it agreed that they should be conducted at discrete intervals, using the data available at one point in time. In 2005, the Committee developed requirements and guidelines for the *Implementation* process (IWC, 2005c). Some final details had required further analytical work and this was completed at Anchorage.

North Pacific Bryde's whales

This year, the Committee successfully completed the *Implementation* for western North Pacific Bryde's whales. This was the first *Implementation* undertaken using the new requirements and guidelines.

North Atlantic fin whales

At the 2005 Annual Meeting, the Committee initiated the *pre-Implementation Assessment* of North Atlantic fin whales (IWC, 2006c). To progress this work, a co-operative intersessional Workshop was held in March 2006 with the NAMMCO[1] scientific committee on general scientific issues of common interest, particularly with respect to stock structure, abundance and catch history (IWC, 2007b). The results of that Workshop were discussed and endorsed at the 2006 Annual Meeting and it was agreed that the *pre-Implementation Assessment* was complete (IWC, 2007d). For practical reasons (i.e. so that it did not conflict with the completion of the Bryde's whale *Implementation*), it was agreed that the North Atlantic fin whale *Implementation* would begin after the 2007 Annual Meeting. The process for beginning this *Implementation* was reviewed in Anchorage and the First Intersessional Workshop is scheduled for April 2008.

Bycatches of large whales

The RMP calculates a limit for the number of non-natural removals, not simply a catch limit for commercial whaling. It is therefore important to estimate the numbers of whales removed from the population by indirect means, such as bycatches in fishing gear and ship strikes.

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[1] North Atlantic Marine Mammal Commission.

In reviewing this issue, the Scientific Committee agreed that priority should be given to those areas where the RMP *Implementations* had been or were likely to be completed and implemented – such as the northwestern Pacific and the northeastern Atlantic. Four steps are required to estimate bycatches: (1) identification of the relevant fisheries; (2) description and categorisation of those fisheries to allow a sampling scheme to be devised; (3) identification of a suitable sampling strategy or strategies; and (4) design and implementation of the sampling scheme to enable estimation of the total bycatch.

The Committee has reviewed general methods for estimating bycatches. These fall under two headings: (1) those based on fisheries data and observer programmes; and (2) those based on genetic data. The former have been used successfully for several small cetacean populations. The Committee agreed that independent observer schemes are generally the most reliable means of estimating bycatch rates in a statistically rigorous manner, but that they may not always be practical and will require careful design. It is reviewing progress by the European Union in addressing sampling strategies. The Committee received information on bycatches and entanglement of large whales from Massachusetts, Hawaii, Alaska and Scotland and considered relevant information from ACCOBAMS[2].

Genetic approaches potentially represent a relatively new way of estimating bycatches. In 2005, a Workshop was held to examine genetic methods based on market sampling (IWC, 2006a). As a result of that Workshop, the Committee agreed that the market sampling approach provided a potentially useful method to supplement bycatch reporting schemes. Any such bycatch estimates would be improved considerably if carried out in conjunction with the use of data from DNA registers on whales entering the market. In 2006, a list of requirements as a pre-requisite to holding a second workshop was agreed (IWC, 2007e); at the 2007 meeting it was agreed that further work was required before holding a second workshop. The Committee requested information on Japanese regulations related to bycatches. The Committee also discussed issues related to risks of entanglement and the fate of entangled whales.

Other sources of anthropogenic mortality: vessel strikes

The Committee spent some time considering issues related to ship strikes. It received reports on estimation methods and results from Massachusetts, Hawaii and Alaska, as well as progress on previous recommendations from Italy, the Canary Islands and mainland Spain. It was pleased to receive a progress report on the development of a database which is being developed to incorporate ship strike data from around the world in a consistent manner.

DEVELOPMENT OF AN ABORIGINAL WHALING MANAGEMENT PROCEDURE

With the completion of the RMP in 1994, the Commission asked the Scientific Committee to begin the process of developing a new procedure for the management of aboriginal subsistence whaling that took into account the different management objectives for such whaling when compared to commercial whaling. This is an iterative and ongoing effort. The Commission will establish an Aboriginal Whaling Scheme that comprises the scientific and logistical (e.g. inspection/observation) aspects of the management of all aboriginal fisheries. Within this, the scientific component might comprise some general aspects common to all fisheries (e.g. guidelines and requirements for surveys and for data *c.f.* the RMP) and an overall AWMP within which there will be common components and case-specific components. The Committee has developed a proposal for aspects of the scheme (IWC, 2003).

In 2002, the Committee completed its work with respect to the Bering-Chukchi-Beaufort Seas stock of bowhead whales. It agreed a *Strike Limit Algorithm (SLA)* for bowhead whales and this was adopted by the Commission (IWC, 2003) and has subsequently been used to provide catch advice. In 2004, the Committee agreed an *SLA* for the eastern stock of gray whales (IWC, 2005d); this was adopted by the Commission and has been used to provide management advice.

The situation for the Greenlandic fisheries for fin and minke whales is more difficult. A considerable amount of research, especially concerning stock identity, is required and to this end, the Committee has developed a research programme in cooperation with Greenlandic scientists. High priority is being accorded to this work and a Workshop on progress with respect to Greenlandic fisheries will be held in March 2008.

ASSESSMENT OF STOCKS SUBJECT TO ABORIGINAL SUBSISTENCE WHALING

Up to 2007, aboriginal subsistence whaling was permitted for Denmark (Greenland, fin and minke whales), the Russian Federation (Siberia, gray and bowhead whales), St Vincent and The Grenadines (Bequia, humpback whales) and the USA (bowhead and gray whales). It is the responsibility of the Committee to provide scientific advice on safe catch limits for such stocks, where possible using appropriately developed *SLA*s. Where *SLA*s have not yet been developed, the Committee provides advice on a more *ad hoc* basis, carrying out major reviews according to the needs of the Commission in terms of establishing catch limits and the availability of data. It also carries out brief annual reviews of each stock.

At the 2007 meeting, the Committee had to provide management advice for all of the stocks considered. It had also been asked by Denmark to consider the status of all large whale species off West Greenland and in particular the bowhead and humpback whales. The Commission sets catch limits based on a 'need statement' from the countries involved and scientific advice on whether that need is sustainable. The Committee stressed to the Commission its view that the appropriate way to provide long-term management advice is using specially developed *SLA*s; it emphasised the difficulties associated with providing interim *ad hoc* advice.

Eastern gray whales

Based on the submitted need statement, the Committee confirmed the *Gray Whale SLA* was in accord with a total for the 2008-12 seasons of 620 with a maximum of 140 in any one year, which the Commission set. An *Implementation Review* for eastern gray whales is scheduled for 2007.

Bering-Chukchi-Beaufort Seas stock of bowhead whales

This year the Committee completed the first *Implementation Review* for bowhead whales; the review had begun in 2005 as a result of discussions at the in-depth assessment

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[2] Agreement on the Conservation of Cetaceans of the Black Sea, Mediterranean Sea and Contiguous Atlantic Area.

undertaken in 2004 (IWC, 2005b). The most recent abundance estimate (for 2001) is 10,500 (95%CI 8,200-13,500) giving a rate of increase between 1978 and 2002 of 3.2% (95%CI 1.4%, 5.1%). A major component of the *Implementation Review* was to complete work on the re-evaluation of stock structure for the bowhead whales found in the Bering, Chukchi and Beaufort Seas. This has been a major undertaking and has involved three intersessional workshops since 2005 as well as considerable field, laboratory and analytical work. As a result of this extensive work, the Committee agreed that the available evidence supports the existing single stock hypothesis for these whales. In addition, it noted that simulation testing had shown that the *Bowhead SLA* was robust to the several single and multiple stock structure hypotheses examined. The results from the *Bowhead SLA* revealed that the existing catch limits remain acceptable. In view of this, the Commission agreed a catch limit for the 2008-2012 period of a total of not more than 280 landed whales, with no more than 67 strikes in any one year.

Common minke and fin whales off West Greenland

The Committee had previously stressed that its inability to provide any advice on safe catch limits was a matter of great concern.

This year, the Committee was extremely pleased to receive and accept new abundance estimates for the common minke whale (10,800, 95%CI 3,600-32,400) and fin whale (3,200, 95%CI 1,400-7,200) off West Greenland, based on a traditional aerial survey carried out in 2005.

For the common minke whale, in addition to the new abundance estimate, progress has been made on incorporating the sex ratio data into an assessment. It is hoped that a final decision on whether a suitable assessment method can be designed will be made at the 2008 Annual Meeting. Despite progress made, the Committee agreed that the Commission should exercise caution when setting catch limits for this stock and set an interim 1-year catch limit. It noted that depending on assumptions made, the estimated replacement yield based on the lower confidence interval of the abundance estimate ranges from 170-230 animals.

For the fin whale, in addition to a new abundance estimate (see above), the Committee was also pleased, for the first time, to have an acceptable assessment method for this stock and it used this to provide interim management advice for this stock. For the preferred estimate of productivity, the Committee agreed that the population lay between 75% and 97% (lower 5% credibility and estimated posterior median values, respectively) of its unexploited abundance and that catches of between 14 and 26 would still allow the population to grow. The next priority for this stock is to determine an appropriate *SLA*.

After considerable discussion at the Commission meeting, the following catch limits were adopted:

(i) no more than 19 fin whales struck annually for the years 2008-2012;
(ii) no more than 200 common minke whales struck annually for the years 2008-2012 with an annual review by the Scientific Committee.

Common minke whales off East Greenland

Catches from East Greenland are believed to come from the Central Stock of common minke whales that numbers well over 60,000 animals. The Committee agreed that the present catch of 12 animals from East Greenland pose no threat to this stock. The Commission set a catch limit of up to 12 common minke whales struck annually for the years 2008-2012.

Bowhead whales off West Greenland

The Committee has agreed that whilst a comprehensive review of the available stock structure is required, the present working hypothesis is that there is a single East Canada-West Greenland stock. The agreed estimate for part of this stock off West Greenland is 1,230 (95%CI 500-2,490). On occasions in the past the Committee has provided interim management advice on the basis of the lower 1% confidence interval, in this case five whales. The Commission agreed to a strike limit of two bowhead whales for the years 2008-2012, subject to annual advice from the Scientific Committee.

Humpback whales off St Vincent and the Grenadines

In 2002, after considerable debate in the Commission, a catch of up to 20 whales for the period 2003-07 was agreed. The Committee has received positive confirmation that eastern Caribbean humpback whales are part of the West Indies breeding population (abundance in 1992/93 – 11,570, 95% CI 10,100-13,200) and agreed that the catch limit set by the Commission would not harm the stock. The Committee agreed that renewal of the present catch limit would not harm the stock. The Commission agreed a catch limit of up to 20 humpback whales off St Vincent and The Grenadines for the years 2008-12.

HISTORIC ABUNDANCE ESTIMATION, GENETIC METHODS

In 2004, in the light of a genetic modelling paper published in 2003 (Roman and Palumbi 2003), the Committee had considered the general methodological issue of estimating carrying capacity and/or pre-exploitation population size in the context of the Committee's assessment work. As a result of its discussions, the Committee agreed that such genetic methods have the potential to be one of a suite of tools that can be used to examine pre-exploitation abundance but that there are a number of limitations and uncertainties that must be considered when examining such data in a present-day management context. The Committee had agreed that the estimates of historic abundance provided in the Roman and Palumbi paper for the initial pre-whaling population sizes of humpback, fin and common minke whales in the North Atlantic have considerably more uncertainty than reported, and cannot be considered reliable estimates of immediate pre-whaling population size. Particularly important in this regard is the mismatch between the time-period to which genetic estimates apply (i.e. the time period is difficult to determine and extremely wide) and the population sizes of whales immediately prior to exploitation. It also agreed that the paper provides no information to suggest that changes are required in either the RMP or AWMP approaches to management (IWC, 2005b).

The Committee had identified further work necessary to assess whether genetically-based estimates of 'initial' abundance can provide useful information for the management of cetaceans; little progress had been made in this regard and at the 2006 meeting the Committee agreed that it should not consider this issue further until additional publications describing methodological and analytical progress are available (IWC, 2007c). No new information was presented in Anchorage.

STOCK IDENTITY

Of general concern to the assessment of any cetaceans is the question of stock identity. Examination of this concept in the context of management plays an important role in much of the Committee's work, whether in the context of the RMP, AWMP or general conservation and management. In recognition of this, the Committee has established a Working Group to review theoretical and practical aspects of the stock concept in a management context. The Committee has noted that it is important, in any application of stock structure methods, to examine the sensitivity of conclusions to different *a priori* decisions about the definition of initial units, and as to which population structure hypotheses to examine.

A specialist Workshop to examine the use of simulation testing to assess the performance of methods to identify population structure was held in January 2003 (IWC, 2004). The Workshop developed a suitable simulation framework to allow evaluation of genetic methods used in inferring population structure both in general terms (the issue is of great relevance to conservation and management outside the IWC) and from a specifically IWC viewpoint (particularly in an RMP/AWMP context).

This is a complex project that must proceed in an iterative fashion. Great progress was made on the most challenging module, i.e. the development and validation of a program to simulate realistic genetic datasets, at an intersessional workshop in March 2006 (IWC, 2007a). In particular, it led to completion of the computing work needed to simulate datasets and complete the control program that generates genetic samples, passes the samples to the boundary setting methods, runs the management algorithms, and collates the performance statistics. At the same time the technical specifications for the initial TOSSM trials (demographic structure, genetic structure, initialising the population matrix, harvesting and catch control, sampling and trials) were completed.

In Anchorage, the Committee received the results of exploratory runs for two commonly used population genetics models (STRUCTURE and BayesAss) for particular plausible, albeit difficult, scenarios. Interestingly both methods performed poorly in terms of estimating the quantities they were designed to estimate and consequently performed poorly in a management setting. The Committee has identified three future tasks: (1) broaden the suite of methods to be tested; (2) move from exploratory testing to an initial set of performance trials; and (3) further develop the control program.

The Committee also considered a new statistical method for estimating genotyping error rates based on mother-foetus pairs. Particular attention was paid to developing a set of guidelines for the use of genetic data in RMP and AWMP work. Initial discussions in Anchorage considered: (1) experimental design (quality control for samples, data and analysis); (2) procedural implementation of data quality checks; (3) presentation of data and associated errors; and (4) assessment of error rates. It is hoped to complete this work at the 2008 annual meeting.

COMPREHENSIVE ASSESSMENT OF WHALE STOCKS

The 'Comprehensive Assessment' of whale stocks

The 'Comprehensive Assessment' can be considered as an in-depth evaluation of the status of all whale stocks in the light of management objectives and procedures; this would include the examination of current stock size, recent population trends, carrying capacity and productivity. Clearly, it is not possible to 'comprehensively assess' all whale stocks simultaneously, and the Committee has been working in an iterative manner towards this, initially concentrating on stocks that have recently or are presently being subject to either commercial or aboriginal subsistence whaling. Some of these stocks have already been discussed in the sections on the RMP and AWMP.

Antarctic minke whales

The Committee has carried out annual surveys in the Antarctic (south of 60°S) since the late 1970s. The last agreed estimates for each of the six management Areas for minke whales were for the period 1982/83 to 1989/90. At the 2000 meeting, the Committee agreed that whilst these represented the best estimates for the years surveyed, they were no longer appropriate as estimates of current abundance. An initial analysis of available recent data had suggested that current estimates might be appreciably lower than the previous estimates.

Subsequently, considerable time has been spent considering Antarctic minke whales with a view to obtaining final estimates of abundance and considering any trend in these. This has included a review of data collection methods and analytical methodology. After considering many of the factors affecting abundance estimates, there is still evidence of a decline in the abundance estimates, although it is not clear how this reflects any actual change in minke abundance. Three hypotheses that might explain these results have been identified:

(1) a real change in minke abundance;
(2) changes in the proportion of the population present in the survey region at the time of the survey;
(3) changes in the survey process over time that compromise the comparability of estimates across years.

A considerable amount of work has been undertaken and further work is ongoing. The final part of the Third Circumpolar Survey undertaken as part of the IWC's SOWER research programme has been completed and preliminary work suggests that the estimated abundance may be down to about 40% of the estimates from the Second Circumpolar Survey. Experimental work to examine possible causes has been undertaken on the cruises since 2004/05. Work to finalise an assessment of Antarctic minke whale is continuing in a number of ways and as a minimum it is hoped to agree abundance estimates at the 2008 meeting. In order to achieve this, a specialist Workshop will be held in early 2008.

Southern Hemisphere blue whales

The Committee is beginning the process of reviewing the status of Southern Hemisphere blue whales. In Anchorage, the Committee reviewed information on distribution, stock structure and movements from a number of areas. With respect to abundance and trends, the Committee agreed that: (1) on average, the Antarctic blue whale population increased at a rate of 8.2% per annum (95% CI 3.8–12.5%) between 1978/79 and 2003/2004; and (2) had an estimated circumpolar population size of at least 2,300 (95% CI 1,150–4,500) in 1997/98. However, despite this encouraging news, Antarctic blue whales remain at a very small fraction of their unexploited level.

The Committee reviewed progress towards undertaking an in-depth assessment and has developed a workplan for next year.

Southern Hemisphere humpback whales

Considerable progress has been made in recent years in working towards an assessment of humpback whales. Attention has focussed both on data from historic whaling operations and on newly acquired photo-identification, biopsy and sightings data. In 2006, considerable progress was made towards completing an assessment for three breeding stocks (A: off eastern South America, D: off western Australia and G: off western South America), particularly as a result of an intersessional Workshop held in Hobart, Australia in April 2006. At the 2006 Annual Meeting (IWC, 2007c), the Committee reviewed the results of assessment modelling. It agreed that of the three stocks assessed, the most reliable results were those for Breeding Stock A. This is because there was trend information from surveys on the breeding grounds and less uncertainty about catch allocation from the feeding grounds. It agreed that there has been an increase in abundance in recent decades but that the stock remains well below initial unexploited levels. For Breeding Stock G, the only trend information available was for the feeding grounds and there was also uncertainty about possible stock structure within this stock. For Breeding Stock D, although there is breeding ground trend information and an absolute estimate of abundance, catch allocation is less certain and perhaps influenced by mixing with Breeding Stock E.

In Anchorage, priority was given to trying to complete the Comprehensive Assessment for Southern Hemisphere humpback whale Breeding Stocks B and C off the western and eastern African coasts, respectively. With respect to stock structure it was noted that interchange of whales from different breeding populations on the feeding ground and the migratory process between breeding stocks and feeding stocks are not yet well understood. For Breeding Stock B there is an indication of sub-population structure but this is poorly understood. Any assessments performed at this time should combine information from both putative sub-stocks. For Breeding Stock C there is also an indication of multiple stocks. A more in-depth comparison between sub-areas is required. A number of research recommendations were made that should enable progress towards agreed assessments for these Breeding Stocks in 2008. In addition, the Committee welcomed a novel genetic model approach to estimate minimum abundance in a historic population trajectory for a species undergoing a bottleneck and recommended further research on this.

North Pacific common minke whales

After the completion of the *Implementation* of North Pacific common minke whales in 2003, it was agreed that preparations should begin for an in-depth assessment of common minke whales in the North Pacific, with special emphasis on the J-stock.

This year, the Committee was pleased with the substantial intersessional progress made including receiving results from three cruises and a successful collaboration between Japanese and Korean scientists for genetic analysis. With respect to stock structure, there is now sufficient information available to begin specifying some plausible hypotheses for stock structure but the Committee recommends biopsy sampling for some areas where data are sparse. This will require co-operation amongst range states.

Similarly in terms of distribution and abundance, the Committee was pleased to receive some new information from Japanese and Korean surveys. It was especially pleased to hear that permission had been granted by the Russian Federation for surveys within its EEZ. It requested co-operative work by all range states to fill in information gaps and the Committee was pleased to receive a summary of a workshop of range state scientists held in Korea in late 2006. Work on combining the information obtained from a large number of partial surveys in the region is continuing.

North Atlantic right whales

The Committee has paid particular attention to the status of the North Atlantic right whale in the western North Atlantic in recent years and is extremely concerned about this population, which, whilst probably the only potentially viable population of this species, is in serious danger (*ca* 300 animals). By any management criteria applied by the IWC in terms of either commercial whaling or aboriginal subsistence whaling, there should be no direct anthropogenic removals from this stock.

This year, the Committee once again noted that individuals are continuing to die or become seriously injured as a result of becoming entangled in fishing gear or being struck by ships. It repeated that it is a matter of absolute urgency that every effort be made to reduce anthropogenic mortality in this population to zero. This is perhaps the only way in which its chances of survival can be directly improved. There is no need to wait for further research before implementing any currently available management actions that can reduce anthropogenic mortalities.

The Committee reviewed progress on a number of research and management recommendations concerning this stock.

Western North Pacific gray whales

This is one of the most endangered populations of great whales in the world. There are a number of proposed oil and gas-related projects in and near its only known feeding ground. The population is very small (about 120), and suffers from a low number of reproductive females (about 23), low calf survival, male-biased sex ratio, dependence upon a restricted feeding area and apparent nutritional stress in some years. Other major potential concerns include behavioural reactions to noise (notably in light of increasing industrial activity in the area) and the threat of an oil spill off Sakhalin which could cover all or part of the Piltun area and thus potentially exclude animals from this feeding ground. Again this year, the Committee stressed the urgency of reducing anthropogenic mortality to zero – particularly in the light of four fatal entanglements in fishing gear since 2005. The Committee made a number of mitigation suggestions in this regard and welcomed the intentions of the Japanese authorities to address this issue urgently. Related to this concern is the issue of obtaining better information on the migratory route(s) and breeding grounds of western gray whales. An important aid to this is the use of telemetry but any work in this regard must be undertaken with great care given the precarious state of the population. Given this, the Committee has established a co-ordination group to work with the IUCN facilitated Western Gray Whale Advisory Panel (WGWAP; see http://www.iucn.org/themes/marine/sakhalin/) to ensure that if telemetry work is carried out, it is done to the highest specifications. The Commission has established a voluntary fund for such purposes.

With respect to the WGWAP, the Committee strongly supports its efforts to develop a framework for collaborative research, monitoring and mitigation efforts between oil companies, independent experts, national programmes and authorities and the IWC and other intergovernmental organisations. It particularly urged that all companies in the area co-operate with this process.

EFFECTS OF ENVIRONMENTAL CHANGE ON CETACEANS

There is an increasing awareness that whales should not be considered in isolation but as part of the marine environment; detrimental changes to their habitat may pose a serious threat to whale stocks. The Committee has examined this issue in the context of the RMP and agreed that the RMP adequately addresses such concerns. However, it has also emphasised that the species most vulnerable to environmental threats might well be those reduced to levels at which the RMP, even if applied, would result in zero catches. Over a period of several years, the Committee has developed two multi-national, multi-disciplinary research proposals. One of these, POLLUTION 2000+, has two aims: to determine whether predictive and quantitative relationships exist between biomarkers (of exposure to and/or effect of PCBs) and PCB levels in certain tissues; and to validate/calibrate sampling and analytical techniques. Phase I of POLLUTION 2000+ was completed and reviewed last year (Reijnders *et al*., 2007) and work to develop Phase II is continuing. The other, SOWER 2000, was developed to examine the influence of temporal and spatial variability in the physical and biological Antarctic environment on the distribution, abundance and migration of whales; an important part of that work involves cooperation with other organisations working in the region such as CCAMLR and Southern Ocean GLOBEC. The main body of analytical work will be presented at the 2008 Annual Meeting.

Infectious and non-infectious diseases and impact on cetaceans

The Committee received the results of a 2-day Workshop held just before the Anchorage meeting. Three major topics were discussed: harmful algal blooms (HABs) and associated biotoxins; infectious diseases; and modelling and risk assessment. The Committee recognised that there are increases in the frequency, type and duration of HABs and increases in biotoxin and pathogen related diseases in cetaceans throughout the world. Furthermore, it recognised the need for increased research and standardised reporting in a wide number of disciplines dealing with cetacean health. There is a need for a better understanding of the epidemiology and clinical aspects of infectious and non-infectious diseases that may affect cetacean population status. Finally, the Committee noted that, for most cetacean species, there are currently insufficient disease-specific data to allow modelling exercises to be informative. Data and analytical gaps were identified and *inter alia* the Committee established a Working Group on Cetacean Emerging and Resurging Diseases that will report to the 2008 Annual Meeting.

Handling and release of entangled cetaceans

Five items were discussed at the Commission's request: (1) use of data from release programmes to improve knowledge of the magnitude of entanglements; (2) impact of entanglements at the population level; (3) practical guidelines for dealing with entanglements; (4) types of data that can be collected from entangled/trapped whales; and (5) use of other data that can enhance understanding of entanglement issues (e.g. stranding and scarring data). The Committee emphasised the potential danger in attempting to release large whales from entanglements, and recommended that those who wish to establish disentanglement teams in their countries should work with the appropriate local governmental authorities and seek training from professionals with a track record of safety and success. Data on the fate of released whales are useful to evaluate the success of release operations. However, in conclusion, the Committee emphasised that the most valuable use of disentanglement data is for developing new fishing gear and practices that prevent lethal entanglements of large whales. This is especially important in situations where entanglement is inhibiting the recovery of extremely endangered species or populations.

Other habitat related issues

The Committee agreed that there is a need to hold a workshop on the potential effects of climate change on cetaceans and a scoping meeting for such a workshop will be held before the 2008 Annual Meeting. It also reviewed progress on matters related to acoustic disturbance of cetaceans, particularly related to military exercises and seismic surveys. The Committee repeated a number of its recommendations from last year with respect to collecting baseline information and taking precautionary mitigation measures. The Committee also discussed matters related to sea ice.

Ecosystem modelling

The question of ecosystem modelling in the context of cetacean conservation is an important one and has been addressed by the Scientific Committee on a number of occasions before. Last year the Committee agreed to work collaboratively with both CCAMLR and FAO initiatives (IWC, 2007c). It also agreed on the following with respect to the applicability of ecosystem models for the use of the Committee in providing advice to the Commission:

spatial modelling is a valuable tool to explore possible effects of anthropogenic stressors;

there is a great need for the proper incorporation of uncertainty in ecosystem models;

there is a critical lack of data, in particular at the lower trophic levels, to evaluate the reliability of models;

some models can be useful to generate hypotheses regarding trophic dynamics; and finally

that there is a need for an increased collaboration between scientists designing field studies and those developing analytical models.

In Anchorage, the Committee reviewed progress on a number of issues, particularly collaboration with CCAMLR and FAO. With respect to the former, a joint Workshop will be held in summer 2008 on the modelling of krill predators in the Antarctic. The terms of reference for the Workshop include: reviewing types, relative importance and uncertainties in data required for modelling approaches;

reviewing available input data; summarising the nature of the available data; and identifying and prioritising knowledge gaps. With respect to FAO, the results of an expert consultation on 'modelling ecosystem interactions for informing an ecosystem approach to fisheries' will be reported to the 2008 Annual Meeting. The Committee also reviewed progress in the development of ecosystem models.

SMALL CETACEANS

Despite disagreement within the Commission over the management responsibilities of the IWC with respect to small cetaceans, it has been agreed that the Scientific Committee can study and provide advice on them. As part of this programme, the Committee has reviewed the biology and status of a number of species and carried out major reviews of significant directed and incidental catches of small cetaceans.

In 2001, the Government of Japan had indicated that it would no longer co-operate with the Committee on small cetacean related matters. In 2002, the Committee referred to the great value of the information provided by the Government of Japan on the status of small cetaceans in previous years and respectfully requested that the Government of Japan reconsider its position on this matter and resume the valuable contribution of Japanese scientists to its work on small cetaceans. Unfortunately, this has still not yet happened.

This year, the primary topic was a review of population structure, systematics and status of killer whales. In general, our knowledge of killer whales varies considerably from region to region. In some parts of the world, for example the northwest coast of the USA and Canada, local killer whale populations have been studied for many years; in other areas such as Europe studies are on the increase but, particularly for high seas habitats, knowledge remains sparse. The Committee encourages the continuation of long-term programmes and the establishment of new programmes to increase our understanding of killer whales worldwide. With respect to status, the Committee expressed concern over: (1) the southern resident killer whale population from the coasts of Washington State and British Columbia; (2) killer whales in Greenland; (3) killer whales found near the Strait of Gibraltar; and (4) killer whales of the Oyashio Current ecosystem.

The Committee also reviewed progress on previous recommendations. In recent years, the Committee has repeatedly expressed concern over the critical conservation status of the Chinese river dolphin the baiji; and made recommendations accordingly. This year, it was saddened to receive information that leads us to agree with the conclusions of the scientists who conducted a comprehensive international survey, that the baiji is probably extinct. The Committee expressed its great concern that, despite extensive scientific discourse for more than two decades, little effort was made to implement any real conservation measures. Such highly endangered species require swift and decisive human intervention before they are extinct.

With the probable extinction of the baiji, the vaquita of the upper Gulf of California is probably the most endangered cetacean species. Available information suggests that the current population decline is possibly close to 10% annually, with a critical threshold in approximately 8 years. The Committee reiterated its extreme concern for this species and strongly recommended that resources be found to design and implement a comprehensive programme to eliminate entangling nets from the range of the vaquita through a buy-out programme or other system of compensation to affected fishing communities. Such a programme should include appropriate enforcement and control measures.

The Committee also expressed concerns over a number of issues, including the catches of small cetaceans off West Greenland, the capture of *boto* for bait in the central Brazilian Amazonas and the hand-harpoon hunt for Dall's porpoise populations in the western North Pacific.

Finally, the Committee repeated previous requests for all Governments to submit relevant information on direct and incidental catches of small cetaceans in their national progress reports and for improved information on stock identity and abundance.

SCIENTIFIC ASPECTS OF WHALEWATCHING

The major topic this year concerned quantitative methods for assessing the impacts of whalewatching on cetaceans. In assessing biological impacts of whalewatching on cetaceans the Committee first reviewed some terminological and theoretical aspects before entering into a detailed discussion on methodology for impact studies. Two case studies reporting on population-level effects were considered. The Committee agreed that such long-term studies in areas where whalewatching activities are taking place, especially those studies that measure vital rates over time, are extremely valuable. The Committee requested the Commission to encourage Contracting Governments to provide long-term funding for longitudinal studies. The Committee also received information on short-term impacts, noting that vessel interaction studies should begin before whalewatching traffic reaches saturation point. There is some evidence that in some areas habitat degradation is influencing whale behaviour but determining the mechanism requires further work. It was also noted that a meta-analysis of recent studies would be valuable and an intersessional working group will address this issue.

Last year, the Committee had agreed that it was necessary to concentrate research effort on understanding the interactions between whalewatching impacts on cetaceans and other anthropogenic disturbances and ecological factors (IWC, 2007c). To do so, the Committee had proposed a dedicated Workshop to develop a global scale research design and recommended that such a Workshop be held. The Committee this year agreed that this Workshop should be held prior to the 2008 Annual Meeting.

Given the location of the meeting, whalewatching in Alaska was discussed as a separate item. These operations are highly seasonal, and the main target species are humpback whales and killer whales. For application in other situations, the Committee expressed interest in the design of a study aimed at using ferries to gather survey data and to help assess collision risk, and the Committee recommended the collection of such basic information about the whalewatching industry worldwide. The Committee also reviewed: data sources from platforms of opportunity of potential value to the Committee; reports from a number of intersessional working groups; potential impacts of 'swim with' programmes; progress on developing a compendium of whalewatching guidelines and regulations from around the world; and risk to cetaceans from colliding with whalewatching vessels.

REVIEW AND COMMENT ON SCIENTIFIC PERMITS ISSUED FOR SCIENTIFIC RESEARCH

All proposed scientific permits have to be submitted for review by the Scientific Committee following guidelines issued by the Commission. However, in accordance with the Convention, the ultimate responsibility for issuing them lies with the member nation.

An intersessional meeting to review the results from the JARPA research program was convened in Tokyo in December 2006. The report of the JARPA Review Workshop will be published in the 2008 supplement to the Journal; a very short summary of the Workshop is given below.

In summary, considerable data have been collected by the JARPA programme by both lethal and non-lethal methods, but there was disagreement at the Workshop regarding the analyses presented and the interpretation of some of these data. A number of recommendations for further analyses were made. Much progress has been made in addressing Antarctic minke whale abundance and trends and, provided that the recommendations from the workshop are followed, the Committee may be able to agree estimates, although the confidence intervals are wide and probably will preclude information on trends becoming available. For humpback whales the abundance estimates provided useful steps towards acceptable estimates of abundance.

A considerable amount of work has been undertaken on population structure since the mid-term JARPA Review held in 1997 (IWC, 1998). It was agreed that there are at least two stocks of Antarctic minke whales present in the JARPA research area, and an area of transition in the region around 150°-165°E was suggested. The data do not support the current IWC Management Areas for Antarctic minke whales. Samples from the breeding areas would greatly facilitate these analyses, and are likely to be required to resolve issues relevant to stock structure and mixing within the JARPA research area.

The estimation of natural mortality was the main initial objective of JARPA. However, the confidence limits around the current estimate spanned such a wide range that the parameter is still effectively unknown. More precise estimates of natural mortality rates depend on the use of commercial catch-at-age data, but there are some yet unresolved problems with those data.

The Committee welcomed the oceanographic and krill-related work undertaken since the 1997 Workshop. The Committee also agreed that considerable relevant data had been collected by the JARPA programme on matters related to body condition and feeding. However, it is clear that the nature of the analyses presented at the 2006 Workshop meant that relatively little progress had been made in addressing the role of Antarctic minke whales in the ecosystem. However, a number of more refined analyses were presented and discussed at the Anchorage meeting.

Levels of toxic metals and organochlorines were low compared with whales in the Northern Hemisphere.

In conclusion, the Committee concurred with the view of the 1997 Workshop that 'The results of the JARPA programme, while not required for management under the RMP, have the potential to improve management of minke whales in the Southern Hemisphere' in a number of ways. As has been the case in past Committee discussions on the respective merits of lethal and non-lethal methodology, it was not possible to reach consensus amongst the participants.

Three continuing permits were discussed this year.

JARPA II was a new proposal two years ago. Its stated objectives of the new long-term research programme proposal are: (1) monitoring of the Antarctic ecosystem; (2) modelling competition among whale species and developing future management objectives; (3) elucidation of temporal and spatial changes in stock structure; and (4) improving the management procedure for the Antarctic minke whale stocks.

The proposed catches for the full programme were: 850 (with 10% allowance) Antarctic minke whales, 50 humpback whales (not to begin for two years) and 50 fin whales (10 in the first two years). There was considerable disagreement over the value of this research both within the Scientific Committee and the Commission. As in previous years, there was severe disagreement within the Committee regarding advice that should be provided on a number of issues, including: the relevance of the proposed research to management, appropriate sample sizes and applicability of alternate (non-lethal) research methods.

JARPN II is a long-term research programme primarily aimed at feeding ecology in the context of contributing to the 'conservation and sustainable use of marine living resources in the western North Pacific, especially within Japan's EEZ.' The programme involves the taking of 150 minke whales, 50 Bryde's whales, 50 sei whales and 10 sperm whales in the western North Pacific. Again there is considerable disagreement within the Committee over the value of this research.

The Icelandic research programme on common minke whales in Icelandic waters continued in 2006. The main objective of the project concerns feeding ecology, energetics and multispecies modelling, but several additional subprojects are included in the programme. In 2006, 60 common minke whales were caught under special permit in accordance with the original research proposal. A total of 161 common minke whales have been caught since the start of the research programme in 2003 and it is expected to be completed in 2007. Again, as in the past, different views on the value of this research were expressed in the Scientific Committee.

An important part of the discussions in Anchorage centred around improving the review process for scientific permit proposals. The Committee agreed that the process suggested last year (DeMaster *et al*., 2007) represented a great improvement on the existing process. A few items left over from last year were completed. The key feature of the process is the holding of a specialist Workshop to review proposals for, and results from scientific permits. The Committee agreed that a Standing Steering Group (SSG) established by the Chair of the Scientific Committee would develop an initial list of potential candidates to serve as independent experts at the Workshop. The final list would be agreed by the Chair, Vice-Chair, and Head of Science. Further, the Committee agreed that the Terms of Reference for the specialist Workshop should be developed by the SSG and submitted to the Scientific Committee at the annual meeting prior to the Workshop. The Committee also agreed that scientists selected to be proponents of a proposal for a special permit can participate in the specialist Workshop but that participation will be limited to (1) providing information to the invited experts in addition to that contained in the proposal or research results and (2) answering questions posed by the invited experts. The findings and recommendations in the Workshop report will only reflect the opinions of the independent experts.

Finally, the Committee agreed that there is a desire to ensure that the process of reviewing new proposals and that for the review of existing proposals should be effectively the same and should encompass the process of scientific transparency and independence outlined in DeMaster *et al.* (2007). The Committee recommended the adoption of the revised process for new proposals and in principle to periodic and final reviews. It was recognised that additional work was needed to implement this new process for the review of results. The Committee anticipated that a final protocol will be adopted at the 2008 Annual Meeting. This protocol will then allow for orderly review of results from JARPNII and the Icelandic programme. The Committee was informed that no new Special Permit proposals are anticipated in the foreseeable future.

WHALE SANCTUARIES

In 2004, when reviewing the Southern Ocean Sanctuary (SOS), the Committee endorsed a number of recommendations that were to be implemented generically to the review of sanctuary proposals.

(1) The purpose(s) of IWC Sanctuaries should be better articulated through a set of refined overall objectives (e.g., preserving species biodiversity; promoting recovery of depleted stocks; increasing whaling yield). In particular, the relationships between the RMP and the Sanctuary programme should be articulated.
(2) Appropriate performance measures both for Sanctuaries in general, and the SOS in particular, should be developed. These performance measures should link the refined objectives of the SOS with monitoring programmes in the field.
(3) Systematic inventory and research programmes should be established or further developed so as to build the required information base for a Sanctuary management plan and subsequent monitoring programmes.
(4) A Sanctuary management plan should clearly outline the broad strategies and specific actions needed to achieve Sanctuary objectives.
(5) A monitoring strategy that measures progress toward achieving the Sanctuary objectives should be developed and subsequently implemented. A key component of this monitoring strategy would be the development of tangible indicators to monitor progress.
(6) Review criteria that reflect the goals and objectives of the Sanctuary (as described above) should be established.
(7) The Sanctuary management plan should be refined periodically to account for ecological, oceanographic and possible other changes in an adaptive fashion.

In previous years, the Committee has received requests to review proposals for a South Atlantic Sanctuary and a South Pacific Sanctuary. There has been disagreement within the Committee over whether such Sanctuaries can be justified scientifically. This year no proposals were received for review.

G.P Donovan
Editor

REFERENCES

DeMaster, D., Palka, D., Bjørge, A. and Donovan, G. 2007. Report of the Scientific Committee. Annex P. Revised Suggestions for Improved Review of Special Permit Proposals and Results Within the Scientific Committee. *J. Cetacean Res. Manage. (Suppl.)* 9: 350-52.

International Whaling Commission. 1998. Report of the Intersessional Working Group to Review Data and Results from Special Permit Research on Minke Whales in the Antarctic, Tokyo, 12-16 May 1997. *Rep. int. Whal. Commn* 48:377-412.

International Whaling Commission. 2003. Report of the Scientific Committee. Annex E. Report of the Standing Working Group on the Development of an Aboriginal Subsistence Whaling Management Procedure (AWMP). *J. Cetacean Res. Manage. (Suppl.)* 5:154-255.

International Whaling Commission. 2004. Report of the Workshop to Design Simulation-based Performance Tests for Evaluating Methods Used to Infer Population Structure from Genetic Data, 21-24 January 2003, La Jolla, USA. *J. Cetacean Res. Manage. (Suppl.)* 6:469-85.

International Whaling Commission. 2005a. Chair's Report of the Fifty-sixth Annual Meeting. Annex E. Chair's Proposals for a Way Forward on the RMS. *Ann. Rep. Int. Whaling Comm.* 2004:82-91.

International Whaling Commission. 2005b. Report of the Scientific Committee. *J. Cetacean Res. Manage. (Suppl.)* 7:1-62.

International Whaling Commission. 2005c. Report of the Scientific Committee. Annex D. Report of the Sub-Committee on the Revised Management Procedure. Appendix 2. Requirements and Guidelines for *Implementation. J. Cetacean Res. Manage. (Suppl.)* 7:84-92.

International Whaling Commission. 2005d. Report of the Scientific Committee. Annex E. Report of the Standing Working Group (SWG) on the Development of an Aboriginal Subsistence Whaling Management Procedure (AWMP). *J. Cetacean Res. Manage. (Suppl.)* 7:115-24.

International Whaling Commission. 2006a. Report of the Initial Workshop in the Use of Market Sampling to Estimate Bycatch of Large Whales. *J. Cetacean Res. Manage. (Suppl.)* 8:357-65.

International Whaling Commission. 2006b. Report of the Scientific Committee. *J. Cetacean Res. Manage. (Suppl.)* 8:1-65.

International Whaling Commission. 2006c. Report of the Scientific Committee. Annex D. Report of the Sub-Committee on the Revised Management Procedure (RMP). *J. Cetacean Res. Manage. (Suppl.)* 8:78-90.

International Whaling Commission. 2007a. Report of the 2nd TOSSM (Testing of Spatial Structure Models) Workshop. *J. Cetacean Res. Manage. (Suppl.)* 9:489-98.

International Whaling Commission. 2007b. Report of the Joint NAMMCO/IWC Scientific Workshop on the Catch History, Stock Structure and Abundance of North Atlantic Fin Whales, 23-26 March 2006, Reykjavík, Iceland. *J. Cetacean Res. Manage. (Suppl.)* 9:451-68.

International Whaling Commission. 2007c. Report of the Scientific Committee. *J. Cetacean Res. Manage. (Suppl.)* 9:1-73.

International Whaling Commission. 2007d. Report of the Scientific Committee. Annex D. Report of the Sub-Committee on the Revised Management Procedure. *J. Cetacean Res. Manage. (Suppl.)* 9:88-128.

International Whaling Commission. 2007e. Report of the Scientific Committee. Annex J. Report of the Sub-Committee on Estimation of Bycatch and Other Human-Induced Mortality. *J. Cetacean Res. Manage. (Suppl.)* 9:215-26.

Reijnders, P., Wells, R., Aguilar, A., Donovan, G., Bjørge, A., O'Hara, T., Rowles, T. and Siebert, U. 2007. Report of the Scientific Committee. Annex K. Report of the Standing Working Group on Environmental Concerns. Appendix 2. Report from POLLUTION 2000+: Phase I. *J. Cetacean Res. Manage. (Suppl.)* 9: 261-74.

Roman, S. and Palumbi, S.R. 2003. Whales before Whaling in the North Atlantic. *Science* 301:508-10.

Geographical variations in the external body proportions of Baird's beaked whales (*Berardius bairdii*) off Japan

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ABSTRACT

The use of morphometrics in stock identification studies for cetaceans has been widely employed. In this study, 14 measurements of external body proportions of 172 Baird's beaked whales caught by small-type whaling operations off the Pacific coast of Japan, the Sea of Japan and the Sea of Okhotsk from 1988 to 2004 were examined using canonical discriminant analysis (CANDISC) and ANCOVA with body length as a covariate. The canonical variates obtained from the CANDISC could discriminate between whales from the Pacific coast and the Sea of Japan for both males and females, although some overlap was observed. The flipper size (maximum width and straight length) of the Pacific coast whales was significantly larger (3.9-8.3%) than that of the Sea of Japan whales. The canonical variates of the Sea of Okhotsk whales were located in the middle area between the Pacific coast and the Sea of Japan and a significant difference was not observed, however the Sea of Okhotsk samples consisted of data measured by several researchers and so a sampling error may have been introduced. The morphological differences observed between the Pacific coast and the Sea of Japan whales suggest different stocks occur in these two waters.

KEYWORDS: BAIRD'S BEAKED WHALE; SMALL-TYPE WHALING; MORPHOMETRICS; PACIFIC OCEAN; SEA OF JAPAN; SEA OF OKHOTSK; NORTHERN HEMISPHERE; ASIA; MIGRATION; DISTRIBUTION

INTRODUCTION

Baird's beaked whale (*Berardius bairdii*) belongs to the family Ziphiidae and attains an adult body length of 10-12m (Balcomb, 1989). This species is found in the North Pacific, from the Pribilof Islands and Alaska south to southern California in the east and from Kamchatka and the Sea of Okhotsk to southeast Japan in the west (Balcomb, 1989). In and around the waters off Japan, the existence of three putative stocks (Pacific coast off Japan, the southern Sea of Okhotsk, and the Sea of Japan) has been suggested from earlier studies based on sighting records and whaling operations data (Kasuya, 1986; Kasuya and Miyashita, 1997; Omura *et al*., 1955), but final conclusions have not yet been reached due to a lack of biological materials and data, especially for whales in the Sea of Japan.

This species is a target species for small-type whaling conducted in the coastal waters off Japan. The current annual quota for this species permitted by the Fisheries Agency of Japan is 66 whales (52 in the Pacific coast off Japan, 4 in the Sea of Okhotsk, and 10 in the Sea of Japan), which was set for 2005 onwards (Kishiro, 2005). For effective management of these fisheries and the populations of these whales, it is necessary to clarify its stock structure.

A comparison of multi-measurements of body proportions has been commonly used to obtain information on stock structure for several cetacean species, including fin whales (*Balaenoptera physalus*), common minke whales (*B. acutorostrata*), Bryde's whales (*B. edeni*) and Dall's porpoise (*Phocoenoides dalli*) (Amano and Miyazaki, 1996; Christensen *et al*., 1990; Jover, 1992; Kato *et al*., 1992; Kato and Yoshioka, 1995). In this study, this method is applied to Baird's beaked whales.

MATERIALS AND METHODS

Measurement data

Since 1988, the National Research Institute of Far Seas Fisheries (NRIFSF) has examined almost all harvested Baird's beaked whales at whaling land stations and collected biological data and samples including external measurements. To minimise problems because of measurements being taken by different people, only data collected by the author have been used in the Pacific coast samples (collected from 1992 to 2001) and the Sea of Japan samples (from 1999 to 2004), although for the Sea of Okhotsk samples, small sample sizes mean that data measured by several researchers and held by the NRIFSF were used (those data were collected from 1988 to 2004). The number of samples used in this study are summarised in Table 1. Fig. 1 shows the catch locations of those whales.

As shown in Fig. 2, a total of 18 external measurements were collected from the whales landed at the whaling land stations at Ayukawa, Miyagi prefecture and Wadaura, Chiba prefecture (Pacific coast samples), Hakodate, Hokkaido (Sea of Japan samples) and Abashiri, Hokkaido (Sea of Okhotsk samples). All measurements except for V12 to V18 were measured on a straight and parallel plane to the body axis. Measurements V13, V14, V15, and V16 were excluded from the geographic comparisons due to the small sample size (those parts of the animal were often cut off by fishermen before measurements could be taken) and the difficulty in obtaining an exact measurement, which might result in bias. After outliers were excluded by plotting the data against body length (V1), all values were log-transformed to minimise the size differences between the absolute values of different measurements.

Multivariate comparison

To examine the difference between the morphological features among whales on the Pacific coast, the Sea of Japan, and the Sea of Okhotsk, a multivariate approach was used. In order to address the effect of the difference of body size by geographical area (sampling groups), a principal component analysis (PCA) was first conducted using 14 variables (measurements V1 to V12, V17 and V18). The PCA transforms the original variables into new variables that have zero intercorrelation and new variables (principal components) which have positive values in all eigenvectors;

Table 1

Number of samples used in this study.

Area	Year	Male	Female	Total	Researcher* (No. of whales measured)
Pacific coast of Japan	1992-2001	47	31	78	TK (78)
Sea of Japan	1999-2004	21	20	41	TK (41)
Sea of Okhotsk	1988-2004	34	19	53	HK (9), HY (2), JiT (2), JT (19), KK (2), MA (2), MY (2), RO (4), SK (2), ST (2), TH (2), TI (2), TK (1), TN (2)

*HK: Hidehiro Kato; HY: Hideyoshi Yoshida; JiT: Jiro Takeuchi; JT: Junko Taguchi; KK: Koichi Kimura; MA: Mika Aoki; MY: Mineo Yamamoto; RO: Ryosuke Okamoto; SK: Satoko Kawazu; ST: Shigeo Tabata; TH: Takanori Hara; TI: Tatsuya Isoda; TK: Toshiya Kishiro; TN: Tomoko Nakazato.

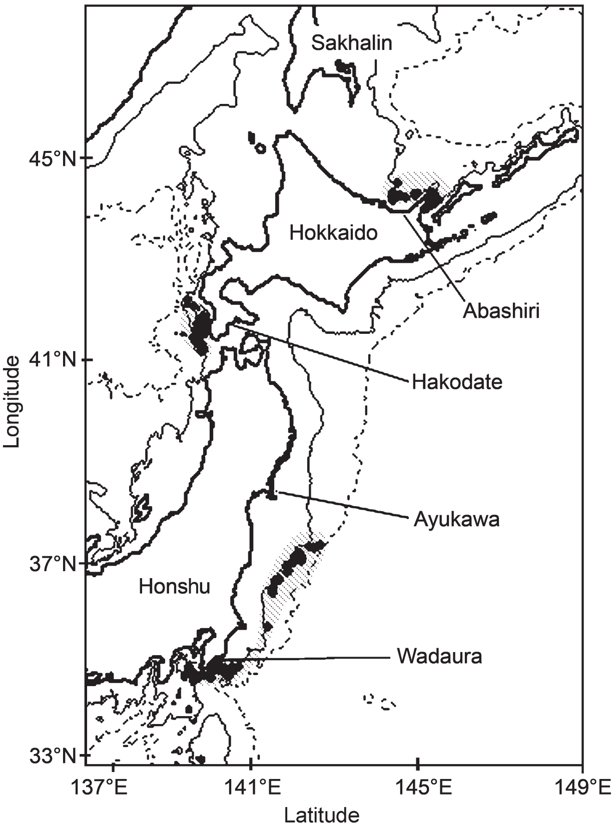

Fig. 1. Catch positions of Baird's beaked whales used in this study. Shaded areas indicate the small-type whaling grounds. Solid and dotted lines indicate the 1,000m and the 3,000m depth contour lines, respectively.

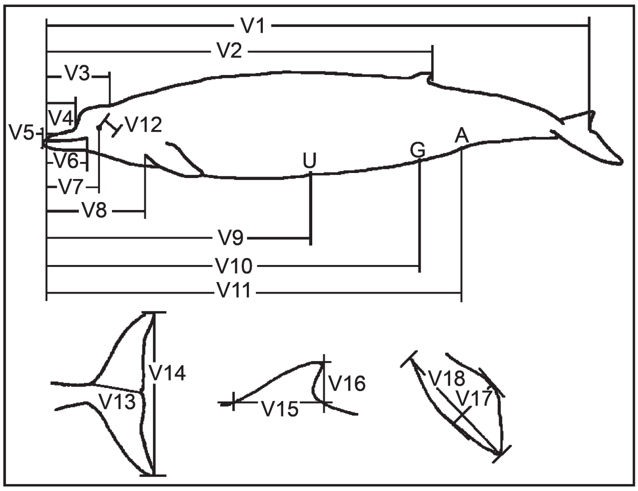

Fig. 2. Schematic diagram of the body proportion measurements of Baird's beaked whales. V1: Body length from tip of snout to notch of flukes; V2: Tip of snout to tip of dorsal fin; V3: Tip of snout to blowhole; V4: Length of snout; V5: Projection of lower jaw beyond tip of snout; V6: Tip of snout to angle of gape; V7: Tip of snout to centre of eye; V8: Tip of snout to anterior insertion of flipper; V9: Tip of snout to umbilicus; V10: Tip of snout to centre of reproductive aperture. V11: Tip of snout to anus; V12: Centre of eye to centre of ear; V13: Fluke length from anterior insertion to notch; V14: Fluke width from tip to tip; V15: Length of base of dorsal fin; V16: Vertical height of dorsal fin; V17: Maximum width of flipper; V18: Straight length of flipper from tip to anterior insertion.

this represents the body size or growth variation of the data (Christensen *et al*., 1990). The remaining components represent the shape variation, and might be not affected by the body size. A canonical discriminant analysis (CANDISC) was then carried out for geographical comparisons, using the scores obtained from the remaining components. Obtained canonical variates were plotted on the first and second axes of the canonical variates by geographic sampling group. Analyses were conducted by sex.

Comparisons of measurements

The comparison of the respective measurements by geographical area (separately by sex) was conducted using an analysis of covariance (ANCOVA) with body length (V1) as a covariate. If no significant relationship with body length was found, an analysis of variance (ANOVA) was conducted. The statistical calculations in this study were conducted using the software package SAS version 8.02.

RESULTS

Multi-measurement comparison

Table 2 shows the mean, standard deviation (SD) and range of respective measurements by sex and geographical area. From the results of the PCA, the first principal component (PRIN1) had positive values in all eigenvectors, and the eigenvalue (ratio of contribution) of the PRIN1 was 42.8% for males and 51.7% for females, respectively. Table 3 shows the canonical variates obtained by the CANDISC using the principal components except for PRIN1. The canonical variate of each whale is plotted in Fig. 3.

The distribution of the canonical variates appeared to reflect the geographic sampling groups in both males and females, although some overlap was observed. In particular, the Pacific coast whales and the Sea of Japan whales were separately distributed along the first canonical axis and the Sea of Okhotsk whales were distributed in and around the middle area between the Pacific coast and the Sea of Japan groups. The squared distance between the geographic areas and the probability of those distances being larger than the Mahalanobis' distance (SAS Institute Inc., 2000) is shown in Table 4. The null hypothesis (that the whales are from same population) was rejected for the comparison between the

Table 2

The sample size, mean, standard deviation (SD) and range of respective measurements by sex and area.

		Pacific coast of Japan					Sea of Okhotsk					Sea of Japan				
Sex	Measurements	n	Mean (cm)	SD	Max.	Min.	n	Mean (cm)	SD	Max.	Min.	n	Mean (cm)	SD	Max.	Min.
Male	V1	47	998.9	37.55	1,090	886	34	997.8	78.82	1,080	700	21	940.3	36.80	1,015	840
	V2	46	717.4	27.19	764	635	22	703.5	68.89	780	505	21	673.1	25.14	713	595
	V3	46	107.3	6.85	119	84	28	107.4	11.10	124	71	21	109.4	5.33	119	95
	V4	46	60.5	4.83	71	46	29	58.0	8.02	75	34	21	60.6	4.04	69	54
	V5	42	7.5	2.10	12	2.7	23	7.2	2.72	13.8	2	21	6.7	1.39	9.3	3.7
	V6	46	59.8	4.47	74	50	27	62.2	6.78	73	42	21	63.2	4.86	72	53
	V7	45	92.4	5.21	103	81	23	93.5	11.04	110	62	21	95.1	6.32	108	82
	V8	46	158.9	10.09	187	140	24	160.4	20.19	191	102	21	155.7	8.42	173	134
	V9	46	440.9	18.29	480	390	24	438.0	33.50	479	350	21	415.4	18.11	440	371
	V10	45	648.8	26.28	711	580	23	641.8	57.23	690	460	21	611.7	22.94	640	542
	V11	46	722.0	28.27	790	635	24	711.4	61.06	773	505	21	678.5	27.28	730	602
	V12	41	21.6	1.31	24	19	22	21.7	1.79	25	17.5	21	21.4	1.11	23.5	19
	V13	36	83.0	7.61	105	65	20	81.5	10.30	103	66	21	79.4	7.53	94	69
	V14	16	280.6	16.21	314	252	10	271.9	15.44	289	245	16	251.6	15.89	280	220
	V15	44	59.1	4.65	70	49	19	58.2	9.35	74	40	21	57.7	5.35	68	49
	V16	45	25.1	3.82	38	19	20	25.1	2.92	30	19	21	22.3	2.42	27	19
	V17	43	42.4	2.02	47	37	19	40.8	3.55	48	31	21	38.9	2.91	44	29
	V18	45	125.0	6.42	141	110	16	123.6	7.56	135	107	21	115.0	4.87	123	106
Female	V1	31	1,023.0	47.26	1,088	899	19	1,008.1	55.34	1,094	874	20	970.2	51.36	1,075	866
	V2	31	738.3	37.33	794	640	14	728.8	41.84	789	640	19	695.2	36.11	756	628
	V3	31	110.9	5.20	119	96	17	114.4	8.58	134	103	20	114.1	7.59	127	100
	V4	31	63.3	4.23	72	56	18	63.2	5.24	72	52	20	63.2	6.35	77	49
	V5	29	7.0	2.08	12.5	4	15	7.5	2.28	11.6	3.4	20	6.7	1.54	10	4.8
	V6	31	62.7	4.09	75	52	18	66.2	5.51	79	58	19	65.8	5.24	73	57
	V7	31	95.7	5.28	107	84	17	98.9	8.44	120	87	20	98.8	6.03	106	85
	V8	30	159.7	11.61	180	138	14	162.1	12.94	183	142	20	163.8	11.14	187	141
	V9	30	446.4	23.68	479	390	15	445.7	30.86	494	401	20	434.3	22.88	491	401
	V10	31	709.3	35.96	750	614	16	694.2	45.37	769	619	20	676.9	36.19	735	609
	V11	31	744.9	39.12	793	644	16	734.9	40.31	790	649	20	706.2	37.41	766	638
	V12	30	21.9	1.44	24	19	16	21.3	1.95	25	18	20	21.3	1.07	24	19
	V13	26	86.5	7.86	100	71	12	78.2	8.26	96	65	20	78.1	6.80	93	65
	V14	7	282.9	14.42	297	255	3	276.3	23.18	303	261	12	258.2	12.73	278	239
	V15	30	63.1	5.12	75	53	12	64.7	7.04	80	55	20	59.9	5.88	78	52
	V16	29	25.3	2.98	32	20	14	26.4	3.05	31	21	20	24.4	3.69	32	17
	V17	31	42.2	2.22	46	36	13	40.7	2.95	45	35	19	38.8	1.42	41	36
	V18	31	125.9	7.92	139	97	9	120.6	8.50	131	108	20	114.9	6.72	129	102

Table 3

The canonical coefficients obtained from the Canonical discriminant analysis using 13 principal components (PRIN2-14) based on the 14 external measurements.

	Male		Female	
Variable	1st Canonical variate	2nd Canonical variate	1st Canonical variate	2nd Canonical variate
PRIN2	0.5731	0.2021	0.6334	0.1949
PRIN3	-0.0489	0.3865	-0.2641	0.4539
PRIN4	0.2159	0.0222	0.9820	0.1076
PRIN5	-0.7411	0.1609	0.4361	-0.8428
PRIN6	0.2024	-0.1880	0.8443	-0.0613
PRIN7	-0.1401	0.1771	-0.3544	-0.2609
PRIN8	-0.5336	0.5086	-0.2245	0.0227
PRIN9	-0.1189	0.5943	-0.2018	0.2050
PRIN10	-0.6265	-0.1482	0.0795	-0.7011
PRIN11	-0.1917	-0.4298	-0.3169	1.3358
PRIN12	-0.5115	-1.7969	0.3363	0.4149
PRIN13	1.9044	-1.5993	-0.4152	2.7024
PRIN14	1.0454	-2.4695	0.4682	-3.8847

Pacific coast and the Sea of Japan groups ($p<0.01$), but accepted for the Pacific coast and the Sea of Okhotsk and for the Sea of Japan and the Sea of Okhotsk groups respectively.

Difference in respective body parts

The number of measurements compared by the ANCOVA was five (V2, V8, V9, V10 and V11) for males and six (V2, V9, V10, V11, V17 and V18) for females. Table 5 shows the least square mean of the measurements obtained from the ANCOVA between the three waters. Results indicated that measurement V17 (the maximum width of the flipper) from the Pacific coast females was significantly longer than those of both the Sea of Japan and the Sea of Okhotsk females, and measurement V18 (the straight length of the flipper from anterior insertion to tip) from the Pacific coast females was also significantly longer than those of the Sea of Japan females (Tukey-Kramer's test, $p<0.05$).

Results of the ANOVA for the rest of the measurements are shown in Table 6. In males, measurements V17 and V18 from the Pacific coast were significantly longer than those from the Sea of Japan, whilst V17 from the Sea of Okhotsk was also significantly longer than for the Sea of Japan (Tukey-Kramer's test, $p<0.05$).

The measurements for which a significant difference was observed both involved the flipper (V17 and V18). Based on the least square means, the Pacific coast females had 3.9% (V17) to 4.3% (V18) larger flippers than those of the Sea of Japan, and the mean length of the flipper of the Pacific coast males was 8.0% (V18) to 8.3%(V17) larger than that of the Sea of Japan.

DISCUSSION

The morphological differences between the geographical areas observed in this study can be summarised as follows:

(1) morphological features based on the multi-measurements were significantly different between the Pacific coast whales and the Sea of Japan whales;
(2) the Pacific coast whales had 3.9-8.3% larger flippers than those of the Sea of Japan whales for both sexes.

Some measurements of the flippers of the Sea of Okhotsk whales were also significantly different from those from the Pacific coast and the Sea of Japan whales. However, the results of the multi-measurement comparisons showed no significant difference between the Sea of Okhotsk and other waters. As shown in Fig. 3, the Sea of Okhotsk whales were located between the Pacific coast and the Sea of Japan whales, with a large overlap with the Sea of Japan whales. One possibility is that this reflects some migration of whales from the Sea of Japan to the Sea of Okhotsk and the presence of more than one stock in these waters. However, the Sea of Okhotsk samples used in this study included data measured by a variety of researchers, most of whom were temporary persons with little experience of field surveys. The inclusion of these data might explain the large SD observed for the Sea of Okhotsk samples (Table 2) and makes it difficult to reach a reliable conclusion for the Sea of Okhotsk whales.

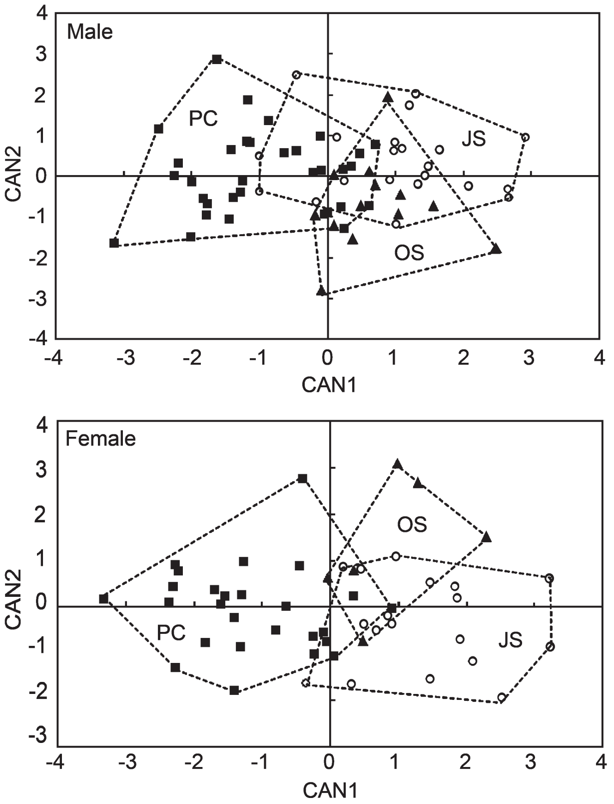

Fig. 3. Distribution of the canonical variates obtained by the canonical discriminant analysis. Open circle: the Sea of Japan sample (JS); closed square: the Pacific coast sample (PC); closed triangle: the Sea of Okhotsk sample (OS).

Although measurement bias may exist even in data collected by a single person, this bias is minimal in the comparison between data and thus the results of the differences found from the comparison between the Pacific coast and the Sea of Japan whales are thought to reflect true differences between stocks.

Omura *et al.* (1955) reported that the body length of Baird's beaked whales caught in the Sea of Japan was about four feet smaller than from other waters, based on catch data collected from small-type whaling between 1948 and 1952. They also reported that the length at sexual maturity of the whales was 32-33 feet for males, and 33-34 feet for females and they proposed that only young whales approached the coast in the whaling ground of the Sea of Japan. If body proportions change with growth then the difference in body proportions will be affected by body size. However, such a change was not detected in the range of body lengths used in this study and body length factor was eliminated as a covariate and/or a principal component. Therefore, those effects are thought to be minimal in the body proportion differences observed in this study. To examine the possible differences in segregation as suggested by Omura *et al.* (1955) requires further studies (e.g. on body length composition and age, growth and sexual or physical maturity) and such work is ongoing by the NRIFSF.

Table 4

The squared distance of the canonical variates between the areas (upper right corner) and the probability of the distance larger than the Mahalanobis' distance with a null hypothesis of same population (lower left corner). Values with underlines indicate significant difference between the areas.

	Male			Female		
Area	Pacific coast of Japan	Sea of Okhotsk	Sea of Japan	Pacific coast of Japan	Sea of Okhotsk	Sea of Japan
Pacific coast of Japan	-	3.264	3.944	-	6.039	6.259
Sea of Okhotsk	0.0515	-	1.291	0.1083	-	3.051
Sea of Japan	0.0015	0.8021	-	0.0008	0.6687	-

Table 5

The least square mean of respective measurements by sex and area obtained from the ANCOVA with body length as covariate. Values with the same superscript are significantly different (Tukey-Kramer test, $p<0.05$).

	Male			Female		
Measurements	Pacific coast of Japan (cm)	Sea of Okhotsk (cm)	Sea of Japan (cm)	Pacific coast of Japan (cm)	Sea of Okhotsk (cm)	Sea of Japan (cm)
V2	703.9	699.5	700.6	723.0	726.4	717.8
V8	156.0	157.9	162.4	-	-	-
V9	434.4	435.5	429.3	438.4	443.2	446.0
V10	637.2	637.2	636.3	694.5	690.3	699.1
V11	709.1	706.1	706.8	729.4	731.2	729.1
V17	-	-	-	$41.5^{a,b}$	40.4^{a}	39.9^{b}
V18	-	-	-	123.5^{c}	119.3	118.2^{c}

Table 6

Comparison of the mean of respective measurements that had no significant relationship with body length. Values with the same superscript are significantly different (ANOVA with Tukey-Kramer test, $p<0.05$).

	Male			Female		
Measurments	Pacific coast of Japan (cm)	Sea of Okhotsk (cm)	Sea of Japan (cm)	Pacific coast of Japan (cm)	Sea of Okhotsk (cm)	Sea of Japan (cm)
V3	107.3	107.4	109.4	110.9	114.4	114.1
V4	60.5	58.0	60.6	63.3	63.2	63.2
V5	7.5	7.2	6.7	7.0	7.5	6.7
V6	59.8	62.2	63.2	62.7	66.2	65.8
V7	92.4	93.5	95.1	95.7	98.9	98.8
V8	-	-	-	159.7	162.1	163.8
V12	21.6	21.7	21.4	21.9	21.3	21.3
V17	42.4^{a}	40.8	38.9^{a}	-	-	-
V18	125.0^{b}	123.6^{c}	$115.0^{b,c}$	-	-	-

According to studies on sighting records and whaling operations, Baird's beaked whales appear in early summer off the Boso Peninsula near the southern limit of their distribution range on the Pacific coast off Japan, with numbers peaking in late Autumn off the Pacific coast of Hokkaido (Kasuya and Miyashita, 1997). In the Sea of Japan, past catch records from 1948-1952 indicate the occurrence of whales in Toyama Bay (at about 37°N) and off the Sea of Japan coast off Hokkaido (41-42°N) in June to August (Omura *et al*., 1955) and the majority of the catch in 1999 to 2004 was in the Sea of Japan coast off Hokkaido in May to June. Those whaling grounds are characterised by the presence of deep waters greater than 1,000m near the coast (Fig. 1); the maximum depth of these waters exceeds 3,000m. Baird's beaked whales are known to bottom feed over the continental slope on the Pacific coast at depths between 1,000 and 3,000m (Kasuya and Miyashita, 1997) and mainly feed on damsel fish and squid which are abundant in waters >1,000m (Ohizumi *et al*., 2003; Walker *et al*., 2002). The main prey found in the stomach contents were rat-tails and hakes in the Pacific coast of Japan, while pollock and squid were also important prey in the southern Sea of Okhotsk (Ohizumi *et al*., 2003). This suggests that the topographic features of the sea bottom may act as barriers between stocks. The Tsugaru Strait between the Sea of Japan and the Pacific Ocean comprises waters <200m in depth and Kasuya (1986) proposed that this Strait potentially blocks migration between these waters. Since there are no sightings or catch records for this species in this strait, despite intensive searching effort made during the recent whaling operations based on the land stations at Hakodate, southern coast of Hokkaido in 1999 to 2004, the results of this study are consistent with those of Kasuya (1986). The morphological differences observed in this study between whales from the Sea of Japan and the Pacific Ocean probably reflect the fact that migration between the two stocks can not take place.

The relationships between the whales in the southern Sea of Okhotsk and other waters could not be clarified using the morphological examinations conducted in this study, but should be resolved by other studies such as the genetic examination using samples from the catch or biopsy skin sampling and the direct satellite tracking. These studies will be conducted in the near future.

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REFERENCES

Amano, M. and Miyazaki, N. 1996. Geographic variation in external morphology of Dall's porpoise, *Phocoenoides dalli*. *Aquat. Mamm.* 22(3): 167-74.

Balcomb, K.C. 1989. Baird's beaked whale – *Berardius bairdii* Stejneger, 1883; Arnoux's beaked whale – *Berardius arnuxii* Duvernoy, 1851. pp.261-88. *In*: Ridgway, S.H. and Harrison, R. (eds). *Handbook of Marine Mammals. River Dolphins and the Larger Toothed Whales*. Academic Press, London and San Diego. i-xix+422pp.

Christensen, I., Haug, T. and Wiig, Ø. 1990. Morphometric comparison of minke whales *Balaenoptera acutorostrata* from different areas of the North Atlantic. *Mar. Mammal Sci*. 6(4): 327-38.

Jover, L. 1992. Morphometric differences between Icelandic and Spanish fin whales (*Balaenoptera physalus*). *Rep. int. Whal. Commn* 42: 747-50.

Kasuya, T. 1986. Distribution and behavior of Baird's beaked whales off the Pacific coast of Japan. *Sci. Rep. Whales Res. Inst., Tokyo* 37: 61-83.

Kasuya, T. and Miyashita, T. 1997. Distribution of Baird's beaked whales off Japan. *Rep. int. Whal. Commn* 47: 963-68.

Kato, H., Kishiro, T., Fujise, Y. and Wada, S. 1992. Morphology of minke whales in Okhotsk Sea, Sea of Japan and off the East coast of Japan, with respect to stock identification. *Rep. int. Whal. Commn* 42: 437-42.

Kato, H. and Yoshioka, M. 1995. Biological parameters and morphology of Bryde's whales in the western North Pacific, with reference to stock identification. Paper SC/47/NP11 presented to the IWC Scientific Committee, May 1995 (unpublished). 19pp. [Paper available from the Office of this Journal].

Kishiro, T. 2005. Baird's beaked whale, *Beradius bairdii*, Sea of Japan, Sea of Okhotsk and Pacific Ocean. pp.320-23. *In*: Muto, F. (eds). *The Current Status of International Fishery Stocks in 2005*. Fisheries Agency and Fisheries Research Agency, Tokyo. 467pp. [In Japanese].

Ohizumi, H., Isoda, T., Kishiro, T. and Kato, H. 2003. Feeding habits of Baird's beaked whales *Berardius bairdi*, in the western North Pacific and Sea of Okhotsk off Japan. *Fishery Science* 69: 11-20.

Omura, H., Fujino, K. and Kimura, S. 1955. Beaked whale *Berardius bairdi* off Japan, with notes on *Ziphius cavirostris*. *Sci. Rep. Whales Res. Inst., Tokyo* 10: 89-132.

SAS Institute Inc. 2000. *SAS/Stat User's Guide, Version 8*. SAS Institute Inc., Cary, North Carolina. 1,464pp.

Walker, W.A., Mead, J.G. and Brownell, R.L., Jr. 2002. Diets of Baird's beaked whales, *Beradius bairdii*, in the southern Sea of Okhotsk and off the Pacific coast of Honshu, Japan. *Mar. Mammal Sci*. 18(4): 902-19.

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Estimates of large whale abundance in Greenlandic waters from a ship-based survey in 2005

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ABSTRACT

A ship-based line transect survey of large whales in East and West Greenland was conducted in September 2005. The survey platform primarily targeted capelin, *Mallotus villosus*, using acoustic methods and systematically covered the east and west coasts of Greenland from the coast to the shelf break (approximately 200m). The surveyed area comprised 81,000km^2 in East Greenland and 225,000km^2 in West Greenland. A total of 194 sightings of 13 cetacean species were obtained and standard line transect methods were used to derive abundance estimates of the four most commonly encountered large cetaceans. Fin whales, *Balaenoptera physalus*, were most abundant in East Greenland (3,214, 95% CI=980-10,547) with lower abundances estimated for West Greenland (1,980, 95% CI=913-4,296). Sei whales, *B. borealis*, were frequently encountered in the same areas as fin whales, but the estimated abundance in East Greenland (763, 95% CI=236-2,465) was lower than in West Greenland (1,599, 95% CI=690-3,705). Humpback whales, *Megaptera novaeangliae*, were found both in offshore and coastal areas of West Greenland (1,306, 95% CI=570-2,989) and in low numbers in East Greenland (347, 95% CI=48-2,515). Finally, common minke whale, *B. acutorostrata*, abundance was estimated at 1,848 (95% CI=197-17,348) for East Greenland and 4,479 (95% CI=1,760-11,394) for West Greenland. Inclusion of sightings of unidentified large baleen whales in West Greenland distributed in proportion to species and strata increased abundance estimates for fin, sei, and humpback whales to 2,824 (95% CI=1,346-5,925), 2,009 (95% CI=948-4,260), and 1,514 (95% CI=560-4,089), respectively. Despite good conditions and considerable effort, few cetaceans were observed in the northernmost strata in West Greenland. This suggests that the southbound fall migration of large whales from North West Greenland had already started by the time the survey was initiated. The abundance estimates presented in this study are negatively biased. No corrections were applied for whales missed by observers or for whales submerged during the passage of the survey platform, which should cause a particularly large negative bias, for the estimates of common minke whale abundance.

KEYWORDS: FIN WHALE; COMMON MINKE WHALE; HUMPBACK WHALE; SEI WHALE; SURVEY-VESSEL; NORTHERN HEMISPHERE; ABUNDANCE ESTIMATE; *g*(0); DISTRIBUTION

INTRODUCTION

Information on the abundance of large whales in Greenland waters, including fin whales, *Balaenoptera physalus*, sei whales, *B. borealis,* humpback whales, *Megaptera novaeangliae*, and common minke whales, *B. acutorostrata*, is scarce and outdated. During 1982/83, the first ship-based cetacean sighting surveys were conducted in West Greenland by the Greenland Fisheries Research Institute (m/v *Regina Maris* and m/v *Kathleen*). Inclement weather conditions prevented the collection of sufficient sightings for abundance estimates from these surveys and no abundance estimates were calculated. After this, aerial surveys were used as the survey platform to increase coverage during the relatively small window of time when survey conditions are optimal in Greenlandic waters.

Between 1983 and 1993, visual aerial surveys of large cetaceans were conducted nine times in West Greenland. Only two times during this decade (cue-counting surveys in 1987/88 and again in 1993) did the surveys provide useful abundance estimates of large whales (Hiby and Hammond, 1989; Larsen, 1995; Larsen *et al*., 1989). From these surveys, fin whale abundance was estimated at 1,096 (95% CI=520-2,100) in West Greenland in 1987/88 (IWC, 1992). In 1993, another estimate of approximately 200 fin whales was obtained, but was considered unrealistically low due to poor survey coverage (Larsen, 1995). In 2002 and 2004, visual aerial photographic surveys were conducted (Witting and Kingsley, 2005) and resulted in an estimated abundance of fin whales (980, 95% CI=402-2,392), similar to that obtained in 1987/88.

Abundance estimates of common minke whales were also obtained from the cue counting survey in 1993 and were estimated at 8,371 (95% CI=2,414-16,929) whales in West Greenland (Larsen, 1995). This estimate was larger (but not significantly different) than the estimate obtained on the 1987/88 survey (3,266 common minke whales, 95% CI=1,700-5,710) (IWC, 1990, p.43). The visual photographic surveys in 2002 and 2004 resulted in an abundance estimate of only 510 common minke whales (95% CI=138-1,889). This estimate was considered problematic for a number of reasons, including the fact that it seemed unrealistically low because the annual take in West Greenland (about 170 common minke whales) has remained relatively stable for the past 20 years (for a full discussion see IWC, 2006). Sei whale abundance has never been estimated in Greenland.

Humpback whale abundance has been estimated in Greenland based on visual and photographic surveys, as well as photo-identification (ID) techniques. Photo-ID surveys for humpback whale abundance were conducted off West Greenland in July and August 1988-93 (Larsen and Hammond, 2004). The surveys covered the coast between 62° and 66°N offshore to the 200m depth contour. A combined estimate over five years of surveys resulted in an estimate of 360 humpback whales (95% CI=314-413) in summer. Other estimates of humpback whale abundance in West Greenland include a line transect analysis of the visual aerial survey data from 1993 (Kingsley and Witting, 2001), which resulted in an uncorrected estimate of 599 (95% CI=237-1,512), as well as an estimate of 400 humpbacks based on sightings of 3 whales (CV=0.64) collected during aerial photographic surveys in 2002 and 2004 and the assumption that humpback whales spend a quarter of their time at the surface. However, no variance was associated with the coarse correction factor applied to these data (Witting and Kingsley, 2005).

It is important to notice that except for the photographic surveys in 2002-04, all previous surveys were conducted between mid July and late-August to cover the peak occurrence of common minke whales along the West Greenland coast. In particular common minke whales have shown affinity for southbound movements in September (Heide-Jørgensen *et al*., 2001; Víkingsson and Heide-Jørgensen, 2005) and surveys conducted in September may not capture all of the whales found earlier in the summer.

In 2004, the Scientific Committee of the International Whaling Commission (IWC) had stated that it is difficult to provide satisfactory advice on sustainable takes from Greenlandic stocks without recent and robust abundance estimates (IWC, 2005). Available estimates of all large baleen whale abundance in West Greenland waters at that time were either outdated or unreliable. Thus, there was an urgent need for abundance estimates in Greenland given that common minke and fin whales are taken annually in Greenlandic waters, with removals in West Greenland between 1999-2004 averaging 172 common minke whales and 9 fin whales. Additionally, a total of 9 humpback whales were caught in 2004/05 as bycatch in pond nets and in a crab fishery that utilises bottom traps attached to surface buoys.

This manuscript reports on a ship-based survey of large cetaceans conducted in West and East Greenland in September 2005. Abundance estimates were developed for all large whale species where sufficient sightings were available. These provide updated abundance estimates for large cetaceans in Greenland waters as well as updating knowledge on distribution and numbers at both coasts. A simultaneous aerial survey provided additional information about abundance and distribution of large whales in West Greenland (Heide-Jørgensen *et al*., 2007).

METHODS

Field methods

The Icelandic fisheries research vessel r/v *Bjarni Saemundsson* RE 30 (length 56m and height to upper deck 7m) was used as the platform for the sighting survey. The survey was conducted between 2 September and 3 October 2005 during a systematic acoustic survey targeting capelin, *Mallotus villosus*, on the West and East Greenland shelf.

Observations were made from a wooden box (length: 180cm, width: 226cm, height of walls: 145cm) built with an effective windshield on the roof of the bridge. Four cetacean observers scanned in pairs from the main platform, each covering 90 degrees in front of the vessel. Observers had an angle board mounted in front of them and a distance stick on a string around their neck. The length of the strings was such that one mm from the horizon corresponded to a declination angle of 0.1 degree, when measuring standing on the observation platform. The eye height of the observers was approximately 10.3m above sea level. When a whale or a cue of a whale was observed, the observer immediately measured the angle to the sighting with the angle board and the distance from the horizon to the sighting with the distance stick, which was later converted into distance from the boat to the whale. When the horizon was not visible or in the instances when a sighting was too brief for the observer to measure both angle and distance, the observer would estimate the distance by eye.

The observers were trained to estimate distances through distance estimation experiments, where a zodiac with a radar reflector was placed at distances between 100-1,600m to the boat (within the survey field). The observers estimated the distance by eye and then measured the distance using distance sticks. The real distance to the zodiac was measured with a laser rangefinder (Zeiss, Halem II) and the radar of the ship by the captain. Initially all observers' slightly underestimated distances exceeding 1,000m, both when estimated by eye and when measured with distance sticks. This underestimation was likely to have been reduced after the distance training, as the observers became aware of the bias. A second distance estimation experiment was scheduled to test this, but it could not be carried out due to low visibility and bad weather.

The observers only used binoculars for species identification after recording a whale sighting. On-effort observations were carried out during all hours of daylight and when weather conditions permitted (Beaufort sea state <6 and visibility >500m).

Measurements of angle and distance were noted in a sighting log together with date, time, position, group size and composition, swimming direction and surface behaviour. An effort log was kept every half hour or less if observation conditions changed. The effort log contained information about the date, time, location, bearing of the ship, weather and visibility. Positional information was obtained with a handheld Global Positioning System (GPS) or from instruments on the bridge.

The survey was designed to systematically cover the area between the coast of West Greenland and offshore (up to 100km) to the shelf break. Transect lines were placed in an east-west direction and the survey started at the northernmost lines. Some fjord areas including Vaigat, Disko Bay and Nuuk Fjord were also covered. Ferry time between Iceland and the surveyed area in West Greenland was used for whale sightings as weather permitted. Based on expected densities of whales the surveyed area was divided into 6 strata, with 1 stratum in East Greenland and 5 strata in West Greenland (Fig. 1). The Disko Bay area and the Nuuk Fjord were considered separate strata.

Analysis

Abundances of fin, sei, humpback and common minke whales were estimated using *Distance* 4.1 (Thomas *et al*., 2001). Based on the minimum Akaike Information Criteria (AIC), the half-normal key, $k(y) = \exp(-y^2/(2\times A^2))$, with one cosine adjustment was chosen separately for each species for fitting the detection functions of grouped, perpendicular sighting distances. Effort (L) and sightings (n) during sea states of < Beaufort 6 were included for fin, sei and humpback whales abundance estimations following Buckland *et al*. (1992) and Víkingsson *et al*. (In Press). Only sightings and effort at sea states of < Beaufort 3 were included in the calculation of common minke whale abundance. Different right truncations were chosen for each species and common detection functions for all strata were derived. On-effort sightings in standard survey mode outside strata were included in the detection functions and in pod size estimates, but not in encounter rates (Table 1). Except for common minke whales, where all sightings were of individual whales, pod sizes combined for all strata were estimated by regression of *ln*(pod size) against the estimated probability of detection (Buckland *et al*., 2001). Encounter rate, n/L, and the empirical variance was estimated and used to derive standard errors following Buckland *et al.* (2001). Confidence intervals were calculated following Burnham *et al*. (1987, p.212), assuming the abundance estimates had a log-normal distribution.

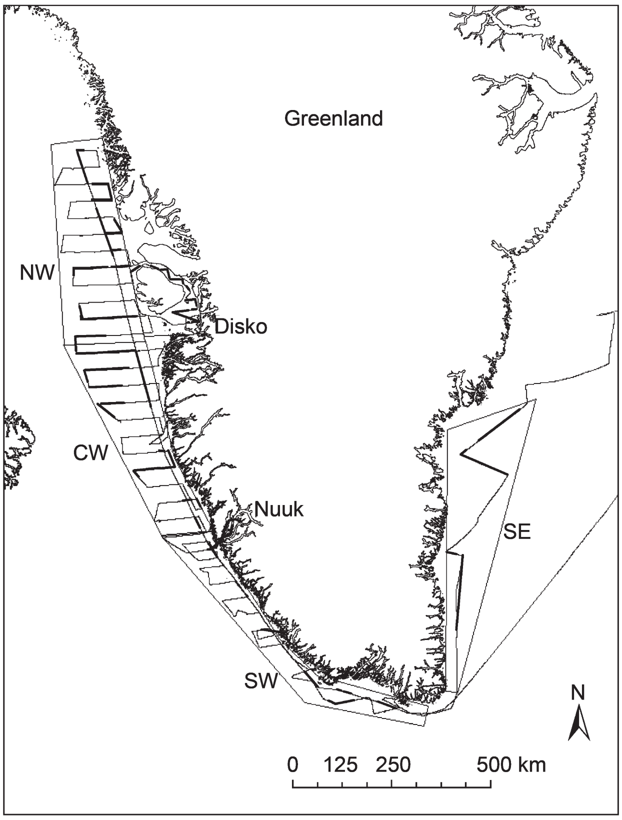

Fig. 1. Survey transect lines (thin lines), realised survey effort (thick lines) and delineation of strata for the ship-based survey of large cetaceans in Greenland in September 2005 in Beaufort sea states <6.

RESULTS

A total of 222 hours of on-effort observations were made where approximately 1,622 n.miles were covered in sea states < Beaufort 6 and 760 n.miles were covered in sea states of <3 (Fig. 1). During the survey, 194 sightings of 531 individual whales were made, including 13 different species (Table 1). The largest species diversity was observed in the Denmark Strait and off East Greenland's coast, where 11 of the 13 cetacean species were seen. No cetaceans were observed north of the Disko Bay in West Greenland (Fig. 1).

Distribution of whales

Six species of baleen whales were seen: blue whales (*Balaenoptera musculus*); fin whales; common minke whales; sei whales; humpback whales; and right whales (*Eubalaena glacialis*). Fin whales were most often found in dense aggregations in offshore areas, particularly along the East Greenland coast and southwest of Disko Bay. Sei whales did not extend as far north, but were otherwise found in the same areas as fin whales. Common minke whales were observed in the same areas as fin whales but in lower numbers. The humpback whale was the only species observed both offshore and inshore (Figs 2 and 3). One northern right whale and two blue whales were observed in East Greenland in the same area (65.1842°N 29.9558°W) on 3 September (Fig. 4).

Sightings of odontocetes included sperm whales, *Physeter macrocephalus*, pilot whales, *Globicephala melas*, white-sided dolphins, *Lagenorhynchus acutus*, white-beaked dolphins, *Lagenorhynchus albirostris*, killer whales, *Orcinus orca* and an unidentified beaked whale. Most odontocetes were seen in East Greenland (Fig. 5). White beaked dolphins were seen close to Cape Farewell and the one unidentified beaked whale, *Ziphiidae sp*., was seen in a deep canyon between the coastal banks in South West Greenland. Sperm whales were observed off the east coast of Greenland and once in coastal waters on the west coast (Fig. 5).

Abundance estimates

Fin whales were detected at distances of up to 2km and sei whales at distances of up to 2.5km. Sightings were truncated at 1,800m to reduce the effect of measurement error on distant sightings. Both fin and sei whales had a high detection probability up to ~800m from the platform and there was a peak between 50 and 150m close to the trackline. The reason for this peak was not known. The detection function showed a satisfactory fit to the distribution of the 45 perpendicular distances of fin whale sightings (Fig. 6, χ^2 goodness-of-fit statistic not significant, p=0.53) and the effective search half-width (esw=944m) could be estimated with low variance (CV=0.12, Table 2). There were no sightings of fin whales in North West Greenland and in Disko Bay and the abundance was higher

Table 1

Sightings of different species of marine mammals during the survey. Observations are included from all Beaufort sea states and areas that are not included in the abundance estimation. In parenthesis are the unidentified sightings apportioned to species.

	Number of sightings				
Species	Total	Used in detection function	Used in abundance estimation	Outside survey region	Number of individuals
Blue whale	2	-	-	-	2
Fin whale	54	45 (57)	41 (53)	4 (4)	87
Sei whale	21	64 (81)	18 (23)	1 (1)	33
Humpback whale	30	26 (29)	21 (24)	5 (5)	46
Unidentified large cetacean	39	-	-	-	48
Northern right whale	1	-	-	-	1
Minke whale	14	12	10	2	14
Sperm whale	10	-	-	-	13
Beaked whale	1	-	-	-	1
Killer whale	2	-	-	-	8
Long-finned pilot whale	2	-	-	-	11
White-beaked dolphin	4	-	-	-	18
Atlantic white-sided dolphin	4	-	-	-	140
Unidentified dolphin	2	-	-	-	100
Harbour porpoise	2	-	-	-	3
Seal	14	-	-	-	79

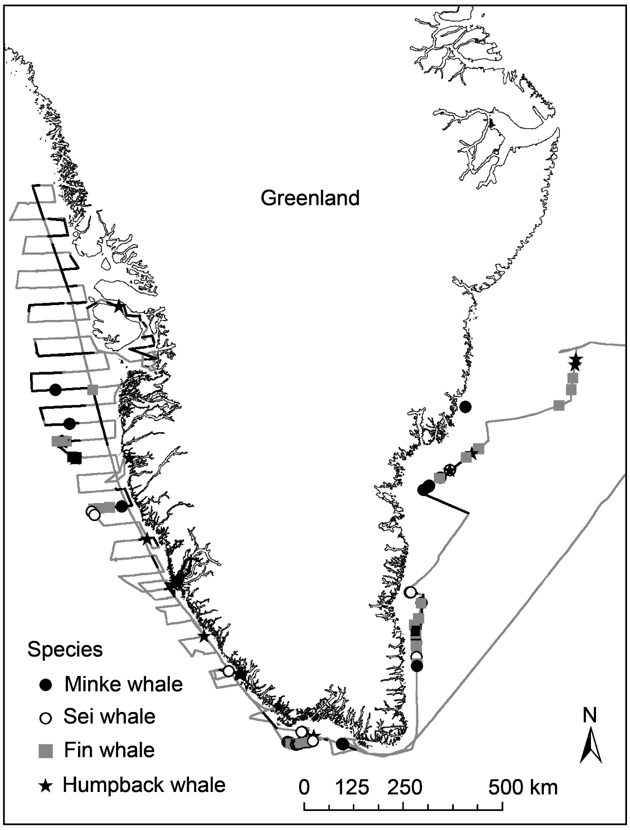

Fig. 2. Sightings of the four large cetaceans targeted in the ship based survey in Greenland September 2005. On-effort sections of transect lines (thick lines) are shown together with the sightings. [●]=common minke whales, [○]=sei whales, [■]=fin whales and [★]=humpback whales.

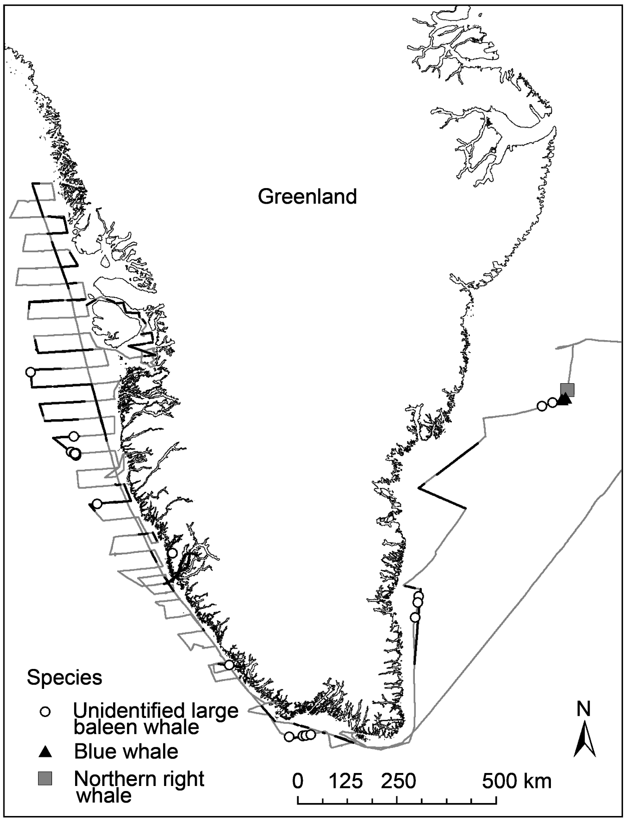

Fig. 4. Sightings of blue whales [▲], northern right whale [■] and unidentified large baleen whales [○].

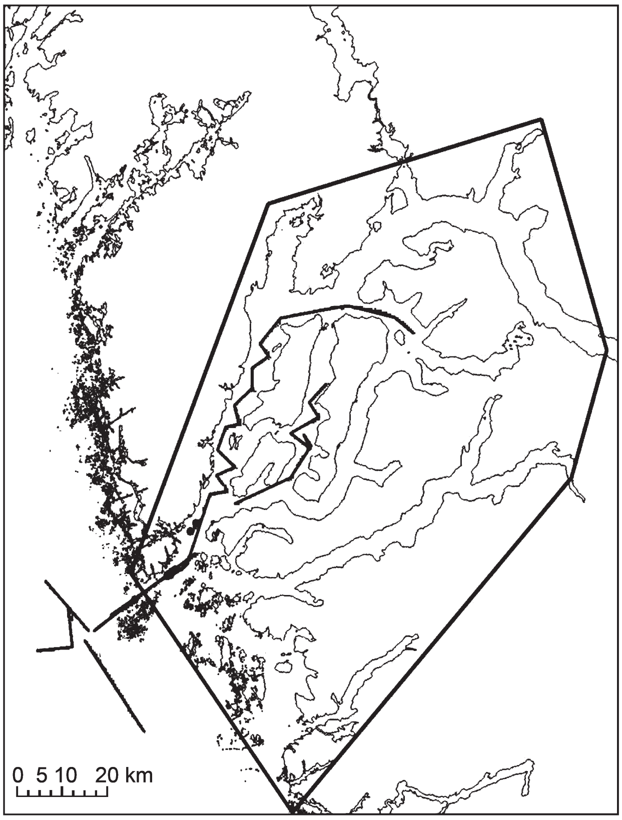

Fig. 3. Effort and sightings of humpback whales inside Nuuk Fjord. The polygon shows the stratum area used for extrapolating the density estimate.

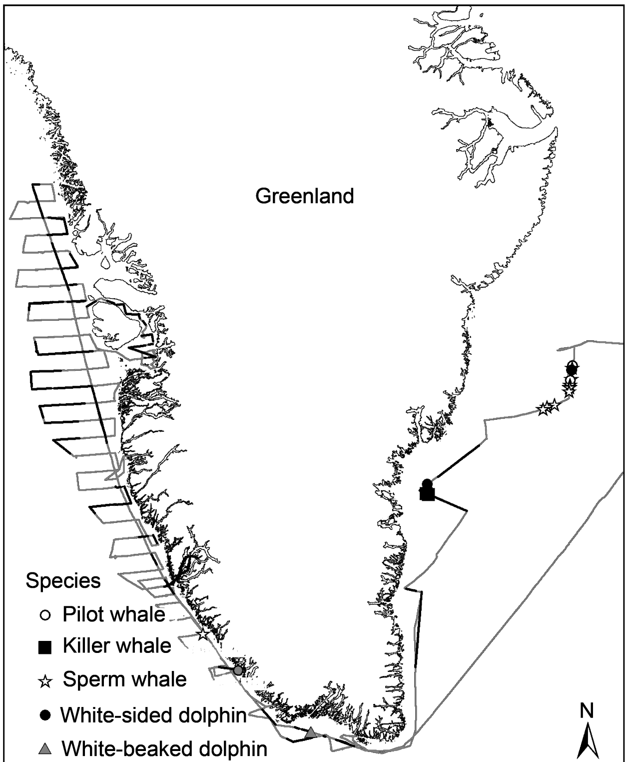

Fig. 5. Sightings of sperm whales [☆], pilot whales [○], white-sided dolphins [●], white-beaked dolphins [△], killer whales [■] and unidentified beaked whale [●].

in East Greenland (*n*=3,214 fin whales, CV=0.48) than in South Greenland (i.e. Centralwest and Southwest, *n*=1,980 fin whales, CV=0.38).

The detection function for the 18 sei whales sightings alone (*esw*=978m) was very similar to the detection function of the combined sightings of fin whales and sei whales (*esw*=927m), except that the CV for the sei whales was twice (0.20) the CV for the combined data set (0.10). It was consequently decided to estimate the sei whale abundance utilising both fin and sei whale distance estimates for deriving a common detection function (Fig. 7 and Table 2, χ^2 goodness-of-fit statistic not significant, *p*=0.62). The largest abundance of sei whales was estimated in the southernmost part of West Greenland (*n*=1,599 sei whales, CV=0.42) and lower numbers were found in East Greenland (*n*=763 sei whales, CV=0.47).

Only 27 humpback whale sightings were available for estimating the detection function (Fig. 8) and the detection function provided an *esw* of 622m (CV=0.15, χ^2 goodness-of-fit statistic not significant, *p*=0.72). Humpback whales were seen in all strata except for North West Greenland and the largest numbers were found in South Greenland (*n*=944 humpback whales, CV=0.53) with lower numbers in East Greenland (*n*=347 humpback whales, CV=0.85, Table 2). A separate abundance estimate was developed for Nuuk Fjord based on 106 n.miles zig-zag coverage of 4.3% of the area of the fjord complex (Fig. 3) and 10 sightings of humpback whales which revealed an abundance of 145 whales (CV=0.38). However, all areas of the fjord were not evenly sampled and the abundance therefore should be used with caution (see Discussion).

Table 2A

Summary statistics for abundance estimates of fin whales and sei whales. For both species only effort during Beaufort sea states <6 was included.

	Fin whale					Sei whale				
Effective search half-width	944m					Fin and sei observations: 927m				
n	45 observations, right truncation >1,800					64 observations, right truncation >1,800				
CV	0.12					0.10				
Stratum	NW	DB	CW	SW	SE	NW	DB	CW	SW	SE
Area of stratum (km^2)	82,518	15,780	72,342	51,684	81,065	82,518	15,780	72,342	51,684	81,065
Sightings (*n*)	0	0	12	8	21	0	0	3	10	5
Effort (*L*) n.miles	449	163	475	177	252	449	163	475	177	252
Transects	18	16	20	15	5	18	16	20	15	5
Sighting rate (*n/L*)	0	0	0.03	0.05	0.08	0	0	0.01	0.06	0.02
CV			0.53	0.52	0.46			1.06	0.44	0.45
Density of pods	0	0	0.01	0.01	0.02	0	0	0.01	0.02	0.01
CV			0.54	0.53	0.48			1.06	0.45	0.46
Expected pod size	0	0	1.7	1.7	1.7	0	0	1.6	1.6	1.6
CV			0.08	0.08	0.08			0.06	0.06	0.06
Density of whales	0	0	0.01	0.02	0.04	0	0	0.01	0.03	0.01
CV			0.55	0.53	0.48			1.06	0.45	0.47
Abundance	0	0	871	1,109	3,214	0	0	217	1,382	726
CV			0.55	0.54	0.48			1.06	0.45	0.47
Total West Greenland	1,980 (CV=0.38, 95% CI=913-4,296)					1,599 (CV=0.42, 95% CI=690-3,705)				
Total East Greenland	3,214 (CV=0.48, 95% CI=980-10,547)					763 (CV=0.47, 95% CI=236-2,465)				

Table 2B

Summary statistics for abundance estimates of humpback whales and minke whales. For humpback whales only effort during Beaufort sea states <6 was included and for minke whales effort was restricted to sea states less than 3.

	Humpback whale						Minke whale				
Effective search half-width	622m						216m				
n	26, right truncation >1,600						12, right truncation >350m				
CV	0.15						0.25				
Stratum	NW	DB	CW	NF	SW	SE	NW	DB	CW	SW	SE
Area of stratum (km^2)	82,518	15,780	72,342	2,843	51,684	81,065	82,518	15,780	72,342	51,684	81,065
Sightings (*n*)	0	1	2	10	6	2	0	0	2	3	5
Effort (*L*)	449	163	475	106	177	252	217	60	149	60	274
Transects	18	16	20	31	15	5	12	8	9	7	8
Sighting rate (*n/L*)	0	0.01	0.01	0.10	0.03	0.01	0	0	0.01	0.05	0.02
CV		1.17	0.89	0.34	0.50	0.83			0.49	0.49	1.21
Density of pods	0	0.01	0.01	0.04	0.01	0.01	0	0	0.02	0.06	0.02
CV		1.18	0.89	0.37	0.52	0.84			0.55	0.55	1.24
Expected pod size	0	1.3	1.3	1.3	1.3	1.3	0	0	1	1	1
CV		0.09	0.09	0.09	0.09	0.09					
Density of whales	0	0.01	0.01	0.05	0.02	0.01	0	0	0.01	0.06	0.02
CV		1.18	0.90	0.38	0.53	0.85			0.55	0.55	1.24
Abundance	0	52	165	145	944	347	0	0	1,219	3,260	1,848
CV		1.18	0.90	0.38	0.53	0.85			0.55	0.55	1.24
Total West Greenland	1,306 (CV=0.42, 95% CI=570-2,989)						4479 (CV=0.46, 95% CI=1,760-11,394)				
Total East Greenland	347 (CV=0.85, 95% CI=48-2,515)						1848 (CV=1.24, 95% CI=197-17,348)				

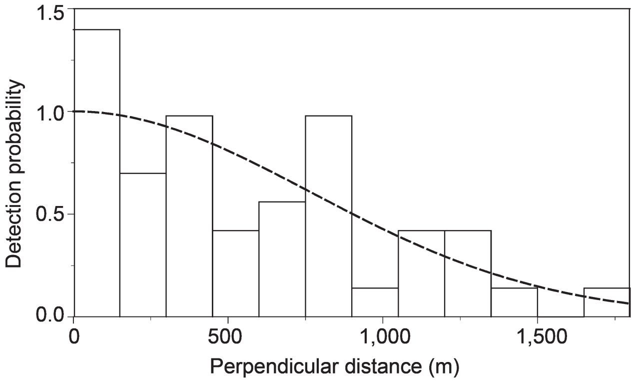

Fig. 6. Detection function for fin whales grouped in 150m intervals (n=45).

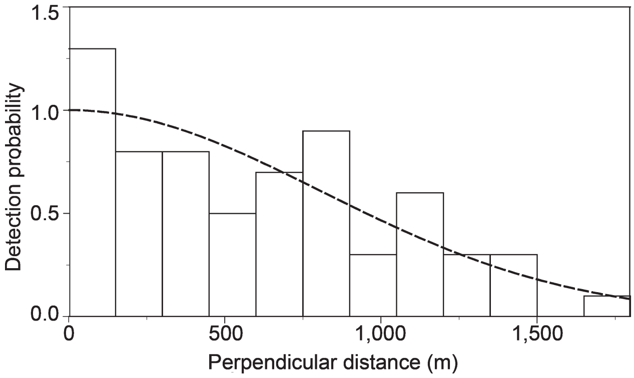

Fig. 7. Detection function for fin and sei whales combined grouped in 150m intervals (n=66).

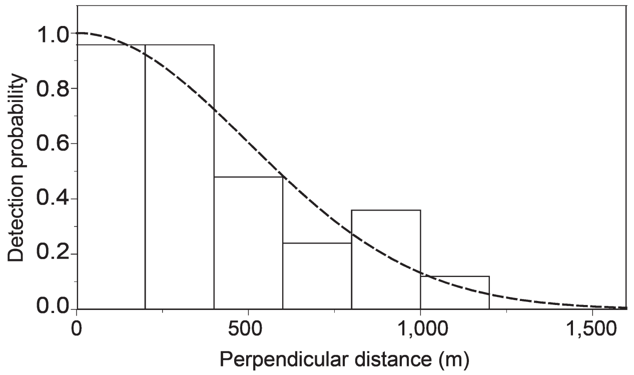

Fig. 8. Detection function for humpback whales grouped in 200m intervals (n=26).

Only 12 common minke whales were sighted, including sightings outside strata *en route* to and from Iceland. This low number does not provide sufficient data for a robust estimation of the detection function (Fig. 9). This is also reflected in the relatively large CV (0.25) for determination of the *esw* (216m, χ^2 goodness-of-fit statistic not significant, p=0.65). The low *esw* for common minke whales probably reflects the difficulty in detecting this species. Nevertheless estimates of common minke whale abundance were developed for the three areas where sightings occurred and with effort in sea states of < Beaufort 3 (Fig. 10). The largest numbers of common minke whales were in the southern part of West Greenland (4,479 common minke whales, CV=0.46) with fewer on the east coast (Table 2).

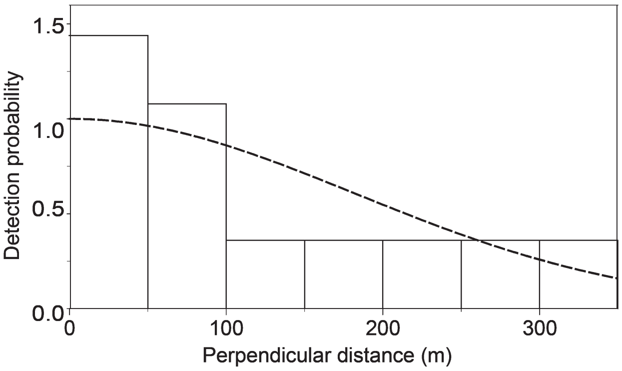

Fig. 9. Detection function for common minke whales grouped in 50m intervals (n=12).

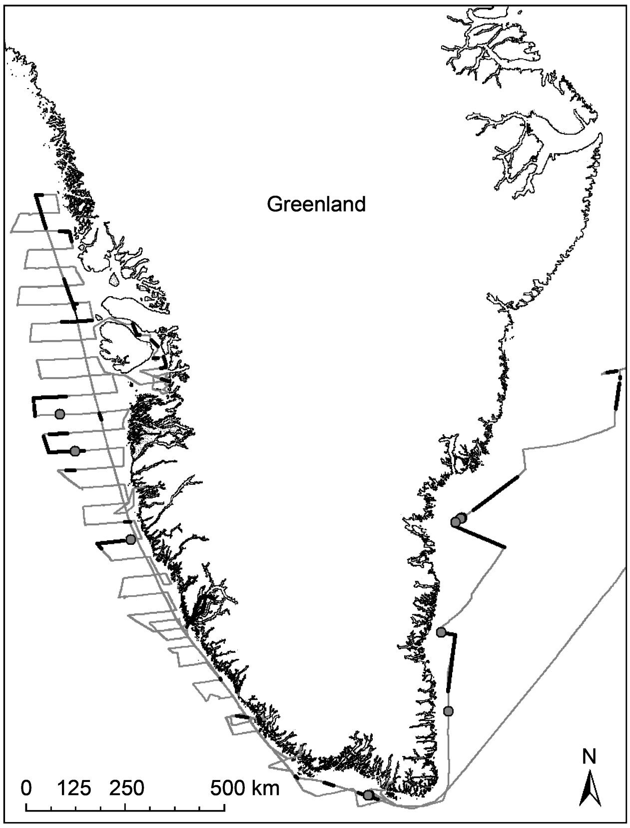

Fig. 10. Survey transect lines (thin lines), realized survey effort (thick lines) in Beaufort sea state <3 and common minke whale sightings.

A total of 35 sightings of blows of unidentified large baleen whales were recorded. In order to include these in more complete abundance estimates, the sightings were attributed to the three possible species (fin, humpback and sei whales, Table 3). The unidentified blows were apportioned to the six strata in proportion to the occurrence of each species in each stratum and the associated distance measurements were apportioned randomly to the three species. Thus, both new encounter rate estimates and new detection functions including variance estimates were derived. The inclusion of unidentified sightings resulted in a 43% increase in the abundance estimate for fin whales in West Greenland (raised to 2,824 fin whales, CV=0.38). The sei whale abundance increased by 26% with a slightly improved precision and the humpback whale abundance estimate increased in West Greenland (by 16%) with lower precision yet declined in East Greenland due to the change in *esw*.

Table 3

Summary statistics for abundance estimates of fin, sei, and humpback whales including unidentified sightings. For both species only effort during Beaufort sea states <6 was included.

	Fin whale			Sei whale			Humpback whale				
Effective search half-width	960m			Fin and sei observations: 982m			718m				
n	57 observ., right truncation >1,800			81 observ., right truncation >1,800			29, right truncation >1,600				
CV	0.11			0.09			0.14				
Stratum	CW	SW	SE	CW	SW	SE	DB	CW	NF	SW	SE
Area of stratum (km^2)	72,342	51,684	81,065	72,342	51,684	81,065	15,780	72,342	2,843	51,684	81,065
Sightings (*n*)	17	11	25	4	13	6	1	3	10	8	2
Effort (*L*) nmi	475	177	252	475	177	252	163	475	106	177	252
Transects	20	15	5	20	15	5	16	20	31	15	5
Sighting rate (*n/L*)	0.01	0.06	0.10	0.01	0.07	0.02	0.01	0.01	0.10	0.05	0.01
CV	0.52	0.50	0.48	0.87	0.39	0.39	1.17	0.89	0.34	0.62	0.83
Density of pods	0.10	0.02	0.03	0.01	0.02	0.01	0.01	0.01	0.03	0.02	0.01
CV	0.52	0.51	0.50	0.88	0.40	0.41	1.18	0.90	0.37	0.64	0.84
Expected pod size	1.7	1.7	1.7	1.6	1.6	1.6	1.3	1.3	1.3	1.3	1.3
CV	0.07	0.07	0.07	0.06	0.06	0.06	0.09	0.09	0.09	0.09	0.09
Density of whales	0.02	0.03	0.05	0.01	0.03	0.01	0.01	0.01	0.05	0.02	0.01
CV	0.52	0.51	0.50	0.88	0.41	0.41	1.18	0.90	0.38	0.64	0.85
Abundance	1,263	1,562	3,917	279	1,731	882	46	219	129	1,119	309
CV	0.52	0.51	0.50	0.88	0.41	0.41	1.18	0.90	0.38	0.64	0.85
Total West Greenland	2,824 (CV=0.38, 95% CI=1,346-5,925)			2,009 (CV=0.37, 95% CI=948-4,260)			1,514 (CV=0.51, 95% CI=560-4,089)				
Total East Greenland	3,917 (CV=0.50, 95% CI=1,122-13,672)			882 (CV=0.41, 95% CI=313-2,484)			309 (CV=0.85, 95% CI=43-2,240)				

DISCUSSION

Biases and problems with survey design

The sampling design used in this survey was not optimal for a cetacean survey and the realised survey effort was restricted by inclement weather conditions. It can specifically be argued that the South West strata in West Greenland had particularly uneven and poor coverage and that transect lines running parallel to the coast might follow density gradients of whales. One option is to eliminate the part of South West strata with poor coverage from the abundance estimates which reduces the abundance to about 2/3 for both estimates based on identified blows and those where unidentified blows were apportioned to species and strata (Table 4). This, however, leaves a large uncovered area in West Greenland where there are high densities of whales.

One option for eliminating the potential problem of transects running parallel to the coast is to include only east-west transects in the abundance estimates. However, this does not have a major impact on the abundance estimates, as a recalculation with only east-west transects only slightly changed the abundance estimates (Table 4). This is probably due to the fact that the bathymetry in West Greenland does not follow simple east-west gradients but is characterised by deep trenches with intersecting banks (Fig. 1). In addition, the distribution of whales is not a simple function of bathymetry in this region but rather is determined by complex oceanographic features, including areas of upwelling that potentially can be found in many areas across several strata.

The estimate of 145 humpback whales in the Nuuk Fjord alone initially seems high. Clearly the ship-based survey did not provide random or uniform coverage of the entire fjord

Table 4

Summary statistics for abundance estimates for fin, sei, humpback and minke whales under alternative assumptions for West Greenland. Approximately half of the South West Greenland stratum was removed when the area with poor coverage was removed from that stratum. CVs indicated in parenthesis.

Estimation options			Species			
Sightings	Transects	Coverage	Fin whale	Sei whale	Humpback whale	Minke whale
Identified blows	East-west going	Areas with poor coverage in SW Greenland and Nuuk Fjord eliminated	na	na	509 (0.49)	na
Identified blows	East-west going	Area with poor coverage in SW Greenland eliminated	1,317 (0.54)	1,031 (0.53)	663 (0.37)	4,068 (0.40)
Identified blows	East-west going	Continuous	1,777 (0.48)	1,604 (0.45)	1,141 (0.45)	5,307 (0.43)
Identified blows	All	Area with poor coverage in SW Greenland eliminated	1,520 (0.41)	1,026 (0.45)	829 (0.36)	3,239 (0.41)
Identified blows	All	Continuous	1,980 (0.38)	1,599 (0.42)	1,306 (0.42)	4,479 (0.46)
Unidentified blows apportioned to species and strata	All	Area with poor coverage in SW Greenland eliminated	2,115 (0.40)	1,291 (0.40)	926 (0.34)	na
Unidentified blows apportioned to species and strata	All	Continuous	2,824 (0.38)	2,009 (0.37)	1,514 (0.51)	na
Correction for perception bias $g(0)$=0.56, SE=0.07	All	Continuous	na	na	na	7,998 0.47

na = not applicable.

complex. Only about one fifth of the fjord was sampled and the density was extrapolated to other unsurveyed parts of the fjord under the unproven assumption of uniform density. If the estimated density is only applied to the sampled area then a conservative estimate of 29 whales, three times the number of sightings, is obtained. This however leaves 80% of the area without an abundance estimate. Satellite tracking studies and local observations demonstrate that humpback whales use the entire Nuuk Fjord as delineated by the stratum (Heide-Jørgensen and Laidre, 2007; Fig. 3, GINR unpublished data), and therefore it is not unreasonable to extrapolate samples collected in the northern part of the mouth and in two fjord arms to the entire area shown in Fig. 3. In any case, the estimate from the Nuuk Fjord only contributes ~10% of the total abundance estimate for humpback whales in West Greenland.

Many sightings of large baleen whales could not be assigned to a species. If these 35 undetermined sightings were included in the abundance estimates in proportion to the correctly identified sightings of the four target species, then the abundance estimates increase as much as 43% for fin whales (resulting in a revised estimate of 2,824 fin whales, 95% CI=1,346-5,925). Similarly the abundance estimates for sei and humpback whales increase by 26% and 16%, respectively (Table 4).

All the abundance estimates presented in this manuscript are likely negatively biased for at least two reasons. First, no corrections have been made for whales submerged during the passage of the survey vessel or whales missed by the observers. This may be less of a problem for fin and sei whales, which can be seen at long distances from the vessel, but is certainly of concern for common minke whales, which are smaller and less conspicuous. Common minke whales in West Greenland are hunted intensively and considering the skittish behaviour of common minke whales in West Greenland, attraction to ships seems unlikely. The issue of ship avoidance (Palka and Hammond, 2001) was not addressed in this study. Secondly, the survey did not cover the entire stock area used by any of the whales in either East or West Greenland. The survey covered the banks of both areas, but whales were sighted at the borderlines of several strata indicating a connection to a larger unsurveyed area.

Abundance of fin whales

No fin whales were sighted in the northern survey strata (North West and in Disko Bay) despite good conditions and considerable effort. Fin whales have frequently been observed in these areas (Heide-Jørgensen *et al*., 2003; Kapel, 1979;1984;1985; Kapel and Larsen, 1982;1983; Larsen, 1981) and the lack of sightings might be due to the late seasonal coverage. Fin whales were however estimated to occur in large numbers in Central West (1,263) and South West Greenland (1,562) as well as in East Greenland (3,917). The survey in East Greenland only covered parts of the distribution of fin whales between the coast and Iceland, where an estimated abundance of 24,000 fin whales was obtained in 2001 (Víkingsson *et al*., In Press). The abundance of fin whales in West Greenland (1,980 95% CI=913-4,296) estimated by using only identified blows was larger, although not significantly higher, than the estimate from the aerial surveys in 1987 and 1988 (IWC, 1992) and lower than the estimate from the 2005 autumn aerial survey accepted by the IWC Scientific Committee (Heide-Jørgensen *et al*., 2007; IWC, In press) of 3,200 (95% CI 1,400-7,200).

Abundance of sei whales

The high number of sightings and high abundance of sei whales in West Greenland was somewhat surprising. Sei whales are traditionally believed to occupy more southern areas of the North Atlantic (Cattanach *et al*., 1993) and have not been found often in West Greenland. Kapel (1985) summarised observations and catches of sei whales in West Greenland waters in the 18th, 19th and 20th Centuries. The first confirmed sighting of a sei whale in Greenland was from Norwegian catches in 1924. During 1924-57, 18 sei whales were confirmed caught and a similar number of catches are unconfirmed, of which only four seem to be plausible sei whales. Kapel (1985) report that the erratic occurrence of sei whales in West Greenland waters may be related to the sea surface temperature, especially the influx of warm Irminger water to the southern part of Davis Strait. In 2005 the warmest sea surface temperatures were observed in West Greenland since 1876 (GINR unpublished data), and these warm temperatures may be related to the large abundance of sei whales in the area.

Abundance of humpback whales

An estimated abundance of 1,306 humpback whales (CV=0.42, 95% CI=570-2,989) from identified blows in West Greenland and 347 humpback whales in East Greenland (CV=0.85, 95% CI=48-2,515) is approximately three times larger than any previous estimates of this species in Greenland waters. Photo-ID surveys of humpback whales conducted off West Greenland during the 1990s resulted in an estimate of 360 humpback whales (CV=0.07) in West Greenland in summer (Larsen and Hammond, 2004). At that time three concentration areas were identified: an area off Nuuk, an area at approximately 63°30’N, and an area off Paamiut. This survey did not intensely cover any of these three areas, yet still resulted in a significantly larger abundance estimate than in the past, suggesting the present estimates may even be low. This survey covered a wider range of the humpback whale distribution in West Greenland than any previous surveys and thus has a more complete, although less intense, coverage of the humpback whale distribution in West Greenland. The long-distance movements and broad use of the West Greenland coast has recently been revealed by satellite tracking studies (Heide-Jørgensen and Laidre, 2007), suggesting humpback whales use a large area of West Greenland and have a broad distribution. Part of the difference in present and past abundances of humpback whales may be explained by a growth in the abundance of humpback whales in West Greenland, which is not unreasonable to assume given observations in other areas of the North Atlantic. Sigurjónsson and Gunnlaugsson (1990) observed an increase in humpback whale numbers around Iceland of 11.2% per annum between 1970 and 1988. Pike *et al*. (2005) observed an even higher growth rate for humpback whales around Iceland from the North Atlantic Sighting Surveys (NASS). Based on an assumed growth of 10% per year since 1990 and a presumed abundance of 500 humpback whales in West Greenland in 1990, a present-day (2005) abundance should be on the order of approximately 2,000 whales. This is within the confidence limits of the present abundance estimates.

Abundance of common minke whales

The relatively low number of sightings of common minke whales severely reduced the precision of the abundance estimates in this study. Estimation of a detection function was only possible through inclusion of sightings *en route* to and from Iceland. The variance on the common minke whale abundance estimates was very high, but it is important to note that correction for whales that were submerged during the passage of the survey platform and whales missed by the observers would raise the lower confidence limit of the estimate substantially.

One option for improving the accuracy of the common minke whale estimate is to use a correction factor for whales missed by the observer ($g(0)$) developed in a different survey. Øien (1990) used a double platform design to estimate $g(0)$ in an area west of Svalbard, where common minke whales occur in high densities. A large proportion of the common minke whale sightings were missed by the primary platform ($g(0)$=0.56, SE=0.07) and applying this correction factor gives a partially corrected abundance estimate for West Greenland of 7,998 common minke whales (CV=0.47, 95% CI=3,048-20,988). The $g(0)$ estimate was developed on a different survey platform with different observers and in an area with high densities of common minke whales where whale spotters presumably are more efficient (Øien, 1990). In addition, the correction does not include whales that were diving during the passage of the survey platform. In any case we believe that the corrected estimate probably provides an abundance estimate that is closer to the actual abundance of common minke whales in West Greenland in late autumn 2005. These estimates are not significantly different from the estimate accepted by the IWC Scientific Committee from an autumn 2005 aerial survey (Heide-Jørgensen *et al*., 2007; IWC, In press) of 10,800 (95% CI 3,600-32,400).

Few sightings of common minke whales were made on the offshore banks of West Greenland, an area where they used to be frequently encountered (Kapel and Larsen, 1982). There has been no hunting of common minke whales in this offshore area since the ban on commercial whaling in 1985 and the lack of whales in this region cannot be attributed to harvest. It is well known that common minke whales travel extensively, and recent satellite tracking studies off Iceland show that this species can move 1,000km in just two months, reaching the Cape Verdes Isles from Icelandic waters in just 60 days. It is highly possible that common minke whales inhabiting Greenlandic waters are a temporary population that move in and out of important areas, as observed in Iceland (Heide-Jørgensen *et al*., 2001; Víkingsson and Heide-Jørgensen, 2005). This makes it difficult to relate the present abundance estimate to any actual stock size.

Other species

Species diversity in cetacean sightings was much higher in East Greenland but abundance estimates could not be derived for all species. One northern right whale was sighted east of Greenland in an area slightly north and east of the whaling ground known by the whalers as the ‘Cape Farewell whaling ground’ used by American whalers during 1868-98 for finding right whales (Reeves and Mitchell, 1986). This is also the area where right whales have been sighted in recent years (Reeves *et al*., 2004). Few odontocete whales were seen in West Greenland, these fish eaters seem to be sighted more typically in East Greenland in contrast to the many baleen whales sighted feeding on zooplankton in West Greenland.

CONCLUSIONS

The ship-based survey presented here provides a somewhat sporadic effort along East and especially South West Greenland. In some cases the patchy effort also leads to questionable extrapolations of densities to unsurveyed areas. The survey however provides insight into what can be accomplished by a ship-based cetacean survey effort in Greenland.

The abundance estimates for large cetaceans obtained during this survey are in some cases larger than expected and confirm that the waters of Greenland support large numbers of baleen whales during this season. The extensive ship survey coverage, coupled with the verification of high numbers of sightings and large group sizes by a concurrent aerial survey (Heide-Jørgensen *et al*., 2007), suggest abundances are considerably larger than previously reported.

This survey was conducted late in the season. No whales were seen in the northernmost strata along West Greenland and only humpback whales were sighted in Disko Bay. Presumably most large whales were on their southbound exodus from Greenland by September (Heide-Jørgensen *et al*., 2001; Víkingsson and Heide-Jørgensen, 2005) and this may have resulted in a reduced abundance relative to that which would have been estimated earlier in the summer.

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REFERENCES

Buckland, S.T., Anderson, D.R., Burnham, K.P., Laake, J.L., Borchers, D.L. and Thomas, L. 2001. *Introduction to Distance Sampling: Estimating Abundance of Biological Populations*. Oxford University Press, Oxford, UK. vi+xv+432pp.

Buckland, S.T., Cattanach, K.L. and Gunnlaugsson, T. 1992. Fin whale abundance in the North Atlantic, estimated from Icelandic and Faroese NASS-87 and NASS-89 data. *Rep. int. Whal. Commn* 42: 645-51.

Burnham, K.P., Anderson, D.R., White, G.C., Brownie, C. and Pollock, K.H. 1987. *Design and Analysis Methods for Fish Survival Experiments Based on Release-Recapture. American Fisheries Society Monograph 5*. American Fisheries Society, Bethesda, Maryland. x+437pp.

Cattanach, K.L., Sigurjónsson, J., Buckland, S.T. and Gunnlaugsson, T. 1993. Sei whale abundance in the North Atlantic, estimated from NASS-87 and NASS-89 data. *Rep. int. Whal. Commn* 43: 315-21.

Heide-Jørgensen, M.P., Borchers, D., Witting, L., Simon, M., Laidre, K., Rosing-Asvid, A. and Pike, D.G. 2007. Final estimates of large whale abundance in West Greenland waters from an aerial survey in 2005. *J. Cetacean Res. Manage*. Submitted.

Heide-Jørgensen, M.P. and Laidre, K. 2007. Autumn space-use-patterns of humpback whale (*Megaptera novaeangliae*) in West Greenland. *J. Cetacean Res. Manage*. Submitted.

Heide-Jørgensen, M.P., Nordoy, E.S., Øien, N., Folkow, L.P., Kleivane, L., Blix, A.S., Jensen, M.V. and Laidre, K.L. 2001. Satellite tracking of minke whales (*Balaenoptera acutorostrata*) off the coast of northern Norway. *J. Cetacean Res. Manage*. 3(2): 175-78.

Heide-Jørgensen, M.P., Witting, L. and Jensen, M.V. 2003. Inshore-offshore movements of two fin whales *Balaenoptera physalus* tracked by satellite off West Greenland. *J. Cetacean Res. Manage.* 5(3): 214-45.

Hiby, A.R. and Hammond, P.S. 1989. Survey techniques for estimating abundance of cetaceans. *Rep. int. Whal. Commn (special issue)* 11: 47-80.

International Whaling Commission. 1990. Report of the Scientific Committee. *Rep. int. Whal. Commn* 40:39-79.

International Whaling Commission. 1992. Report of the Comprehensive Assessment Special Meeting on North Atlantic Fin Whales, Reykjavík, 25 February-1 March 1991. *Rep. int. Whal. Commn* 42:595-644.

International Whaling Commission. 2005. Report of the Scientific Committee. *J. Cetacean Res. Manage. (Suppl.)* 7:1-62.

International Whaling Commission. 2006. Report of the Scientific Committee. Annex E. Report of the Standing Working Group (SWG) on the Development of an Aboriginal Whaling Management Procedure (AWMP). *J. Cetacean Res. Manage. (Suppl.)* 8:91-109.

International Whaling Commission. In press. Report of the Scientific Committee. *J. Cetacean Res. Manage. (Suppl.)* 10.

Kapel, F.O. 1979. Exploitation of large whales in West Greenland in the twentieth century. *Rep. int. Whal. Commn* 29: 197-214.

Kapel, F.O. 1984. Whale observations off West Greenland in June-September 1982. *Rep. int. Whal. Commn* 34: 621-27.

Kapel, F.O. 1985. On the occurrence of sei whales (*Balaenoptera borealis*) in West Greenland waters. *Rep. int. Whal. Commn* 35: 349-52.

Kapel, F.O. and Larsen, F. 1982. Whale sightings from a Norwegian small-type whaling vessel off West Greenland, June-August 1980. *Rep. int. Whal. Commn* 32: 521-30.

Kapel, F.O. and Larsen, F. 1983. Whale sightings off West Greenland in June-September 1981. *Rep. int. Whal. Commn* 33: 657-66.

Kingsley, M.C.S. and Witting, L. 2001. A preliminary analysis of aerial survey observations of humpback whales in Greenland waters. Paper SC/53/NAH23 presented to the IWC Scientific Committee, July 2001, London (unpublished). 51pp. [Paper available from the Office of this Journal].

Larsen, F. 1981. Observations of large whales off West Greenland, 1979. *Rep. int. Whal. Commn* 31: 617-23.

Larsen, F. 1995. Abundance of minke and fin whales off West Greenland, 1993. *Rep. int. Whal. Commn* 45: 365-70.

Larsen, F. and Hammond, P.S. 2004. Distribution and abundance of West Greenland humpback whales *Megaptera novaeangliae*. *J. Zool., London*. 263: 343-58.

Larsen, F., Martin, A.R. and Nielsen, P.B. 1989. North Atlantic Sightings Survey 1987: report of the West Greenland aerial survey. *Rep. int. Whal. Commn* 39: 443-46.

Øien, N. 1990. Estimates of $g(0)$ for minke whales based on an independent observer experiment during the Norwegian sightings surveys in July 1988. *Rep. int. Whal. Commn* 40: 331-35.

Palka, D.L. and Hammond, P.S. 2001. Accounting for responsive movement in line transect estimates of abundance. *Can. J. Fish. Aquat. Sci.* 58: 777-87.

Pike, D.G., Paxton, C.G.M., Gunnlaugsson, T. and Víkingsson, G.A. 2005. Trends in the distribution and abundance of cetaceans from aerial surveys in Icelandic coastal waters 1986-2001. *NAMMCO Sci. Publ.* 6. [Paper NAMMCO SC/12/11].

Reeves, R.R., Josephson, E. and Smith, T.D. 2004. Putative historical occurrence of North Atlantic right whales in mid-latitude offshore waters: 'Maury's Smear' is likely apocryphal. *Marine Ecology. Progress Series* 282: 295-305.

Reeves, R.R. and Mitchell, E. 1986. American pelagic whaling for right whales in the North Atlantic. *Rep. int. Whal. Commn (special issue)* 10: 221-54.

Sigurjónsson, J. and Gunnlaugsson, T. 1990. Recent trends in abundance of blue (*Balaenoptera musculus*) and humpback whales (*Megaptera novaeangliae*) off west and southwest Iceland, with a note on occurrence of other cetacean species. *Rep. int. Whal. Commn* 40: 537-51.

Thomas, L., Strindberg, S., Marques, F.F.C., Borchers, D.L., Buckland, S.T., Anderson, D.R., Burnham, K.P., Hedley, S.L. and Pollard, J.H. 2001. Distance 4.0. Beta 4. Research Unit for Wildlife Population Assessment, University of St Andrews, UK. [Available at: *http://www.ruwpa.st-and.ac.uk/distance/*].

Víkingsson, G.A. and Heide-Jørgensen, M.P. 2005. A note on the movements of minke whales tracked by satellite in Icelandic waters in 2001-2004. Paper SC/57/O9 presented to the IWC Scientific Committee, June 2005, Ulsan, Korea (unpublished). 3pp. [Paper available from the Office of this Journal].

Víkingsson, G.A., Pike, D.G., Desportes, G., Øien, N. and Gunnlaugson, T. In Press. Distribution and abundance of fin whales (*Balaenoptera physalus*) in the Northeast and Central Atlantic as inferred from the North Atlantic Sightings Surveys 1987-2001. *NAMMCO Sci. Publ.* 7.

Witting, L. and Kingsley, M. 2005. Abundance of marine mammals off West Greenland, 2002-2004. Paper SC/57/AWMP3 presented to the IWC Scientific Committee, June 2005, Ulsan, Korea (unpublished). 13pp. [Paper available from the Office of this Journal].

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Cetacean diversity around the Mozambique Channel island of Mayotte (Comoros archipelago)

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ABSTRACT

The Indian Ocean was designated as a whale sanctuary in 1979. While cetacean research has been conducted throughout the sanctuary, few studies have been conducted to assess the diversity, distribution and abundance of cetaceans inhabiting the waters surrounding the islands in the northern Mozambique Channel. In order to contribute to management and conservation efforts in this area, a series of small boat-based surveys were undertaken around the island of Mayotte from July 2004 to August 2005 to assess the diversity of cetaceans in the lagoon and surrounding waters, i.e. external barrier reef slope, insular slope (200-1,000m) and oceanic (>1,000m) waters. During this period, more than 284 hours were spent at sea on-effort and 17 cetacean species were recorded around Mayotte (*n*=286 sightings). One mysticete (1 Balaenopterid) and sixteen odontocetes (1 Kogid, 1 Physeterid, 13 Delphinids and 2 Ziphiids) were observed: spinner dolphin, *n*=118; pantropical spotted dolphin, *n*=61; Indo-Pacific bottlenose dolphin, *n*=44; humpback whale, *n*=37; melon-headed whale, *n*=5; Blainville's beaked whale, *n*=4; Indo-Pacific humpback dolphin, *n*=4; common bottlenose dolphin, *n*=2; Risso's dolphin, *n*=2; false killer whale, *n*=2; dwarf sperm whale, *n*=2; sperm whale, *n*=1; pygmy killer whale, *n*=1; short-finned pilot whale, *n*=1; Fraser's dolphin, *n*=1; and Longman's beaked whale, *n*=1. In addition to these 17 species recorded during dedicated surveys, two other cetacean species were observed opportunistically and subsequently identified as the Ginkgo-toothed beaked whale and the blue whale. The relatively large diversity of cetaceans around Mayotte is attributed to the wide range of marine habitats, such as coastal, reef-associated and oceanic, within close proximity to one another.

KEYWORDS: INDIAN OCEAN; MOZAMBIQUE CHANNEL; ODONTOCETES; DIVERSITY; SURVEY-VESSEL; SPINNER DOLPHIN; PANTROPICAL SPOTTED DOLPHIN; INDO-PACIFIC BOTTLENOSE DOLPHIN; HUMPBACK WHALE; MELON-HEADED WHALE; BLAINVILLE'S BEAKED WHALE; INDO-PACIFIC HUMPBACK DOLPHIN; COMMON BOTTLENOSE DOLPHIN; RISSO'S DOLPHIN; FALSE KILLER WHALE; DWARF SPERM WHALE; SPERM WHALE; PYGMY KILLER WHALE; SHORT-FINNED PILOT WHALE; FRASER'S DOLPHIN; LONGMAN'S BEAKED WHALE; HABITAT; DISTRIBUTION; SOUTHERN HEMISPHERE

INTRODUCTION

In 1979, the International Whaling Commission (IWC) accepted a proposal to create a large sanctuary in the Indian Ocean that comprised the waters of the Northern Hemisphere from the coast of Africa to 100°E, including the Red and Arabian Seas and the Gulf of Oman; and the waters of the Southern Hemisphere in the sector from 20°E to 130°E, with the southern boundary set at 55°S (de Boer *et al*., 2002; Leatherwood and Donovan, 1991). Cetacean research has been conducted throughout the Indian Ocean Sanctuary although most studies to date have focused on continental coastal waters (Cockcroft *et al*., 1990;1991; Cockcroft *et al*., 1992; Findlay and Best, 1996; Findlay *et al*., 1994; Karczmarski, 1996; Karczmarski and Cockcroft, 1999). Some studies have been undertaken around the islands of the western reaches of the Indian Ocean Sanctuary: Seychelles (Keller *et al*., 1982); Madagascar (Rosenbaum *et al*., 1997); Zanzibar (Amir *et al*., 2002; Amir *et al*., 2005a; Amir *et al*., 2005b; Stensland *et al*., 2006); and Mauritius (Corbett, 1994). Currently, no published data exist for the Comoros archipelago and the wider Mozambique Channel.

The Comoros archipelago is a cluster of four islands situated in the northern Mozambique Channel, between Madagascar and Mozambique (Fig. 1). The main island of Mayotte and its surrounding islets, currently under French administration, are located on the eastern edge of the Comoros archipelago and Mayotte is, geologically, the oldest island (Quod *et al*., 2000). This overseas territory is considered by the French government to be a priority area in the context of the National Biodiversity Strategy, especially regarding marine biodiversity. The World Conservation Union (IUCN) lists Mayotte, as well as the neighbouring islands of the Union of the Comoros and Madagascar, as a global biodiversity hotspot.

Mayotte supports a growing human population concentrated along the coast. As a result, both its terrestrial and marine biodiversities are threatened by land-use practices, coastal development, pollution, overfishing and the development of recreational activities in the lagoon and surrounding waters, including whalewatching. In response to these growing concerns, a large Marine Protected Area (MPA) network project has recently started with the primary objective of determining the diversity of species found in the lagoon of Mayotte and its surrounding waters. No published data are available on the status of marine mammals in the waters surrounding Mayotte and the Comoros archipelago. In order to contribute to the baseline knowledge on cetacean populations within the waters of Mayotte and the Indian Ocean Sanctuary, dedicated small boat surveys were conducted from July 2004 to August 2005 in order to assess cetacean diversity in the lagoon and adjacent slope waters. These data provide a preliminary description of cetacean diversity in this poorly studied area.

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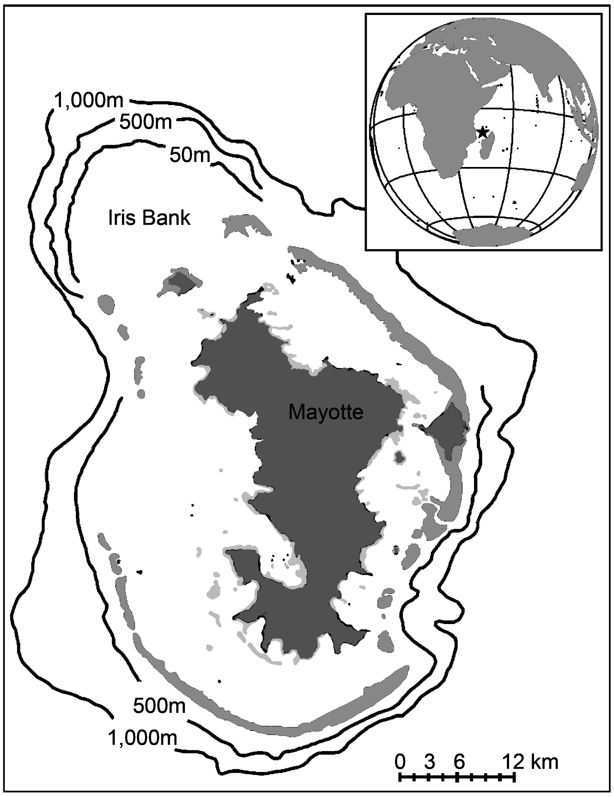

Fig. 1. Location of the island of Mayotte and its lagoon complex. The dark grey area is the barrier reef. The light grey areas represent the fringing reef and the double barrier reef, in the south-west.

MATERIALS AND METHODS

Study area

Mayotte (12°50'S, 45°10'E) is situated in the northern Mozambique Channel between Madagascar and the African mainland (Fig. 1). The island is made up of two major parts: the main island of Grande Terre where most of the population lives (approximately 360km^2*)*; and the smaller Petite Terre (approximately 13km^2), which is embedded in the barrier reef (Quod *et al*., 2000). Mayotte is almost entirely surrounded by a 197km long barrier reef, with a second double-barrier in the southwest. Adjacent to the northern extent of the lagoon is the immerged reef complex of Iris Bank (approximately 215km^2).

The inner lagoon ranks among the largest lagoons in the world (1,500km^2) (Quod *et al*., 2000), averaging 20m in depth, with deeper waters reaching 80m in the west. Numerous deep passes are present in the barrier reef, many of which are the beds of old rivers. The main island is surrounded by a fringing reef (195km), which is discontinuous where there are river mouths. Some 20 small islets are present in the lagoon ranging from 1 to 242ha in size and are surrounded by fringing reefs. Approximately 670ha of mangrove forests occur around the main island, especially in protected bays (Quod *et al*., 2000).

Data collection and analysis

From July 2004 to August 2005, small boat based surveys were undertaken by the Observatoire des Mammifères Marins de Mayotte, coordinated by the Direction de l'Agriculture et de la Forêt and the Office National de la Chasse et de la Faune Sauvage.

Several types of boats were used: a 7m catamaran equipped with two, four-stroke, 60hp outboard engines; a 7m boat equipped with two, two-stroke, 40hp outboard engines; a 6.40m cabin boat equipped with one, four-stroke, 150hp outboard engine. Surveys were conducted throughout the study period during daylight hours, i.e. between 07:00h and 18:00h, in seastate conditions not exceeding Beaufort 3. Survey vessels did not follow pre-defined transects but every attempt was made to sample each habitat type within the surrounding waters of Mayotte. Observation effort concentrated mostly in the lagoon and over the insular slope. Limited survey effort was also applied in waters more than 1,000m deep. From July 2004 to August 2005, a total of 284 hours were spent actively searching for marine mammals around Mayotte. Effort varied according to month, with more effort occurring during the austral summer.

For each sighting, the species, group size (maximum, minimum, best estimate), geographic position and primary behavioural activity were recorded. Cetaceans were identified to their species level using morphological characters and compared to a published identification guide (Jefferson *et al*., 1993). The objectives of the surveys varied according to season and species. Surveys conducted during July to October 2004 were mostly dedicated to the assessment of humpback whale (*Megaptera novaeangliae*) distribution, occurrence, group composition and habitat use. From November 2004 to August 2005, surveys concentrated on the assessment of dolphin distribution, abundance, habitat use and social organisation.

RESULTS

From July 2004 to August 2005, a total of 17 cetacean species were encountered around Mayotte (*n*=286 sightings, Table 1): humpback whale (*n*=37), sperm whale (*Physeter macrocephalus*, *n*=1), spinner dolphin (*Stenella longirostris*, *n*=118), pantropical spotted dolphin (*S. attenuata*, *n*=61), Indo-Pacific bottlenose dolphin (*Tursiops aduncus*, *n*=44), melon-headed whale (*Peponocephala electra*, *n*=5), Blainville's beaked whale (*Mesoplodon densirostris*, *n*=4), Indo-Pacific humpback dolphin (*Sousa chinensis*, *n*=4), Common bottlenose dolphin (*T. truncatus*, *n*=2), Risso's dolphin (*Grampus griseus*, *n*=2), false killer whale (*Pseudorca crassidens*, *n*=2), dwarf sperm whale (*Kogia sima*, *n*=2), pygmy killer whale (*Feresa attenuata*, *n*=1), short-finned pilot whale (*Globicephala macrorhynchus*, *n*=1), Fraser's dolphin (*Lagenodelphis hosei*, *n*=1), and Longman's beaked whale (*M. pacificus*, *n*=1).

In addition to these 17 species recorded during dedicated surveys, two other cetacean species were identified opportunistically by the first author. A beaked whale was encountered from a small boat in February 2005 and identified *in situ* as a ginkgo-toothed beaked whale (*M. ginkgodens*) off the east coast, around the 1,200m isobath. However, no photographs were available to confirm the specific identification of this animal. A group of three blue whales (*Balaenoptera musculus*) was encountered from an aircraft in August 2006 off the east coast, around the 300m isobath.

DISCUSSION

In the western Indian Ocean, 25 cetacean species have been recorded, including six baleen whales, ten toothed whales and nine delphinids (De Lestang, 1993). Of the nine delphinids, the Indo-Pacific humpback dolphin, bottlenose dolphin, spinner dolphin, pantropical spotted dolphin and striped dolphin were the most frequently encountered (de Boer *et al*., 2002; De Lestang, 1993). With the exception of

Table 1

Number of cetacean sightings (mono-specific groups), cumulated numbers of individuals and group size characteristics (July 2004-August 2005).

Species	No. sightings	% sightings	Mean group size	Group size range
Odontocetes				
Spinner dolphin	118	41.259	70.5	3-400
Pan-tropical spotted dolphin	61	21.329	78.5	3-300
Indo-Pacific bottlenose dolphin	44	15.385	6.3	1-12
Melon-headed whale	5	1.748	310	200-450
Blainville's beaked whale	4	1.4	2.5	1-5
Indo-Pacific humpbacked dolphin	4	1.4	2.2	1-3
False killer whale	2	0.7	125	100-150
Dwarf sperm whale	2	0.7	1.5	1-2
Risso's dolphin	2	0.7	11	2-20
Bottlenose dolphin	2	0.7	80	40-120
Longman's beaked whale	1	0.4	1	-
Pygmy killer whale	1	0.4	4	-
Short-finned pilot whale	1	0.4	60	-
Fraser's dolphin	1	0.4	120	-
Sperm whale	1	0.4	11	-
Mysticetes				
Humpback whale	37	12.937	2.1	1-4
Total	**286**	**100%**	**-**	**-**

striped dolphins (*S. coeruleoalba*), the assemblage of dolphin species frequently encountered in Mayotte is similar to the rest of the western Indian Ocean.

Compared to similar oceanic islands, the diversity of cetaceans observed around Mayotte appears to be high, with the majority being delphinid species. However, few studies have been dedicated to describing cetacean diversity in similar insular tropical islands/archipelagos. Recently, surveys were undertaken around the main Hawaiian islands to investigate the structure of odontocete populations, both in coastal and oceanic waters (Baird *et al*., 2003). During 521 hours of effort, 14 odontocete species were recorded (Baird *et al*., 2003). In Great Abaco (northern Bahamas), in slope waters associated with Little Bahama Bank, only nine odontocete species were recorded (MacLeod *et al*., 2004). Most of the odontocetes reported by MacLeod *et al*. (2004) belonged to the ziphiid family, which may be due to a substantial effort undertaken in deep slope waters; a habitat preferentially used by this cetacean family (e.g. for Blainville's beaked whale; MacLeod and Zuur, 2005). In French Polynesia, where considerable survey effort has been undertaken around the Marquesas and the Society Islands, 11 delphinid species were recorded. Most of the diversity was constituted by oceanic species (Gannier, 2000; 2002).

The diversity of cetaceans occurring around Mayotte could be attributed to the presence of a wide range of marine habitats within close proximity to one another. The presence of reef complexes and shallow waters provide a habitat characteristic of that used by resting spinner dolphins as well as pantropical spotted dolphins during their diurnal movements (Norris, 1991; Norris *et al*., 1985; Psarakos *et al*., 2003). In the lagoon, productive waters associated with mangrove systems, as well as fringing reef complexes, provide potential habitats for Indo-Pacific bottlenose and humpback dolphins (Ross *et al*., 1994; Wells and Scott, 1999).

For the *Tursiops* data reported here, the distinction between Indo-Pacific and common bottlenose dolphins was based on visual criteria available in the literature (Ross and Cockcroft, 1990; Shirakihara *et al*., 2003) and molecular identification is currently in progress. At present, the IWC recognises only these two species of *Tursiops* (IWC, 2000). The Indo-Pacific bottlenose dolphin is smaller than the common bottlenose dolphin and the former develops ventral spotting at about the time of sexual maturity (Ross and Cockcroft, 1990). Around Mayotte, both species occur. *T. aduncus* has been observed in the lagoon and adjacent waters associated with reef complexes. It is commonly observed and photo-ID indicates high levels of site-fidelity (unpublished data). *T. truncatus* is significantly longer, heavier and darker than this coastal species and although rarely seen, has been observed in deeper waters outside the lagoon.

The proximity of the steep insular slope and deep oceanic waters close to the barrier reef allow for possible encounters with pelagic species, such as the largest delphinids, beaked whales and sperm whales. Other odontocete species (especially oceanic species) that have been documented in the western Indian Ocean region such as the striped dolphin, the rough-tooted dolphin (*Steno bredanensis*) and Cuvier's beaked whale (*Ziphius cavirostris*) (de Boer *et al*., 2002; Peddemors, 1999; Robineau, 1975), have not yet been observed around Mayotte during systematic surveys. In general, the occurrence of oceanic species was quite low. This is attributable to the low search effort undertaken in waters deeper than 500m. Effort was significantly higher in the coastal waters of the lagoon and along the external slope of the barrier reef. This may explain the high encounter rate of spinner dolphins, pantropical spotted dolphins (along the barrier reef) and Indo-Pacific bottlenose dolphins (in coastal waters).

The humpback whale and the blue whale are the only baleen whale species that have been recorded around Mayotte. Other species that have been documented in the Indian Ocean include: Bryde's whales (*B. edeni*); sei whales (*B. borealis*); fin whales (*B. physalus*); and minke whales (*B. acutorostrata*) (Anderson, 2005; Kasuya and Wada, 1991; Robineau, 1991). However, these baleen whales seem to occur in deeper waters further offshore. The low amount of effort in the oceanic waters of Mayotte and in the wider Mozambique Channel could explain the absence of these other baleen whales, while the protected waters of the lagoon of Mayotte and associated reef complexes provide characteristic conditions for wintering humpback whales

(Balcomb and Nichols, 1982; Dawbin, 1966; Whitehead and Moore, 1982). The observation of the three blue whales close to the barrier reef seems to be exceptional, as this species is generally oceanic (Kasuya and Wada, 1991).

The waters surrounding Mayotte appear to be an exceptional area for cetacean abundance, especially for a large and diversified dolphin community. More accurate studies on distribution, encounter rate, absolute abundance and habitat preference are currently being undertaken to clarify the status of these populations. The close proximity of diverse habitat types to each other and subsequent accessibility of a wide range of species underline the interest of these waters as a pilot field site for tropical cetacean studies.

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REFERENCES

Amir, O.A., Berggren, P. and Jiddawi, N. 2002. The incidental catch of dolphins in gillnets fisheries in Zanzibar, Tanzania. *Western Indian Ocean J. Mar. Sci.* 1: 155-62.

Amir, O.A., Berggren, P., Ndaro, S.G.M. and Jiddawi, N. 2005a. Feeding ecology of the Indo-Pacific bottlenose dolphin (*Tursiops aduncus*) incidentally caught in the gillnet fisheries off Zanzibar, Tanzania. *Estuarine, Coastal and Shelf Science* 63: 429-37.

Amir, O.A., Jiddawi, N. and Berggren, P. 2005b. The occurrence and distribution of dolphins in Zanzibar, Tanzania with comments on the differences between two species of *Tursiops*. *Western Indian Ocean J. Mar. Sci.* 4: 85-93.

Anderson, R.C. 2005. Observations of cetaceans in the Maldives, 1990-2002. *J. Cetacean Res. Manage.* 7(2): 119-36.

Baird, R.W., McSweeny, D.J., Webster, D.L., Gorgone, A.M. and Ligon, A.D. 2003. Studies of odontocete population structure in Hawaiian waters: results of a survey through the main Hawaiian Islands in May and June 2003. Contract number AB133F-02-CN-0106. 25pp. NOAA, Western Administrative Support Center, Seattle, Washington, USA.

Balcomb, K.C. and Nichols, G. 1982. Humpback whale censuses in the West Indies. *Rep. int. Whal. Commn* 32: 401-06.

Cockcroft, V.G., Ross, G.J.B. and Peddemors, V.M. 1990. Bottlenose dolphin *Tursiops truncatus* distribution in Natal's coastal waters. *S. Afr. J. Mar. Sci* 9: 1-10.

Cockcroft, V.G., Ross, G.J.B. and Peddemors, V.M. 1991. Distribution and status of bottlenose dolphin *Tursiops truncatus* on the south coast of Natal, South Africa. *S. Afr. J. Mar. Sci* 11: 203-09.

Cockcroft, V.G., Ross, G.J.B., Peddemors, V.M. and Borchers, D. 1992. Estimates of density and undercounting of bottlenose dolphins off northern Natal, South Africa. *S. Afr. J. Wildl. Res.* 22: 102-09.

Corbett, H.D. 1994. The occurrence of cetaceans off Mauritius and in adjacent waters. *Rep. int. Whal. Commn* 44: 393-98.

Dawbin, W.H. 1966. The seasonal migratory cycle of humpback whales. pp.145-70. *In*: Norris, K.S. (eds). *Whales, Dolphins, and Porpoises*. University of California Press, Berkeley and Los Angeles. xv+789pp.

de Boer, M.N., Baldwin, R., Burton, C.L.K., Eyre, E.L., Jenner, K.C.S., Jenner, M.N.M., Keith, S.G., McCabe, K.A., Parsons, E.C.M., Peddemors, V.M., Rosenbaum, H.C., Rudolph, P. and Simmonds, M. 2002. Cetaceans in the Indian Ocean Sanctuary: A review. Paper SC/54/O5 presented to the IWC Scientific Committee, April 2002, Shimonoseki, Japan (unpublished). 60pp. [Paper available from the Office of this Journal].

De Lestang, J.N. 1993. Status of marine mammals in the Eastern African region. Report to UNEP, Regional Seas and Studies Series.

Findlay, K.P. and Best, P.B. 1996. Estimates of the numbers of humpback whales observed migrating past Cape Vidal, South Africa, 1988-1991. *Mar. Mammal Sci.* 12(3): 354-70.

Findlay, K.P., Best, P.B., Peddemors, V.M. and Gove, D. 1994. The distribution and abundance of humpback whales on their southern and central Mozambique winter grounds. *Rep. int. Whal. Commn* 44: 311-20.

Gannier, A. 2000. Distribution of cetaceans off the Society Islands (French Polynesia) as obtained from dedicated surveys. *Aquat. Mamm.* 26: 111-26.

Gannier, A. 2002. Cetaceans of the Marquesas Islands (French Polynesia): distribution and relative abundance as obtained from a small boat dedicated survey. *Aquat. Mamm.* 28(2): 198-210.

International Whaling Commission. 2000. Report of the Scientific Committee. *J. Cetacean Res. Manage. (Suppl.)* 2: 1-65.

Jefferson, T.A., Leatherwood, S. and Webber, M.A. 1993. *FAO Species Identification Guide. Marine Mammals of the World.* FAO, Rome. 320pp.

Karczmarski, L. 1996. Ecological studies of humpback dolphins *Sousa chinensis* in the Algoa Bay region, Eastern Cape, South Africa, PhD thesis, University of Port Elizabeth. 202pp.

Karczmarski, L. and Cockcroft, V. 1999. Daylight behaviour of humpback dolphins in Algoa Bay, South Africa. *Z. Saugetierkunde* 64: 19-29.

Kasuya, T. and Wada, S. 1991. Distribution of large cetaceans in the Indian Ocean: data from Japanese sightings records, November-March. *UNEP Mar. Mamm. Tech. Rep.* 3: 139-70.

Keller, R.W., Leatherwood, S. and Holt, S.J. 1982. Indian Ocean cetacean survey, Seychelles Islands, April through June 1980. *Rep. int. Whal. Commn* 32: 503-13.

Leatherwood, S. and Donovan, G.P. 1991. *Cetaceans and Cetacean Research in the Indian Ocean Sanctuary*, *Marine Mammal Technical Report No.3*. UN Environment Programme, Nairobi. vii+287pp.

MacLeod, C.D., Hauser, N. and Peckham, H. 2004. Diversity, abundance and structure of the cetacean community in summer months east of Great Abaco, Bahamas. *J. Mar. Biol. Assoc. UK* 84: 469-74.

MacLeod, C.D. and Zuur, A.F. 2005. Habitat utilisation by Blainville's beaked whales off Great Abaco, Northern Bahamas, in relation to seabed topography. *Mar. Biol.* 174: 1-11.

Norris, K.S. 1991. *Dolphin Days – The Life and Times of a Spinner Dolphin*. W.W. Norton and Co., New York, New York. 335pp.

Norris, K.S., Würsig, B., Wells, R.S., Würsig, M., Brownlee, S.M., Johnson, C. and Solow, J. 1985. The behavior of the Hawaiian spinner dolphin, *Stenella longirostris*. *SWFSC Admin. Rep. No.* LJ-85-06C. 213pp. [Contract NOAA 79-ABC-00090].

Peddemors, V.M. 1999. Delphinids of southern Africa: a review of their distribution, status and life history. *J. Cetacean Res. Manage.* 1(2): 157-65.

Psarakos, S., Herzing, D. and Marten, K. 2003. Mixed-species associations between pantropical spotted dolphins (*Stenella attenuata*) and spinner dolphins (*Stenella longirostris*) off Oahu, Hawai'i. *Aquat. Mamm.* 29: 390-95.

Quod, J.P., Naim, O. and Abdourazi, F. 2000. The Comoros archipelago. pp.243-52. *In*: Sheppard, C. (eds). *Seas at the Millennium: An Environmental Evaluation*. Pergamon Press, Oxford.

Robineau, D. 1975. Echouage d'un *Ziphius cavirostris* Cuvier, 1823 (Cetacea, Hyperoodontidae) dans l'archipel des Comores (Ocean Indien). *Mammalia* 39: 513-15. [In French].

Robineau, D. 1991. Balaenopterid sightings in the western tropical Indian Ocean (Seychelles area), 1982-1986. *UNEP Mar. Mamm. Tech. Rep. 3*: 171-78.

Rosenbaum, H.C., Walsh, P.D., Razafindrakoto, Y., Vely, M. and DeSalle, R. 1997. First description of a humpback whale breeding ground in Baie d'Antongil, Madagascar. *Conserv. Biol.* 11(2): 312-4.

Ross, G.J.B. and Cockcroft, V.G. 1990. Comments on Australian bottlenose dolphins and taxonomic status of *Tursiops aduncus* (Ehrenburg 1832). pp.101-28. *In*: Leatherwood, S. and Reeves, R.R. (eds). *The Bottlenose Dolphin*. Academic Press, San Diego. i-xviii+653pp.

Ross, G.J.B., Heinsohn, G.E. and Cockcroft, V.G. 1994. Humpback dolphins – *Sousa chinensis* (Osbeck, 1765), *Sousa plumbea* (G. Cuvier, 1829) and *Sousa teuszii* (Kükenthal, 1892). pp.23-42. *In*: Ridgway, S.H. and Harrison, R. (eds). *Handbook of Marine Mammals Volume 5. The First Book of Dolphins*. Academic Press, London and San Diego. 416pp.

Shirakihara, M., Yoshida, H. and Shirakihara, K. 2003. Indo-Pacific bottlenose dolphins *Tursiops aduncus* in Amakusa, western Kyushu, Japan. *Fish. Sci.* 69(3): 654-56.

Stensland, E., Carlén, I., Särnblad, A., Bignert, A. and Berggren, P. 2006. Abundance, distribution and behavioural ecology of Indo-Pacific bottlenose (*Tursiops aduncus*) and humpback (*Sousa chinensis*) dolphins off the south coast of Zanzibar. *Mar. Mammal Sci.* 22: 667-82.

Wells, R.S. and Scott, M. 1999. Bottlenose dolphin *Tursiops truncatus* (Montagu, 1821). pp.137-82. *In*: Ridgway, S. and Harrison, R. (eds). *Handbook of Marine Mammals – the Second Book of Dolphins*. Academic Press, San Diego.

Whitehead, H. and Moore, M.J. 1982. Distribution and movements of West Indian humpback whales in winter. *Can. J. Zool.* 60: 2203-11.

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Sighting history and observations of southern right whales following satellite tagging off South Africa

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ABSTRACT

In September 2001, satellite tags were deployed on 21 southern right whales (*Eubalaena australis*) in South African coastal waters, including eight cows accompanied by newborn calves. To date there have been 26 re-sightings of 11 of these individuals (or their calves) at intervals of 27-1,502 days. So far, 85.7% of the females with calves have been re-sighted with a second calf, at intervals comparable to those that the same individuals showed before tagging. All tags seem to have been shed between 27 and 36 months of tagging. Superficial and remote examination of wound sites indicated the frequent formation of divots with accompanying scarring and cyamids, but little sign of localised (and none of regional) swelling.

KEYWORDS: AFRICA; SOUTHERN RIGHT WHALE; SATELLITE TAGGING; REPRODUCTION; SURVIVORSHIP; SOUTHERN HEMISPHERE

INTRODUCTION

Efforts to attach radio or satellite tags to large whales have been ongoing since 1962 (Watkins, 1978) and 1983 (Montgomery, 1987) respectively. Initially, most of these deployments were on very small numbers of individuals that represented negligible proportions of the populations concerned. As the technology and associated results improved, however, there has been increasing realisation of the potential value of the technique for addressing questions of considerable importance to the conservation of small and endangered populations. At the same time, concerns have arisen that if the technique itself should cause problems (injury, disease) to the tagged individual that may compromise its survival or reproductive rates, then this might be an inappropriate technology to use under such circumstances. In reaction to a proposal to tag individuals from the small and endangered Western North Pacific stock of gray whales (*Eschrichtius robustus*), the Scientific Committee of the International Whaling Commission agreed to review the general issue of the use of telemetry and its potential effects on whales at its 2008 meeting (IWC, In press), when the report of a Marine Mammal Commission Workshop on the subject will be available.

Unfortunately, in most cases once the transmitter of a satellite-tagged animal ceases to function it becomes just another member of its population. In the cases of most large populations of whales, this means that the chances of re-locating it to examine its physical well-being or reproductive status are slim indeed. Furthermore, while a physical examination might suffice to test for obvious injury or disease, testing for impaired survival or reproduction demands that the future history of that individual be monitored over at least one reproductive cycle, and the result compared either with the pre-tagging history of the same individual, or with the post-tagging history of other, untagged individuals from the same population. Such opportunities only really exist in relatively small, well-studied populations (Kraus *et al*., 2000).

Since 1979, annual aerial photographic surveys of southern right whales (*Eubalaena australis*) have been carried out off South Africa, and a catalogue of some 1,000 known individuals has been compiled, mostly mature females with reproductive histories. This paper examines the sighting histories both pre- and post-tagging (where known) and observations of tag sites for 21 southern right whales on which satellite tags were deployed off South Africa in 2001.

MATERIAL AND METHODS

In September 2001, satellite transmitters were deployed on 21 southern right whales in South African waters. These were intended principally as trials of a modified tag before its deployment on North Atlantic right whales.

The tags were stainless steel cylinders 1.8cm in diameter and 24cm long, deployed from a crossbow and designed to be almost completely subdermal (with a stopper preventing the tag from becoming completely embedded). The outer end of the tag carried a 15cm aerial and a 4cm saltwater switch, while two sets of spring tines radiating from the body of the tag increased tag retention. The tag was coated with a long-lasting antibiotic prior to deployment (Mate *et al*., 2007).

Sixteen of the tags were deployed in St. Sebastian Bay on the south coast of South Africa between 8 and 13 September, and five outside Saldanha Bay on the west coast between 21 and 26 September (Fig. 1). Eight tags were placed on cows with calves, all in St. Sebastian Bay, while the remaining 13 were placed on animals without calves (Table 1).

Annual photographic surveys for right whales have been carried out on the South African coast since 1979. The principal targets of these surveys have been cow-calf pairs, and only rarely (i.e. where a second adult was present with a cow-calf pair) have other animals been photographed. Nevertheless, for adult females these potentially provide both pre- and post-tagging information on calving intervals, and for younger animals might provide a year of birth and

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Table 1

Details of satellite tag deployments on southern right whales in South African waters, 2001.

Tag no.	Date deployed	Sex	Grouping	Prior sighting history	Age (yr)[1]	Days with locations
827	8 Sep.	F	With calf	Calved 1997	>10	27
839	8 Sep.	-	1 of 2 subadults	None	-	119
843	8 Sep.	F	With calf	Calved 1992	>15	39
1385	8 Sep.	F	With calf	Calved 1998	>9	1
826	8 Sep.	F	Single	Calved 1983, 1998	>24	36
825	8 Sep.	-	Adult with subadult	Seen 1991 with cow-calf	>10	38
824	8 Sep.	-	Single juvenile near SAG	None	-	0
848	8 Sep.	M	Juvenile from SAG	None	-	123
823	8 Sep.	F	With calf	[Photos too poor to match]	-	25
23034	12 Sep.	-	1 of 3 juveniles	None	-	69
838	12 Sep.	M	1 of 2 juveniles	None	-	66
837	12 Sep.	F	1 of 2 adults	None	-	<1
847	12 Sep.	F	With calf	First observed calving	>6	57
834	12 Sep.	F	With calf	Calved 1998	>9	0
835	13 Sep.	F	With calf	Calved 1987, 1992, 1995, 1998	>20	0
10826	13 Sep.	F	With calf	Seen as calf in 1979, calved 1989, 1992, 1996	22	<1
836	21 Sep.	F	1 of 3 adults	[Photos too poor to match]	-	81
23037	22 Sep.	M	1 of 3 adults	None	-	65
23031	22 Sep.	M	1 of 5	Seen as calf in 1996	5	161
831	22 Sep.	-	1 of 3	None	-	35
4172	26 Sep.	M	Single juvenile	None	-	137

[1] Unless seen as calf, age estimated for females assuming animal was at least 6 years old when seen with first calf.

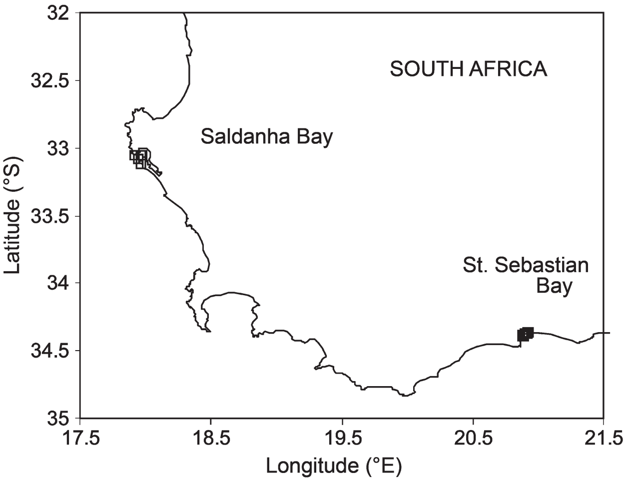

Fig. 1. Coast of Western Cape, South Africa, showing locations of satellite tagging of southern right whales, September 2001.

therefore age at tagging. Photographs of all animals on which satellite tags were deployed have been compared with this catalogue (up to and including the 2005 survey).

Periodic boat-based surveys have been carried out for right (and other) whales on the South African coast, notably from 1995 to 1997 as part of a genetic sampling project, from 1999 to 2001 as part of a humpback whale migration study on the west coast and from 2003 to date as part of a study of a right whale feeding ground on the west coast. Photo-identification has been a major component of all these studies, and where such pictures have been sorted and catalogued, they have been matched with the satellite-tagged animals.

Finally, commercial whalewatching operators were alerted to the presence of satellite-tagged right whales shortly after the tags were deployed, and opportunistic photographs of right whales believed to be tagged, or with wounds possibly caused by tags, were received from some operators. These have been matched with the satellite-tagged animals.

In assessing the status of the wound associated with the tag site, the criteria used by Kraus *et al.* (2000) were adopted, namely, for occurrence of scars: none, white scar, a scar and divot, and a divot and cyamids; and for occurrence of swelling: none, localised, and regional. A divot was defined as an indentation of varying size, localised swelling as a bulge less than 30cm in diameter and regional swelling as a bulge estimated at 30-90cm in diameter.

If no part of the tag could be seen, it was considered to have been shed. This assumption was based on the observation that whales with protruding tags were re-sighted subsequently without any visible sign of the tag.

RESULTS

Two individuals (tags 823 and 836) were insufficiently photo-identified at the time of tagging, so for these individuals there is no available post-tagging information. Of the remaining 19 individuals, 10 (or their calves) have been re-sighted to date, and 26 re-sightings (including of one unidentified individual) have occurred at intervals of 27 to 1,502 days after tagging (Table 2).

Of the seven cows with calves that were tagged and photo-identified adequately, six have been re-sighted with a second calf, five after three years and one after four years, for an average of 3.2 ± 0.4 years. The preceding calving intervals for these seven individuals were 0, 3, 3, 3, 4, 5 and 9 years, for an average (excluding the 0) of 4.5 ± 2.1 years. The calf of the tagged cow with a subsequent 4-year interval was itself seen alone 12.5 and 17 months later, suggesting that its mother had completed its reproductive cycle successfully.

Although it is difficult to make exact determinations from the photographs taken on aerial surveys, part or all of the tag seemed to be present at all sightings up to 836 days after tagging, whereas all re-sightings after 1,098 days indicated that the tag had been shed. ‘Protruding’ tags were recorded as early as 75 days post-tagging, however, so it is possible that some were lost well before 836 days.

Table 2

Details of re-sightings of satellite-tagged right whales on the South African coast.

Tag no.	Date seen	Days post-tagging	Notes on sighting	Tag seen	Scar[1]	Swelling[2]
827	11 Oct. 01	33	From air, with calf	Yes	1	1
827	12 Oct. 04	1,130	From air, with calf	No	4	1
843	14 Oct. 01	36	From air, with calf	Yes	1	1
843	13 Oct. 04	1,131	From air, with calf	No	1	1
1385	10 Oct. 01	32	From air, with calf	Yes	1	1
1385	11 Oct. 01	33	From air, with calf	Yes	1	1
1385	12 Oct. 04	1,130	From air, with calf	[No view]	-	-
826	14 Oct. 01	36	Aerial survey, single	Yes	1	1
837	14 Sep. 04	1,098	Whale watching	No	4	1
847	11 Oct. 01	29	From air, with calf	Yes	1	1
847	5 Dec. 02	420	From boat, in pair	Yes	4	1
847	11 Oct. 04	1,125	From air, with calf	No	2	1
834	10 Oct. 01	28	From air, with calf	Yes	1	1
834	26 Nov. 01	75	Video, with calf	Yes[3]		
834	13 Oct. 04	1,127	From air, with calf	No	3	1
10826	10 Oct. 01	27	From air, with calf	Yes	1	1
10826	30 Sep. 02	382	From boat, calf alone	-	-	-
10826	13 Feb. 03	518	From boat, calf alone	-	-	-
10826	10 Oct. 05	1,461	From air, with calf			
10826	20 Nov. 05	1,502	Whalewatching	No	4	1
23031	20 Oct. 03	758	Aerial survey, 1 of 5	[Too far]	-	-
23031	8 Nov. 03	777	From boat, 1 of 4	Yes[3]	3	1
23031	6 Jan. 04	836	From boat, 1 of 5	Yes[3]	3	1
23031	8 Oct. 04	1,112	From boat, 1 of 4	No	2	1
23034	2 Oct. 02	385	From boat, 1 of 5	Yes[3]	4	1
Unid.	6 Dec. 02	~ 430	From boat, 1 of 5	Yes	4	2

[1] 1 = none, 2 = white, 3 = scar + divot, 4 = divot + cyamids. [2] 1 = none, 2 = localised, 3 = regional. [3] Tag protruding.

No divot was noticeable at the tag site before 385 days after tagging (although there were no observations between days 36 and 385). After that date scars were recorded as none (1), white scar (2), scar + divot (3) and divot + cyamids (6). Localised swelling was recorded in a single case; otherwise the wound sites were remarkable for their lack of swelling.

DISCUSSION

The satellite-tagging experiment was not designed with a specific follow-up monitoring phase, so these observations are largely opportunistic and take advantage of ongoing research programmes and other activities. The sample of animals is also small so that the power to detect any but major effects is low. Nevertheless, the finding that six out of seven (85.7%) of the cows tagged with calves gave birth to a subsequent calf within intervals comparable to those prior to tagging suggests that the procedure had no major impact on reproductive output (or short-term survival). The efficiency of detecting cows with calves on these surveys has been estimated as 74-82% (Best *et al*., 2001), so the seventh female may have given birth subsequently and gone undetected, or it may still give birth (post-tagging monitoring has only persisted for four years to date). While the survival rate of the dependent calves cannot be evaluated directly from these data, none of the females subsequently gave birth after two years, an interval normally associated with the peri-natal loss of the first calf (Elwen and Best, 2004), while the calf from the sole 4-year calving interval clearly survived to nutritional independence.

Since monitoring efforts were largely directed towards adult females, it is no surprise that the re-sighting rate of known males (1/5) was lower than that of known females (8/11). Furthermore, the mean residence time of unaccompanied southern right whales (including males) in coastal waters is much shorter (20.4 days) than that of cows with calves (70.9 days), providing less opportunity for re-sighting them (Burnell and Bryden, 1997). Consequently it should not be concluded from the lower re-sighting rate of males that their survival was adversely affected by tagging.

Available evidence suggests that all instruments were shed between 27 and 36 months (and possibly sooner) of tagging. There was a noticeable lack of swelling at all but one of the wound sites examined, although divots (both with and without cyamids) were a common feature for all re-sightings after one year or more. Furthermore, because re-sightings tended to occur at annual intervals (when right whales were present in coastal waters) it is possible that swellings occurred but were resolved in the intervening periods.

In summary, the deployment of satellite tags in southern right whales off South Africa appeared to have no major effect on the reproductive success of adult females or (by inference) the survival of their calves. Although divots plus scars and accompanying cyamids were a common feature of wound sites, even after the tags themselves were shed, there was little sign of the localised (and none of the regional) swelling seen in North Atlantic right whales. These conclusions are, of course, based on a very small sample size (with correspondingly low statistical power) and are unable to address any possible longer term effects.

Additionally, it is unclear how applicable these results might be to other large whale populations. North Atlantic right whales, for instance, have a thinner and more variable blubber layer than southern right whales (Angell, 2006), and seem to carry a higher incidence of skin lesions of unknown aetiology (Pettis *et al*., 2004), so it is conceivable that the impacts of the tags could be different in this species (although the extreme inter-annual variability in reproductive success in this population (Kraus *et al*., 2001) might make it difficult to conclusively establish effects).

REFERENCES

Angell, C.M. 2006. Body fat condition of free-ranging right whales, *Eubalaena glacialis* and *Eubalaena australis*. PhD thesis, Boston University, Boston. 256pp.

Best, P.B., Brandão, A. and Butterworth, D.S. 2001. Demographic parameters of southern right whales off South Africa. *J. Cetacean Res. Manage. (special issue)* 2: 161-69

Burnell, S.R. and Bryden, M.M. 1997. Coastal residence periods and reproductive timing in southern right whales, *Eubalaena australis*. *J. Zool. (Lond.)* 241: 613-21.

Elwen, S.H. and Best, P.B. 2004. Female southern right whales *Eubalaena australis*: are there reproductive benefits associated with their coastal distribution off South Africa? *Marine Ecology. Progress Series* 269: 289-95.

International Whaling Commission. In press. Report of the Scientific Committee. *J. Cetacean Res. Manage. (Suppl.)* 10.

Kraus, S., Quinn, C. and Slay, C. 2000. *Report of a Workshop on the Effects of Tagging on North Atlantic Right Whales*. New England Aquarium, Boston, USA. 15pp. [Available from: The New England Aquarium, Central Wharf, Boston, MA 02110, USA].

Kraus, S.D., Hamilton, P.K., Kenney, R.D., Knowlton, A.R. and Slay, C.K. 2001. Reproductive parameters of the North Atlantic right whale. *J. Cetacean Res. Manage (special issue)* 2: 231-36.

Mate, B., Mesecar, R. and Lagerquist, B. 2007. The evolution of satellite-monitored radio tags for large whales: one laboratory's experience. *Deep Sea Research II* 54 (Special Issue: Bio-logging science: logging and relaying physical and biological data using animal-attached tags. Proceedings of the 2005 International Symposium on Bio-logging Science): 224-47.

Montgomery, S. (ed.) 1987. Report on the 24-26 February 1987 Workshop to Assess Possible Systems for Tracking Large Cetaceans. US Dept. of Commerce NTIS Report no. MMS87-0029. 53pp.

Pettis, H.M., Rolland, R.M., Hamilton, P.K., Brault, S., Knowlton, A.R. and Kraus, S.D. 2004. Visual health assessment of North Atlantic right whales (*Eubalaena glacialis*) using photographs. *Can. J. Zool.* 82: 8-19.

Watkins, W.A. 1978. A radio tag for big whales. *Oceanus* 21(2): 48-54.

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A note on movements of two fin whales (*Balaenoptera physalus*) tracked by satellite telemetry from the Faroe Islands in 2001

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ABSTRACT

In August 2001, two fin whales were tagged with satellite linked radio transmitters 90km east of the Faroe Islands (62°N, 7°W). One whale that was tracked for 48 days resided on the Faroe shelf inside the 500m depth contour, with movements ranging within 190km from the tagging site. Another whale that was tracked for 116 days moved south to 46°N, 21°W, i.e. the same latitude as the Bay of Biscay, during the first 16 days of the tracking, which corresponds to a straight line distance of 2,830km. After residing at this latitude for three weeks, it moved northeast again, during two weeks, to an area north-west of Ireland. For the following two month period, it mainly moved within 54-58°N, at depths of 1,000-2,500m. A total of 132 positions were received from the two whales, most of relatively low accuracy, but still applicable for depicting large scale movements.

KEYWORDS: FIN WHALE; SATELLITE TRACKING; TELEMETRY; MOVEMENTS; NORTHERN HEMISPHERE; ATLANTIC OCEAN

INTRODUCTION

Knowledge about stock identity and migration of North Atlantic fin whales (*Balaenoptera physalus*) is limited (Donovan, 1991; IWC, 1992; 2007; NAMMCO, 2001). Fin whales migrate to feeding areas at higher latitudes in spring and summer, but are largely absent from the same waters in winter (Bloch *et al*., 2000). Although believed to have a more southerly distribution during winter (Sergeant, 1977), their wintering grounds in the North Atlantic are unknown. Genetic investigations at feeding grounds have suggested several independent populations across the North Atlantic, and indicated more than one breeding unit (Bérubé *et al*., 1998; Danielsdóttir, 1999; Daníelsdóttir *et al*., 1991). The stock boundaries accepted by the International Whaling Commission (IWC) in the mid-1970s divided the species into seven stocks or independent management units (Donovan, 1991; IWC, 1992). The division was based mainly on indirect evidence from former catch and sighting data (see Sergeant, 1977). Jonsgård and Rørvik (1975) concluded that fin whales in the waters around the Faroe Islands most likely belong to a West Norway – Faroe Islands stock. For fin whales in West Norway, more recent genetic studies have concluded that they are distinct from those taken in coastal waters of Iceland (Bérubé *et al*., 1998; Danielsdóttir, 1999; Daníelsdóttir *et al*., 1991). An earlier study comparing reproductive parameters (average length at sexual maturity, mean time of mating and parturition and pregnancy rate) also indicated that they were distinct from whales in North Norway (Haug, 1981). In 1982, 13 fin whales were marked with Discovery tags in Faroese waters. One mark was recovered 26 days later, near the tagging position (Bloch and Joensen, 1984). Fin whales from Faroese waters have so far not been included in any comparative population studies. The NAMMCO Working Group on Fin Whales concluded in 2000 that in order to give precise management options for fin whales in Faroese waters, and in North Atlantic in general, more information is needed on stock identity (NAMMCO, 2001). The more recent technical development of satellite transmitters, tracked by the Argos satellite-based data collection and location system, have given the opportunity to investigate *in situ* movements of marine mammals for extended time periods. Therefore, such studies may address questions about migration and site fidelity, and thus stock identity, of these animals. One major problem when tagging larger whales has been deployment techniques, since these animals cannot be handled during the tagging operation. However, new techniques for remote deployment of tags have recently become available (Heide-Jørgensen *et al*., 2001a). In 2000 and 2001 satellite tags were mounted on fin whales in Faroese waters, in order to study their movements and site fidelity. This paper describes movements of two fin whales successfully tracked using the Argos system.

MATERIAL AND METHODS

The satellite transmitters used in the study were of the type ST-15, manufactured by Telonics Inc., USA. These tags weighed 110g and were equipped with a saltwater conductivity switch only allowing transmissions when the switch was out of water. The tags were programmed to have a duty cycle of 24 hours actively transmitting followed by a 72 hour inactive period in order to prolong battery life. The repetition period was 45 seconds and the total number of transmissions each day was set to 500. Nominal longevity based on two M1 batteries was 25 days, but expected longevity with the programmed duty cycle was about 100 days. The tags were mounted to a 27cm long steel anchor bolt with barbs for penetrating the blubber and anchoring the tag at the surface of the body (see also Heide-Jørgensen *et al*., 2001b; Heide-Jørgensen *et al*., 2003). The equipment used for deploying the tags was the Air Rocket Transmitter System (see Heide-Jørgensen *et al*., 2001a; Fig. 1). Potential tagging localities for fin whales were selected from available observation and distribution data for the relevant time of the year (Bloch *et al*., 2000). Two procedures were used in the course of tagging. In 2000, fin whales were tagged from the LYNX helicopter located onboard the

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Danish fisheries inspection vessel *Triton* (112.3m), operating periodically in Faroese waters. Whales were discovered from the helicopter, re-spotted under the surface, and as the whale broke the surface, usually on the third blow, the helicopter dove and from an altitude of ca. 25m a tag was shot in the back of the whale (Fig. 1). In 2000 and again in 2001, fin whales were tagged from the Faroese fisheries inspection vessel *Tjaldur* (44.5m). A platform was constructed on the bow of the vessel from which the tags were fired (Fig. 1). The ship carefully tracked and approached whales, and when a whale was surfacing at a suitable distance (<30m), a tag was shot into the back of the whale. Effort was made to place the tags as high as possible on the back (near the centre line), in the area midway between the blowhole and the dorsal fin, to increase the probability of the antenna and salt-water switch being dry when the whale surfaced.

Satellite transmitter data were made available from Argos Data Collection and Location Service (*www.cls.fr*). The location data varied in accuracy, as indicated by the location class provided by Argos. In order to predict accuracy of locations (i.e. location classes 3, 2 or 1), the Argos receiving unit needs, among other transmission standards, a minimum of four uplinks during one satellite pass, lasting on average 10min. The accuracy of these locations is in 68% of cases given to be within 1,000m from actual transmitter locations. For less accurate locations (i.e. location classes 0, A or B) no predicted accuracy is given by Argos. Experimental studies have shown that location class A may have about same precision quality as location class 1, but that location classes 0 and B can have very low precision, although in most cases not exceeding 10,000m (Hays *et al*., 2001; Raum-Suryan *et al*., 2004; Vincent *et al*., 2002). In the present study no filter processing in order to identify erroneous locations (e.g. Austin *et al*., 2003; Vincent *et al*., 2002), was applied to the data. Movements are presented by the most accurate location or average of most accurate locations given each fourth day (i.e. duty cycle of transmitters). By this method, large errors from aberrant locations are reduced and estimated swimming speed is also less biased, since influence from low accuracy will be most significant when locations are close (Heide-Jørgensen *et al*., 2001b; Heide-Jørgensen *et al*., 2003).

RESULTS

All tagging attempts were conducted in good weather conditions in July and August, on the shelf and slope east and southeast of the Faroes. A total of 11 fin whales were equipped with satellite transmitters; five tagged from helicopter and two from vessel in 2000, and four tagged from vessel in 2001. One tag, fired from helicopter in 2000, missed the target and was lost. Two tags, mounted on 7 and 8 August 2001, within the same area 90km east of the islands, gave useful uplinks to be received and identified by the Argos data collecting system.

A total of 132 locations were obtained from the two whales, of which 125 (95%) were of unknown accuracy, i.e. location class 0, A or B (Table 1). In three incidents, when transmitters were active, no location was obtained, the longest gap being 12 days between subsequent locations. The average number of locations obtained each active transmitter day was 3.4 (range:0-11) for the two transmitters combined; both with similar performance.

The two active tags provided signals for total periods of 48 and 116 days respectively (Table 1). During the tracking period, these two whales showed different movement patterns. The whale with the shorter track (ID no. 20685) stayed on the shelf inside the 500m depth contour during the total 48 day tracking period (Fig. 2). Within the first four days of tracking, it moved to the southern part of the shelf, then turned and moved northeast again. For the rest of the tracking period, it stayed east of the Faroe Islands. When contact was lost, it was 80km west of the tagging site. The

Fig. 1. Fin whale is being approached by helicopter, ready to tag (above), platform arrangement on bow of M/S *Tjaldur* (middle) and typical position and angle of tag when fired from ship (bottom).

Table 1

The period of tag operation, distance travelled, speed and location quality for two fin whales tagged on 7 and 8 August 2001 (day 218/219) in Faroese waters. Standard deviation is given in parentheses. The given ARGOS accuracy of positions with location class 3 = 0-150m, 2 = 150-350m, 1 = 350-1,000m and for 0, A and B = accuracy not given.

						Distribution of positions by accuracy quality (location class)					
ID no.	Tracking period	No. of days	No. of positions	Total distance travelled (km)	Daily horizontal speed	3	2	1	0	A	B
20685	08/08/01-25/09/01	48	29	724	15km day^{-1} (17)	-	-	-	-	13	16
26712	07/08/01-01/12/01	116	103	9,279	80km day^{-1} (116)	1	1	5	5	16	75

total distance travelled was 724km, but geographically restricted within a range of 200km. The average daily movement was 21km (range 5-61km day^{-1}).

The whale tracked for the longer period (ID no. 26712) made a long southbound movement. After tagging it started moving southeast (Fig. 3), and was tracked south to 47°N, 27°W; i.e. approximately the same latitude as the northern part of Bay of Biscay. This movement covered 2,830km in 16 days and was confirmed by location class 3 and 2 positions. The average surface swimming speed, during the movement from the tagging site south to 47°N was 177km day^{-1}. The whale stayed at this latitude for a month, first moving east and then west again, towards the same location it had 32 days earlier. Thereafter it moved in a north-east direction, and fourteen days later it was located in an area north-west of Ireland (56°N, 12°W). For the next two months, until contact was lost, it stayed northwest of Ireland, with circular motions in an area of 400km, with steep slope and depths of 1,000-4,000m. The total distance travelled was 9,279km. The average daily movement for the whole period was 82km (range 9-447km day^{-1}).

DISCUSSION

Both the helicopter and large vessel were useful platforms for remote tagging of fin whales in Faroese waters, where tags were applied from distances up to 25m. However, whilst the helicopter was useful in high density areas, where at best four tags could be deployed during a one-hour flight, all of the tags deployed from the helicopter failed, probably

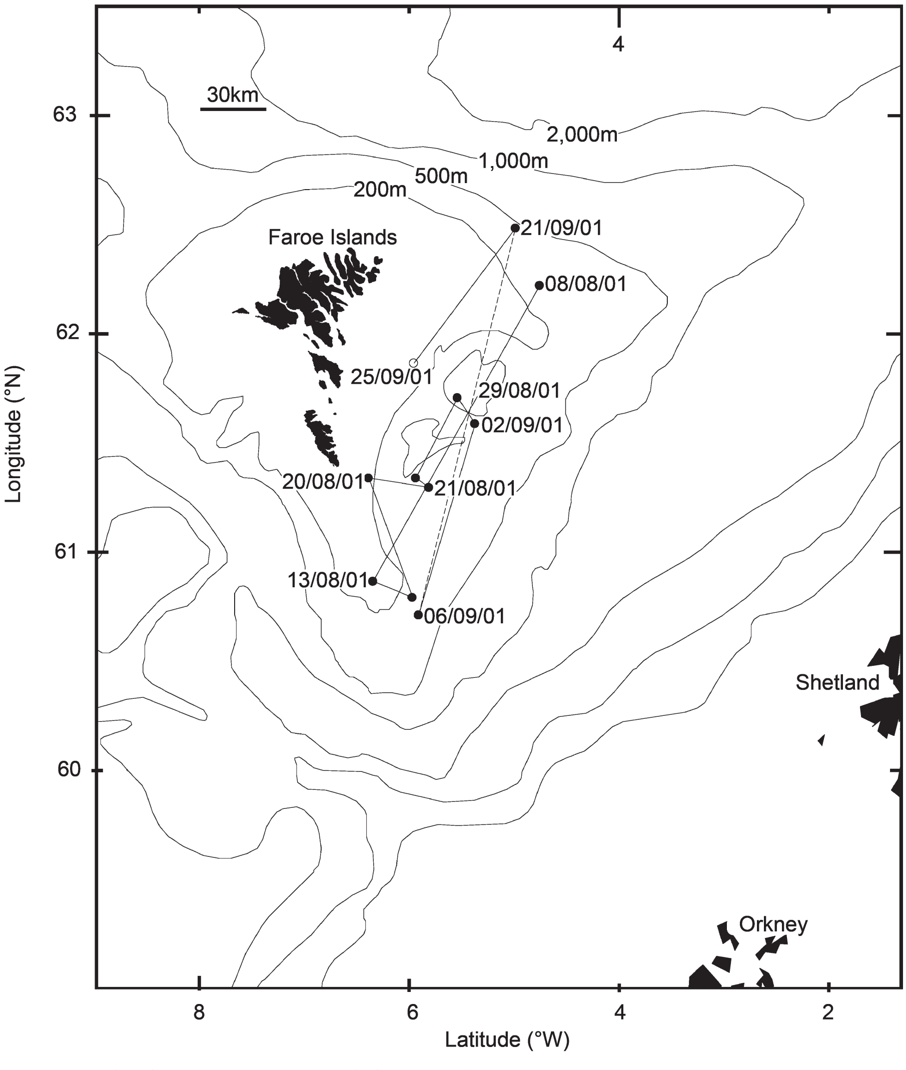

Fig. 2. Movements of a fin whale (ID no. 20685) tagged in Faroese waters 8 August 2001 and tracked until 25 September (48 days). One location is given every fourth day (dashed lines indicates when consecutive positions are apart by more than one 4-day period).

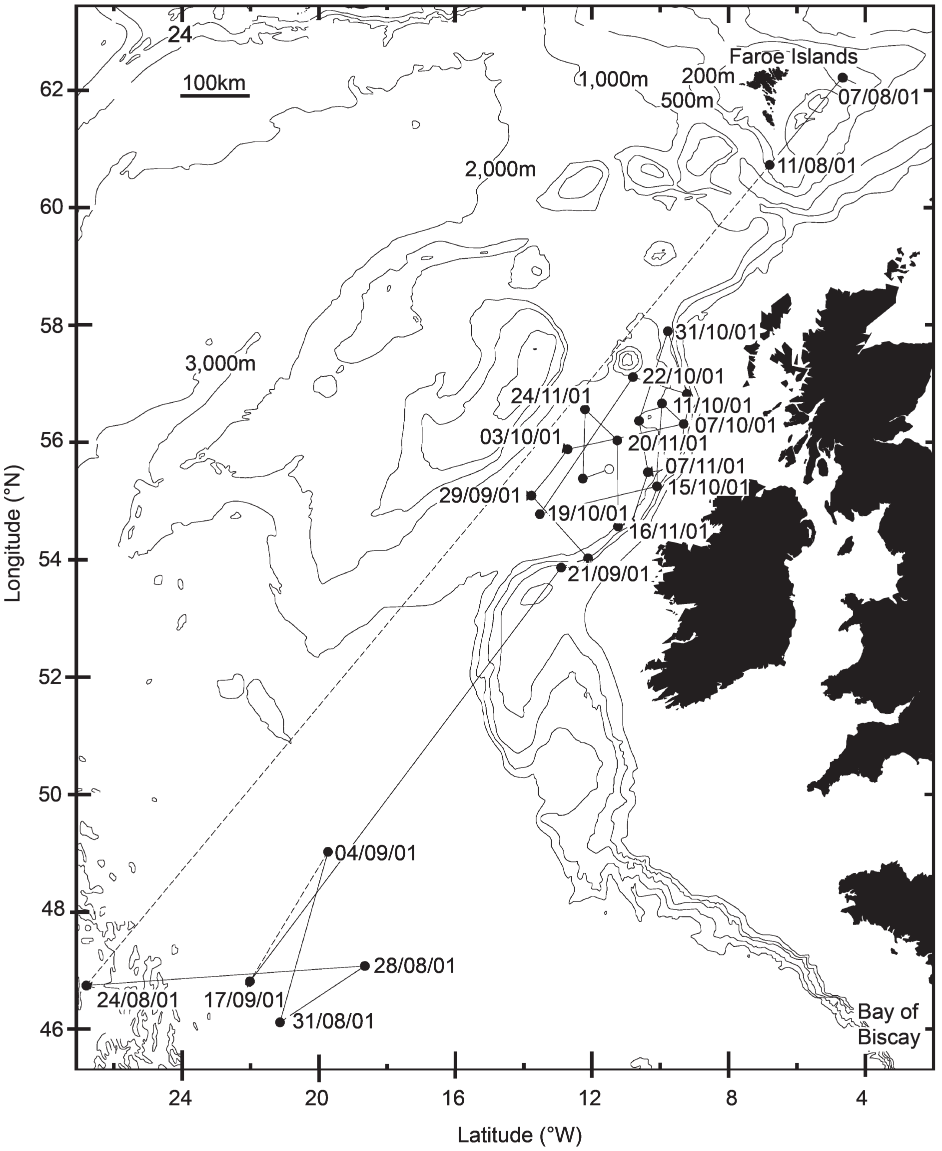

Fig. 3. Movements of a fin whale (ID no. 26712) tagged in Faroese waters 7 August 2001 and tracked until 1 December (116 days). One location is given every fourth day (dashed lines indicates when consecutive positions are apart by more than one 4-day period).

as a result of the heavy impact caused by the extra speed caused by the altitude of the helicopter. Observed problems with longevity of tags have been battery drainage or quick tag expulsion (Heide-Jørgensen *et al*., 2001b; Watkins *et al*., 1996), but in this study the problem seemed to be that tags could not stand the mechanical stress of firing or of hitting the whale body. One tag detached from the anchor bolt after being launched. In an attempt to solve this problem, tags were mounted using a long rod (Heide-Jørgensen *et al*., 2003). One tag attained expected battery longevity, while one tag stopped transmitting before expected battery exhaustion, perhaps because it fell off.

Tags were kept small, in order to reduce drag and use the ARTS launching gun, the trade-off being battery capacity. Tag longevity was prolonged from the nominal 25 days to above 100 days by only allowing transmission when a whale surfaced, creating a 25% duty cycle and limiting the number of transmissions each day. One position each fourth day was considered adequate for generalised large-scale tracking of fin whales in the Faroes. Therefore, an average of 3.3 locations transmitted each day fulfilled the objective of the study, although 95% of all locations had a relatively low precision. The reason for this was low uplink frequency, bad uplink quality or non-optimal distribution of uplinks across the Doppler curve. Information on precision (i.e. standard deviation of distributions within each location class) is only available when four or more uplinks are received for each satellite pass, lasting about 10min (Austin *et al*., 2003). Low uplink frequency may be caused by low surfacing times. Stone *et al*. (1992) reported a respiration rate of 48 breaths h^{-1}, a surface duration of 55s and a blow rate of around 3 for fin whales from Gulf of Maine. Assuming this respiration behaviour, the tracked whales may have been at the surface on average 10 times during a satellite pass. With a repetition period of 45s, this would allow the tag to transmit at blow one and again at blow three. The more likely problem with low uplink frequency could be because tags were placed low on the back of the whales, i.e. close to the waterline. Not being out of the water when the whale surfaced, the saltwater switch would not dry and let the tag transmit. This may be especially true during bad weather. Fin-mounted tags on pilot whales from the same area have performed better (Bloch *et al*., 2003), which could be because tags mounted on the dorsal fin may shed water quicker than tags mounted on the back.

Satellite tracking of large cetaceans usually provides locations with low accuracy (e.g. Heide-Jørgensen *et al*., 2006; Heide-Jørgensen *et al*., 2003; Mate *et al*., 1999) and the consequence of using such data may be misleading tracks and unrealistic speed estimates (Austin *et al*., 2003; Mate *et al*., 1999). In the present study, 69% of all positions were of location class B, which implies low accuracy. Experimental studies have demonstrated that most Argos locations with low accuracy still lie inside 10,000m from true location (Hays *et al*., 2001; Vincent *et al*., 2002). Since location data were only available every fourth day, swimming speed estimates were averaged for each 4-day period, which reduced the impact from erroneous locations (Heide-Jørgensen *et al*., 2003). The purpose of the present study was large-scale tracking of fin whales in the North Atlantic. Creating a 4-day transmitter cycle gave useful tracks, although smaller-scale details were lost.

Fin whales can be observed in Faroese waters year round, but they are mainly present from mid-July to mid-October (Bloch and Ofstad, 2000). They are most frequently encountered in the slope area around the shelf (Bloch *et al*., 2000). Whale 20685 was relatively stationary on the shelf, at depths less than 500m, for one and a half months in summer. It was mainly moving in the area where a thermal boundary between shelf and Oceanic water is located (Hansen, 1985); an area rich in both plankton (Gaard, 2000) and pelagic and demersal fish species (Jákupsstova, 2002;2004). Fin whales are relatively frequently encountered in this area (Bloch *et al*., 2000), which was most likely a feeding ground for the whale. Whale 26712, tracked for nearly four months, left the Faroes shelf immediately after tagging and moved south to the deep waters east of the mid-Atlantic ridge, midway between the Faroes and the Azores. In these waters, 3-4,000m deep, its behaviour was the most dynamic, swimming at high speed in different directions during the entire track, perhaps because prey patches were not frequently encountered. After 12 days, it started moving northeast again, following the continental slope west of the British Isles. This part of the route confirmed a common movement pattern seen for the species, which often is associated with bathymetric features deeper than 1,500m (Heide-Jørgensen *et al*., 2003; Panigada *et al*., 2005; Watkins *et al*., 1996). Upon reaching the area northwest of Ireland, whale 26712 moved with slow swimming speed for the next two months in a fairly defined patch, presumably feeding in the slope waters.

The present study has demonstrated that fin whales are capable of moving long distances in the North Atlantic quickly. Watkins *et al*. (1984) observed, when tracking a fin whales from Iceland towards East Greenland during 9.5 days, an average swimming speed of 7.4km h^{-1}, which equals the swimming speed of whale 26712 during the first 16 days of tracking. A swimming speed of greater than 7km h^{-1} for an extended time has been demonstrated for blue whales (*Balaenoptera musculus*) (Mate *et al*., 1999). Whether or not this is a consequence of a short-term tag effect, as hypothesised by Mate *et al*. (1999), is unclear, but this directed swimming speed was not observed for whale 20712. The effect of tagging is considered minor on fin whales (Watkins *et al*., 1996), at least when only penetrating the blubber.

Watkins *et al*. (1984) found, from their track of a fin whale in Icelandic waters, evidence for east-west movements and mixing between fin whales in Icelandic and Greenlandic waters, while the tracking of two fin whales in Greenlandic waters by Heide-Jørgensen *et al*. (2003) gave evidence for a connection between fin whales in inshore and offshore waters. The present study is the first direct evidence that mixing occurs between the Spain-Portugal-British Isles stock of fin whales and fin whales around the Faroe Islands. Whale 26712 moved from Faroese waters in August, but in December was still present at 55°30'N. This suggests that the observed movement was not the onset of the migration towards a wintering ground. The observation that fin whales remain in northern North Atlantic waters until at least the onset of winter is an interesting discovery, although perhaps not uncommon (Bloch, 1998).

The present study has indicated that fin whales around the Faroe Islands may be a northern component of the Spain-Portugal-British Isles stock of fin whales. This contradicts a proposed Faroe-West-Norway stock of fin whales (Donovan, 1991; Jonsgård, 1966; Jonsgård and Rørvik, 1975) and may indicate the presence of only one stock in the southern waters of the eastern North Atlantic, as suggested for the south-western side of the North Atlantic (IWC, 1992), which is certainly a future prospect for investigation.

It could be that Faroese waters, by their location, act as migration corridor for surrounding fin whale stocks when moving to and/or from their summering grounds. If so, site-fidelity for fin whales in the area would be weak, perhaps also a response to fluctuating environmental conditions, such as high annual variations in primary production, notably in Faroese waters and affecting all trophic levels (Gaard *et al*., 2002). This may result in more plastic movement patterns among the whales utilising the Faroese waters for feeding. Satellite tracking has proven a promising method for gaining insight into fin whale movements and seasonal distribution, which can provide important information for evaluating the stock structure of fin whales in North Atlantic.

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REFERENCES

Austin, D., McMillan, J.I. and Bowen, W.D. 2003. A three-stage algorithm for filtering erroneous argos satellite locations. *Mar. Mammal Sci*. 19(2): 371-83.

Bérubé, M., Aguilar, A., Dendanto, D., Larsen, F., Notarbartolo di Sciara, G., Sears, R., Sigurjónsson, J., Urban-Ramirez, J. and Palsbøll, P.J. 1998. Population genetic structure of North Atlantic and Mediterranean Sea fin whales, *Balaenoptera physalus* (Linnaeus 1758): analysis of mitochondrial and nuclear loci, and comparison with the Sea of Cortez fin whale population. *Mol. Ecol*. 7: 585-99.

Bloch, D. 1998. A review of marine mammals observed, caught or stranded over the last two centuries in Faroese Waters. *The Shetland Sea Mammal Report, 1997*: 15-37.

Bloch, D., Heide-Jørgensen, M.P., Stefanson, E., Mikkelsen, B., Ofstad, L.H., Dietz, R. and Andersen, L.W. 2003. Short-term movements of long-finned pilot whales *Globicephala melas* around the Faroe Islands. *Wildlife Biology* 9: 47-58.

Bloch, D. and Joensen, J.S. 1984. Appendix 1. Denmark (Faroe Islands). Progress report on cetacean research 1982. *Rep. int. Whal. Commn* 34: 194-95.

Bloch, D., Mikkelsen, B. and Ofstad, L.H. 2000. Marine mammals in Faroese waters with special attention to the south-south-eastern sector of the region. GEM Report to the Environmental Impact Assessment Programme. 40pp. [Available from the author].

Bloch, D. and Ofstad, L.H. 2000. Fin whales *Balaenoptera physalus* in the Faroes. Paper SC/8/FW/4 presented to NAMMCO Working Group on North Atlantic Fin Whales, 12-14 May 2000, at Torshavn. [Available from the author].

Danielsdóttir, A.K. 1999. Review of the genetic stock structure of North Atlantic fin whales (*Balaenoptera physalus*). Paper SC/7/FW/17 presented to the NAMMCO Scientific Committee Working Group on North Atlantic Minke and Fin Whales, Copenhagen, Denmark, 8-9 April 1999 (unpublished). 6pp.[Available from *www.nammco.org*].

Daníelsdóttir, A.K., Duke, E.J., Joyce, P. and Árnason, A. 1991. Preliminary studies on genetic variation at enzyme loci in fin whales (*Balaenoptera physalus*) and sei whales (*Balaenoptera borealis*) from the North Atlantic. *Rep. int. Whal. Commn (special issue)* 13: 115-24.

Donovan, G.P. 1991. A review of IWC stock boundaries. *Rep. int. Whal. Commn (special issue)* 13: 39-68.

Gaard, E. 2000. The plankton community structure on the Faroe Shelf, PhD thesis, Norwegian College of Fishery Science, University of Tromsø, Tromsø, Norway.

Gaard, E., Hansen, B., Olsen, B. and Reinert, J. 2002. Ecological features and recent trends in the physical environment, plankton, fish stocks and seabirds in the Faroes shelf ecosystem. pp.245-65. *In*: Sherman, K. and Skjoldal, H.R. (eds). *Large Marine Ecosystems in the North Atlantic*. Elsevier Science, The Netherlands. 464pp.

Hansen, B. 1985. The circulation of the northern part of the Northeast Atlantic. *Rit Fisk*. 9: 110-26.

Haug, T. 1981. On some reproduction parameters in fin whales *Balaenoptera physalus* (L.) caught off Norway. *Rep. int. Whal. Commn* 31: 373-78.

Hays, G.C., Åkesson, B.J., Godley, P., Luschi, P. and Santidrian, P. 2001. The implications of location accuracy for the interpretation of satellite-tracking data. *Anim. Behav*. 61: 1035-40.

Heide-Jørgensen, M.P., Kleivane, L., Øien, N., Laidre, K.L. and Jensen, M.V. 2001a. A new technique for deploying satellite transmitters on baleen whales: Tracking a blue whale (*Balaenoptera musculus*) in the North Atlantic. *Mar. Mammal Sci*. 17(4): 949-54.

Heide-Jørgensen, M.P., Nordoy, E.S., Øien, N., Folkow, L.P., Kleivane, L., Blix, A.S., Jensen, M.V. and Laidre, K.L. 2001b. Satellite tracking of minke whales (*Balaenoptera acutorostrata*) off the coast of northern Norway. *J. Cetacean Res. Manage*. 3(2): 175-78.

Heide-Jørgensen, M.P., Laidre, K.L., Jensen, M.V., Dueck, L. and Postma, L.D. 2006. Dissolving stock discreteness with satellite tracking: bowhead whales in Baffin Bay. *Mar. Mammal Sci*. 22(1): 34-45.

Heide-Jørgensen, M.P., Witting, L. and Jensen, M.V. 2003. Inshore-offshore movements of two fin whales *Balaenoptera physalus* tracked by satellite off West Greenland. *J. Cetacean Res. Manage*. 5(3): 214-45.

International Whaling Commission. 1992. Report of the Comprehensive Assessment Special Meeting on North Atlantic Fin Whales, Reykjavík, 25 February-1 March 1991. *Rep. int. Whal. Commn* 42:595-644.

International Whaling Commission. 2007. Report of the Joint NAMMCO/IWC Scientific Workshop on the Catch History, Stock Structure and Abundance of North Atlantic Fin Whales, 23-26 March 2006, Reykjavík, Iceland. *J. Cetacean Res. Manage*. 9:451-68.

Jákupsstova, H. 2002. The pelagic fish stocks, pilot whales and squid in Faroese waters – migration pattern, availability to fisheries and possible links to oceanographic events. ICES CM 2002(N:07). 38pp.

Jákupsstova, H. 2004. Fiskiskapur vid Føroyar í 100 ár. Fiskirannsóknarstovan (Faroese Fisheries Laboratory). 98pp. [In Faroese; Available from *www.frs.fo*].

Jonsgård, Å. 1966. Biology of the North Atlantic fin whale *Balaenoptera physalus* (L). Taxonomy, distribution, migration and food. *Hvalråd. Skr*. 49: 1-62+2maps.

Jonsgård, Å. and Rørvik, C.J. 1975. Report of the Scientific Committee, Annex M. A note on the stock of fin whales, *Balaenoptera physalus* (L.), off the west coast of Norway and the Faroes. *Rep. int. Whal. Commn* 25: 166-73.

Mate, B.R., Lagerquist, B.A. and Calambokidis, J. 1999. Movements of North Pacific blue whales during the feeding season off Southern California and their southern fall migration. *Mar. Mammal Sci*. 15(4): 1246-57.

North Atlantic Marine Mammal Commission. 2001. Report of the Scientific Committee, Annex 4. Report of the NAMMCO Scientific Committee Working Group on North Atlantic fin whales. *NAMMCO Annual Report* 2000:274-94.

Panigada, S., Notarbartolo di Sciara, G., Zanardelli Panigada, M., Airoldi, S., Borsani, J.F. and Jahoda, M. 2005. Fin whales (*Balaenoptera physalus*) summering in the Ligurian Sea: distribution, encounter rate, mean group size and relation to physiographic variables. *J. Cetacean Res. Manage*. 7(2): 137-46.

Raum-Suryan, K.L., Rehberg, M.J., Pendleton, G.W., Pitcher, K.W. and Gelatt, T.S. 2004. Development of disersal, movement patterns, and haul-out use by pup and juvenile Steller sea lions *Eumetopias jubatus* in Alaska. *Mar. Mammal Sci*. 20(4): 823-50.

Sergeant, D.E. 1977. Stocks of fin whales *Balaenoptera physalus* L. in the North Atlantic Ocean. *Rep. int. Whal. Commn* 27: 460-73.

Stone, G.S., Katona, S.K., Mainwaring, A., Allen, J.M. and Corbett, H.D. 1992. Respiration and surfacing rates of fin whales, *Balaenoptera physalus*, observed from a lighthouse tower. *Rep. int. Whal. Commn* 42: 739-45.

Vincent, C., McConnell, B.J., Ridoux, V. and Fedak, M.A. 2002. Assessment of ARGOS location accuracy from satellite tags deployed on captive gray seals. *Mar. Mammal Sci*. 18(1): 156-66.

Watkins, W.A., Moore, K.E., Sigurjónsson, J., Wartzok, D. and Notarbartolo-di-Sciara, G. 1984. Fin whale *Balaenoptera physalus* tracked by radio in the Irminger Sea. *Rit Fisk*. 8(1): 1-14.

Watkins, W.A., Sigurjonsson, J., Wartzok, D., Maiefski, R.R., Howey, P.W. and Daher, M.A. 1996. Fin whales tracked by satellite off Iceland. *Mar. Mammal Sci*. 12: 564-69.

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Autumn space-use patterns of humpback whales (*Megaptera novaeangliae*) in West Greenland

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ABSTRACT

Five humpback whales were tagged with satellite transmitters on their summer feeding grounds in West Greenland in August between 2002 and 2005. Tracking durations lasted between 13 and 111 days and the locations obtained from the whales provided the first insight on the autumn distribution patterns of this species in West Greenland. Whales demonstrated a consistent pattern of rapid and long-distance movements along the West Greenland coast separated by longer-term, focal area use where feeding occurred. Humpback whales in West Greenland feed on capelin (*Mallotus villosus*), sand eels (*Ammodytes* sp.), and krill and these three prey species require different foraging strategies. Generally whales showed high affinity to the coast due to shallow aggregations of capelin. However some use of offshore regions was detected, likely due to concentrations of sand eels. One whale crossed Baffin Bay to Baffin Island, an area not known to support humpback whales. The rapid movements of humpback whales between feeding sites in Greenland and Canada may be a response to variable and dynamic prey resources throughout the summer and autumn seasons.

KEY WORDS: SATELLITE TAGGING, MOVEMENTS, HUMPBACK WHALES, GREENLAND; NORTHERN HEMISPHERE; FEEDING; FOOD/PREY; MOVEMENTS

INTRODUCTION

Humpback whales (*Megaptera novaeangliae*) are one of the characteristic species of baleen whales found in West Greenland. They arrive predictably from southern breeding grounds in May and remain in the area at least throughout autumn. Humpback whales occur seasonally in areas such as Disko Bay and Paamiut, yet may also occur year round at other coastal sites such as Nuuk Fjord. Resightings of individual whales indicate that the West Indies is the main breeding ground for whales that feed in West Greenland (e.g. Stevick *et al*., 2003). As discussed below, the abundance off West Greenland is estimated to be over 1,000 animals (e.g. see Heide-Jørgensen *et al*., 2007; IWC, In press).

Humpback whales utilise several different prey species in West Greenland, particularly sand eels (*Ammodytes* sp.), krill and capelin (*Mallotus villosus*). Between 1959 and 1976, 22% of stomachs sampled contained sand eels (Kapel, 1979), a species which occurs in large abundance on the banks off West Greenland at depths ranging between 50 and 200m. Additionally, 42% of the stomachs contained capelin, a small forage fish that moves inshore to spawn in the littoral zone in summer. Humpback whales have been observed to make bubble curtains and lunge feed around these surface schools of capelin. Few capelin are found offshore on the banks, as shown by an acoustic survey covering West Greenland from Kap Farvel to Disko Island in 2005 (GINR unpubl. data). Krill and plankton also form a significant part of the humpback whale diet in West Greenland, 28% of stomachs contained krill and 8% a mix of prey (Kapel, 1979). Northern krill (*Meganyctiphanes norvegica*) occur in high densities on coastal areas of the banks, peaking at 65°N (GINR unpublished data). Observations of bright orange defaecation from humpback whales in West Greenland during an aerial survey in September 2005 also confirm that this is an important prey item.

Little is known about the movements of humpback whales around Greenland or how whales move between foraging sites. Identifying focal areas where humpback whales frequently occur and forage in summer is important for both understanding how whales use the coast of West Greenland and for future work to identify critical prey species concentrations. Furthermore, large changes in physical oceanography have been identified along the banks of West Greenland. Sea surface temperatures (0-40m depth) have dramatically increased over the past 50 years, with maximum recorded value of 3.8°C in 2005 (Ribergaard *et al*., 2006). Thus, it is important to identify feeding grounds for humpback whales in order to more closely monitor changes in the local hydrology and how those changes might manifest themselves on prey species. This study reports on satellite tracking of humpback whales in West Greenland between 2002 and 2005 with the purpose of describing movement patterns and focal area use sites with respect to potential prey resources.

METHODS

Daily searches for whales were conducted from small boats in Nuuk Fjord between 20 August and 22 September 2002 and 17 and 31 August 2003, as well as near the town of Qeqertarsuaq, Disko Island, between 9 and 18 August 2005 (Fig. 1). When a whale was sighted the boat moved towards the whale until it dove. The process was repeated again until the whale was surfacing in a predictable manner, which usually took less than half an hour. Tags were deployed when the whale was positioned alongside the boat, 4-5m away and when the whale remained at the surface long enough to place the tag in a good position.

The humpback whales were tagged using two different configurations of satellite-linked radio transmitters. In one configuration, transmitters (SPOT2, Wildlife Computers,

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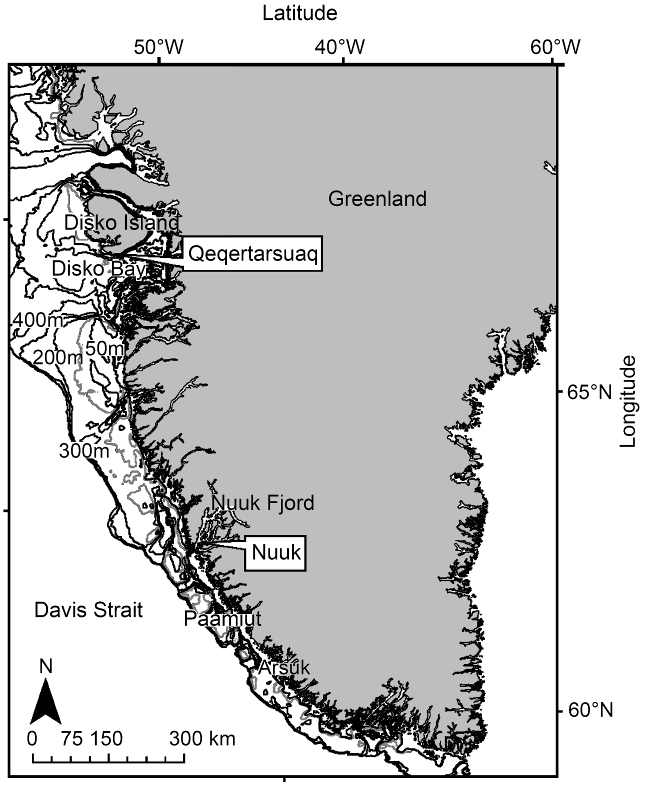

Fig. 1. Map of the West Greenland coast and localities mentioned in the text.

Redmond, Washington) were equipped with two M1 lithium thianyl batteries and glued to a cup-shaped stainless steel base (referred to as 'can tags'). The 'can' dimensions were 45×32mm. The anchor was a 33cm titanium spear (diameter 8mm) welded to the can and equipped with three foldable leaf-like barbs and a sharp pointed tip. The can tags had an expected battery longevity of 20,000 transmissions and were programmed to provide 250 transmissions every other day. A second configuration had the transmitter (SPOT3 and 5) and a single AA-cell mounted in a 10cm long and 2cm wide stainless steel cylinder (referred to as 'implant tags') connected to a 13cm spear with one set of barbs and a triangular double-edged blade. This tag provided 50,000 transmissions.

All tags in 2002 and 2003 were deployed using an 8m fibreglass pole. The tag was mounted on the tip of the pole and secured by a nylon line in case of failed deployments. The titanium spear was pushed through the skin and into the blubber and once the tag was implanted the nylon line was cut by a sharp edge on the pole. The tags in 2005 were deployed with the 'ARTS' (Air Rocket Transmitter System), a pneumatic air gun (see detailed description in Heide-Jørgensen *et al.,* 2001). All satellite tags were positioned high on the whales' back so that transmissions could be received by the satellite.

Locations were collected using the Argos System (see Harris *et al*., 1990). Location qualities were provided by Service Argos and coded based on predicted accuracy. Location codes were LC B, A and 0-3 in order of increasing accuracy of position. All location qualities received on a particular day were used to calculate an average daily position for each whale over the entire tracking period. Average daily positions were mapped and tracklines were created for individuals whales.

RESULTS

Ten humpback whales were tagged with satellite transmitters in August 2002-05 in West Greenland. Five of the instruments provided only short-term data or lasted for less than five days and thus are not reported here. Of the remaining five, three tags provided data for <20 days (Table 1) whereas two tags provided information on movements for up to 111 days.

All whales demonstrated the typical movement pattern of rapid and long-distance movements between specific foraging sites, either coastal or offshore. Whales remained localised at these foraging sites for anywhere between one week to one month before again rapidly moving to another site along the coast. Focal sites were Disko Bay and Nuuk Fjord.

In 2002, two humpback whales were tagged in the Nuuk Fjord. Contact was lost with both whales within three weeks, however both animals had moved quickly out of the Nuuk Fjord and headed south, with some residency time in the outer part of the Nuuk archipelago (Fig. 2).

In 2003, two whales were also tagged in the Nuuk Fjord area. One whale tagged on 17 August (no. 20690-03) moved immediately from West Greenland across Baffin Bay, northwest to Exeter Sound on the east coast of Baffin Island (Fig. 3). It spent about a week at this site before heading northwest back to Greenland into Disko Bay. When it returned to Greenland, it travelled to Green Island (Grønne Ejland) in eastern Disko Bay before moving to the south coast of Disko Island. The whale spent almost three weeks within a few kilometres of the shore, where dense schools of capelin occur on the coast each year (Fig. 4). It departed Disko Bay and took a direct offshore route to the Arsuk area. The whale returned to the Nuuk Fjord around mid-November and remained at this site until contact was lost.

The second whale tagged on 25 August 2003 in Nuuk Fjord (no. 20692) went south along the coast and reached the same area in south Greenland (around Arsuk) in early September as visited by whale no. 20690 in 2003 (Fig. 5). In early October this animal returned north to Nuuk Fjord and remained at this site until 11 November, when contact was lost.

Table 1

Humpback whales tagged with satellite transmitters in August in West Greenland between 2002 and 2005. Position of the satellite transmitter on the whale is indicated by L and R (left or right), F, M, or B (forward of midline, midline, or behind midline) and H or L (high or low).

ID number	Day	Year	Estimated length	Tagging position	Transmitter type	Deployment	Position on whale	Duration of contact	Average speed km day^{-1}
20690-02	24	2002	~13m	64°03,780 51°40,230	Can	Pole	RHM	18	10.5
20689	29	2002	~14m + calf	3nm north of Nuuk	Can	Pole	RHM, 30cm under dorsal fin	13	27.2
20690-03	17	2003	~12-14m	64°10,113 51°50,860	Implant	Pole	RBH	111	30.1
20692	25	2003	~14m	64°12,720 51°42,339	Implant	Pole	LMH	75	23.3
21810	11	2005		69°14,350 53°40,222	Implant	ARTS		14	54.9

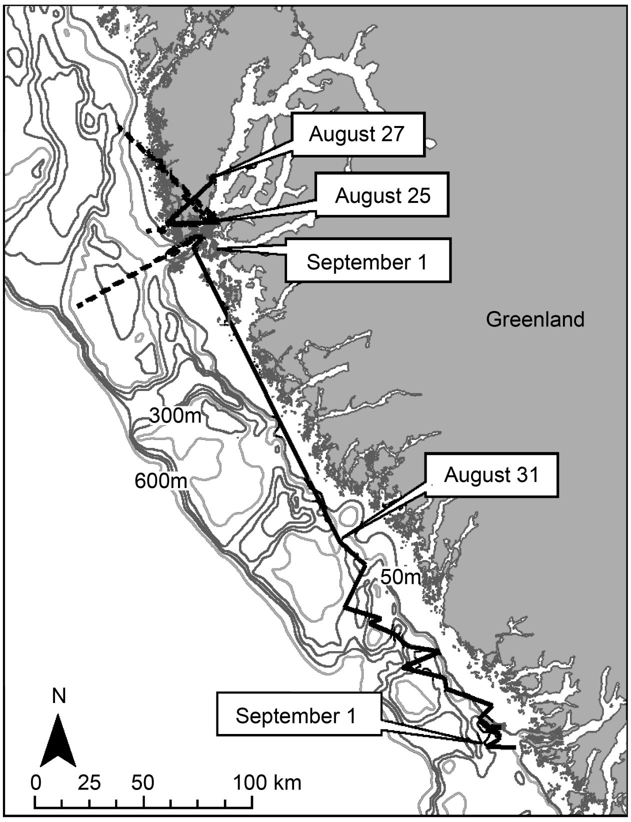

Fig. 2. Movement patterns of humpback whale no. 20689 (solid line) and no. 20690-02 (dashed line) on 29 and 24 August 2002 in Nuuk Fjord, West Greenland.

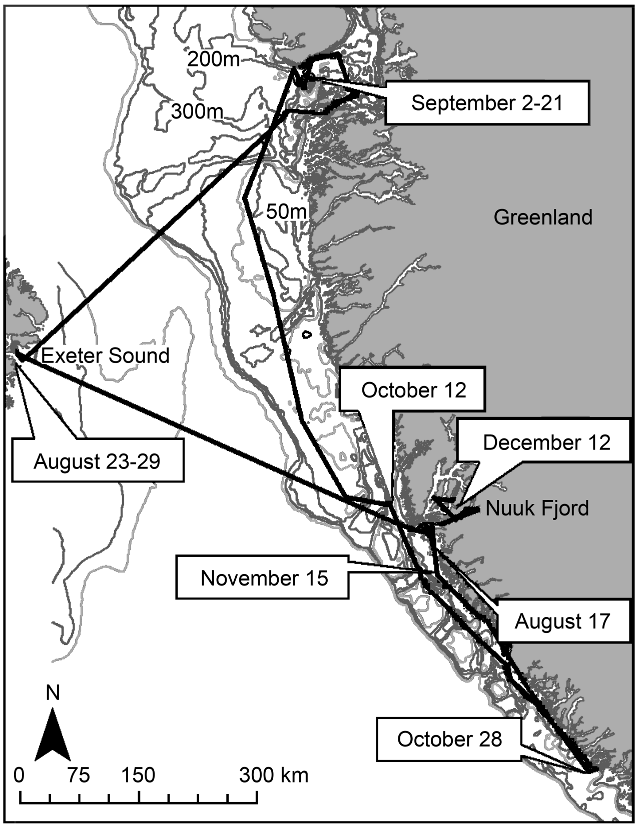

Fig. 3. Movement patterns of humpback whale no. 20690-03 tagged on 17 August 2003 in Nuuk Fjord, West Greenland.

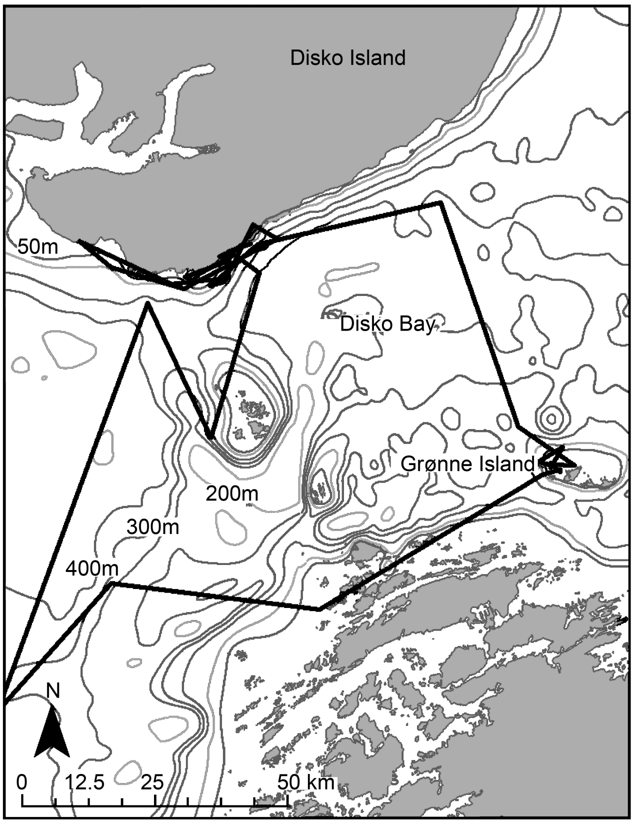

Fig. 4. Coastal area use of a humpback whale (no. 20690-03) in Disko Bay, West Greenand (see Fig. 3 for full track).

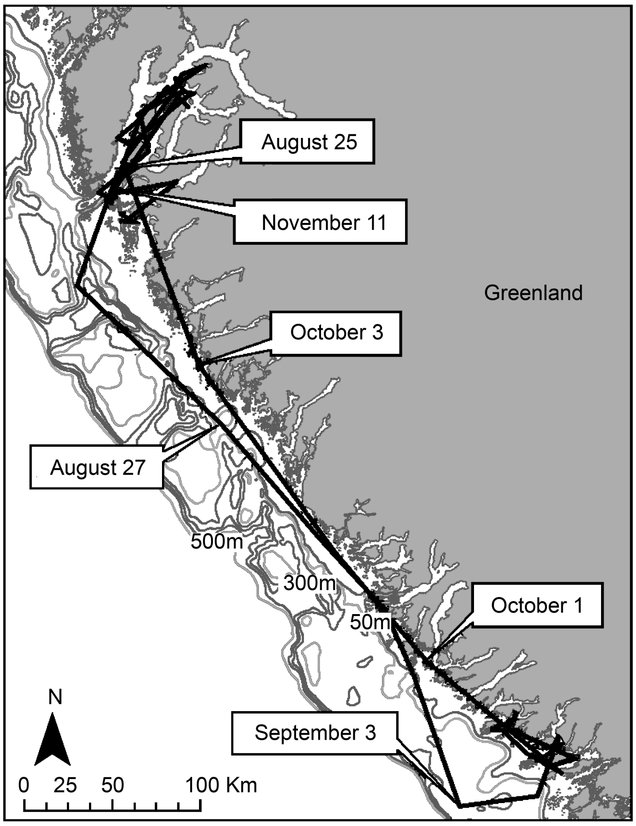

Fig. 5. Movement patterns of humpback whale no. 20692 tagged on 25 August 2003 in Nuuk Fjord, West Greenland.

In 2005, one whale was tagged on 11 August 2005 near Disko Island (no. 21810). This whale immediately travelled south across the West Greenland banks and stopped at Nuuk (around 19 August), before continuing south until contact was lost on 25 August (Fig. 6).

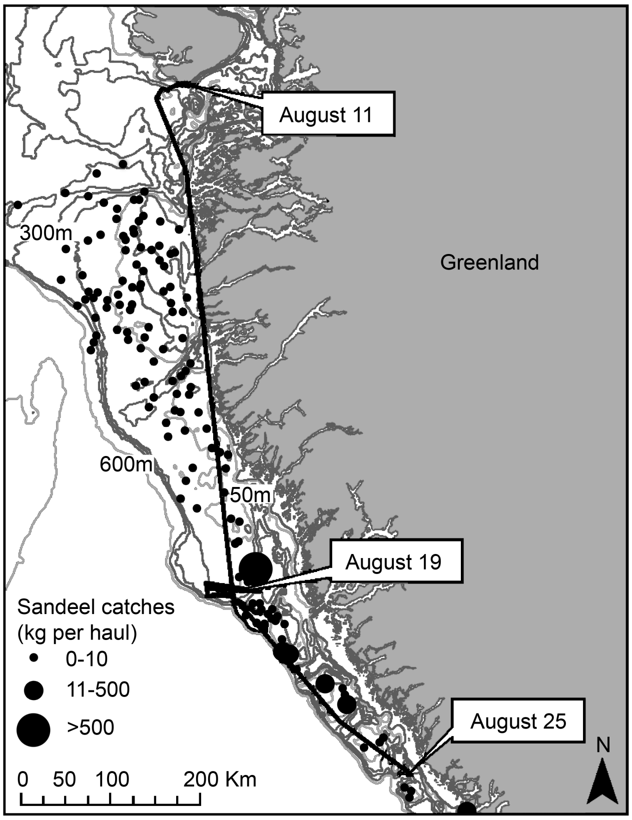

Fig. 6. Movement patterns of humpback whale no. 21810 tagged on 11 August 2005 near Disko Island, West Greenland. Concentrations of sand eels (*Ammodytes* sp.) estimated from bycatches from standardised scientific trawl (30min hauls) samples for northern shrimp (*Pandalus borealis*) are indicated by dots (GINR unpublished data).

All whales covered long distances (>200km) over the relatively short tracking periods and made rapid shifts between focal areas, where they were then stationary for several days to weeks at a time. With the exception of one animal tracked in 2005 (no. 21810) whales used areas very close to the shore (e.g. Fig. 4). Whale no. 21810 made a brief stop on the banks off Nuuk, a site where high concentrations of sand eels occur, as demonstrated from bycatches during standardised scientific trawl samples for northern shrimp (*Pandalus borealis*) (GINR unpubl. data).

The average daily speed of each whale, determined from the distance between daily average positions, varied between 10 to 55km^{-1} day (Table 1). Speeds were as high as 200km^{-1} day for long-distance travel (i.e. across Baffin Bay) and for offshore movements along West Greenland (see Fig. 7, no. 20690-03). Travel in coastal areas was considerably slower, indicating these areas were either explored at a different spatial scale or used as feeding grounds. Offshore areas, with the exception of no. 21810, were only used for migrating between feeding sites.

DISCUSSION

Movements

Humpback whales evidently use a large range along the West Greenland coast for summer foraging activities and do not appear to be stationary in any particular area for more than a month. There are clearly some preferred sites for foraging, these include Disko Bay, Nuuk Fjord and the Arsuk area and all whales tracked rapidly shifted between preferred sites. Previous photo-identification population estimates were based on sampling in three areas in West Greenland: an area off Nuuk, an area at approximately 63°30'N; and an area off Paamiut (Larsen and Hammond, 2004). Abundance in these areas was estimated at 360 (95% CI=314-413) in 1988-93. None of the whales tracked in this study spent time in the vicinity of these three areas and, assuming no major changes in distribution over time, the population estimates from 1988-93 would inadequately cover the current range of humpback whales in West Greenland and thus be underestimates. More recent abundance estimates obtained on aerial (1,218; 95% CI=423-3,508) and ship-based surveys (1,306; 95% CI=570-2,989) in 2005 provide better total coverage of the area used by humpback whales in summer and this could, together with a population increase between the surveys, explain the higher abundance estimates in 2005 (Heide-Jørgensen *et al*., 2007).

Both humpback whales tagged in 2003 used nearly all of the Nuuk Fjord and movements extended into the far reaches of this site. The extensive travels in the complex fjord system at Nuuk in autumn are probably related to searching for schools of capelin. Whales have been observed lunge feeding at this site in summer and capelin are clearly the target prey species. This is also in agreement with the almost year-round observations of presumably young immature humpback whales in the fjord (GINR unpublished data).

The movement of one whale across Baffin Bay is the first evidence that humpback whales occur on the east coast of Baffin Island. This also demonstrates that West Greenland humpback whales may be connected to other less well defined humpback whale feeding concentrations in northeast Canada.

Relation to food resources

Many inshore areas in West Greenland are known for their conspicuous abundance of spawning capelin in the shallows during summer. The south coast of Disko Island, the area around Grønne Ejland, the Nuuk Fjord and the area at Arsuk in South Greenland are all particularly well known as capelin concentration areas with good feeding opportunities for humpback whales. Movements of whales in this study support the idea that humpback whales target these concentration sites. Scientific acoustic surveys for capelin have failed to find any major offshore concentrations of capelin in late summer of 2005 (GINR unpublishead data). Nearly all capelin detected on dedicated surveys have been found in coastal and shallow areas. However, bycatch data in scientific trawl studies have shown that some capelin are indeed present in the deep trenches between the banks and on the western slopes of the banks. However these capelin occur at >400m and are likely an inaccessible prey source for foraging humpback whales. Thus, it is likely that the movements and area use patterns of humpback whales in West Greenland are largely dictated by the coastal occurrence of capelin in surface waters of inshore shallow

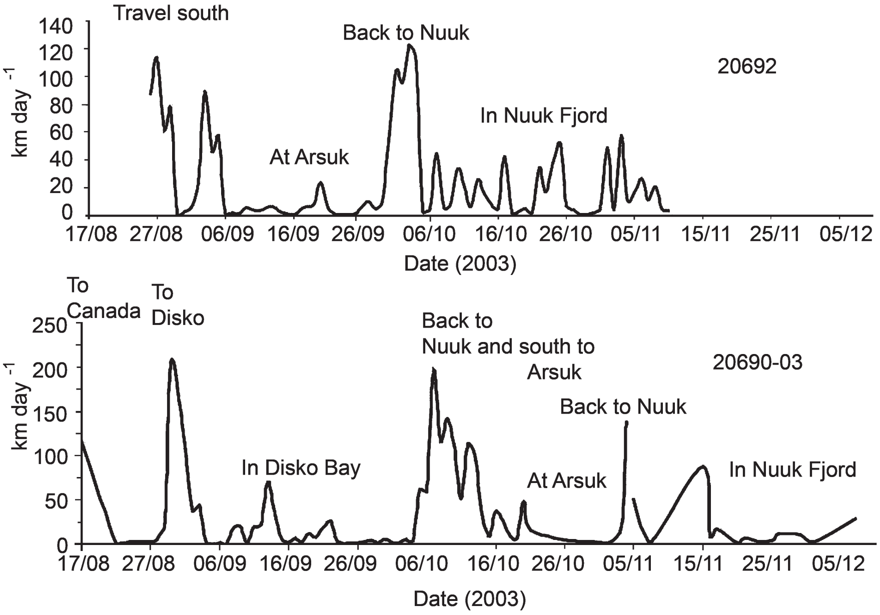

Fig. 7. Changes in daily speed (km day^{-1}) of two humpback whales calculated from differences in daily average positions.

(<100m) areas in summer. In the autumn, capelin schools are supposedly more dispersed and in deeper waters, thus humpback whales must search more actively.

Bottom dwelling sand eels are another likely food source for humpback whales in West Greenland. These fish occur in specific areas on the offshore banks, however are a less optimal prey species (with respect to capelin) because they do not occur in similarly dense schools. Furthermore, they are usually found at deeper depths (50-200m) and they never occur in spawning swarms on beaches. The trackline of a whale tagged in 2005 paused over an area with particularly high concentrations of sand eels, however, the extent to which humpback whales may prefer this prey item over capelin is unknown.

Sightings of humpback whales on Baffin Island have not previously been reported and it was unexpected that a whale tagged in Greenland immediately moved from the productive West Greenland shelf to the Baffin Island coast. It is possible some capelin resources occur in inshore areas of the east coast of Baffin Island, however the only other alternate prey sources available would be schools of polar cod or copepods and krill. A high abundance of capelin has not been documented along the coast of Baffin Island, however, capelin have been visually observed in Cumberland Sound on East Baffin (E.W. Born, pers. comm.). This area is about 200km south of where the whale tagged in Nuuk was located along the coast.

Satellite tracking of individual whales is an ideal technology for the quantification of space use patterns of cetaceans. This study, although limited in sample size, clearly demonstrates the potential of the technique. The whales moved quickly over large areas probably exploiting food resources both at specific coastal sites and offshore on the banks. The rapid and directional movements of the whales between specific sites suggest previous experience with localities with predictable food resources. Although humpback whales have three very different prey types available for summer feeding in West Greenland, they seem to be able to shift between habitats where one or more of these prey can be found. These shifts are probably in response to the fluctuating and somewhat unpredictable nature of the occurrence of these prey species in the dynamic West Greenland ecosystem. Unlike most other North Atlantic large marine ecosystems, the West Greenland ecosystem borders the high Arctic and the sub-Arctic and is highly susceptible to small changes in inflow of warm water from the Irminger current along southwest Greenland. Extensive changes in sea surface temperatures in this area likely impact recruitment and distribution of prey resources utilised by humpback whales. It is not known how these prey populations, and thus the whales, will respond to these changes.

This study reports on the first movement data collected from humpbacks on their summer feeding grounds in West Greenland. Humpback whales also feed at three other sites in the North Atlantic: the Gulf of Maine, eastern Canada, and the eastern North Atlantic (Stevick *et al*., 2001). Mark-recapture studies of movements of animals at these other sites also confirm high site fidelity to focal areas interspersed with long-distance movements. None of these other aggregations have been satellite-tracked therefore is it unknown to what extent their movements, travel speeds or travel distances are similar to the whales on their feeding grounds in West Greenland.

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REFERENCES

Harris, R.B., Fancy, S.G., Douglas, D.C., Garner, G.W., Amstrup, S.C., McCabe, T.R. and Pank, L.F. 1990. Tracking wildlife by satellite: current systems and performance. *United States Fish and Wildlife Service Special Scientific Report – Fisheries* 30: 1-53.

Heide-Jørgensen, M.P., Kleivane, L., Øien, N., Laidre, K.L. and Jensen, M.V. 2001. A new technique for deploying satellite transmitters on baleen whales: Tracking a blue whale (*Balaenoptera musculus*) in the North Atlantic. *Mar. Mammal Sci*. 17(4): 949-54.

Heide-Jørgensen, M.P., Simon, M.J. and Laidre, K.L. 2007. Estimates of large whale abundance in Greenland waters from a ship-based survey in 2005. *J. Cetacean Res. Manage*. 9(2) [This volume].

IWC. In press. Report of the Scientific Committee. Annex E. Report of the Standing Working Group (SWG) on the Development of an Aboriginal Subsistence Whaling Management Procedure (AWMP) *J. Cetacean Res. Manage. (Suppl.)* 10.

Kapel, F.O. 1979. Exploitation of large whales in West Greenland in the twentieth century. *Rep. int. Whal. Commn* 29: 197-214.

Larsen, F. and Hammond, P.S. 2004. Distribution and abundance of West Greenland humpback whales *Megaptera novaeangliae. J. Zool., London*. 263: 343-58.

Ribergaard, M.H., Kliem, N. and Jespersen, M. 2006. *HYCOM for the North Atlantic Ocean with special emphasis on West Greenland waters*. Danish Meteorological Institute Technical Report 06-07. [Available from *http://www.dmi.dk/dmi/tr06-07.pdf]*.

Stevick, P.J., Allen, J., Clapham, P.J., Hammond, P.S., Katona, S.K., Larsen, F., Lien, J., Mattila, D.K., Palsbøll, P.J., Sears, R., Sigurjonsson, J., Smith, T.D., Víkingsson, G. and Øien, N. 2001. Population spatial structuring on the feeding grounds in North Atlantic humpback whales. *J. Zool., London*. 270: 244-55.

Stevick, P.T., Allen, J., Bérubé, M., Clapham, P.J., Katona, S.K., Larsen, F., Lien, J., Matilla, D.K., Palsbíll, P.J., Robbins, J., Sigurjónsson, J., Smith, T.D., Øien, N. and Hammond, P.S. 2003. Segregation of migration by feeding ground origin in North Atlantic humpback whales (*Megaptera novaeangliae*). *J. Zool., London*. 259: 231-37.

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Consistent acoustic size estimation of sperm whales using clicks recorded from unknown aspects

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ABSTRACT

The multipulse structure of sperm whale clicks offers a unique way to acoustically estimate body length, as the inter-pulse intervals within the clicks relate to the two-way travel time within and thereby to the size of the hypertrophied nose in this species. Despite its large potential to allow the estimation of length acoustically, the technique has only been used in a few studies to assess the length composition of sperm whale populations. Its limited use may relate to the fact that only some clicks within a click series normally display the regular multipulsed structure required for size estimation. The inter-pulse intervals of usual clicks vary with the recording aspect to the clicking whale and the pulse delays are not necessarily directly related to the length of the spermaceti organ. To overcome these difficulties, a method is provided to estimate sperm whale body lengths, based on averages of cepstra derived from a large number of clicks recorded from whales in unknown recording aspects. This study shows that the two-way travel time in the spermaceti organ can consistently be estimated by a peak in the averaged cepstra when a large number of clicks are analysed. This method is shown to give a consistent estimation of the size of the spermaceti organ when recording the whale in an unknown orientation and also when recordings are heavily influenced by surface reflections.

KEYWORDS: SPERM WHALE; VOCALISATION; SURVEY; ACOUSTICS; MONITORING

INTRODUCTION

Estimation of length in marine mammals plays an important role in the assessment of stock size and can be used to derive the age and stage of sexual maturity of the individuals (Angliss *et al*., 1995; Koski *et al*., 1993). Photogrammetric techniques are used to measure the length of whales at sea (Cosens and Anders, 2003; Dawson *et al*., 1995; Gordon, 1990; Jaquet, 2006; Miller *et al*., 2004). These techniques require good weather and considerable effort if a reasonable fraction of a population is to be covered, especially for deep-diving species that spend little time at the surface (Watkins *et al*., 1999). In addition, there are some biases associated with photographic measurements of body size (Angliss *et al*., 1995).

The multipulse structure of sperm whale clicks (Backus and Schevill, 1966) offers a unique way to estimate the body length of individuals acoustically. This potential was first appreciated by Norris and Harvey (1972) from combined observations of the click structure and nasal anatomy of this species. As part of their original theory on sperm whale sound production, the authors proposed that the time between the pulses (the inter-pulse interval or IPI) within a single sperm whale click is given by the two-way travel time in the spermaceti organ. Norris and Harvey envisioned that most of the sound energy generated at the *museau de singe*, a valve-like structure of connective tissue, escapes the nose directly and that fractions of sound energy are reflected backwards by an air sac (the distal sac) into the spermaceti organ and subsequently forward by another air sac lining the skull (the frontal sac). These internal reflections repeat themselves, generating a train of pulses with decaying amplitude.

The Norris and Harvey theory has been amended by Møhl *et al*. (1981) and Møhl (2001), who proposed that the bulk of the sound energy is first directed backwards into the spermaceti organ while only a small portion of the initial sound energy leaks directly into the water, generating the first *p*0 pulse (Fig. 1, top panel). The primary sound pulse (*p*1) is emitted into the water from the junk after reflection from the frontal air sac and is followed by the *p*2 pulse after one more round through the spermaceti organ. This so-called bent horn model has been corroborated by more recent findings (Madsen *et al*., 2002; Møhl *et al*., 2003; Zimmer *et al*., 2005a; Zimmer *et al*., 2005b).

The underlying concept for acoustic length estimation of sperm whales is that the IPIs are given by the distance between the sound reflectors and the speed of sound in the spermaceti oil, measured by Flewellen and Morris (1978) and Goold *et al.* (1996). Knowing the allometric relationship between the size of the nose and the overall body size of the sperm whale (Clarke, 1978), the length of the whale can be estimated acoustically. Alternatively, the relationship between IPI and body length may be derived directly by acoustic and photogrammetric studies of the same individuals (Gordon, 1991; Rhinelander and Dawson, 2004). Thereby one may envisage a simple technique to survey large areas for the size composition of sperm whale populations.

Even though the potential for acoustic length estimation was proposed more than 30 years ago, the technique has only been explored in few studies (Adler-Fenchel, 1980; Drouot *et al*., 2004; Gordon, 1991; Leaper *et al*., 1992; Marcoux *et al*., 2006; Pavan *et al*., 2000; Rendell and Whitehead, 2004; Rhinelander and Dawson, 2004). One of the main reasons for this could be that the pulses within clicks seldom display the clear pattern of regular intervals needed for consistent measurement. Adler-Fenchel (1980) found that only about 11% of the total number of clicks met the criteria for analysis based on signal-to-noise ratio and phase relationship between consecutive pulses within the clicks. Gordon (1991) reported frequent incidences of ‘anomalous clicks’, with a less well-defined pulse structure. He suggested that variations in click structure might be

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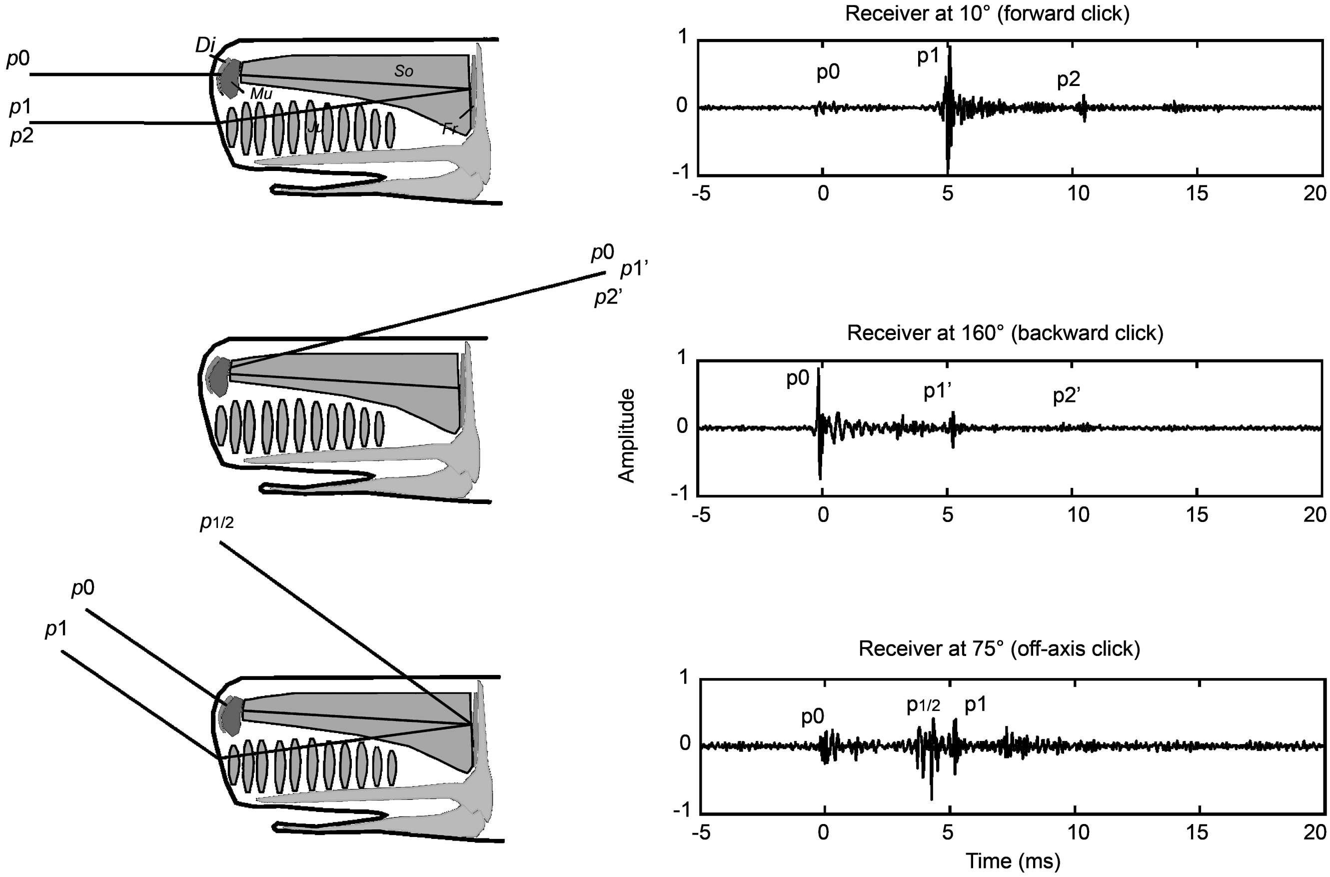

Fig. 1. Schematic drawing of a sperm whale head (left) and corresponding multi-pulse structure of usual clicks (right), with the receiver at different bearings (from Zimmer *et al*., 2005a). Top panel is a nearly on-axis click (*So*: spermaceti organ; *Ju*: junk; *Mu*: *museau de singe*; *Di*: distal sac; *Fr*: frontal sac). Middle panel is a click recorded at a caudal aspect. Bottom panel is a usual click recorded at an angle of 75°. Nasal passages are omitted for simplicity. The pulses $p1$ and $p2$ are represented with the same line, where $p2$ is subjected to an additional internal reflection from the distal to the frontal sac (not shown here) before leaving the junk with the assumed same path as $p1$. Clicks were selected from whale no.2 (n=1,997, Table 1).

caused by changes in the reflective characteristics of the head or the relative orientation of the whale and the receiver. In addition, Goold (1996) found few clicks with a pulse structure well-suited for measuring IPIs and he therefore stated that no reliable measurements of IPI could be derived from single sperm whale clicks. He proposed that the failure of the methods based on individual clicks might be the results of off-axis distortion from a directional source.

Rhinelander and Dawson (2004) examined IPI stability in photographically identified individuals and found that the measured inter-pulse intervals were stable over short periods of time. Their recordings were taken right after the whale's fluke up from a location on top of the footprint and were limited to the first minutes of the dive to minimise any changes in the IPI.

In summary, previous attempts to measure inter-pulse intervals in clicks have been made with manual measurements on individual clicks, where clicks that do not comply with the clear multi-pulse pattern are removed from the analysis (Goold *et al*., 1996; Rendell and Whitehead, 2004; Rhinelander and Dawson, 2004).

Zimmer *et al.* (2005a) have recently shown that a geometric model consistent with the bent horn theory of sperm whale sound production (Møhl *et al*., 2003) can explain the varying multi-pulse structure of off-axis clicks. Using clicks recorded from known aspects to the whale, they demonstrate that the $p1$ pulse indeed exits from the frontal area of the junk, whereas the initial $p0$ pulse exits from the nose at the site close to the sound-producing *museau de singe* (Madsen *et al*., 2003). Further, they show that an intermediate pulse (named $p1/2$) seen in off-axis recordings, is generated by the reflection of the initial pulse from the frontal sac (Fig. 1, bottom panel). The $p1/2$ can have delays between 0, merging with the $p0$ when recorded behind the whale (Fig. 1, middle panel), and the two-way travel time of the spermaceti organ, merging with $p1$ (Fig. 1, top panel) when recorded right in front of the whale (Zimmer *et al*., 2005a). These findings have made it clear that some of the pulse structures of clicks, such as the $p0$-$p1/2$ and $p0$-$p1$ intervals, vary with the recording aspect of the clicking whale. Therefore, sperm whale length cannot readily be estimated correctly from the pulse timings of a single click recorded off the body axis of the whale, without knowing its relative aspect. Further complications may be introduced by interference with surface-reflected paths confusing the original inter-pulse interval patterns.

In this paper, the findings of Zimmer *et al.* (2005a) are exploited to test a method for estimating the inter-pulse intervals of sperm whale usual clicks, using single hydrophone recordings. From Zimmer *et al.*'s findings and the predictions of the bent horn model (Møhl *et al*., 2003), it is hypothesised that other inter-pulse intervals within a click, such as the $p1$-$p2$, remain constant, independent of aspect. However, even though the regular inter-pulse intervals pattern will be found in all clicks including those recorded off-axis directions, they might be obscured by additional aspect-dependent peaks. Rather than being based on inter-pulse interval measurements of a single click, or short sequences of clicks recorded with the whale at a known aspect, a method is presented here that calculates the mean of cepstra (Bogert *et al*., 1963) derived from long click sequences. The study shows that the two-way travel time in the spermaceti organ can be estimated from a distinct peak in the averaged cepstrum after processing of a few hundreds clicks. The method is robust for whales recorded in different aspects, for recordings with interfering surface-reflected paths, as well as for recordings of limited bandwidth and dynamic range, and these findings are discussed in the light of the potential for passive acoustic monitoring of sperm whale populations with single hydrophone recordings.

MATERIALS AND METHODS

In this paper, the term ‘click’ refers to a ‘normal’ sperm whale click. Further, the term ‘inter-pulse interval’ is used to describe any interval between two pulses in the click, and the term ‘nominal IPI’ as the longitudinal two-way travel time in the spermaceti organ of the sperm whale nose.

The datasets used for the analysis are listed in Table 1. The Mediterranean dataset consists of two sperm whales that were recorded in the Ligurian Sea (northwestern part of the Mediterranean Sea) in 2000 and 2001 during sea trials organised by the NATO Undersea Research Centre (NURC). The passive sonar system developed at NURC consists of a horizontal line array of 128 hydrophones, a real-time digital beamformer and a sonar display system. The hydrophone array was towed at a depth of about 80m, just below the thermocline. The hydrophones of the towed array were set to an effective saturation level of 140 $\mathrm{dB}_{\mathrm{peak}}$ *re*: 1μPa and sampled with 16 bit resolution at 31.25kHz, providing a maximum bandwidth of about 15kHz. To suppress the low frequency flow and ambient noise, the data were filtered with a 3kHz high-pass filter. Click sequences were recorded from two sperm whales tracked for 7 and 10 complete foraging dives, respectively. To develop the technique described here, recordings from a single hydrophone were focused on. The aspect information for clicks in Fig. 1 is taken from the work of Zimmer *et al.* (2005a).

The Indian Ocean dataset consists of a single sperm whale dive recorded off the Seychelles from the research vessel *Odyssey* of the Ocean Alliance (*www.oceanalliance.org*). Recordings were made while drifting close to the fluke up of a single male sperm whale performing foraging dives and producing usual clicks and buzzes. Recordings were performed with a towed two-element array. For the present recordings the array was allowed to sink to an estimated depth of about 70m. Analogue signals from the hydrophones were amplified and band-pass filtered with a 2-pole cut-off and corner frequencies (-3dB) at 1.6 and 12kHz. The amplified, filtered output signal was interfaced with a PC desktop computer and digitised with a stereo 16-bit sound card sampling at 48kHz.

The Faroe Islands dataset was recorded in 1975 in the Skálafjordur from a sperm whale trapped in the fiord. Recordings were made with a B&K 8100 stationary hydrophone deployed at a depth of 6m, and stored on a Nagra IV-D tape recorder. The frequency response was flat to about 20kHz.

The North Atlantic datasets were collected off Andenes (Northern Norway) during summers 2000 and 2005. The first sperm whale was recorded in 2000 from five independent platforms with hydrophones at depths between 5 and 30m. For details on the recording geometry see fig. 3 in Møhl *et al.* (2003). The signals were recorded on digital tape recorders (Sony TCD-D3, 7, 8 and 10) sampling at 48kHz. The platforms were spaced more than 300m apart. The second sperm whale was recorded in 2005 from two separate platforms with hydrophones (B&K 8101 and Reson 4034) deployed at 30m and 15m depth, respectively. The two platforms were more than 500m apart while the animal was diving. The signals were recorded on digital tape recorders (Sony TCD-D7) at a sampling frequency of 48kHz. A digital tag recorder (Dtag, Johnson and Tyack, 2003) attached to the whale provided inter-click interval information of click sequences that allowed for identification of the same whale on the two separate platforms.

All sperm whales recorded were within an estimated 1-2km from the hydrophones and the depth of the whale varied from near surface to deep water, sometimes within the same click sequence. For all whales, only usual clicks were selected for the analysis. Clicks from creaks have a lower intensity compared to usual clicks, rendering analysis difficult or impossible (Madsen *et al*., 2002). The number of clicks analysed for each whale is reported in Table 1. Clicks were detected by a custom-written click detector with *MatLab* (*Math works 6.0*).

Cepstrum analysis (Bogert *et al*., 1963; Oppenheim *et al*., 1968) was used to determine the repeated patterns within the interpulse intervals of usual clicks. The real-valued cepstrum analysis (where the term ‘cepstrum’ is simply ‘spectrum’ with the first four letters in reverse order) takes as input the time series x_t and constructs the cepstrum C_t by the nonlinear transformation:

$$C_t = \left| FFT^{-1}(\log\left| FFT(x_t)\right|)\right| \tag{1}$$

where FFT is the fast Fourier transform and FFT^{-1} is the inverse fast Fourier transform and denotes the absolute value (Zimmer *et al*., 2003). The cepstrum converts the

Table 1

Datasets used for the measurements of inter-pulse intervals of sperm whale usual clicks. Clicks within each dataset are known to be from the same whale. Clicks are consecutive from the same dive recorded in open ocean, except for the whale in the Faroe Islands which was recorded in a shallow fiord. Clicks from datasets 1, 2 and 4 are all usual clicks recorded during a single dive. The North Atlantic dataset from 2005 consists of two distinct click sequences (141 and 831 clicks) recorded from the same whale during the same dive from two separate platforms. Estimated nominal IPIs are from the cepstral averages of all clicks.

Data set	Number of clicks	Origin	Year	Recording type	Hydrophone depth (m)	Sampling frequency (kHz)	Estimated nominal IPI (ms)
Whale no. 1	2,303	Mediterranean Sea	2000	Single hydrophone from towed array	80	31.25	5.71 ± 0.05[§]
Whale no. 2	1,997	Mediterranean Sea	2001	Single hydrophone from towed array	80	31.25	5.44 ± 0.1[§]
Whale no. 3	252	North Atlantic	2000	5 drifting hydrophones	5 and 30	48	6.86 (0.02[#])
Whale no. 4	141 + 831	North Atlantic	2005	2 drifting hydrophones	15 and 30	48	6.98 (0.02[#])
Whale no. 5	2,549	Indian Ocean	2002	Single hydrophone from towed array	70	48	7.70 ± 0.1[§]
Whale no. 6	292	Faroe Islands	1975	Drifting hydrophone	6	20*	7.58 ± 0.01[§]

*Frequency response of the recording system. [§]Width of the cepstral peak, defined at 50% of its amplitude. [#]IPI deviation between the separate platforms.

logarithm of the power spectrum back into a time domain presentation (C_t), where peaks appear at delay times identical to the time between repeating structures (pulses) in the original time signal (sperm whale click). For the cepstral peak to appear, the length of the time window used in the analysis must be at least twice as long as the inter-pulse interval. Here a duration of 50ms was chosen. The click cepstra were subsequently averaged. The Matlab code for averaging cepstra of a click series and subsequent measurement of the nominal inter-pulse interval is provided in Appendix A.

RESULTS

The cepstral analysis was run for six whales and the results are listed in Table 1. The averaged cepstra from whale no.1 gave an estimated nominal IPI of 5.71ms. For whale no.2, an on-axis click was selected (10^0 aspect, see Fig. 1) and the nominal IPI was measured as the interval between *p*1 and *p*2 peaks in the Hilbert transformed click. This value fitted with the averaged cepstral peak at a value of 5.44ms (dotted line in Fig. 2). The averaged cepstra for an increasing number of consecutive clicks taken from whale no.2 are shown in Fig. 2. The average of 5 and 10 clicks shows several peaks from which the nominal IPI is difficult or impossible to discriminate. A predominant peak starts to emerge after averaging 100 clicks. By using all the 1,977 clicks available for the dive, a distinct peak has stabilised at the end of the plateau. The shape of the curve reflects the degree of variation of the inter-pulse intervals within the clicks. The peak indicates repeated measurements with the same value, whereas the plateau to the left of the peak represents the varying aspect-dependent inter-pulse intervals (e.g. *p*0-*p*1/2).

Cepstrum statistics for whale no.3 are shown in Fig. 3 (top panel). Stations *r*0, *r*1 and *r*6 gave a clear peak at a value of 6.86ms, while the averaging of clicks from stations *r*3 and *r*4 gave a less clear result, but centred around the above value. The two click sequences from whale no.4 were processed separately and the averaged click cepstrum is shown in Fig. 3 (bottom panel). The black curve corresponds to 141 clicks recorded from one platform and the grey curve to 831 clicks recorded from the second one. The two peaks of the estimated nominal IPI, which were obtained by averaging clicks from different stages of the same dive and from independent platforms, matched at a value of 6.98ms.

The averaged cepstra for an increasing number of clicks from whale no.5, for which no information about the size of the whale or its relative orientation were available, are shown in Fig. 4. In this case averaging 100 clicks is not enough to generate a clear peak, which starts to emerge from 1,000 clicks and onwards. The cepstrum statistics of the first 500 clicks where the measurement might be taken at the end of the plateau, would give a nominal IPI of 7.65ms. This would lead to a difference in whale length of about 8cm (Rhinelander and Dawson, 2004), compared to the nominal IPI derived from all clicks (7.70ms, Table 1).

The averaged cepstra for whale no.6 are shown in Fig. 5. The distance between *p*1 and *p*2 was measured from one of the Hilbert transformed clicks (inset, Fig. 5), and the peak matching with this interval is at 7.6ms. The two broader peaks around 2 and 3ms correspond to the surface reflections in the recordings. They clearly stand out in the clicks and can easily be discriminated from the peak of the nominal IPI, but they are smeared due to variations in the recording geometry during the click sequence.

DISCUSSION

Recording aspect and inter-pulse intervals of clicks

Fig. 1 shows how the multipulse structure of a sperm whale click varies with the recording aspect. Considering that sperm whales usually dive deep (Papastavrou *et al*., 1989)

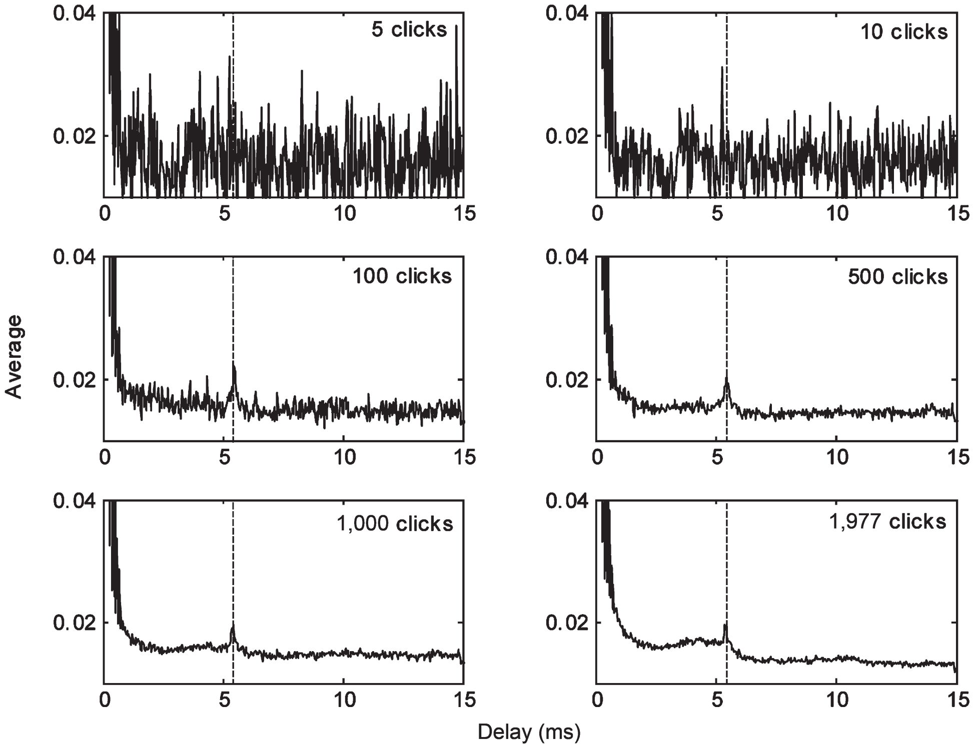

Fig. 2. Average values of the cepstrum for 5, 10, 100, 500, 1,000 and 1,977 consecutive clicks from the same dive from whale no.2 (n=1,977, Table 1). The dashed line corresponds to the nominal IPI measured by hand from an on-axis click between *p*1 and *p*2. The delay in ms on the x axis is termed quefrency in cepstrum analysis (Bogert *et al*., 1963).

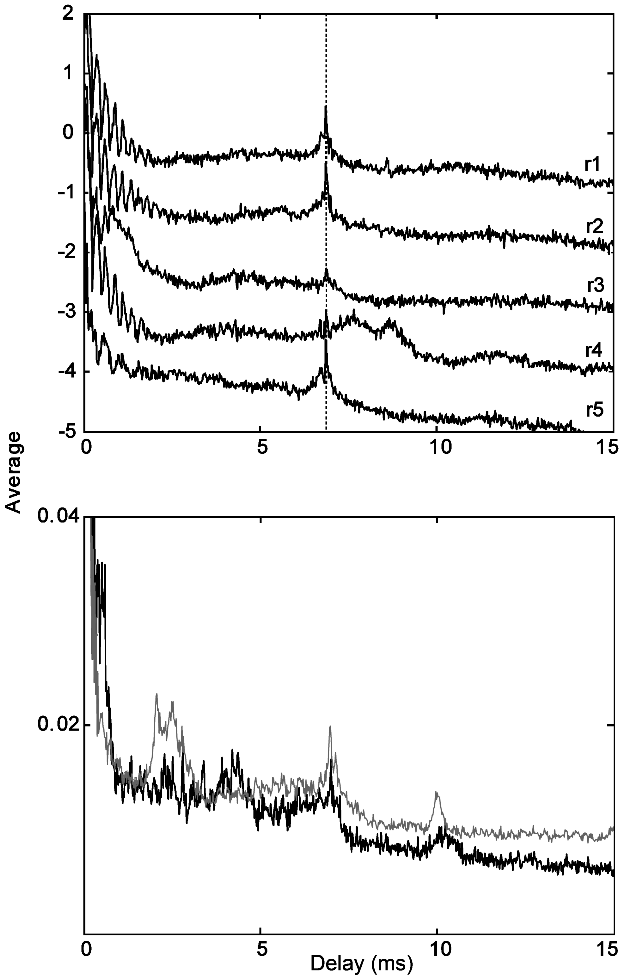

Fig. 3. Cepstral averages for clicks recorded in the North Atlantic. Top panel: clicks are from the same whale recorded simultaneously from 5 platforms located in different directions from the whale (whale no.3, Table 1). Peaks from stations *r*1, *r*2, *r*3 and *r*5 are marked with a dashed line and match at 6.86ms. Averages are shifted vertically for clarity. Bottom panel: clicks are from the same whale but recorded at different stages of the same dive from two separate platforms (*n*=141 black curve and *n*=831 grey curve, whale no.4, Table 1). The peaks of the nominal IPI match at 6.98ms, while the other peaks before 5ms and at 10ms are other reflections. The delay in ms on the *x* axis is termed quefrency in cepstrum analysis (Bogert *et al*., 1963).

and at a steep angle (Miller *et al*., 2004) and normally stop clicking during the ascent phase of the dive (Jaquet *et al*., 2001; Madsen *et al*., 2002; Teloni *et al*., 2003), the chance of recording on-axis clicks in front of the whale (Fig.1, top panel) when working with surface hydrophones is small (Møhl *et al*., 2003). In addition, if the high intensity and large bandwidth of the *p*1 pulse (Møhl *et al*., 2003) are not considered when choosing the recording settings, the signals will most likely be clipped in the dynamic as well as in the frequency range. When recording from behind (Fig. 1, middle panel), the *p*0 pulse is the most intense pulse, as it leaks out of the spermaceti organ with a backward-directed beam in the opposite direction of the *p*1 pulse projected out in front of the whale (Zimmer *et al*., 2005b). The second pulse seen in this caudal aspect has made one round through the spermaceti organ and then re-radiated from the whale at a site very close to the *p*0 pulse. This pulse is called the *p*1' pulse and the consecutive pulse the *p*2' pulse, to indicate that these pulses are not emitted through the junk like their relatives *p*1 and *p*2. Thus, the pulses recorded at the receiver in aspects larger than 90 degrees are not the *p*1 and *p*2 pulses leaving the junk, but the pulses (named *p*1' and *p*2') that leak from the spermaceti organ after reflection at the distal sac. It is seen that the inter-pulse intervals can easily be derived when recording behind the animal, as is often the case for IPI measurements made over the footprint of a diving whale (Goold and Jones, 1995; Gordon, 1987; Rhinelander and Dawson, 2004). Thus, the multipulse structure stands out clearly when recorded on the body axis, either in front of the animal or behind it, and the nominal IPIs can be derived.

As part of the energy of the pulse reflected by the frontal sac might leak from the spermaceti organ (Zimmer *et al*., 2005a), the multipulse structure is still present, but the nominal inter-pulse interval pattern is cluttered by additional aspect-dependent pulse delays (Fig. 1, bottom panel). This may lead to confusion when inspecting a single click, both in the time and cepstral domains (Fig. 6, panels C and D). In addition, surface-reflected paths may interfere with the direct clicks, leaving the analyst with even more confusing pulse patterns to choose amongst.

The key to the nominal IPI: averaging cepstra derived from click sequences

These problems in deriving the nominal IPI call for an automated method. The approach derived here relies on the analysis by Zimmer *et al*. (2005a): every click of a sperm whale will contain both inter-pulse intervals corresponding to the nominal IPI and additional IPIs depending on the aspect of the whale with respect to the hydrophone. In addition, there may be interpulse intervals caused by interference with surface-reflected paths, and such intervals will depend on the depth of the recording geometry between the hydrophone and the clicking whale. In many clicks, the aspect-dependent interclick intervals may dominate the picture completely, but according to the outline above, the nominal inter-pulse interval will always be there, in every single click. Thus, from a long series of clicks where the aspect, range and depth of the whale may vary considerably, all aspect- and geometry-dependent effects may be averaged out, and the nominal IPI is left as a reliable estimator of the two-way travel time in the spermaceti organ, which in turn conveys the size of the nose and thereby the size of the animal.

Cepstrum analysis is a convenient tool to extract inter-pulse intervals from sperm whale clicks. It has the advantage of not being sensitive to errors in temporal alignment between extracted clicks. Due to the variations in amplitudes of the various pulses in a click, the click detector may easily misalign the clicks according to a specific pulse. The cepstrum, however, is insensitive to such jitter in the alignment, as long as the time window extracted for every click is large enough to cover the whole click. Thereby time-consuming and tedious hand-processing of clicks is avoided. The application of cepstrum analysis in measuring inter-pulse intervals was first exploited by Goold (1996), but it has been applied in practice only a few times (Pavan *et al*., 1997; Teloni *et al*., 2000).

Instead of cepstrum analysis, autocorrelation analysis is a viable alternative for measuring repeated patterns within the clicks (Goold, 1996; Rhinelander and Dawson, 2004). Averaging the autocorrelation function for the clicks in a sequence would render results very similar to those described below for the cepstrum analysis of sperm whale clicks. If sperm whale clicks contain multiple pulses then cepstrum analysis is the preferred method as it designed to estimate the periodicity of multi-pulse structures.

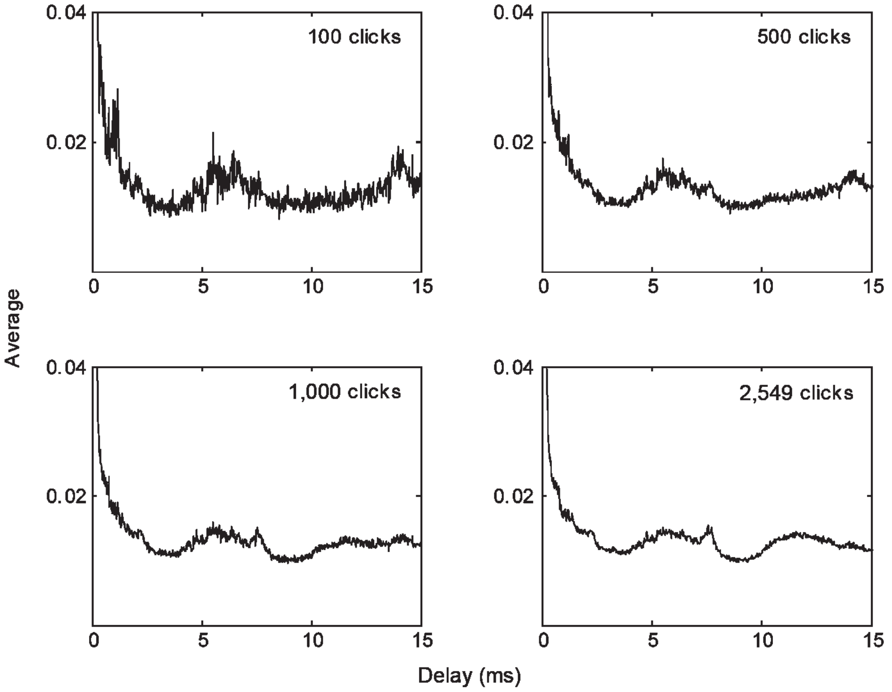

Fig. 4. Average values of the cepstrum for 100, 500, 1,000 and 2,549 clicks. Clicks are the total consecutive usual clicks (n=2,549, Table 1) from the same dive from whale no.5. The delay in ms on the x axis is termed quefrency in cepstrum analysis (Bogert *et al*., 1963).

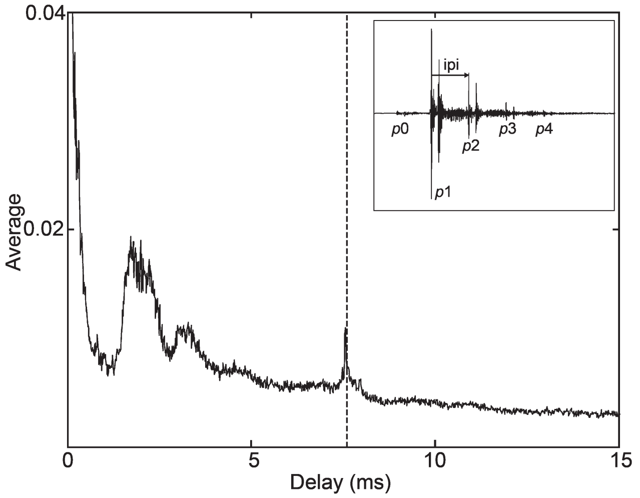

Fig. 5. Cepstral averages for all clicks (n=292) recorded from whale no.6 in the Faroe Islands. The solid line crossing the peak at 7.6ms represents the nominal IPI measured as the distance between $p1$ and $p2$ (click in the inset, where the pulses are marked as $p0$, $p1$, $p2$ and $p3$). The two broad peaks at around 2 and 3ms are surface reflections. The delay in ms on the x axis is termed quefrency in cepstrum analysis (Bogert *et al*., 1963).

Test of cepstral measurements

Averaging of click cepstra does not always give results as clear as those for whale no.2 (Table 1 and Fig. 2). In the recording from a male sperm whale in the Indian Ocean (Fig. 4), the nominal IPI started to become apparent only after averaging 500 clicks and was never as well-defined as for the Mediterranean whale. Surface reflections are prominent in the click recorded from whale no.5. However, the effect of surface reflection should quite rapidly be averaged out, as the inter-pulse interval would vary with slant angle to the whale and hydrophone depth (Fig. 5).

In some cases, however, it may not be possible to average out the effects of surface reflections. The dataset recorded in the North Atlantic in 2000 was from five synchronised recording platforms, spaced more than 350m apart, where the hydrophone depths ranged 5-30m. Station $r4$, in particular, has a less defined peak followed by a larger hump (Fig. 3, top panel). This platform was recording from a 5m deep hydrophone close to being on top of the whale (see fig. 3a in Møhl *et al*., 2003). This would have resulted in surface reflections, giving inter-pulse intervals close to the nominal IPI. As the receiver is situated right on top of the whale, the inter-pulse interval created by the surface reflection is changing only slowly with time so that this effect is not easily averaged out. It therefore seems important to use longer hydrophone cables or to vary the depth of the hydrophone during the recording to avoid this effect.

Consistent IPIs can be derived from different platforms with different hydrophones in different aspects to the same whale, as shown from the averaged cepstra of two click sequences recorded from different stages of the same dive and from independent platforms (Fig. 3, bottom panel).

Dataset criteria: how many clicks are needed to measure the IPI?

In this study it has been shown that the nominal IPI can be estimated from the average of cepstra from sequences of clicks. The shape of the averaged cepstral peak depends on the coverage of different recording aspects around the whale. This is due to the fact that a click cepstrum would show any inter-pulse interval contained in the clicks and some of these intervals have been demonstrated to be aspect-dependent (Zimmer *et al*., 2005a). The recording aspect is given by the small scale movements of the whale combined with the relative aspect of the whale to the receiver. Therefore, it is difficult to estimate a minimum number of clicks to be recorded in order to average out the aspect-dependent peaks and obtain a reliable estimate of the nominal IPI. In addition, the signal-to-noise ratio and the presence of surface reflections may also affect the effectiveness of the method. Likewise, the width of the averaged peak will also depend on the above-mentioned parameters and may therefore not be easy to assess. For the

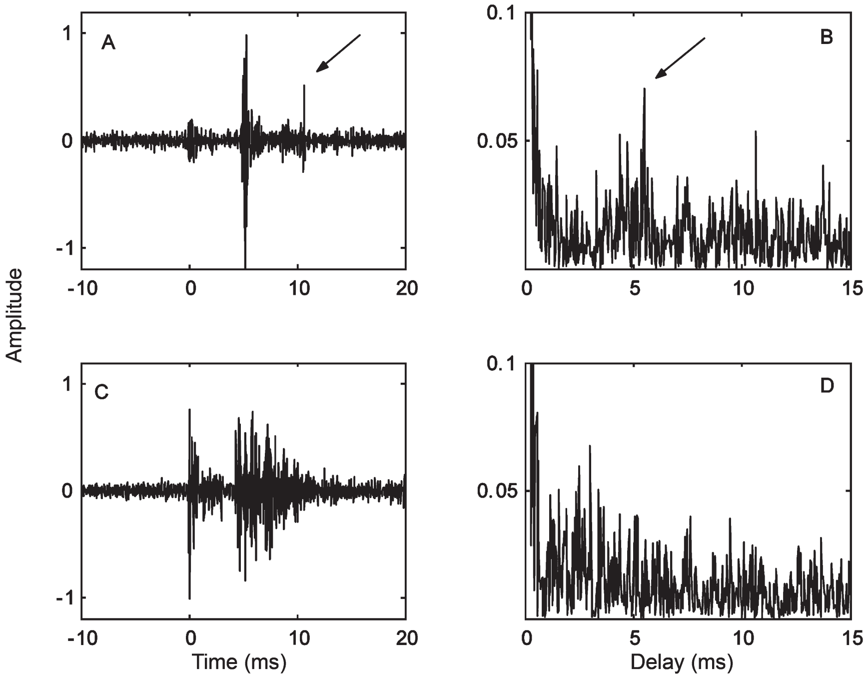

Fig. 6. Waveform (left panels) and corresponding cepstrum (right panels) of an on-axis click (top) and an off-axis click (bottom). Note that no obvious multi-pulse structure is recognisable for the off-axis click. The arrow in the on-axis click shows the *p*2 pulse in the waveform and the corresponding peak in the cepstrum. Clicks was selected from whale no.2 (*n*=1,997, Table 1). The delay in ms on the *x* axis of the right panels is termed quefrency in cepstrum analysis (Bogert *et al*., 1963).

single hydrophone data sets the width of the cepstral peak (defined at 50% of its maximum) ranges from 50μs to 100μs (Table 1). For the independent measurements of the nominal IPI obtained in various directions from the whale (whales 3 and 4 in Table 1) the maximum IPI deviation is only 20μs.

A complete sperm whale's dive generally contains 1,200-2,000 usual clicks (Madsen *et al*., 2002; Wahlberg, 2002). Results from high-resolution digital tags recording the whale's movements at a fine scale indicate that sperm whales are consistently moving and rotating while echolocating on prey and considerable depth excursions occur during the bottom phase of a dive (Johnson and Tyack, 2003; Miller *et al*., 2004; Zimmer *et al*., 2003). By using all usual clicks from a complete dive, with the whale moving underwater at an unknown distance, bearing and aspect, one can assume that the recorded clicks cover a substantial range of different aspects of the emitting whale in respect to the receiver (Zimmer *et al*., 2005b).

In general, the shape of the curve differs for different datasets, depending on the number and signal-to-noise ratio of clicks that have been averaged, and different data sets have different convergence rates. The distribution around the peak when increasing the number of clicks (Figs 2 and 4) gives an indication of the quality of the recordings and may be used to judge if the number of clicks is appropriate for the nominal IPI measurement. It should be noted that, according to the theory outlined above, there is no pulse interval longer than the two-way travel time in the spermaceti organ, except for the nominal IPI plus the distance between the monkey lips and junk exit point divided by the speed of sound in water.

The performance of this technique will depend on how quickly the cepstral nominal IPI peak will emerge during averaging and on how accurately the IPI can be derived. Thus, the performance depends on the signal-to-noise ratio and width of the cepstral nominal IPI peak (see above), which will both depend on the signal-to-noise ratio as well as the bandwidth of the pulses in the click. Depth-dependent effects in the nominal IPI may also influence the width of the peak: as the sperm whale is diving, the sound velocity of the spermaceti oil will change (Goold *et al*., 1996) and so will the IPI. From the limited data available to date it can be inferred that this effect is less than 0.2ms for a dive from the surface to a depth of 1,000m (Madsen *et al*., 2002; Wahlberg *et al*., 2003). This translates to an error in length estimation of 0.6% for IPIs of 5ms and 2% for IPIs of 7ms (Rhinelander and Dawson, 2004). The observed smearing of the averaged cepstral peak is therefore possibly an effect of the whale changing its depth while diving.

Variations in the nominal IPI may also occur due to the action of the sound generator. As air is driven past the monkey lips and fills up the distal air sac during a click train, it is expected that the sound path from the frontal and distal air sacs might shorten by a few centimetres, which may cause some 100s of μs of smearing of the averaged cepstral peak. Smearing of the peak may also occur if most clicks were recorded from an aspect where the dominating aspect-dependent inter-pulse intervals (such as the *p*0-*p*1/2, or *p*0-*p*1) are close to the nominal IPI throughout the click sequence.

If clicks straight in front of or behind the whale cannot be recorded, a large number of clicks should be used instead. This increases the probability of averaging several aspects of the recorded whale and thereby emphasising the inter-pulse intervals that correspond to the two-way travel time in the spermaceti organ, the nominal IPI. The empirical exploration suggests that 200 to 1,000 clicks seem to be sufficient in the data set used here.

CONCLUSIONS

Click sequences from different sperm whales have been used to test an automatic and robust method for the acoustic size estimation of the sperm whale nasal complex by exploiting the modified bent horn model for sperm whale sound production (Møhl *et al*., 2003; Zimmer *et al*., 2005a). This method makes use of a click detector followed by cepstrum analysis and therefore does not require visual inspection of individual sperm whale clicks. The nominal IPI is measured from averaged cepstra, as all other inter-pulse interval components are aspect-dependent and thereby reduced through averaging. The method allows measurements largely independent of whale depth, recording equipment or recording aspect to the whale.

Here only usual clicks were used for the analysis, although other types of clicks were present in the recordings. Coda clicks have been used for size estimation of sperm whales (Marcoux *et al*., 2006; Rendell and Whitehead, 2004), but it is not clear if the production of this type of click follows the same mechanisms as for usual clicks (Madsen *et al*., 2002). If this is the case, any aspect-dependent inter-pulse intervals that may occur in coda clicks should be taken into account when using codas for size estimation. Moreover, these clicks seem largely emitted by maturing and mature females (Marcoux *et al*., 2006), which would introduces a bias in application of this technique to male sperm whales, young animals or to populations where coda click are not as abundant as in the Pacific, like in the Mediterranean Sea (Teloni, 2005).

The method presented here offers a reliable tool for acoustic size estimation of the spermaceti organ, which could be further related to the overall size of the whale (Clarke, 1978). We did not calculate the length of the whales as the objective of this study was to test a consistent method for measuring IPIs that the published regressions (Gordon, 1991; Rhinelander and Dawson, 2004) are based upon. More data on the relationship between the IPI and total length for a large range of whale sizes are required to apply the acoustic measure of IPIs to population studies, but a consistent method for reliable derivation of the nominal IPI required for this is now available. Long click sequences from diving sperm whales are needed in order to improve the probability that the whale may be recorded from different aspects. Considering that sperm whales emit a usual click on average every second (Whitehead and Weilgart, 1990), it would be necessary to record an animal for approximately fifteen minutes in order to record a thousand clicks. Recordings from a single hydrophone are sufficient for this work as information on the range and aspect of the whale is not required. This method can be applied to acoustic surveys, where long sequences of sperm whale clicks are collected, avoiding time-consuming hand-processing and allowing for size estimation of clicking whales for which the relative orientation is unknown.

A common problem with acoustic size estimation is that of several whales clicking simultaneously. In this case, the technique presented here needs to be augmented with the capability to discriminate between different whales, e.g. by resolving the bearing to the individual whales with two or more hydrophones. Automatic real time detection software (for example *RainbowClick* from *www.ifaw.org*) that allow the observer to assign sequences of clicks to individual whales might facilitate the analysis in case of multiple animal recordings.

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REFERENCES

Adler-Fenchel, H.S. 1980. Acoustically derived estimate of the size distribution for a sample of sperm whales (*Physeter catodon*) in the western North Atlantic. *Can. J. Fish. Aquat. Sci*. 37: 2358-61.

Angliss, R.P., Rugh, D.J., Withrow, D.E. and Hobbs, R.C. 1995. Evaluations of aerial photogrammetric length measurements of the Bering-Chukchi-Beaufort Seas stock of bowhead whales (*Balaena mysticetus*). *Rep. int. Whal. Commn* 45: 313-24.

Backus, R.H. and Schevill, W.E. 1966. *Physeter* clicks. pp.510-28. *In*: Norris, K.S. (eds). *Whales, Dolphins and Porpoises*. Univ. Calif. Press, Berkeley. 789pp.

Bogert, B.P., Healy, M.J.R. and Tukey, J.W. 1963. The quefrency analysis time series for echoes: cepstrum, pseudoautocovariance, cross-cepstrum, and saphe cracking. pp.209-43. *In*: Rosenblatt, M. (eds). *Symposium on Time Series Analysis*. Wiley, New York.

Clarke, M.R. 1978. Structure and proportions of the spermaceti organ in the sperm whale. *J. Mar. Biol. Assoc. UK* 58: 1-17.

Cosens, S. and Anders, B. 2003. Size- and age-class segregation of bowhead whales summering in northern Foxe Basin: a photogrammetric analysis. *Mar. Mammal Sci*. 19(2): 284-96.

Dawson, S.M., Chessum, C.J., Hunt, P.J. and Slooten, E. 1995. An inexpensive, stereophotographic technique to measure sperm whales from small boats. *Rep. int. Whal. Commn* 45: 431-36.

Drouot, V., Gannier, A. and Goold, J. 2004. Diving and feeding behaviour of sperm whales (*Physeter macrocephalus*) in the northwestern Mediterranean Sea. *Aquat. Mamm*. 30: 419-26.

Flewellen, C. and Morris, R.J. 1978. Sound velocity measurements on samples from the spermaceti organ of the sperm whale (*Physeter catodon*). *Deep Sea Research* 25: 269-77.

Goold, J. 1996. Signal processing techniques for acoustic measurement of sperm whale body lengths. *J. Acoust. Soc. Am*. 100: 3431-41.

Goold, J., Bennel, J.D. and Jones, S.E. 1996. Sound velocity measurements in spermaceti oil under the combined influences of temperature and pressure. *Deep Sea Research* 43: 961-69.

Goold, J.C. and Jones, S.E. 1995. Time and frequency domain characteristics of sperm whale clicks. *J. Acoust. Soc. Am*. 98(3): 1,279-91.

Gordon, J.C.D. 1987. The behaviour and ecology of sperm whales off Sri Lanka. PhD thesis, Darwin College, University of Cambridge. 347pp.

Gordon, J.C.D. 1990. A simple photographic technique for measuring the length of whales from boats at sea. *Rep. int. Whal. Commn* 40: 581-88.

Gordon, J.C.D. 1991. Evaluation of a method for determining the length of sperm whales (*Physeter catodon*) from their vocalizations. *J. Zool. (Lond.)* 224: 301-14.

Jaquet, N. 2006. A simple photogrammetric technique to measure sperm whales at sea. *Mar. Mammal Sci*. 22: 862-79.

Jaquet, N., Dawson, S.M. and Douglas, L. 2001. Vocal behaviour of male sperm whales: why do they click? *J. Acoust. Soc. Am*. 109: 2254-59.

Johnson, M. and Tyack, P.L. 2003. A digital acoustic recording tag for measuring the response of wild marine mammals to sound. *IEEE J. Ocean. Engr*. 28: 3-12.

Koski, W.R., Davis, R.A., Miller, G.W. and Withrow, D.E. 1993. Reproduction. pp.239-74. *In*: Burns, J.J., Montague, J.J. and Cowles, C.J. (eds). *The Bowhead Whale. Special Publication No.2*. The Society for Marine Mammalogy, Lawrence, Kansas. 787pp.

Leaper, R., Chappell, O. and Gordon, J. 1992. The development of practical techniques for surveying sperm whale populations acoustically. *Rep. int. Whal. Commn* 42: 549-60.

Madsen, P.T., Carder, D., Au, W.W., Nachtigall, P., Møhl, B. and Ridgway, S. 2003. Sound production in neonate sperm whales. *J. Acoust. Soc. Am*. 113: 2988-91.

Madsen, P.T., Payne, R., Kristiansen, N.U., Wahlberg, M., Kerr, I. and Møhl, B. 2002. Sperm whale sound production studied with ultrasound time/depth recording tags. *J. Exp. Biol.* 205: 1899-906.

Marcoux, M., Whitehead, H. and Rendell, L. 2006. Coda vocalisations recorded in breeding areas are almost entirely produced by mature female sperm whales (*Physeter macrocephalus*). *Can. J. Zool.* 84(4): 609-14.

Miller, P.J.O., Johnson, M.P., Tyack, P. and Terray, E.A. 2004. Swimming gaits, passive drag and buoyancy of diving sperm whales *Physeter macrocephalus*. *J. Exp. Biol.* 207: 1953-67.

Møhl, B. 2001. Sound transmission in the nose of the sperm whale *Physeter catodon*. A post mortem study. *J. Comp. Physiol.* 187: 335-40.

Møhl, B., Larsen, E. and Amundin, M. 1981. Sperm whale size determination: outline of an acoustic approach. *FAO Fisheries Series No. 5 (Mammals in the Seas)* 3: 327-32.

Møhl, B., Wahlberg, M., Madsen, P.T., Heerfordt, A. and Lund, A. 2003. The monopulsed nature of sperm whale clicks. *J. Acoust. Soc. Am.* 114: 1143-54.

Norris, K.S. and Harvey, G.W. 1972. A theory of the function of the spermaceti organ of the sperm whale (*Physeter catodon*). pp.397-417. *In*: Galler, S.R., Schmidt-Koering, K., Jacobs, G.J. and Belleville, R.E. (eds). *Animal Orientation and Navigation*. NASA, Washington DC. Special Publication 262.

Oppenheim, A.V., Schafer, R.W. and Stockham, T.G. 1968. Nonlinear filtering of multiplied and convolved signals. *Proc. IEEE* 56: 1264-91.

Papastavrou, V., Smith, S.C. and Whitehead, H. 1989. Diving behaviour of the sperm whale, *Physeter macrocephalus*, off the Galapogos Islands. *Can. J. Zool.* 67(4): 839-46.

Pavan, G., Hayward, T.J., Borsani, J.F., Priano, M., Manghi, M., Fossati, C. and Gordon, J. 2000. Time patterns of sperm whale codas recorded in the Mediterranean Sea 1985-1996. *J. Acoust. Soc. Am.* 107(6): 3487-95.

Pavan, G., Priano, M., Manghi, M. and Fossati, C. 1997. Software tools for real-time IPI measurements on sperm whale sounds. *Proceedings IOA, Loughborough, UK* 19: 157-64.

Rendell, L. and Whitehead, H. 2004. Do sperm whales share coda vocalizations? Insights into coda usage from acoustic size measurements. *Anim. Behav.* 67: 865-74.

Rhinelander, M.Q. and Dawson, S.M. 2004. Measuring sperm whales from their clicks: stability of interpulse intervals and validation that they indicate whale length. *J. Acoust. Soc. Am.* 115: 1826-31.

Teloni, V. 2005. Patterns of sound production in diving sperm whales in the northwestern Mediterranean. *Mar. Mammal Sci.* 21: 446-57.

Teloni, V., Zimmer, W.M.X., Fossati, C., Manghi, M., Pavan, G. and Priano, M. 2000. Variability of temporal and spectral click characteristics of sperm whales (*Physeter macrocephalus*). *Eur. Res. Cet.* 14: 91-95.

Teloni, V., Zimmer, W.X.M., Johnson, M. and Tyack, P.L. 2003. Inter click interval variation of deep-diving sperm whales in the Mediterranean Sea. *European Cetacean Society Conference Guide and Abstracts* 17: 84-85.

Wahlberg, M. 2002. The acoustic behaviour of diving sperm whales observed with a hydrophone array. *J. Exp. Mar. Bio. Eco.* 281: 53-62.

Wahlberg, M., Madsen, P.T., Møhl, B. and Payne, R. 2003. Acoustic size estimation of sperm whales: effects of directionality and pressure. 1st Conference on Acoustic Communication by Animals, 27-30 July 2003, Maryland.

Watkins, W.A., Daher, M.A., DiMarzio, N.A., Samuels, A., Wartzok, D., Fristrup, K.M., Gannon, D.P., Howey, P.W., Maiefski, R.R. and Spradlin, T.R. 1999. Sperm whale surface activity from tracking by radio and satellite tags. *Mar. Mammal Sci.* 15(4): 1,158-80.

Whitehead, H. and Weilgart, L. 1990. Click rates from sperm whales. *J. Acoust. Soc. Am.* 87(4): 1798-806.

Zimmer, W.M.X., Johnson, M.P., D'Amico, A. and Tyack, P. 2003. Combining data from a multisensor tag and passive sonar to determine the diving behavior of a sperm whale (*Physeter macrocephalus*). *IEEE J. Ocean. Engr.* 28: 13-28.

Zimmer, W.M.X., Madsen, P.T., Teloni, V., Johnson, M.P. and Tyack, P. 2005a. Off-axis effects on the multi-pulse structure of sperm whale usual clicks with implications for the sound production. *J. Acoust. Soc. Am.* 118: 3337-45.

Zimmer, W.M.X., Tyack, P., Johnson, M.P. and Madsen, P.T. 2005b. Three-dimensional beam pattern of regular sperm whale clicks confirms bent-horn hypothesis. *J. Acoust. Soc. Am.* 117: 1473-85.

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Appendix A

```
% Teloni, Zimmer, Wahlberg, Madsen © 2005
% Sperm whales acoustic size estimation
%next three lines to be adjusted
disk=‘disk name:\’;
detFile=[disk ‘click detect\click detector file.txt’];
wavFile=[disk ‘wav\audio file.wav’];
%
%load detection file
a=load(detFile);
tcl=a(:,1);                                     %first column has click times
% sort times in case there are out of order
[Y,I]=sort(tcl);
%
% get click-time and inter click interval
tcl=Y;
ici=diff(tcl);
%retrieve sampling frequency fs
[x,fs]=wavread(wavFile,1);
%extract click and store in big matrix
sta=0.01;                                       %interval before detection [s]
sto=0.04;                                       %length of data to be extracted [s]
off=0;                                   %offset for click time [s]
xx=[];                                   %matrix where to store click data
nd=floor(sto*fs);                        %number of samples to extract
%
ncl=length(tcl);                         %tot number of clicks
for ii=1:ncl
   t=tcl(ii)+off;
   N1=max(1,floor((t-sta)*fs));
   N2=N1+nd-1;
   x=wavread(wavFile,[N1 N2]);
   if length(xx)==0
      xx=zeros(nd,ncl);                  %allocate storage to speed-up execution
   end
   xx(:,ii)=x(:,1);                      %store data (here first channel of multi-channel dataset)
end
%
%
Tc=(0:nd-1)/fs*1000;                            %elapsed time [ms]
C=abs(ifft(log(abs(fft(xx)))));          %cepstrum
Z=mean(C,2);                                    %averaged cepstrum
plot(Tc,Z)
ylim([0 0.1])
xlim([0 20])
```

A note on the acoustic assessment of bottlenose dolphin behaviour around fishing gears in the Asinara Island National Park, Italy

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ABSTRACT

Common bottlenose dolphins co-exist with artisanal fisheries in the Asinara Island National Park area (northwestern Sardinia, Italy) and are blamed for damage to some fisheries. To investigate this, two T-POD echolocation loggers were used between July 2003 and October 2004 to monitor the occurrence and behaviour of dolphins in the proximity of three different fishing gear types. With the support of local fishermen, the T-PODs were opportunistically deployed on trammel nets set for striped red mullet or for lobster and on bottom traps set to catch benthic fish species. Inter-click Intervals (ICI) and the Pulse Repetition Frequency (PRF) have been adopted as indicators of dolphins echolocation behaviour in the proximity of fishing gears (Leeney and Tregenza, 2006). PRF values were found to be consistently higher in proximity to trammel nets for striped red mullets compared to the other gears. Moreover, ICI values in the proximity of red mullet trammel nets were found to be statistically lower than those recorded both around trammel nets for lobster ($p<0.01$) and around traps ($p<0.01$). These findings suggest that feeding related activities by dolphins could be absent or take place at very low levels in the proximity of traps and, to a lesser extent, in the proximity of trammel nets set for lobster, but may occur more regularly around nets for striped red mullet. The results show that static acoustic monitoring can detect significant differences in dolphin echolocation behaviour around different fishing gears. The findings seem to be consistent with previous evidence of interactions between bottlenose dolphins and fishing gear types in the area.

KEYWORDS: VOCALISATION; FEEDING; ACOUSTIC; EUROPE; FISHERIES; COMMON BOTTLENOSE DOLPHIN; ECHOLOCATION; NORTHERN HEMISPHERE; FOOD/PREY

INTRODUCTION

Problems associated with actual or perceived dolphin fishery depredation represent a major challenge to fisheries management today (Reeves *et al*., 2001). Such problems include removal of fish from nets, spoiling of fish in the nets, damaging of the nets and reduced catch rates. In response, fishermen often adopt aggressive methods to keep cetaceans away from their gears (Reeves *et al*., 2001).

This is a documented problem in a number of artisanal fisheries in Mediterranean coastal areas and there is evidence of recent increase in these interactions: Greece (Casale *et al*., 1999); Spain (Brotons and Grau, 2005; De Stephanis, 2004; Gazo *et al*., 2001; Lopez *et al*., 2000); Tunisia (Naceur Lofti, 2000); Morocco (De Stephanis, 2004); Lybia (Hamza, pers. comm.); Cyprus (Reeves *et al*., 2001); Italy (Cannas *et al*., 1994; Diaz Lopez, 2006; Lauriano *et al*., 2004; Quero *et al*., 2000; Tringali *et al*., 2004). The bottlenose dolphin (*Tursiops truncatus*), believed to be the most commonly involved cetacean species (Reeves *et al*., 2001), is the only species regularly reported along the Italian coast (Notarbartolo di Sciara and Demma, 1997).

Assessing and monitoring the quantitative nature of depredation is difficult, due in part to the diversity of the fishing techniques commonly employed on the Italian continental shelf, which is characterised by a wide range of habitats. There is a complex pattern of local adaptations of fishing gears, according to both the target species and local traditions, which has contributed to the current lack of knowledge about actual and perceived interactions.

At Asinara Island and its surrounding waters, the bottlenose dolphin occurs regularly (Lauriano *et al*., 2003) and depredation by this species has been reported for the striped red mullet (*Mullus surmuletus*) fishery by Lauriano *et al*. (2004). In 2003, fishermen decided to adopt measures they believed would reduce depredation, including the use of acoustic deterrent devices (ADD or pingers). This note reports on work to expand that of Lauriano *et al*. (2004) and to gather preliminary data on the use of pingers.

MATERIAL AND METHODS

The study area

The study area (Fig. 1), comprised the coastal waters surrounding Asinara Island National Park (northwestern Sardinia). The eastern side of the Island, dominated by a sea grass meadow, is sheltered from the northwesterly prevailing winds, while the western side, dropping quickly to a depth of 45m, is highly influenced by strong waves caused by the prevailing north and northwesterly winds (Delitala *et al*., 1998). Small fishing boats from the Stintino and Porto Torres harbours are allowed to fish from 150m of the island shore, except in the three no take and no entry zones.

Fishing gears

The fishing gears monitored during the study comprised those types most regularly used in the area.

Traps

Traps are used mainly during summer time in order to catch species such as European conger (*Conger conger*), Moray eel (*Muraena helena*), Black sea bream (*Spondyliosoma cantharus*) and Octopus (*Octopus vulgaris*). Traps are of minor economic importance; in part they are used to catch bait for other minor fishing gears (e.g. long lines and hand lines) and/or they are commonly deployed simultaneously with other gears. The traps are commonly deployed at 40m.

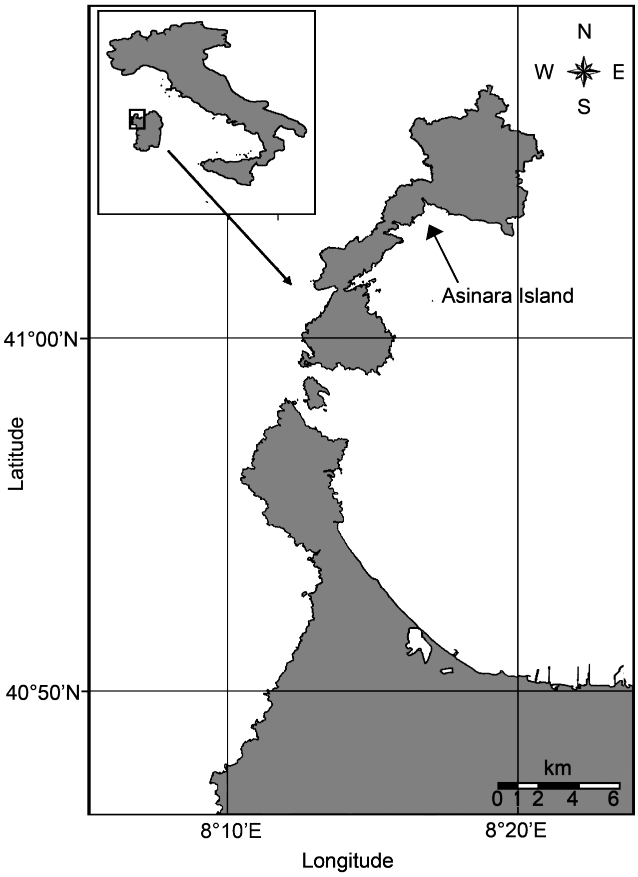

Fig. 1. The study area.

Lobster trammel nets
The target species is the lobster (*Palinurus elephas*) between May and August. The gear has a stretched mesh size of 72mm. The net is left soaking continuously and is inspected every 24 hours or more and is deployed at a mean depth of 63m (Lauriano *et al*., 2004).

Striped red mullet trammel nets
This trammel net targets striped red mullet and is used between September and December. It has a stretched mesh size of 27mm and is normally set before dawn and hauled at the start of sunrise, with a mean deployment time of 172 min. The nets are deployed at a mean depth of 31m (Lauriano *et al*., 2004).

Depredation by bottlenose dolphins has been reported for striped red mullet trammel nets (Lauriano *et al*., 2004) and it is on this gear that from 2003, fishermen decided to attach acoustic deterrent devices. Those used were small, battery-powered devices (High Impact Saver by Savewave[1]), designed to produce broadband ultrasonic signals (5 to 160kHz with a peak source level of 155dB re 1µPa @ 1m).

Acoustic monitoring
Version 3 of the T-POD self-contained cetacean sonar logger (Chelonia Ltd.) was used to collect acoustic monitoring data; analysis of these data was performed using T-POD software v8.1. Although the T-POD was originally designed to detect harbour porpoises (*Phocoena phocoena*), the settings can be adjusted to detect dolphin echolocation and the device's effectiveness in detecting common bottlenose dolphins at sea has recently been demonstrated (Philpott *et al*., 2007). The T-POD logs the times and duration of clicks resembling those from an echolocating target species. Subsequently, the software identifies trains of clicks within the logged data and classifies them as non-cetacean (e.g. boat sonars) or as cetacean trains. Cetacean click trains are further classified by the software into four categories of diminishing reliability (Cet High, Cet Low, doubtful or very doubtful). In this study, all deployments of T-PODs resulted in the logging of many non-cetacean clicks. Data analyses were restricted to the two most reliable categories (Cet High and Cet Low). T-PODs were set to run six successive logging scans of 9.3 seconds each every minute. After an initial phase of testing in the first few days of the study period, during which a range of frequency settings were used, a final setting scheme was developed. The target frequency of the first and fourth scans within a one minute cycle were set to 50kHz and 90kHz was used as the reference frequency; the other four scans had 110kHz as their target frequency and 170kHz as the reference frequency. This scheme was designed to maximise detections, since initial tests indicated that the most reliable dolphin detections occurred using these frequencies.

Deployment was opportunistic, since it depended on help from local fishermen, who attached two T-PODs to their gear in the course of normal fishing operations between 3 July 2003 and 14 October 2004. T-PODs were clamped on trammel nets up to 600m long in the middle of the head rope (Fig. 2a). Traps (lashed in lines of up to 25, giving a total length of up to 250m) were monitored by clamping the T-PODs on the floating rope (Fig. 2b).

Monitoring was conducted both on nets with and without pingers. During the striped red mullet season, onboard observers were employed in order to visually monitor the presence of dolphins around nets.

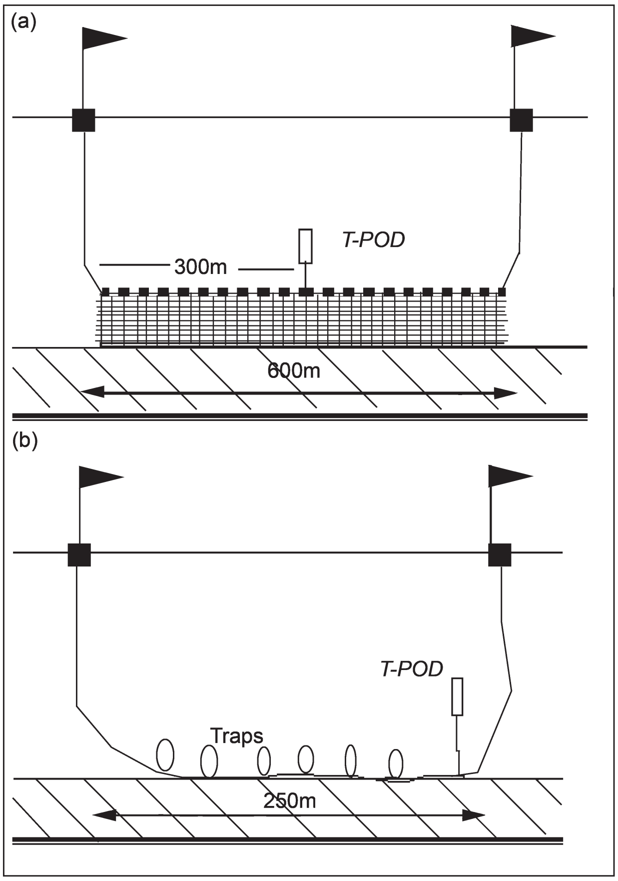

Fig. 2. T-PODs set in the fishing gear: (a) trammel net; (b) trap.

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[1] *www.savewave.net*

Data analysis

In order to gain insights into the presence of dolphins and their behaviour around the nets, the following parameters were considered for the analysis:

Detection Positive Minutes (*DPM*): number of minutes per day that contain at least one dolphin click train;

Pulse Repetition Frequency (*PRF*)*:* number of clicks placed in trains, per second;

Inter-Click Interval (*ICI*)*:* time (in $s \cdot 10^{-5}$) between two consecutive clicks within a train (reciprocal of PRF);

No. of encounters: an encounter was defined as a series of click trains with no silent period over 10 minutes in length. A silent period of 10 minutes in order to distinguish between subsequent encounters has been generally adopted in other studies (Carlström, 2005; Carstensen *et al*., 2006; Philpott *et al*., 2007) and was considered appropriate for the purposes of this study.

RESULTS

The number and duration of deployments (Table 1) were largely determined by the fishing techniques and weather conditions during the different fishing seasons. The longest deployments were recorded on traps (mean=2,413.6min – equivalent to more than 40 hours), followed by trammel nets for lobsters (mean=1,450.4min – more than 24 hours); deployments on trammel nets for red mullets were significantly shorter (mean=178.3min – less than 3 hours). In 2 out of 58 deployments the T-POD stopped functioning shortly after deployment.

Table 1

Sampling effort (recording times in minutes).

		n	Total rec. time
Trammel nets	Red mullet	19	3,388
Trammel nets	Lobster	30	43,513
Traps	-	9	21,722
Total	-	58	68,623

Reliable dolphin detections were recorded during 28 out of the 58 T-POD deployments (Table 2). All dolphin detections on mullet nets were on gears equipped with pingers (number of monitored nets, $n = 2$).

Dolphin detection rates, expressed as the number of click trains per day, were highest on trammel nets for lobster (mean=19.5; SE=4.75; n=29), followed by trammel nets for striped red mullet (mean=8.62; SE=6.52; n=18) and by traps (mean=1.78; SE=1.78; n=9). However, the sample size is too small to adequately compare the detection rates between gear types, or to draw conclusions on the existence of different patterns of dolphin presence in proximity to each gear type.

Table 2

POD deployments with reliable dolphin detections: summary statistics.

	n	No. of encounters	No. of trains	DPM	Trains per DPM
Red mullet	2	4	17	9	1.89
Lobster	25	137	604	310	1.95
Traps	1	19	50	32	1.56

Comparison of average ICI values (Table 3) using multiple t-test showed that values recorded in the proximity of trammel nets for red mullet were significantly lower than those recorded for trammel nets for lobsters ($p<0.01$; df=613.52) and traps ($p<0.01$; df=49.11; t-test for unequal variances, Welch's approximation). No statistically significant difference was found between ICIs recorded around nets for lobster and around traps ($p=0.354$; df=652 – t-test for equal variances; Multiple comparisons overall significance level: $p<0.05$; single t-test significance level – Bonferroni correction: $p<0.01667$).

Table 3

Average inter-click intervals in train positive minutes (ICIs – s^{-5}/click). PRF indicates the corresponding average Pulse Repetition Frequency (= 100,000/ICI) in clicks per seconds.

Fishing gears	ICI	No. of trains	SE	PRF
Red mullet	4,296	17	202.0	23.28
Lobster	56,569	604	1,968.0	1.77
Traps	63,125	50	6,229.3	1.58

The cumulative percentage of dolphin click trains relative to mean PRF values for each of the three types of gear (Fig. 3) show that click trains around striped red mullet fishing gears were concentrated around PRF values of 210-280 clicks s^{-1}. PRF values of less than 140-150 clicks s^{-1} were never recorded around this gear. Around other gear, click trains were mostly at PRF values of less than 40 clicks s^{-1}. No concentrations were found at other PRF values, especially around traps, where about 80% of clicks had PRF values below 40 clicks s^{-1}. Around lobster nets the pattern was similar, although a small proportion of click trains (about 23% of the total) were evenly distributed within a PRF of 100-360 clicks s^{-1}.

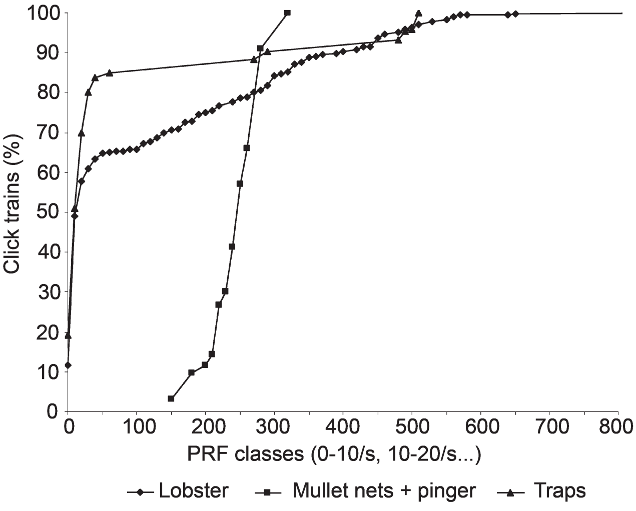

Fig. 3. Cumulative percentage of dolphin click trains relative to mean PRF values for each of the three fishing gears.

DISCUSSION AND CONCLUSION

The use of the T-POD was used to examine it as a potential remote monitoring tool, particularly given the limitations associated with visual assessments during fishing activities, since these often take place at night and/or may last several hours. This opportunistic effort proved successful in detecting significant differences in echolocation behaviour around the different fishing gears.

PRF has been used as a proxy as to how dolphins are using echolocation in a behavioural context (Leeney and Tregenza, 2006). The different distribution patterns of click trains relative to their PRF values found in this study, suggest different echolocation behaviour by dolphins around the different gear types. Although only two nets were monitored for this gear type, in the proximity of striped red mullet nets, the clear prevalence of trains with high PRF values seem to be indicative of feeding related activities. Conversely, the prevalence of lower PRF values around traps and trammel nets for lobsters suggest little or no feeding related activity.

Due to the opportunistic nature of the study, it was not possible to exert control over a number of factors, including locations of deployments and installation of pingers on the nets. This, coupled with the small size of the dataset, does not allow conclusions to be drawn on the extent and nature of the interactions. Although on a few occasions onboard observers assessed the presence of damage on the striped red mullet nets and looked for damaged fish and/or reduced catch rates, the same was not attempted for the lobster nets. Therefore, it is difficult to conclude that depredation was actually occurring on striped red mullet nets, since the results presented here could simply reflect feeding related activities by dolphins in the area where the mullet nets were deployed, regardless of the presence of the nets. However, the study does suggest that the T-POD can be a valuable monitoring tool in the context of a properly designed programme.

One major concern with the use of acoustic deterrent devices is the possibility of habituation (e.g. Cox *et al*., 2001; Northridge *et al*., 2007; Reeves *et al*., 2001). In addition, a ‘dinner bell’ effect of pingers after prolonged exposures has been recognised as a factor that can eventually augment the presence and level of interactions of dolphins with the gears (Reeves *et al*., 2001).

In the study area, acoustic devices have been deployed in the lobster nets since 2003, despite previous evidence indicating that depredation by dolphins on this gear type is negligible. This practice would have exposed animals to the ‘deterrent’ stimulus before the introduction of pingers on striped red mullet nets and thus might have contributed to an habituation effect in the area. In fact, all dolphins detected in the red mullet nets were recorded in 2004, one year after the beginning of the pinger deployment. Similar results were reported by Northridge *et al*. (2007) for the same net type and deterrent devices.

Nevertheless, the overall findings of this study show consistency with results from previous research conducted in the area, in which depredation was found to affect the striped red mullet fishery but not the lobster fishery (Lauriano *et al*., 2004).

After this initial experience of pingers, local fishermen applied the devices to the nets only occasionally and only on a small portion of the fleet (De Negri, pers. comm.).

It is essential that well designed experiments are undertaken in order to address the effectiveness of deterrent devices as potential mitigation measures against depredation; T-PODs and acoustic monitoring can prove a valuable tool in such experiments.

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REFERENCES

Brotons, J.M. and Grau, A. 2005. Bottlenose dolphin and artisanal fisheries interactions in the Balearic Islands: a final report. Abstracts of the 19th Annual Conference of the European Cetacean Society, La Rochelle, France, 2-7 April 2005.

Cannas, A., Fadda, D., Lenti, G., Massidda, P. and Pinna, D. 1994. I danni provocati dai delfini alla piccola pesca in Sardegna (Italia), dati preliminari. *Biol. Mar. Medit.* 1(1): 291-92. [In Italian].

Carlström, J. 2005. Diel variation in echolocation behaviour of wild harbour porpoises. *Mar. Mammal Sci.* 21(1): 1-12.

Carstensen, J., Henricksen, O.D. and Teilmann, J. 2006. Impacts of offshore wind farm construction on harbour porpoises: acoustic monitoring of echo-location activity using porpoise detectors (T-PODs). *Mar. Ecol. Prog. Ser.* 321: 295-308.

Casale, M., Milani, C. and Kallianiotis, A. 1999. Preliminary surveys on the interactions between local populations of *Delphinus delphis* and *Tursiops truncatus* and the coastal fishery in north-eastern Aegean Sea. *Eur. Res. Cet.* 13: 100.

Cox, T.M., Read, A.J., Solow, A. and Tregenza, N. 2001. Will harbour porpoises (*Phocoena phocoena*) habituate to pingers? *J. Cetacean Res. Manage.* 3(1): 81-86.

De Stephanis, R. 2004. Interactions between killer whales and the bluefin tuna fishery in the Strait of Gibraltar. *FINS the Newsletter of ACCOBAMS* 1(2): 6-7. [Available at: *http://www.accobams.org/newsletter/index.htm*].

Delitala, A., Chessa, P., Idini, M. and Petretto, F. 1998. Il clima dell’Asinara. pp.145-49. *In*: Gutierrez, M., Mattone, A. and Valsecchi, F. (eds). *L’isola dell’Asinara. L’ambiente, la storia, il parco.* Poliedro, Nuoro. 296pp. [In Italian].

Diaz Lopez, B. 2006. Interactions between Mediterranean bottlenose dolphins (*Tursiops truncatus*) and gillnets off Sardinia, Italy. *ICES J. Mar. Sci.* 63: 5pp.

Gazo, M., Fernandez-Contreras, M.M., Brotons, J.M. and Aguilar, A. 2001. Interactions between bottlenose dolphins and artisanal fisheries in the Balearic Islands: may acoustic devices be a solution to the problem? *Eur. Res. Cet.* 15: 37.

Lauriano, G., Fortuna, C., Moltedo, G., Mackelworth, P. and Notarbartolo de Sciara, G. 2003. Presenza e distribuzione dei cetacei nelle aree limitrofe al parco nazionale dell’Asinara (Sardegna nord-occidentale). *Biol. Mar. Medit.* 10(2): 848-52. [In Italian].

Lauriano, G., Fortuna, C.M., Moltedo, G. and Notarbartolo di Sciara, G. 2004. Interactions between common bottlenose dolphins (*Tursiops truncatus*) and the artisanal fisher in Asinara Island National Park (Sardinia): assessment of catch damage and economic loss. *J. Cetacean Res. Manage.* 6(2): 165-73.

Leeney, R.H. and Tregenza, N.J.C. 2006. Proceedings of the Workshop Static Acoustic Monitoring of Cetaceans, held at the 20th Annual Meeting of the ECS, Gdynia, Poland, 2 April 2006. *ECS Newsletter* 46 (Special issue): 1-55.

Lopez, A., Santos, B., Gonzalez, A.F., Guerra, A. and Pierce, G. 2000. Ecology and interactions with fisheries of bottlenose dolphin (*Tursiops truncatus*) in NW Spain. *Eur. Res. Cet.* 14: 180-83.

Naceur Lofti, B. 2000. New data about dolphins in Tunisia: interaction between dolphins and fishery craft. *Eur. Res. Cet.* 14: 171.

Northridge, S., Vernicos, D. and Raitsos, D.E. 2007. Dolphin depredation of trammel nets in the Aegean Sea: counting the cost and testing a potential mitigation measure. *Mar. Mammal Sci.* In Press.

Notarbartolo di Sciara, G. and Demma, M. 1997. *Guida dei Mammiferi Marini del Mediterraneo.* 2nd ed. Franco Muzzio Editore, Padova, Italy. 264pp. [In Italian].

Philpott, E., Englund, A., Ingram, S. and Rogan, E. 2007. Using T-PODs to investigate the echolocation of coastal bottlenose dolphins. *J. Mar. Biol. Assoc. U.K.* 87: 11-17.

Quero, M.E., Chiofalo, G., Datta, S., Di Natale, A., Dremiere, P.Y. and Goodson, D. 2000. Interaction between dolphins and artisanal gillnet fishery: methods of fishery damage and sampling. *Eur. Res. Cet.* 14: 48-54.

Reeves, R.R., Read, A.J. and Notarbartolo di Sciara, G. 2001. Report of the Workshop on Interactions between Dolphins and Fisheries in the Mediterranean: Evaluation of Mitigation Alternatives, May 2001, Rome, Italy. Paper SC/53/SM3 presented to the IWC Scientific Committee, July 2001, London (unpublished). 44pp. [Paper available from the Office of this Journal].

Tringali, L.M., Caltavuturo, G. and Puzzolo, V. 2004. A case of opportunistic feeding: bottlenose dolphin interference with the European anchovy fishing in the Gulf of Catania (Ionian Sea). *European Cet. Soc.* 15: 105-07.

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Population estimate and inter-island movement of sperm whales, *Physeter macrocephalus*, in the Eastern Caribbean Sea

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ABSTRACT

When a population extends across international boundaries, management becomes more complex. This is especially true within a confined multinational area such as the Caribbean Sea. The population size of sperm whales in the Eastern Caribbean is estimated and the inter-island movements of individuals are quantified using a database of 1,394 photographic identifications taken between 1984 and 2006 by several research groups. A total of 194 individual sperm whales were identified off the leeward coasts of the islands of Dominica, Guadeloupe, Grenada, St. Lucia and Martinique. Population size was estimated using two-component finite mixture models. About 145 (95% CI=94-219) sperm whales used Lesser Antillean waters in 1995 and this population appears to be growing slowly. There are differences amongst the individuals in their probability of identification. Of all individuals, 57 (29.4%) were identified during more than one year between 1995 and 2006. Long-term reidentification of associated females suggests that social units may be using the area for periods of at least 11 years. Twenty seven confirmed matches were made between islands, the majority (92.6%) of which were between Guadeloupe and Dominica, although there were two longer movements by single individuals between Dominica and the islands of St. Lucia and Grenada. High reidentification rates within the Lesser Antilles and no matches with identifications from nearby seas suggest the population in the Eastern Caribbean Sea is small and quite isolated. As such, we recommend that management actions be taken on a multi-island basis for the Eastern Caribbean, by encouraging the ratification of the SPAW protocols and that the current stock classification for the North Atlantic be reconsidered.

KEYWORDS: ABUNDANCE ESTIMATE; MOVEMENTS; SPERM WHALE; CARIBBEAN SEA; PHOTO-ID; MODELLING; MANAGEMENT; STOCK IDENTITY

INTRODUCTION

An animal's movements are important to several facets of its biology, including behaviour, population structure and conservation (Turchin 1998; Whitehead, 2001a). To effectively manage and conserve a nomadic species a good understanding of its modal and exceptional movements is needed over a range of temporal and spatial scales (Dufault *et al*., 1999). As nations differ in their political, economic, and social attitudes towards conservation, when animals move between national jurisdictions or if a population is spread across international boundaries, management of the human activities that affect their conservation are made more complex.

Cetacean species operate over relatively larger spatial (Stone *et al*., 1990) and temporal (George *et al*., 1999) scales than do most other mammalian species. As a result, movements and stock structure considerations have often been a complicating issue with respect to conservation and management (Donovan, 1991). This is especially true within a confined multinational area, such as the Caribbean Sea, where movements between countries is likely even for species whose movements are far from extreme. For such species, it is important to gain an understanding of how many animals are present, how often they move between national jurisdictions and how long animals are likely to remain within each. This information allows management decisions to be applied over biologically or culturally (discussed in Whitehead *et al*., 2004) appropriate scales rather than being based on biologically arbitrary national boundaries.

The sperm whale (*Physeter macrocephalus*, Linnaeus, 1758) is a highly mobile species which inhabits the Caribbean Sea and is likely to move between islands and political jurisdictions. Over short time periods, of several hours to days, sperm whale movements are generally thought to be based on the availability of food (Whitehead, 2003). When feeding success (determined by defecation rates) is good, animals will remain in one area for longer periods than when feeding conditions are poor (Jaquet and Whitehead, 1999; Whitehead, 2003; Whitehead and Rendell, 2004).

Over larger temporal and spatial scales, it has been shown that movement patterns differ among the sexes, as well as among clans of sperm whales. Mature male sperm whales travel large distances in moving from their high latitude feeding grounds to the breeding grounds in the tropical and subtropical waters and may even move between ocean basins (Dufault *et al*., 1999; Whitehead, 2003). Females and immatures, which live in social units of often matrilineally related individuals (Lyrholm and Gyllensten, 1998; Mesnick, 2001; Mesnick *et al*., 2003; Richard *et al*., 1996), regularly travel over ranges spanning 1,000 to 1,500km while remaining in tropical and subtropical waters year round (Dufault and Whitehead, 1995b; Whitehead, 2003). In an extreme case, the same female sperm whales have been identified moving from the Galapagos Islands to the Gulf of California which are 3,500km apart (Jaquet *et al*., 2003).

Different social units of sperm whales produce different repertoires of vocalisations which allow researchers to categorise units into acoustic clans (Rendell and Whitehead, 2003). Whitehead and Rendell (2004) showed that sperm whales in different clans exhibited different habitat-use and movement patterns suggesting that culture also impacts the movements of sperm whales.

Photo-identification of individual sperm whales has proved to be effective for describing the movements of individuals in a number of areas (Gordon *et al*., 1998; Jaquet

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et al., 2003; Jaquet and Whitehead, 1999; Rendell *et al*., 2004; Whitehead, 1996;2001a; Whitehead and Rendell, 2004). However, only a few studies have examined sperm whale movement at large scales (Coakes, 2003; Jaquet *et al*., 2003; Whitehead, 2003). While small scale studies provide useful data on distribution and abundance within a particular area, the pooling of identification data from a multitude of projects provides a relatively economical way of achieving a large data set over an extended area (e.g. Calambokidis *et al*., 2001).

Photo-identification also provides a powerful tool for estimating the abundance of whale populations when input into mark-recapture techniques (e.g. Hammond, 1986). In order to infer population parameters, most photographic mark-recapture analyses use likelihood techniques, or approximations of them, to find those parameter values most consistent with the temporal pattern of individual identifications, given an assumed population model. Some potential pitfalls exist when applying these methods to the study of live sperm whales. Issues such as mark loss (low in sperm whales; Childerhouse *et al*., 1996; Dufault and Whitehead, 1995a), mortality, geographic spreads of photo identification and whale movement (Cooke, 1986a;1986b) may inflate the population estimate; while heterogeneity reduces the estimate. Heterogeneity occurs when animals differ in their probability of identification due to variations in movement patterns or behaviour. Heterogeneity within female/immature social units appears to be only a small problem (Whitehead, 2001b), but units might differ considerably in their identifiability. Newer and more complex mark-recapture models attempt to account for some of these difficulties. Previous studies have successfully applied mark-recapture methods using photo-identifications to sperm whale populations in several areas (Childerhouse *et al*., 1995; Matthews *et al*., 2001; Whitehead *et al*., 1997; Whitehead *et al*., 1992).

Given the multinational nature of the Eastern Caribbean region, some aspects of the conservation and protection of sperm whales might better be considered on a multi-island basis. Protocols concerning Specially Protected Areas and Wildlife in the Wider Caribbean Area (SPAW Protocol) have already been established by the United Nations Environment Programme (UNEP). Under this agreement, parties recognise that the Caribbean islands are interconnected ecosystems in which an environmental threat in one part represents a potential threat in other parts and stress the importance of establishing regional cooperation to protect marine species and their habitats in the Wider Caribbean Region (UNEP, 2005). Here a population estimate is provided using mark-recapture techniques for a region for which none was previously available and inter-island movements of individuals are identified through a collaborative photo-identification effort of several research groups in an attempt to investigate whether management should be considered on a multi-island basis. This study provides some quantitative support for the arguments to ratify the SPAW protocol.

METHODS

Field methods

As the data were collected from several organisations across 22 years, field methods varied among the projects. Photo-identifications were taken from two main types of study, which were distinguished based on the platform used: identifications collected from research vessels dedicated to sperm whale research and opportunistic identifications taken from whalewatching vessels. The 1984 data were collected while aboard the Ocean Research and Education Society's vessel *R/V Rambler*. Photographs were collected opportunistically and animals were not actively followed. The International Fund for Animal Welfare (IFAW) data from 1995 and 1996 (Gordon *et al*., 1998), the Dalhousie University data from the Sargasso Sea in 2004 and 2005 as well as the Eastern Caribbean Sea in 2005 (Gero, 2005), were collected while groups of female and immature sperm whales were being actively located and followed 24 hours a day both acoustically, using directional and towed hydrophones, and visually by observers, using dedicated auxiliary sailing vessels. The exceptions were the data collected off St. Lucia and Martinique, which were taken by the Dalhousie research vessel while in transit from Dominica to St. Lucia near the end of the field season. A small number of photographs were collected opportunistically aboard motorised catamaran whalewatching vessels equipped with omnidirectional hydrophones while Peter Evans was in Dominica running a Multiple Land Use Project. Identifications collected by Association Evasion Tropical between 2000 and 2003 and by Dalhousie University while in Guadeloupe in 2004 were taken from the Association's whalewatching auxiliary sailing vessel, which actively searched for sperm whales using a directional hydrophone. Finally, the 2006 data from Dominica were collected while on daily trips aboard a motorised catamaran whalewatching vessel also actively searching for whales using an omnidirectional hydrophone. Supplementary data, such as the age/sex class of the animal identified, the exact date and time of the identification and information about social associations, were only readily available for fieldwork completed by the Dalhousie University and IFAW groups.

Data set

The data set consisted of 1,394 high quality, $Q \geq 3$, (Arnbom, 1987) photographic individual identifications of mature male, female or immature sperm whales (calves were excluded) collected from waters adjacent to five Caribbean islands (Dominica, Guadeloupe, Grenada, St. Lucia, and Martinique) in the Eastern Caribbean Sea between 1984 and 2006 (Table 1). The data set was made up of all photographs available from the Eastern Caribbean region in the North Atlantic and Mediterranean Sperm Whale Catalogue (NAMSC), curated by IFAW. An additional 439 identifications taken in the Sargasso Sea (roughly 1,800km north of the eastern Caribbean) from May to June in 2004 and 2005 (Gero, 2005) were included in order to investigate movement between the two Seas.

Analyses

Individual identifications

A quality rating (Q) between 1 and 5 was given to each photograph, where 1 indicated a very poor photograph and 5 indicated a very high quality photograph (Arnbom, 1987; Dufault and Whitehead, 1993). The Q-value was a function of the attributes of the photograph (focus, exposure, angle of fluke relative to the negative plane, angle between the axis of the fluke and the surface of the water and the proportion of the frame filled by the fluke), but not the quality of the markings on the fluke (Arnbom, 1987; Dufault and Whitehead, 1993). This method assumes that all animals are adequately marked for the analysis (Dufault and Whitehead, 1993). Only pictures with a $Q \geq 3$ were used for the analyses.

Table 1

Details of the field projects and identifications ($Q \geq 3$) of sperm whales included in this synthesis for the Eastern Caribbean Sea.

Dates	Nearest island	Project leader	Research group	Field method	No. of photos	Individuals identified
1984	Dominica	George Nichols	Ocean Research and Education Society	Dedicated vessel	18	13
1995	Dominica	Jonathan Gordon	IFAW	Dedicated vessel	218	59
1995	Grenada	Jonathan Gordon	IFAW	Dedicated vessel	6	5
1996	Dominica	Jonathan Gordon	IFAW	Dedicated vessel	81	35
1999	Dominica	Peter Evans	Sea Watch Foundation	Whale watch	7	6
2000	Guadeloupe	Carole Carlson	IFAW	Dedicated vessel	7	6
2000	Guadeloupe	Renato and Caroline Rinaldi	Association Evasion Tropicale	Whale watch	9	8
2001	Guadeloupe	Renato and Caroline Rinaldi	Association Evasion Tropicale	Whale watch	17	15
2002	Guadeloupe	Renato and Caroline Rinaldi	Association Evasion Tropicale	Whale watch	11	9
2003	Guadeloupe	Renato and Caroline Rinaldi	Association Evasion Tropicale	Whale watch	23	22
Feb-Mar 2004	Guadeloupe	Shane Gero	Dalhousie University	Whale watch	23	22
Jan-Apr 2005	Dominica	Hal Whitehead/Shane Gero	Dalhousie University	Dedicated vessel	812	53
Mar 10 2005	Martinique	Hal Whitehead/Shane Gero	Dalhousie University	Dedicated vessel	16	7
Mar 20 2005	St. Lucia	Hal Whitehead/Shane Gero	Dalhousie University	Dedicated vessel	3	3
Jan-Feb 2006	Dominica	Shane Gero	Dalhousie University	Whale watch	143	25
May-Jun 2004	Sargasso Sea	Hal Whitehead/Shane Gero	Dalhousie University	Dedicated vessel	376	104
May-Jun 2005	Sargasso Sea	Hal Whitehead/Shane Gero	Dalhousie University	Dedicated vessel	63	57

Pictures for each individual were matched within and between years, between islands and between seas using a computer-based matching program (Whitehead, 1990).

Based on these identifications, a map was constructed showing the number of individuals identified off each island and the number of confirmed matches between islands (Fig. 1).

Population estimate

Assessments of the population of reliably marked individuals using Lesser Antillean waters were made with a variety of population models. To incorporate the possibility of heterogeneity in either mortality or identification rate (variability in the probability of recapture), two-component finite mixture models were constructed following the methods of Pledger *et al.* (2003) and Whitehead and Wimmer (2005). The models condition on the first identification of each individual, and assume overall identification rates in each year j of n_j/N_j (the number of animals identified during the year divided by the estimated population size that year, as in Seber (1982, p.557)). Heterogeneity is incorporated by having two classes of individual (A and B) which may have different identification and/or mortality rates. The population can also increase or decrease at a constant rate per year. Thus, the full model has the following parameters: N_M, population of individuals using the study at mid-point of sampling (1995); r, proportional rate of increase in population per year; α, proportion of population in class A (with $1-\alpha$ in class B); β, ratio of identifiability of class B animals compared with class A animals; δ_A, mortality rate of class A animals per year; and δ_B, mortality rate of class B animals per year.

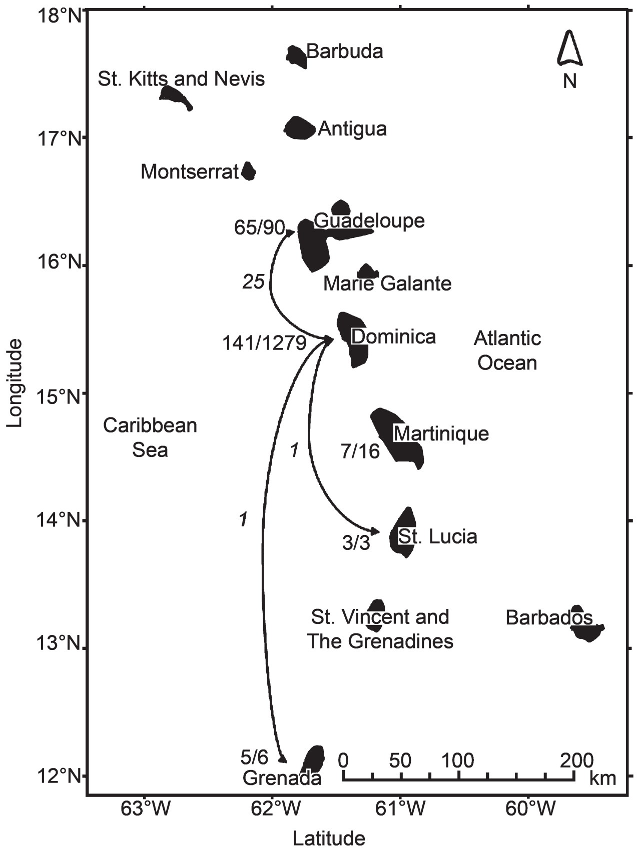

Fig. 1. Movements of identified sperm whales ($Q \geq 3$) in the Eastern Caribbean. Bold numbers indicate the number of individuals and the number of identifications separated by a slash and the italic numbers indicate the number of whales moving between islands.

Simpler models were investigated by using the following restrictions, or combinations of them: $r=0$, no population trend; $\alpha=1$, no heterogeneity; $\beta=1$, no heterogeneity in identification; $\delta_A = \delta_B$, no heterogeneity in mortality; $\delta_A = \delta_B = 0$, $\alpha=1$, $r=0$, closed, homogeneous population. The models examined are listed in Table 2.

Support for the different models was assessed using the Akaike Information Criterion (AIC), with the lowest AIC indicating the preferred model (Burnham and Anderson, 2002). The difference between the AIC of any model and the best fitting, ΔAIC, indicates the relative support for a model compared with the best. Parameter estimates were calculated using likelihood methods. A parametric bootstrap, in which 1,000 simulated data sets were produced using the estimated parameters and observed sampling scheme, was used to examine bias and precision in parameter estimates, following the methodology of Whitehead and Wimmer (2005).

RESULTS

A total of 194 individual sperm whales were identified off the five islands in the eastern Caribbean. The number of individuals identified off each island roughly corresponded

Table 2

Summary of population models fitted to photoidentification data. Models are presented in order of increasing AIC (Akaike Information Criterion). The lowest AIC, indicating the best fit to the data, is starred, and ΔAIC gives the difference between the AIC for a model and that of the best model. A ΔAIC less than 2 indicates there is substantial support for the less well fitting model. The final column indicates qualitatively the support for the model based upon ΔAIC using the criteria of Burnham and Anderson (2002, p.70).

	Closed?	Trend?	Heterogeneity in:				
Model	$\delta_A = \delta_B = 0$ $\alpha = 1, r = 0$	$r \neq 0$	Identifiability? $\beta \neq 1$	Mortality? $\delta_A \neq \delta_B$	AIC	ΔAIC	Support for model
Heterogeneity in identifiability + trend	No	Yes	Yes	No	544.00*	0	Yes
Full: Heterogeneity in mortality and identifiability + trend	No	Yes	Yes	Yes	548.98	4.98	Little
Mortality + trend	No	Yes	No	No	549.47	5.47	Little
Heterogeneity in mortality + trend	No	Yes	No	Yes	550.24	6.24	Little
Heterogeneity in identifiability	No	No	Yes	No	556.39	12.39	Very little
Heterogeneity in mortality and identifiability	No	No	Yes	Yes	557.26	13.26	Almost none
Mortality	No	No	No	No	558.35	14.35	Almost none
Heterogeneity in mortality	No	No	No	Yes	559.03	15.03	Almost none
Closed (Schnabel)	Yes	No	No	No	624.16	80.16	None

to the amount of effort within those waters, such that more individuals were identified where more pictures were taken (Table 1).

Identifications between years

A summary of confirmed re-identifications between years is found in Table 3. None of the animals identified in 1984 were identified in later years. Of the 194 individuals identified, 57 were re-identified in different years between 2 and 5 times between 1995 and 2006. Excluding the 1984 study, the longest possible identification span was 11 years (1995-2006), over which time five individuals were re-identified.

Table 3

Observed reidentifications of individual sperm whales in the East Caribbean including waters off Dominica, Guadeloupe, Grenada, Martinique, and St. Lucia between 1984 and 2006. Note: the numbers of identified individuals in each year are given along the diagonal.

1984	13										
1995	0	64									
1996	0	25	35								
1999	0	2	3	6							
2000	0	6	0	0	13						
2001	0	5	2	0	0	15					
2002	0	4	3	0	0	3	9				
2003	0	6	4	0	2	4	1	22			
2004	0	3	4	1	2	2	2	4	22		
2005	0	7	7	1	0	5	2	1	4	63	
2006	0	5	5	1	0	0	0	0	4	13	25
	1984	**1995**	**1996**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**

Following the pattern of identification of long-term companions in the Galapagos/Ecuador area (Christal *et al*., 1998; Whitehead *et al*., 1991), we looked for sets of animals identified with one another between years. Eighteen sets of animals were identified across years (Table 4). Of the 18 associates re-identified, only four were over time scales longer than one year. In one case, all five adult females (ID No. 5130, 5560, 5561, 5563, 5722) of a well studied social unit, dubbed 'the Group of Seven' (Gero, 2005), were observed together off Dominica on 14 different days in 1995 and 1996, three were re-identified in 2001 off the coast of Guadeloupe (association data were not available for the 2001 dataset), and all were then re-identified in 2005 and 2006 off Dominica along with a juvenile male (ID No. 5727) and a male calf (gender determined using sloughed skin in an ongoing genetic analysis; D. Engelhaupt, unpublished data).

Identifications between islands and seas

The total number of individuals identified, along with the total number of identifications, in the waters off each island is shown in Fig. 1. Movements between islands are shown as arrows on the map of the Eastern Caribbean (Fig. 1), along with the number of confirmed inter-island matches. Twenty seven confirmed matches were made between islands. The majority (92.6%) of these were between the neighbouring islands of Guadeloupe and Dominica, the islands for which effort was highest. Of the individuals which moved between Dominica and Guadeloupe for which age/sex data were available (13 of the 25 individuals), all were adult females or immatures. Four sets of animals were identified together in one year off the coast of one island and then in another year off another. In all cases, the islands were Dominica and Guadeloupe. Only single animals were identified between non-neighbouring islands.

Two longer movements by single individuals between non-neighbouring islands were confirmed between Dominica and the islands of St. Lucia and Grenada (Fig. 1). An adult female or immature animal was observed off the coast of Dominica in 1995 then re-identified off St. Lucia in 2005. No class data were available for the animal which was identified in 1995 off Dominica and then again off Grenada 15 days later.

No matches were made between the identifications in the Caribbean Sea and the Sargasso Sea to the north. It is also important to note that no matches were made between years within the Sargasso Sea.

Population size

The results of the two-component finite mixture models are listed in order of best fit in Table 2. The lowest AIC indicated that the heterogeneity in identifiability (variability in the probability of recapture) plus trend model was best supported by the data (Table 2). Although a ΔAIC of <2 has been used as the convention for an indicator of substantial support for a less well fitting model, the full model still had some support, as did the model without heterogeneity in identifiability but including mortality and a trend, and the model with heterogeneity in mortality plus a trend. This same pattern of relative fits of the different models to the

Table 4

Sets of individuals identified together across years. Individuals were considered associated if they were identified on the same day. Only data from the IFAW and Dalhousie research groups, for which association data were available, were considered for this analysis.

	First identification		Second identification		Third identification		Fourth identification	
ID Nos	Year	Island	Year	Island	Year	Island	Year	Island
5583, 5964	1995	Dominica	1996	Dominica				
5579, 5585	1995	Dominica	1996	Dominica				
5555, 5559	1995	Dominica	1996	Dominica				
5142, 5559	1995	Dominica	1996	Dominica				
5550, 5554	1995	Dominica	1996	Dominica				
5144, 5554	1995	Dominica	1996	Dominica				
5146, 5550	1995	Dominica	1996	Dominica				
5550, 5722	1995	Dominica	1996	Dominica				
5151, 5564, 5571, 5579, 5722	1995	Dominica	1996	Dominica				
5151, 5562, 5564, 5130, 5560, 5561, 5722	1995	Dominica	1996	Dominica				
5130, 5560, 5561, 5563, 5722	1995	Dominica	1996	Dominica	2005	Dominica		
5560, 5561, 5563, 5722	1995	Dominica	1996	Dominica	2005	Dominica	2006	Dominica
5560, 5561, 5563, 5722, 5727	2005	Dominica	2006	Dominica				
5563, 5726	2005	Dominica	2006	Dominica				
5151, 5562	1995	Dominica	1996	Dominica	2004	Guadeloupe		
5143, 5150	1996	Dominica	2004	Guadeloupe				
5752, 5753	2005	Dominica	2006	Dominica				
5753, 5757	2005	Dominica	2006	Dominica				
5755, 5756, 5757	2004	Guadeloupe	2005	Dominica				
5756, 5757	2004	Guadeloupe	2005	Dominica	2006	Dominica		

data was found when the data for 1984 (collected a decade earlier than any other) were excluded from the analysis. The parameter estimates from the best supported model and the parametric bootstrap estimates of bias and precision are shown in Table 5. Using the best supported model, the estimated population size using the Lesser Antillean waters in 1995 was N_M=93.8. However, the parametric bootstrap analysis suggests that this is biased downwards, after correcting for bias the estimate is 144.7 (95% CI=93.8-218.5). The estimated rate of mortality plus emigration plus mark change was δ=0.094 yr^{-1} (95% CI=0.035-0.169). The estimated trend in the population size was r=+0.157 yr^{-1} (95% CI= −0.119-0.357), so not significantly different from zero. The estimated proportion of low-identifiability individuals in the population, and the ratio of identifiability between the two classes were too imprecise to bear interpretation (Table 5).

As Pledger *et al*. (2003) and Whitehead and Wimmer (2005) noted, two-component mixture models fit well to data with heterogeneity of more than two classes. Thus the parameter estimates relating to the two supposed classes of sperm whale should not be taken literally. Rather, the analysis indicates that there are differences among the sperm whales using the Eastern Caribbean in their probability of identification in studies based primarily around Dominica and Guadeloupe.

DISCUSSION

The photo-identification analysis conducted here indicates that the animals differ in their identifiability (variability in the probability of recapture). Heterogeneity of capture by differences in movement patterns based on sex, clan membership and behaviour affect population estimates. Typically, heterogeneity of photographic capture appears only to be a small problem between female and immature sperm whales within social units, although younger animals tend to be identified less often (Whitehead, 2001b). It is likely that the lack of sex class information for much of the data, and the inclusion of males in the analysis, has resulted in an increase in heterogeneity of identification. Differences of range use by females of the Eastern Caribbean are also likely to have contributed towards the heterogeneity in identification. Although Gordon *et al*. (1998) found that some large males have been re-identified between years off Dominica, it is still unknown how predictably males return to the same area year after year (Whitehead, 2003). Consistent photo-identification effort from several islands is needed to investigate male breeding ranges. The models also suggest that the Eastern Caribbean population numbers in the low hundreds and may be growing. While this is encouraging, the estimated trend is not significantly different from zero.

Table 5

Parameter estimates for heterogeneity in identifiability plus trend model, together with the mean of the estimates from 1,000 parametric bootstrap replicates, and their 95% confidence intervals. The bias is the mean of the parametric bootstrap estimates of a parameter divided by its original estimate. Corrected estimates and corrected 95% confidence intervals were derived by dividing by the bias.

Parameter	Estimate	Mean of parametric bootstraps	95% CI (lower limit)	95% CI (upper limit)	Bias	Corrected estimate	Corrected 95% CI (lower limit)	Corrected 95% CI (upper limit)
Population in 1995	93.8	60.8	39.4	91.8	0.6	144.7	93.8	218.5
Mortality yr^{-1}	0.119	0.150	0.055	0.269	1.261	0.094	0.035	0.169
Trend yr^{-1}	0.104	0.069	-0.008	0.157	0.663	0.157	-0.019	0.357
Proportion of high identifiability animals	0.28	0.461	0.000	1.000				
Ratio of identifiabilities	0.048	0.265	0.000	1.000				

It is apparent from Fig. 1 that individuals, and probably associated sets of animals, move across the entire area of the Eastern Caribbean for which data were available, a linear distance of 460km. Furthermore, given that the photographs were collected opportunistically and not systematically throughout the region, it is likely that not all individuals in a given area were identified, making it likely that the actual number of inter-island movements was higher than reported here. Continued sampling in this area, and from different islands, should be encouraged. Although these data are sparse and effort differed between sites and among years, the information provided by this multinational collaboration is generally consistent with patterns of social organisation and movement reported elsewhere, summarised in Whitehead (2003).

Slightly less than 30% of individuals were re-identified in more than one year. Repeated identification of sets of associated individuals suggests that social units of female and immature sperm whales may use this area over periods of at least 11 years. In a particularly detailed case, a core set of five adult females were identified associated with five other animals with lags of up to one year (1995 to 1996), but later identified together without those associates (2005 and 2006). These findings are consistent with the current model of sperm whale social structure drawn from studies in the eastern tropical Pacific (Whitehead *et al*., 1991), although it is difficult to determine whether these associates were unit members who have since died or members of another social unit with which the first is preferentially grouped (Whitehead, 2003).

The confirmed inter-island movements are also consistent with current knowledge. Sperm whales are thought to cover distances much greater than the roughly 460km between the islands of Guadeloupe and Grenada as, in the eastern tropical Pacific, units of females and immatures possess ranges spanning 1,000-1,500km (Dufault and Whitehead, 1995b; Whitehead, 2003). Sperm whales have been estimated to be able to travel at average speeds of about 4km h^{-1} (Gordon, 1987; Watkins *et al*., 1999; Whitehead, 1989; Whitehead *et al*., 1992) whether at the surface or at depth foraging. Although sperm whales may potentially cover as much as 96km day^{-1} (4km $h^{-1} \times 24h$), Whitehead (2001a) estimated root-mean-squared displacement to be approximately 50km day^{-1}, based on a likelihood movement analysis on opportunistic sperm whale identification data from the Pacific. Either value would allow for animals to cover the distance between any of the five islands included in this analysis within a matter of days.

Of the five islands included in this study, only three have ratified the SPAW protocols (Guadeloupe and Martinique under France in 2002, and St. Lucia in 2000). Dominica and Grenada have neither signed nor ratified this agreement. With whalewatching growing as a business on all of these islands, these findings indicate that neighbouring islands, in particular Dominica and Guadeloupe, have a vested interest in jointly protecting this shared resource and encouraging their neighbours to ratify and meet international treaty commitments, such as the SPAW protocols. Dominica, Grenada and St. Lucia are members of the International Whaling Commission (IWC), which may provide them a forum to collaborate on these issues.

From a management perspective, it is interesting that no matches were made between any of the identifications in the Caribbean Sea and photo-identifications from the Sargasso Sea, about 1,800km to the north. Similarly, there have been no matches with the Gulf of Mexico 2,700km to the northwest (J. Gordon and N. Jaquet, pers. comm.). The status and stock structure sperm whales of the North Atlantic have not been considered by the International Whaling Commission since the early 1980s. A single stock is listed in the IWC Regulations (Donovan, 1991), supposed partially due to the capture of a male off Spain that had been tagged off Nova Scotia (Mitchell, 1975) and two findings linking males in the Azores to Spain and Iceland (Aguilar, 1985; Martin, 1982). While males may be wide ranging (Dufault *et al*., 1999; Whitehead, 2003), social units of females and immatures appear to have much more confined home ranges (Dufault and Whitehead, 1995b; Whitehead, 2003). It is, therefore, the ranging patterns and habitat-use of the female and immature component of the population which is most relevant for management and conservation. Our findings suggest that the female and immature component of the small Caribbean population, estimated here to be approximately 145 individuals (95% CI=94-219) in 1995, is somewhat segregated from the once heavily hunted Sargasso population (Maury, 1852; Townsend, 1935). If interchange between the seas is minimal and reidentification within the Caribbean is high, it suggests that animals in the Caribbean are able to successfully exploit resources available in a smaller range restricted to the Lesser Antilles, making movement between seas unnecessary. Previous studies support this hypothesis, indicating that animals that are feeding successfully (using defecation rate as a proxy) cover less ground when foraging (Whitehead, 1996; Whitehead and Rendell, 2004). Gero (2005) showed, using defecation as a proxy for feeding success, that the animals in the Eastern Caribbean are foraging more successfully than those in the Sargasso, which is consistent with the hypothesis of a reduced foraging range in the Caribbean. In addition, foraging strategies seem to be culturally inherited (Whitehead and Rendell, 2004) and preliminary results find no evidence of the Caribbean vocal clan occurring anywhere else in the North Atlantic (L. Rendell, unpublished data) such that a restricted foraging range may be passed on between generations within social units of the Caribbean clan. These findings suggest that the Caribbean population is quite isolated, such that impacts on the population in the Eastern Caribbean are unlikely to have repercussions on neighbouring populations. Given that all sperm whales in the North Atlantic are presently considered one management region by the IWC, our findings suggest that reclassification of the stock boundaries should be considered.

CONCLUSIONS

Defining sperm whale stocks is a difficult task as this species is highly mobile (Jaquet *et al*., 2003), sexually segregated (Whitehead and Mesnick, 2003), shows little genetic differentiation within an ocean basin (Dufault *et al*., 1999; Lyrholm and Gyllensten, 1998; Lyrholm *et al*., 1996; Mesnick, 2001) and has socially and culturally complex behaviour and movement patterns, summarised in Whitehead (2003). With an increase in the proportion of sperm whale habitat for which there are population estimates and a better understanding of sperm whale movements, stock definitions can be refined. In this paper, an estimate is provided for a region for which none was previously available and it is shown that movement between national boundaries within the Caribbean Sea is common, but that movement between adjacent seas may not be. Management of this species should be considered on a cooperative, multi-national basis across the Eastern Caribbean area and stock reclassification for the entire North Atlantic should be considered.

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REFERENCES

Aguilar, A. 1985. Further information on the movements of the sperm whale (*Physeter macrocephalus*) in the North Atlantic. *Mammalia* 49(3): 421-24.

Arnbom, T. 1987. Individual identification of sperm whales. *Rep. int. Whal. Commn* 37: 201-04.

Burnham, K.P. and Anderson, D.R. 2002. *Model Selection and Multimodel Inference: a Practical Information-theoretic Approach*. 2nd ed. Springer-Verlag, New York. 488pp.

Calambokidis, J., Steiger, G.H., Straley, J., Herman, L.M., Cerchio, S., Salden, D., Urbán R, J., Jacobsen, J.K., von Zeigesar, O., Balcomb, K.C., Gabriele, C.M., Dahlheim, M.E., Uchida, S., Ellis, G., Miyamura, Y., Ladrón de Guevara P, P., Yamaguchi, M., Sato, F., Mizroch, S.A., Schlender, L., Rasmussen, K. and Barlow, J. 2001. Movements and population structure of humpback whales in the North Pacific. *Mar. Mammal Sci.* 17(4): 769-94.

Childerhouse, S.J., Dawson, S.M. and Slooten, E. 1995. Abundance and seasonal residence of sperm whales at Kaikoura, New Zealand. *Can. J. Zool.* 73(4): 723-31.

Childerhouse, S.J., Dawson, S.M. and Slooten, E. 1996. Stability of fluke marks used in individual photo-identification of sperm whales at Kaikoura, New Zealand. *Mar. Mammal Sci.* 12(3): 447-51.

Christal, J., Whitehead, H. and Lettevall, E. 1998. Sperm whale social units: variation and change. *Canadian Journal of Zoology* 76: 1431-40.

Coakes, A. 2003. Sperm whales (*Physeter macrocephalus*) off the coast of northern Chile: movements, female and immature social structure, and male mating strategies, MSc thesis, Dalhousie University Department of Biology, Halifax, Nova Scotia. 132pp.

Cooke, J.G. 1986a. On the utility of mark-recapture experiments for the detection of trends in whale stocks. *Rep. int. Whal. Commn* 36: 451-55.

Cooke, J.G. 1986b. A review of some problems relating to the assessment of sperm whale stocks, with reference to the western North Pacific. *Rep. int. Whal. Commn* 36: 187-90.

Donovan, G.P. 1991. A review of IWC stock boundaries. *Rep. int. Whal. Commn (special issue)* 13: 39-68.

Dufault, S. and Whitehead, H. 1993. Assessing the stock identity of sperm whales in the eastern equatorial Pacific. *Rep. int. Whal. Commn* 43: 469-75.

Dufault, S. and Whitehead, H. 1995a. An assessment of changes with time in the marking patterns used for photoidentification of individual sperm whales, *Physeter macrocephalus*. *Mar. Mammal Sci.* 11(3): 335-43.

Dufault, S. and Whitehead, H. 1995b. The geographic stock structure of female and immature sperm whales in the South Pacific. *Rep. int. Whal. Commn* 45: 401-05.

Dufault, S., Whitehead, H. and Dillon, M. 1999. An examination of the current knowledge on the stock structure of sperm whales (*Physeter macrocephalus*) worldwide. *J. Cetacean Res. Manage.* 1(1): 1-10.

George, J.C., Bada, J., Zeh, J., Scott, L., Brown, S.E., O'Hara, T. and Suydam, R. 1999. Age and growth estimates of bowhead whales (*Balaena mysticetus*) via aspartic racemization. *Can. J. Zool.* 77: 571-80.

Gero, S. 2005. Fundamentals of sperm whale societies: care for calves. MSc thesis Dalhousie University Department of Biology, Halifax, Nova Scotia. 99pp.

Gordon, J., Moscrop, A., Carlson, C., Ingram, S., Leaper, R., Matthews, J. and Young, K. 1998. Distribution, movements and residency of sperm whales off the Commonwealth of Dominica, Eastern Caribbean: implications for the development and regulation of the local whalewatching industry. *Rep. int. Whal. Commn* 48: 551-57.

Gordon, J.C.D. 1987. The behaviour and ecology of sperm whales off Sri Lanka. PhD dissertation Darwin College, University of Cambridge. 347pp.

Hammond, P.S. 1986. Estimating the size of naturally marked whale populations using capture-recapture techniques. *Rep. int. Whal. Commn (special issue)* 8: 253-82.

Jaquet, N., Gendron, D. and Coakes, A. 2003. Sperm whales in the Gulf of California: residency, movements, behaviour and the possible influence of variation in food supply. *Mar. Mammal Sci.* 19(3): 545-62.

Jaquet, N. and Whitehead, H. 1999. Movements, distribution and feeding success of sperm whales in the Pacific Ocean, over scales of days and tens of kilometers. *Aquat. Mamm.* 25(1): 1-13.

Lyrholm, T. and Gyllensten, U. 1998. Global matrilineal population structure in sperm whales as indicated by mitochondrial DNA sequences. *Proc. R. Soc. Lond. Ser. B.* 265: 1679-84.

Lyrholm, T., Leimar, O. and Gyllensten, U. 1996. Low diversity and biased substitution patterns in the mitochondrial DNA control region of sperm whales: implications for estimates of time since common ancestry. *Mol. Biol. Evol.* 13(10): 1318-26.

Martin, A.R. 1982. A link between the sperm whales occurring off Iceland and the Azores. *Mammalia* 46: 259-60.

Matthews, J.N., Steiner, L. and Gordon, J. 2001. Mark-recapture analysis of sperm whale (*Physeter macrocephalus*) photo-id data from the Azores (1987-1995). *J. Cetacean Res. Manage.* 3(3): 219-26.

Maury, M.F. 1852. Map. Sheet 1 (Washington, 1852), sheets 2-4 (no date).

Mesnick, S.L. 2001. Genetic relatedness in sperm whales: evidnece and culture implications. *Behav. Brain Sci.* 24: 346-47.

Mesnick, S.L., Evans, K., Taylor, B.L., Hyde, J., Escorza-Trevino, S. and Dizon, A. 2003. Sperm whale social structure: why it takes a village to raise a child. pp.170-74. *In*: de Wall, F.B.M. and Tyack, P. (eds). *Animal Social Complexity: Intelligence, Culture and Individualized Societies*. Harvard University Press, Cambridge.

Mitchell, E. 1975. Report of the Scientific Committee, Annex U. Preliminary report on Nova Scotian fishery for sperm whales (*Physeter catodon*). *Rep. int. Whal. Commn* 25: 226-35.

Pledger, S., Pollock, K.H. and Norris, J.L. 2003. Open capture-recapture models with heterogeneity: I. Cormack-Jolly-Seber model. *Biometrics* 59: 786-94.

Rendell, L. and Whitehead, H. 2003. Vocal clans in sperm whales (*Physeter macrocephalus*). *Proc. R. Soc. Lond. Ser. B.* 270: 225-31.

Rendell, L., Whitehead, H. and Escribano, R. 2004. Sperm whale habitat use and foraging success off northern Chile: evidence of ecological links between coastal and pelagic systems. *Marine Ecology. Progress Series* 275: 289-95.

Richard, K.R., Dillon, M.C., Whitehead, H. and Wright, J.M. 1996. Patterns of kinship in groups of free-living sperm whales (*Physeter macrocepahalus*) revealed by multiple molecular genetic analyses. *Proc. Natl Acad. Sci. USA* 93: 8792-95.

Seber, G.A.F. 1982. *The Estimation of Animal Abundance and Related Parameters*. 2nd ed. Charles Griffin and Company Ltd., London. i-xvii+654pp.

Stone, G.S., Flórez-González, L. and Katona, S. 1990. Whale migration record. *Nature* 346: 705-06.

Townsend, C.H. 1935. The distribution of certain whales as shown by logbook records of American whaleships. *Zoologica (NY)* 19(1-2): 1-50+6 maps.

Turchin, P. 1998. *Quantitative Analysis of Movement*. Sinauer Associates, Sunderland, Massachusetts. 396pp.

UNEP. 2005. Text of Protocol concerning specially protected areas and wildlife in the Wider Caribbean Area – Caribbean environment programme portal. [Available from *http://www.cep.unep.org/cartagena-convention/plonearticlemultipage.2005-11-30.9771186458/plonearticle.2005-11-30.40199622007*].

Watkins, W.A., Daher, M.A., DiMarzio, N.A., Samuels, A., Wartzok, D., Fristrup, K.M., Gannon, D.P., Howey, P.W., Maiefski, R.R. and Spradlin, T.R. 1999. Sperm whale surface activity from tracking by radio and satellite tags. *Mar. Mammal Sci*. 15(4): 1,158-1,80.

Whitehead, H. 1989. Formations of foraging sperm whales, *Physeter macrocephalus*, off the Galapagos Islands. *Can. J. Zool*. 67(9): 2131-39.

Whitehead, H. 1990. Computer assisted individual identification of sperm whale flukes. *Rep. int. Whal. Commn (special issue)* 12: 71-77.

Whitehead, H. 1996. Variation in the feeding success of sperm whales: temporal scale, spatial scale and relationship to migrations. *J. Anim. Ecol*. 65: 429-38.

Whitehead, H. 2001a. Analysis of animal movement using opportunistic individual-identifications: Application to sperm whales. *Ecology* 82: 1417-32.

Whitehead, H. 2001b. Direct estimation of within-group heterogeneity in photo-identification of sperm whales. *Mar. Mammal Sci*. 17: 718-28.

Whitehead, H. 2003. *Sperm Whales: Social Evolution in the Ocean*. University of Chicago Press, Chicago. 464pp.

Whitehead, H., Christal, J. and Dufault, S. 1997. Past and distant whaling and the rapid decline of sperm whales off the Galápagos Islands. *Conserv. Biol*. 11(6): 1,387-96.

Whitehead, H. and Mesnick, S.L. 2003. Social structure and effects of differential removals by sex in sperm whales: methodology. Paper SC/55/O12 presented to the IWC Scientific Committee, May 2003, Berlin (unpublished). 12pp. [Paper available from the Office of this Journal].

Whitehead, H. and Rendell, L. 2004. Movements, habitat use and feedings success of cultural clans of South Pacific sperm whales. *J. Anim. Ecol*. 73: 190-96.

Whitehead, H., Rendell, L., Osborne, R.W. and Wursig, B. 2004. Culture and conservation of non-humans with reference to whales and dolphins: review and new directions. *Biol. Conserv*. 120: 427-37.

Whitehead, H., Waters, S. and Lyrholm, T. 1991. Social organization of female sperm whales and their offspring: constant companions and casual acquaintances. *Behav. Ecol. Sociobiol*. 29: 385-89.

Whitehead, H., Waters, S. and Lyrholm, T. 1992. Population structure of female and immature sperm whales (*Physeter macrocephalus*) off the Galapagos islands. *Can. J. Fish. Aquat. Sci*. 49(1): 78-84.

Whitehead, H. and Wimmer, T. 2005. Heterogeneity and the mark-recapture assessment of the Scotian Shelf population of northern bottlenose whales (*Hyperoodon ampulatus*). *Can. J. Fish. Aquat. Sci*. 63: 2573-85.

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Killer whales preying on a blue whale calf on the Costa Rica Dome: genetics, morphometrics, vocalisations and composition of the group

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ABSTRACT

Killer whale (*Orcinus orca*) populations in high latitude, nearshore areas appear to regularly exhibit prey specialisation among two or more sympatric ecotypes, but nearly nothing is known about populations that inhabit open ocean areas or tropical latitudes. On 26 September 2003, during a cetacean survey in the eastern tropical Pacific Ocean, a group of an estimated 19 killer whales was encountered feeding on a calf of a blue whale (*Balaenoptera musculus*); the location was 10°58'N, 88°40'W, 230km west of Nicaragua. The whales were studied for 2.5 hours and during this time skin biopsy samples were collected, acoustic recordings made, aerial and lateral photographs taken and behavioural observations recorded. The 19 individuals identified included 4 males (3 adults, 1 subadult), 5 cow-calf pairs and 5 other females/subadult males. Using aerial photogrammetry, body lengths of 17 different animals were measured: the largest male (who carried the carcass most of the time) was 8.0m long; and the largest female (with a calf) was 6.1m. From 10 biopsy samples, two distinct haplotypes were identified that differed from *resident* (i.e. fish-eating ecotype) killer whales in the northeastern Pacific by one and two base pairs, respectively. The single discrete call recorded was a typical killer whale call but it had a two-part pitch contour that was structurally distinct from calls recorded to date in the North Pacific. These observations reaffirm that calves of even the largest whale species are vulnerable to predation, although by migrating to calving areas in the tropics, where killer whale densities are lower, baleen whales should be able to increase their overall reproductive fitness, as suggested by Corkeron and Connor (1999).

KEYWORDS: KILLER WHALE; PREDATION; GENETICS; MORPHOMETRICS; VOCALISATION; BLUE WHALE; MIGRATION; PACIFIC OCEAN; NORTHERN HEMISPHERE

INTRODUCTION

Killer whales (*Orcinus orca*) are distributed throughout the world's oceans and are generally considered to comprise a single species (Rice, 1998). Recent research, however, has revealed considerable population sub-structuring within regional communities, with up to three ecotypes occurring sympatrically. For example, in the continental shelf waters of the eastern and central North Pacific, three distinct forms of killer whales have been identified: *residents* are neritic fish-eaters; *transients* are neritic mammal-eaters; and *offshores* are an outer coastal form with largely unknown diet preferences but evidence suggests that they feed on fish, including perhaps sharks (Barrett-Lennard and Heise, 2006; Heise *et al*., 2003; Jones, 2006). Three morphologically distinct forms of killer whales have also been described from Antarctica (types A, B, and C), which appear to prey mainly on Antarctic minke whales (*Balaenoptera bonaerensis*), pinnipeds, and fish, respectively (Pitman and Ensor, 2003).

Prey specialisation among different killer whale ecotypes also appears to have contributed to morphological divergences, including significant differences in body size. For example, fish-eating ecotypes in Antarctica are 2-3m smaller than the ecotype that preys on minke whales (Pitman *et al*., 2007). Furthermore, a comparison of body length data and prey preferences from killer whale communities in the western North Pacific, North Atlantic and Antarctic waters, suggests that high latitude populations may regularly comprise a nearshore, diminutive, fish-eating form living in close proximity to a larger, offshore, mammal-eating form (Pitman *et al*., 2007).

High latitude killer whale communities typically seem to include habitat partitioning, prey specialisation, morphological divergence and perhaps ultimately, reproductive isolation among sympatric forms. To date, however, there have been few detailed observations of killer whales that inhabit either deep ocean waters or live in low latitudes to consider how they might fit into this evolutionary scenario. Baird *et al*. (2006) summarised recent killer whale encounters around the Hawaiian Islands, including a group feeding on a humpback whale, and a live-stranded individual that had squid beaks in its stomach. From two tissue samples they collected from two separate encounters they identified two different haplotypes – one identical to 'Gulf of Alaska 2' *transients*; the other differed by one DNA base pair from mammal-eating killer whales in Alaskan coastal waters. Whether these 'island-associated' killer whales were year-round residents or part of a wider-ranging population could not be determined.

In September 2003, while conducting a cetacean survey in the eastern tropical Pacific Ocean, a group of killer whales was encountered feeding on a blue whale calf (*Balaenoptera musculus*). During the encounter, vocalisations were recorded, skin biopsy samples collected and a series of aerial and lateral photographs of nearly all of the whales present were obtained. In this paper, analyses of these acoustic, genetic and photogrammetric data are

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presented and for the first time a group of open-ocean, tropical killer whales of known feeding habits are characterised. Finally, some preliminary comparisons are made with ecotypes described from the northeastern Pacific.

METHODS

Observations were made while conducting a marine mammal sightings survey aboard the NOAA Research Vessel *David Starr Jordan* in the eastern tropical Pacific Ocean (ETP); additional details of the study area and overall survey methods can be found in Jackson *et al*. (2004). Four pairs of 25 × 150mm mounted spotting binoculars were used for detecting and observing cetaceans. After initially sighting the killer whales, they were closed in on and observed for 2.5h. During that time a 5m inflatable launch was deployed to collect biopsy samples and take photographs; a helicopter was launched to take aerial photographs for photogrammetric analysis; and acoustic recordings were obtained from a hydrophone mounted on the bow of the ship. Additional details on each of these activities are presented below.

Biopsy samples were collected for molecular genetics analyses using a crossbow and floating bolts. On returning to the vessel, blubber samples were sectioned from the skin and frozen at −80°C. The skin samples were then split: one half was preserved in a saturated salt solution and dimethyl sulfoxide (DMSO), the other half was flash-frozen in liquid nitrogen. Both halves were then stored at −80°C until they could be analysed at the end of the cruise.

DNA was extracted from the biopsy samples using a Qiagen *DNeasy* extraction kit. The entire mitochondrial control region was amplified in two overlapping segments and sequenced in both directions: the 5' end with the primers 5'-CCTCCCTAAGACTCAAGGAAG-3' (designed at Southwest Fisheries Science Center [SWFSC]) and 5'-CCTGAAGTAAGAACCAGATG-3' (Rosel *et al*., 1995), and the 3' end with the primers 5'-GTGAAACCAGCAACCCGC-3' and 5'-AAGGCTGGGACCAAACCTT-3' (both designed at SWFSC). Sequencing was done using *Big Dye Terminator* reagents and protocols from Applied Biosystems (ABI), with the PCR primers serving as sequencing primers. The products of the sequencing reactions were run on an *ABI 3100* automated genetic analyser, with the sequences edited using *Sequencher* (Gene Codes v.4.1) and aligned by eye.

Underwater vocalisations were recorded during the event using three closely spaced hydrophones mounted in the bow of the ship. The hydrophones had an effective frequency response from 500Hz to 25kHz (± 10dB). The signals were recorded on a Marantz *PMD700* DAT recorder. Acoustic signals were analysed using *Audition* 1.5 (Adobe Corporation) and *Raven* 1.2.1 (Cornell Lab of Ornithology) software.

From the launch, 163 images were taken using a Canon digital 35mm single lense reflex (SLR) camera equipped with an 85-300mm lens; from the helicopter an additional 83 images were taken using a 400mm lens. These images were used to estimate the number of whales present, identify associated animals (defined as animals less than one body length apart in the photos), assign sexes and ages and to match (to the extent possible) biopsy samples with individual animals. The photographs also allowed a qualitative assessment of morphological features (colour patterning, scarring etc.) and presence of barnacles on the dorsal fin. The original photographs are permanently archived at SWFSC, La Jolla, CA.

In order to obtain morphometric measurements, the killer whales and the blue whale calf were photographed from a helicopter equipped with a belly-mounted, large format (126mm) camera (for details of photogrammetric methods see Gilpatrick, 1997; Perryman and Lynn, 1993; Pitman *et al*., 2007). A high resolution, motion-compensating, KA-76 military reconnaissance camera was used that was mounted below the fuselage of a *McDonald-Douglas 500D* helicopter. The photos were taken at a ground speed of 166km h^{-1}, at a height above sea level ranging between 62.6-137.0m. A data acquisition system simultaneously recorded the time and a radar altimeter reading as each photograph was taken. A total of 338 images were taken using this system.

Animals were measured using a computer-based video imaging system (Gilpatrick and Lynn, 1994). Total body length (TL: tip of rostrum to edge of fluke notch), and fluke width were determined only for whales photographed swimming parallel to, and at or near the surface of the water. It has been suggested that, at least for Antarctic killer whale populations, relative fluke width may be a useful taxonomic character (Berzin and Vladimirov, 1983), so fluke-width-to-body-length ratios were calculated whenever possible.

To estimate the precision of our body length measurements, the same methods were used to estimate the length of the 4.9m launch in the water during the event. The launch was photographed six times at altitudes ranging from 130-140m. Estimated lengths averaged 4.9m (range: 4.8-5.0m); the coefficient of variation (CV) was 0.020% and 95% confidence limits of the means (CL) were ± 0.076m. Thus, for a 4.9m target at the sea surface, the variance in the aerial photogrammetric method translated to an estimated error of ± 7.6cm (or ± 1.6%) with a 95% confidence interval.

RESULTS

The event took place on 26 September 2003, at 10°58'N, 88°40'W, 230km off the Pacific coast of Nicaragua (Fig. 1). The water depth was approximately 3,000m, the sea surface temperature was 28°C, the wind speed was 5kt and sighting conditions were excellent. The animals were initially sighted at 11:26 Local Mean Time. They were closed in on and at 11:45 a launch was deployed. The next 2h 25min were spent recording their vocalisations, collecting biopsy samples and photographing individual whales. The launch returned to the vessel at 14:10. A helicopter onboard the ship was launched at 12:02 to take aerial photographs and observe from the air; it returned to the ship at 13:29.

The initial sighting was a series of large blows over the horizon. Due to the close proximity to the Costa Rica Dome (see Discussion), an area where blue whales have been regularly encountered over the years (e.g. Reilly and Thayer, 1990), see also Fig.1, it was immediately suspected they were indeed blue whales. The ship was turned to approach the animals, but found only killer whales and the carcass of a blue whale calf. It was therefore inferred that at least one adult blue whale had been present but had left the area after the calf had been killed.

When closing in, it was immediately clear that a kill had just taken place: the whales were milling and diving in an area of a large and widening oil slick at the surface and scavenging seabirds were just starting to gather. (Over the course of the observations, the birds that came to feed in the slick ultimately included an estimated 100 Galapagos storm-petrels (*Oceanodroma tethys*), 7 Markham's storm-petrels (*O. markhami*) and 10 Tahiti petrels (*Pseudobulweria*

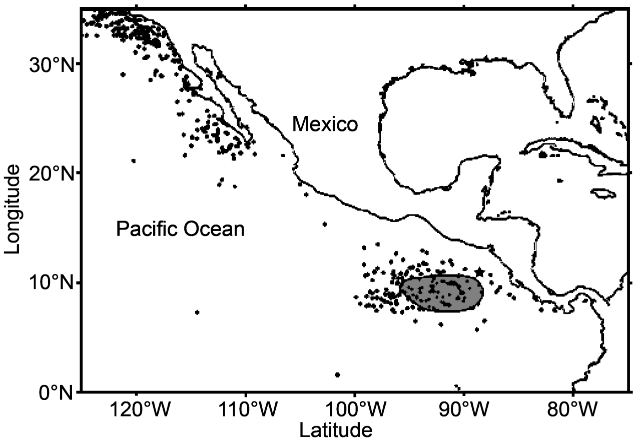

Fig. 1. The eastern tropical Pacific Ocean showing the nominal location of the Costa Rica Dome (shaded area) during the month of September (from Fiedler, 2002; see text). Also shown are sightings of blue whales from research vessels and fisheries observers on tuna purse seine vessels (diamonds, from Ballance *et al*., 2006), and the location where killer whales were observed preying upon a blue whale calf in September 2003 (star).

rostrata)). When the launch was deployed, it went directly to the slick where personnel onboard retrieved a 2.5cm cube of cetacean skin and blubber dropped by a foraging storm-petrel. The sample appeared (and was later genetically confirmed) to be from a blue whale. It was very fresh and still seeping blood.

During the first 10min of the launch, two different killer whales swam by at different times within 5m; they both rolled over on their side underwater and appeared to investigate the launch. Throughout the remainder of the sighting however, all of the killer whales were less inquisitive and increasingly evasive, apparently in response to the launch moving back and forth between subgroups for photographs and biopsy samples. The presence of the helicopter may have also altered the behaviour and groupings of the animals and these factors must be considered in the behavioural descriptions presented below.

From the water surface, other than the oil slick, bird flock and the small chunk of flesh retrieved, there was little evidence that a predation event had taken place. People in the launch did not actually see the blue whale carcass during the first 2h on the water, and observers on the research vessel did not see it at all even though they were less than 1km away and observing through the high-powered binoculars the entire time. Personnel in the helicopter, however, radioed back almost immediately after they were airborne that one of the adult male killer whales was carrying what appeared to be an intact, freshly-killed blue whale calf and that other whales were attempting to feed on it.

Two adult male killer whales took turns in carrying the carcass, but the larger of the two (and the largest animal photographed; see below), carried it most of the time, using his mouth and flippers. A young calf consistently observed with the larger male was often seen trying to feed on the carcass as they travelled together. The larger male released the carcass on several occasions apparently when the launch got too close and each time, after the carcass sank out of sight, another animal that appeared to be an adult female used its rostrum to push it back to the surface where the other whales sometimes took turns feeding on it. On one occasion, at a location where a group had just been at the surface with the carcass, the launch passed over a long piece of blue whale skin and blubber, approximately 2m long and 1m wide that had been stripped off the carcass.

There was evidence of recent aggressive interactions among the killer whales present. At least three photographed individuals had very fresh killer whale tooth rake marks on them. For example, a sub-adult male with the group that was carrying the carcass had tooth rake marks on both his flanks behind the dorsal fin that showed exposed, red flesh; the large male carrying the carcass also had fresh red rake marks on his head and flanks and another female also had red rake marks (Fig. 2d). In addition to fresh rake marks, almost all of the animals had old rake marks (quite heavy on two calves), suggesting that agonistic interactions occurred regularly.

It was not until after about 2h of observation that personnel in the launch finally saw the carcass at the surface, when the blue whale's flukes and, shortly afterward, its head were lifted out of the water. Several minutes later as the carcass was being dragged along the surface, the full length of the blue whale's belly was exposed; there were no visible signs of damage to the animal at either time. Shortly afterwards, observations were terminated and the launch returned to the ship.

Group size, composition and associations

Although the sighting conditions were excellent, it was difficult to estimate the number of killer whales present. They were in separate groups, diving for up to 5min at a time and being evasive. Based on an analysis of all the photographs taken from both the launch and the helicopter, it was estimated that there were 19 individuals present including 4 males (3 adults, 1 subadult [a 'sprouter']), 5 adult females with 5 calves, and 5 other females/subadult males. Photographs of eight of the biopsied animals were matched to photographically-identified individuals (one additional biopsy sample was a duplicate), and the gender of each was genetically determined. From this it was established that two individuals in the 'females/subadult males' category were in fact females.

Throughout most of the sighting the killer whales formed two main groups: a smaller group immediately associated with the blue whale carcass, and a larger group that was usually separated by 200-300m, but moving with the other group. The larger group comprised about eleven individuals, including five cow-calf pairs, and one subadult male or female.

The carcass group comprised approximately seven animals, including 3 males (2 adults and 1 sub-adult), 2 adult (or near adult) females and 2 subadult males/females. This group included the largest male, who was carrying the carcass throughout most of the sighting. These two groups were fairly fluid however and did not appear to represent stable associations during the 2.5h of observations. For example, at least one cow-calf pair initially photographed with the larger group, later joined the carcass group and the calf was photographed from the air several times attempting to feed on the carcass.

There was also a lone adult male that briefly associated with each of the groups during the observation period, but most of the time was by himself on the periphery of both groups.

The distribution of the different haplotypes among the killer whales also indicated that there was probably mixing between the two groups. Two different haplotypes (A and B) were identified among the biopsy samples (see below) and both were present in both groups. For example, the large

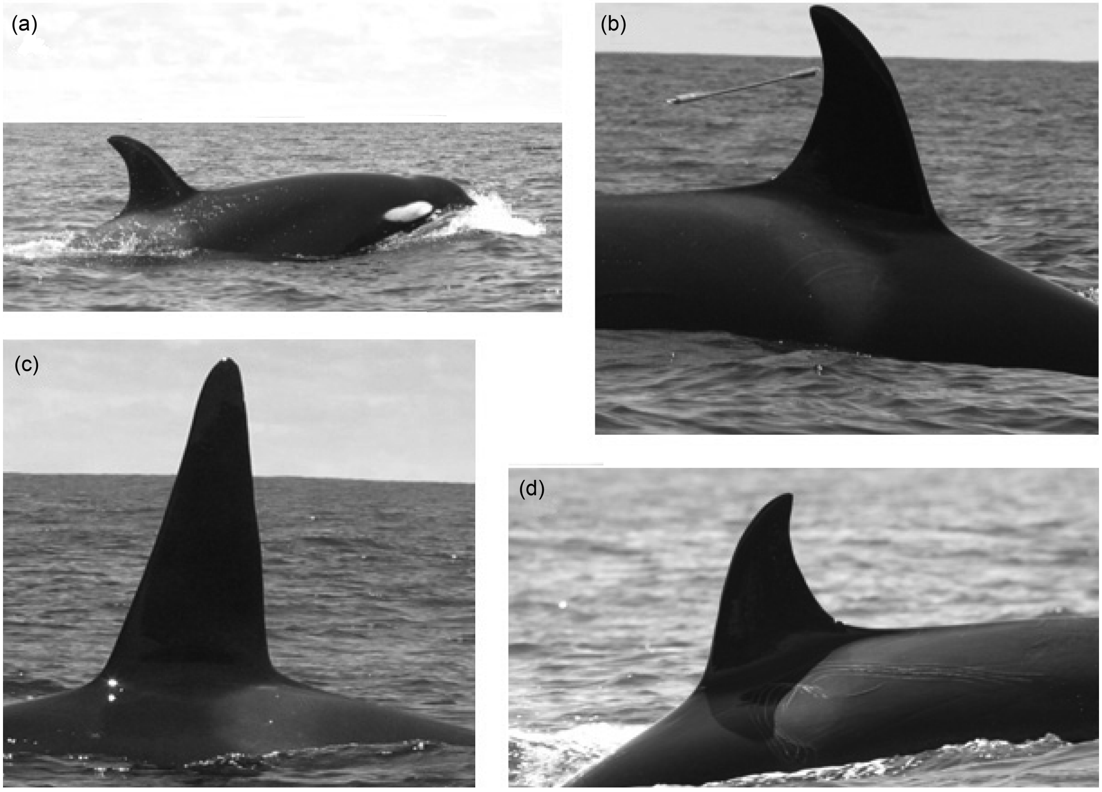

Fig. 2. Killer whales photographed on 26 September 2003, at 10°58'N, 88°40'W, 230km west of the Pacific coast of Nicaragua. (a) Adult female showing eyepatch similar to North Pacific killer whales along with no evident cape pattern; (b) same adult female as in 2a. showing inconspicuous saddle patch and dorsal fin without nicks; biopsy sample was just taken from saddle area; (c) adult male with inconspicuous saddle patch; (d) female showing nick at the base of the dorsal fin, inconspicuous saddle patch and fresh rake marks (with exposed red flesh in colour photographs). Genders were all confirmed genetically; photographs by H. Fearnbach.

male that carried the carcass during the sighting was Haplotype B, while the adult male that accompanied him and also carried the carcass on occasion was Haplotype A. The larger group included an adult female (with a calf) that was Haplotype A, and another female (also with a calf) that was Haplotype B. In addition, the female (with a calf) that moved between the two groups was Haplotype A, as was the adult male that stayed on the periphery throughout most of the sighting.

Morphometrics and morphology

From the photogrammetry, total length (TL) measurements were obtained for 17 different animals. TL for two adult males were 6.9 and 8.0m, respectively, the latter being the largest animal in the group. TL for 10 animals of unidentified sex and age (i.e. females or young males) averaged 5.9m (range: 5.4-6.3m); TL for 5 adult females (i.e. with calves) averaged 5.8m (range: 5.4- 6.1m); TL for 5 calves averaged 3.8m (range: 3.2-4.7m).

Fluke width (FW) could be determined for only two females (TL=5.8 and 6.0m); these measured 1.5m and 1.7m, respectively, which gave FW/TL ratios of 0.26 and 0.28, respectively.

The overall colour patterning and body shape was similar to that of killer whales in the North Pacific, but with at least one noticeable difference. The eyepatch was similar to other North Pacific killer whales and Type A Antarctic killer whales (Pitman and Ensor, 2003), i.e. medium-sized and oriented parallel to the body axis and no dorsal cape was evident (Fig. 2a). There were relatively few nicks on the trailing edge of the dorsal fins of any of the animals photographed: nine had small nicks; two animals had moderate to large notches; and the remaining eight were unmarked (Fig. 2b-d).

A distinctive feature of these animals was the inconspicuousness of the saddle (the pale area on the back, behind the dorsal fin); it was faint in most individuals (Fig. 2b-d) and almost absent in others. No 'open' saddles were seen (i.e. showing a dark incursion into the saddle), characteristic of resident killer whales in the eastern and central North Pacific (Baird and Stacey, 1988). Although this feature could have been overlooked in some cases because of the faintness of the saddle. At least four individuals had barnacles (presumably *Xenobalanus globicipitis*; Kane *et al*., 2006) attached to the trailing edges of their dorsal fins, however the majority did not.

Aerial photogrammetry was also used to estimate that the length of the blue whale calf was approximately 6m. This estimate was less precise than for the killer whales because the carcass was usually at least 1-2m underwater and was never photographed parallel to the surface (the tail or head was usually hanging down).

Population identity and genetics

The mitochondrial control region sequences were 989bp long. The 10 different individuals sampled represented two distinct haplotypes: one (A) being present in eight samples and the other (B) in two (GenBank accession numbers: DQ851147 and DQ851148, respectively). These haplotypes differed from each other by a single transitional base substitution and have not been previously published for killer whales. These sequences are most similar to published northern and southern *resident* and *offshore* haplotypes (Hoelzel *et al*., 2002; Zerbini *et al*., 2007); (GenBank accession numbers: DQ399077-DQ399079). Although this is the first time we have recorded Haplotype B anywhere, we have recorded Haplotype A from other killer whales sampled off Mexico and Panama (SWFSC, unpublished data).

Acoustics

A total of 194 social signals were analysed from the 31.5min of recording. Of these, 189 were pulsed signals and 5 were whistles. Pulsed signals were dominated by a single highly-repetitive discrete (or stereotyped) call, which comprised 68% of the total signals. The remaining 60 pulsed signals were variable in structure and non-repetitive (19%), or could not be identified due to poor signal-to-noise ratio (13%). The single discrete call, shown in Fig. 3, was a two-part signal with a total average duration of 0.88s. (±SE 0.02, *n*=34 calls). The first of the two parts was typically slightly shorter than the second (mean duration 0.37s (±SE 0.02) versus 0.51 (±SE 0.02)). The first part of the signal had a gradually increasing pitch that peaked at a mean sideband interval of 1779Hz (±SE 18.2), before sharply dropping prior to the start of the second part, which had a relatively constant but lower pitch (mean sideband interval 876Hz, ±SE 10.3). The frequency structure of the five whistles analysed was generally similar to narrow-band whistles described for killer whales elsewhere (e.g. Reisch *et al*., 2005). Too few whistles were recorded to determine if these were stereotyped in structure.

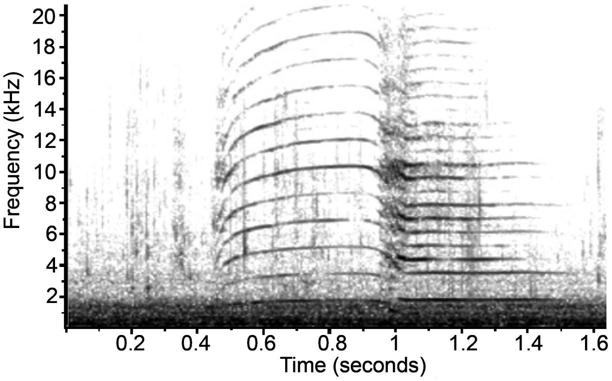

Fig. 3. Spectrogram of discrete call type recorded from killer whales encountered on 26 September 2003, at 10°58'N, 88°40'W, 230km west of the Pacific coast of Nicaragua. The call was digitised at a 44.1kHz sampling rate, and the spectrogram was created with a 512 point FFT, 50% frame overlap and hamming filter.

DISCUSSION

Although killer whales are found in all of the world's oceans, they are relatively uncommon in the tropics (Dahlheim and Heyning, 1999; Forney and Wade, 2006), including the ETP (Wade and Gerrodette, 1993); (Pitman, pers. obs.). Group size in the ETP is also generally small. For example, mean school size for killer whales during the surveys reported here (Wade and Gerrodette, 1993) was 5.4 (CV=0.09, *n*=57); which is similar to Hawaiian waters (Baird *et al*., 2006) where mean group size was 4.2 (SD=2.1, *n*=21). The fact that there were an estimated 19 whales present in the event witnessed, suggests that two or more groups were almost certainly involved. Separate groups may have temporarily associated to assist in the killing of the calf, or possibly another group (or groups) may have appeared after the kill. The presence of fresh tooth rake marks on several individuals, young and adults alike, suggests that there may have been some aggressive, perhaps inter-group, interactions occurring.

The colour patterning of these killer whales was similar to North Pacific killer whales except for their relatively inconspicuous saddle patch. Hawaiian killer whales also show faint saddle patches (Baird *et al*., 2006), and this seems to be typical for tropical killer whales in general, including the tropical Atlantic and Indian oceans (Pitman, pers. obs.). Hawaiian killer whales also had oval scars visible mainly on their saddle patches, which were presumably the healed bites of cookiecutter sharks (*Isistius* sp.; Baird *et al*., 2006), whereas among the numerous photographs of the ETP killer whales, there were few or no bites present. ETP cetaceans in general have relatively few cookiecutter shark bites on them compared, for example, to those in the western Atlantic and western Pacific ocean basins (Pitman, pers. obs.).

The single, discrete call recorded during this encounter was typical of killer whale calls in other regions, i.e. it had a pulsed structure, was less than 1s in duration and was subdivided into distinct parts or segments (Deecke *et al*., 2005; Ford, 1987; Ford, 1991; Strager, 1995; Yurk *et al*., 2002). Groups of killer whales generally produce repertoires of 5-15 different call types, each of which is aurally and spectrographically distinct. These repertoires are often specific to particular matrilineal groups (Ford, 1991; Strager, 1995), although mammal-eating killer whales in British Columbia and southeastern Alaska tend to have population-specific call repertoires (Deecke *et al*., 2005). Although consistent in general structure to killer whale calls elsewhere, the single call type recorded during this encounter had a two-part pitch contour that appears distinct in fine-scale time and frequency structure from killer whale calls recorded and catalogued in other areas of the eastern North Pacific (Deecke *et al*., 2005; Ford, 1987; Yurk *et al*., 2002) and elsewhere (e.g. north Atlantic, Moore *et al*., 1988; Strager, 1995). It is highly likely that the whales recorded during this encounter had additional calls in their repertoire, but did not produce these during the short recording session.

To date, there have been no recorded long-term associations between two different haplotypes within a single group of killer whales among well-studied matrilineal pods in the Northeast Pacific (Barrett-Lennard, 2000; Hoelzel *et al*., 1998). However, short-term associations between different haplotypes have been recorded; for example, groups of killer whales with both Northern and Southern *resident* haplotypes are regularly encountered in Prince William Sound and the fjords of Kenai Peninsula, Alaska (Yurk *et al*., 2002). However, genetic sampling of entire pods of killer whales in other areas of the world is rare, so it is not known how prevalent haplotype mixing is for this species as a whole. In the event described, it is likely that at least two (and perhaps more) separate groups of killer whales temporarily came together for feeding and perhaps socialising. If so, and if the different haplotypes represent animals from different groups, it is unclear what, if anything could prevent interbreeding between the groups we sampled because individuals of both haplotypes freely associated during the episode.

Outside of the northeast Pacific, haplotype similarity is not necessarily a consistent indicator of ecotypic prey specialisation in killer whales. For example, the haplotype of an apparent mammal-eating killer whale in Hawaii was most similar to *transient* (mammal-eating) killer whales in

Alaska (Baird *et al*., 2006), while the two different haplotypes from the event described here differed by one and two base pairs, respectively, from *resident* (fish-eating) killer whales in the Northeast Pacific. More sampling is necessary to determine the relationship between ecotypic and haplotypic variation among killer whale populations and how these relate to killer whale evolution and, perhaps, speciation on a global scale.

Although killer whales are known predators of blue whales (Tarpy, 1979), this is the first reported incidence of a calf taken in the tropics, which raises some interesting questions. The event described here occurred within an oceanographic area known as the Costa Rica Dome (CRD, Fig. 1). The CRD is a 300-500km^2, semi-permanent, hydrographic (vs topographic) feature in the far eastern ETP, with markedly enhanced productivity due to wind- and current-induced upwelling (Fiedler, 2002). It is also the only area in the ETP south of Baja California, Mexico, and north of the Peru Current where blue whales regularly occur (Fig. 1), and it has been suggested that individuals from either Northern or Southern Hemisphere populations may migrate there to feed, to breed or both (Reilly and Thayer, 1990). Blue whale calves measure 6-7m at birth (Sears, 2002); with an estimated length of 6m, it is therefore thought that the blue whale calf seen was born at the CRD. Although it has been shown that at least some Californian blue whales migrate to the CRD during their calving/breeding season (Mate *et al*., 1999), this observation is the first record, to our knowledge, of a neonatal blue whale at the CRD. If blue whales do regularly migrate to the CRD for calving, it could be a predictable feeding area for mammal-eating killer whales in the ETP.

Many baleen whale species undertake extensive seasonal migrations to lower latitudes to mate and give birth, but to date there has been no widely accepted explanation for this behaviour. Corkeron and Connor (1999) postulated that this migration could reduce the risk of killer whale predation on calves (Jones and Swartz, 1984; Pitman *et al*., 2001). They noted that killer whales occur much more commonly in higher latitudes than in the tropics (Forney and Wade, 2006), and that they are the main (and perhaps only) predators of large whale calves. This idea has met with some pointed criticism (Clapham, 2001) and it is also clear from our observation and those of others (e.g. Flórez-González *et al*., 1994), that even in the tropics, calves of large whales are not completely safe from killer whales. However, as an anti-predator strategy, migration does not have to be effective *all* of the time in order to confer evolutionary benefits (Connor and Corkeron, 2001). Migrations that produce even a modest reduction in the number of killer whale encounters (and, therefore, calf mortalities) could significantly increase reproductive success and individual fitness. This is especially true for large baleen whales with their very low reproductive output.

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REFERENCES

Baird, R.W., McSweeney, D., Bane, C., Barlow, J., Salden, D., Antoine, L.K., LeDuc, R.G. and Webster, D.L. 2006. Killer whales in Hawaiian waters: information on population identity and feeding habits. *Pac. Sci*. 60: 523-30.

Baird, R.W. and Stacey, P.J. 1988. Variation in saddle patch pigmentation in populations of killer whales (*Orcinus orca*) from British Columbia, Alaska and Washington State. *Can. J. Zool*. 66(11): 2582-85.

Ballance, L.T., Pitman, R.L., Hewitt, R.P., Siniff, D., Trivelpiece, W.Z., Clapham, P.J. and Brownell Jr, R.L. 2006. pp.215-30. *In*: Estes, J.A., DeMaster, D.P., Doak, D.F., Williams, T.M. and Brownell, R.L. (eds). *Whales, Whaling and Ocean Ecosystems*. University of California Press, Berkeley, California. 402pp.

Barrett-Lennard, L. and Heise, K. 2006. The natural history and ecology of killer whales. pp.163-73. *In*: Estes, J.A., DeMaster, D.P., Doak, D.F., Williams, T.M. and Brownell Jr, R.L. (eds). *Whales, Whaling and Ocean Ecosystems*. University of California, Berkeley, California. 402pp.

Barrett-Lennard, L.G. 2000. Population stucture and mating patterns of killer whales as revealed by DNA analysis. Thesis University of British Columbia, Vancouver, BC. 97pp.

Berzin, A.A. and Vladimirov, V.L. 1983. Novyi vid kosatki (Cetacea, Delphinidae) iz vod Antarktiki. *Zool. Zh*. 62(2): 287-95. [Translated in 1984 as "A new species of killer whale (Cetacea, Delphinidae) from Antarctic waters" by S. Pearson, National Marine Mammal Laboratory, Seattle, WA 98115, USA].

Clapham, P.J. 2001. Why do baleen whales migrate? A response to Corkeron and Connor. *Mar. Mammal Sci*. 17: 432-36.

Connor, R.S. and Corkeron, P. 2001. Predation past and present: killer whales and baleen whale migration. *Mar. Mammal Sci*. 17: 436-39.

Corkeron, P. and Connor, R.S. 1999. Why do baleen whales migrate? *Mar. Mammal Sci*. 15: 1228-45.

Dahlheim, M.E. and Heyning, J.E. 1999. Killer whale *Orcinus orca* (Linnaeus, 1758). pp.281-322. *In*: Ridgway, S.H. and Harrison, R.J. (eds). *Handbook of Marine Mammals*. Academic Press, London. v-xix+486pp.

Deecke, V., Ford, J.K.B. and Slater, P.J.B. 2005. The vocal bevaiour of mammal-eating killer whales: communicating with costly calls. *Anim. Behav*. 69: 395-405.

Fiedler, P.C. 2002. The annual cycle and biological effects of the Costa Rica Dome. *Deep Sea Research* 49: 321-38.

Flórez-González, L., Capella, J.J. and Rosenbaum, H.C. 1994. Attack of killer whales (*Orcinus orca*) on humpback whales (*Megaptera novaeangliae*) on a South American Pacific breeding ground. *Mar. Mammal Sci*. 10(2): 218-22.

Ford, J.K.B. 1987. A catalogue of underwater calls produced by killer whales (*Orcinus orca*) in British Columbia. *Can. Data Rept. Fish. Aquatic Sci*. 633: 165pp.

Ford, J.K.B. 1991. Vocal traditions among resident killer whales (*Orcinus orca*) in coastal waters of British Columbia. *Can. J. Zool*. 69(6): 1454-83.

Forney, K.A. and Wade, P.R. 2006. Worldwide distribution and abundance of killer whales. pp.145-62. *In*: Estes, J.A., Brownell, R.L., DeMaster, D.P., Doak, D.F. and Williams, T.M. (eds). *Whales, Whaling and Ocean Ecosystems*. University of California Press. 418pp.

Gilpatrick, J.W., Jr. 1997. Calibration of radar altimeter readings used in aerial photogrammetry of eastern tropical Pacific dolphins, 1992 and 1993. NOAA Tech. Memo. NOAA-TM-NMFS-SWFSC-226 [Available from *swfsc.noaa.gov/publications*].

Gilpatrick, J.W. and Lynn, M.S. 1994. A test of two photogrammetric measuring instruments used to determine dolphin lengths from vertical aerial photographs. NOAA Tech. Memo. NOAA-NMFS-SWFSC-196. [Available from *swfsc.noaa.gov/publications*].

Heise, K., Barrett-Lennard, L., Saulitis, E., Matkin, C. and Bain, D. 2003. Examining the evidence for killer whale predation on Steller sea lions in British Columbia. *Aquat. Mamm*. 29: 325-34.

Hoelzel, A.R., Dahlheim, M.E. and Stern, S.J. 1998. Low genetic variability among killer whales (*Orcinus orca*) in the eastern North Pacific and genetic differentiation between foraging specialists. *J. Hered*. 89: 121-28.

Hoelzel, A.R., Natoli, A., Dahlheim, M.E., Olavarría, C., Baird, R.W. and Black, N.A. 2002. Low worldwide genetic diversity in the killer whale (*Orcinus orca*): implications for demographic history. *Proc. R. Soc. Lond. Ser. B*. 269: 1467-73.

Jackson, A., Gerrodette, T., Chivers, S., Lynn, M., Olson, P. and Rankin, S. 2004. Marine mammal data collected during a survey in the eastern tropical Pacific Ocean aboard the NOAA ships *McArthur* and *David Starr Jordan*, July 29-December 10, 2003. *NOAA Technical Memorandum NMFS* NOAA-TM-NMFS-SWFSC-366. [Available from *http://swfsc.noaa.gov/publications/TM/SWFSC/NOAA-TM-NMFS-SWFSC-366.pdf*].

Jones, I.M. 2006. A northeast Pacific offshore killer whale (*Orcinus orca*) feeding on a Pacific halibut (*Hippoglossus stenolepis*). *Mar. Mammal Sci*. 22: 198-200.

Jones, M.L. and Swartz, S.L. 1984. Demography and phenology of gray whales and evaluation of whale-watching activities in Laguna San Ignacio, Baja California Sur, Mexico. pp.309-74. *In*: Jones, M.L., Swartz, S.L. and Leatherwood, S. (eds). *The Gray Whale, Eschrichtius robustus*. Academic Press, Inc., Orlando, Florida. xxiv+600pp.

Kane, E., Olson, P. and Gerrodette, T. 2006. The commensal barnacle *Xenobalanus globicipitis* Steenstrup, 1851 (Crustacea: Cirripedia) and its relationship to cetaceans in the eastern tropical Pacific. *NOAA NMFS Admin Report* LJ-06-03. Available from NOAA/NMFS Southwest Fisheries Science Center, 8604 La Jolla Shores Drive, La Jolla, California 92037, USA.

Mate, B.R., Lagerquist, B.A. and Calambokidis, J. 1999. Movements of North Pacific blue whales during the feeding season off Southern California and their southern fall migration. *Mar. Mammal Sci*. 15(4): 1246-57.

Moore, S.E., Francine, J.K., Bowles, A.E. and Ford, J.K.B. 1988. Analysis of calls of killer whales, *Orcinus orca,* from Iceland and Norway. *Rit Fisk*. 11: 225-50.

Perryman, W.L. and Lynn, M.S. 1993. Identification of geographic forms of common dolphin (*Delphinus delphis*) from aerial photogrammetry. *Mar. Mammal Sci*. 9(2): 119-37.

Pitman, R., Balance, L.T., Mesnick, M.L. and Chivers, S. 2001. Killer whale predation on sperm whales: observations and implications. *Mar. Mammal Sci*. 17: 494-507.

Pitman, R.L. and Ensor, P. 2003. Three forms of killer whales (*Orcinus orca*) in Antarctic waters. *J. Cetacean Res. Manage*. 5(2): 131-39.

Pitman, R.L., Perryman, W.L., LeRoi, D. and Eilers, E. 2007. A dwarf form of killer whale in Antarctica. *J. Mammal*. 88(1): 43-48.

Reilly, S.B. and Thayer, V.G. 1990. Blue whale (*Balaenoptera musculus*) distribution in the eastern tropical Pacific. *Mar. Mammal Sci*. 6(4): 265-77.

Reisch, R.L., Ford, J.K.B. and Thomsen, F. 2005. Stability and group-specificity of stereotyped whistles in resident killer whales, *Orcinus orca*, off British Columbia. *Anim. Behav*. 71: 79-93.

Rice, D.W. 1998. *Marine Mammals of the World. Systematics and Distribution. Special Publication No. 4*. The Society for Marine Mammalogy, Allen Press Inc., Lawrence, Kansas. v-ix+231pp.

Rosel, P.E., Haygood, M.G. and Perrin, W.F. 1995. Phylogenetic relationships among true porpoises (Cetacea:Phocoenidae). *Mol. Phylogenet. Evol*. 4: 463-74.

Sears, R. 2002. Blue whale (*Balaenoptera musculus*). pp.112-16. *In*: Perrin, W.F., Wursig, B. and Thewissen, G.M. (eds). *Encyclopedia of Marine Mammals*. Academic Press, New York. 1414pp.

Strager, H. 1995. Pod-specific call repertoires and compound calls of killer whales, *Orcinus orca* Linnaeus, 1758, in the waters of northern Norway. *Can. J. Zool*. 73: 1037-47.

Tarpy, C. 1979. Killer whale attack! *Natl. Geogr*. 155: 542-45.

Wade, P.R. and Gerrodette, T. 1993. Estimates of cetacean abundance and distribution in the eastern tropical Pacific. *Rep. int. Whal. Commn* 43: 477-93.

Yurk, H., Barrett-Lennard, L., Ford, J.K.B. and Matkin, C. 2002. Cultural transmission with maternal lineages: vocal clans in resident killer whales in southern Alaska. *Anim. Behav*. 63: 1103-19.

Zerbini, A.N., Waite, J.M., Durban, J.W., LeDuc, R.G., Dahlheim, M. and Wade, P.R. 2007. Estimating abundance of killer whales in the nearshore waters of Alaska and Aleutian Islands using line transect sampling. *Mar. Biol*. 150(5): 1033-48.

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The voluntary code of conduct for dolphin watching in Port Stephens, Australia: is self-regulation an effective management tool?

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ABSTRACT

In the absence of guidelines or government regulation for a rapidly expanding industry, dolphin watching operators in Port Stephens, New South Wales, Australia, formulated and adopted a voluntary code of conduct in 1996. This code was designed to reduce perceived pressures on dolphins and was updated to conform to the Australian National Guidelines for Cetacean Observation when they were released in 2000. Compliance to this code of conduct was assessed in a shore-based survey over the austral summer of 2002/03. Operator compliance was generally high for: number of dolphin watching boats per dolphin school; time spent by individual operators with dolphins; method of approach to dolphins; and frequency of cruises conducted per day. However, operators did not discriminate between dolphin schools containing calves and those that did not (equating to a breach of the national guidelines) and three of nine regular operators committed most breaches of the code, particularly with regard to boat-handling around dolphins and frequency of cruises conducted per day. The code's aim in reducing exposure of dolphins to boats was not achieved as dolphin schools were subject to consecutive approaches by numerous boats and interactions also involved boats to which the code did not apply. This voluntary code is thus of limited value without revision, education and enforcement. The inability of a voluntary code to manage the number of operators and other watercraft highlights the need for management alternatives that will increase compliance by all users of the waterways. Furthermore, widespread assessments of compliance are necessary, particularly where assessments of the effects of cetacean-based tourism are being conducted. To determine whether identified impacts are a result of inappropriate management strategies, or non-compliance with suitable management, requires that management strategies are tested while simultaneously testing or ensuring compliance.

KEYWORDS: INDO-PACIFIC BOTTLENOSE DOLPHIN; REGULATIONS; SURVEY–SHORE-BASED; SUSTAINABILITY; WHALEWATCHING; SOUTHERN HEMISPHERE; AUSTRALASIA

INTRODUCTION

Tourism focussing on cetaceans boomed in the 1990s, with almost 100 countries engaging in cetacean-based tourism by the year 2000 (Hoyt, 2001). Dolphin watching represents a growing portion of this industry and the activity ranges from the smallest species in remote locations (e.g. Hector's dolphins (*Cephalorhynchus hectori*) in Porpoise Bay, New Zealand; Bejder *et al*., 1999) to the largest delphinids in busy waterways (killer whales (*Orcinus orca*) in Johnstone Strait, Canada; Williams *et al*., 2002). Bottlenose dolphins (*Tursiops* spp.) have become popular targets for dolphin watching operations in many coastal locations around the world (Hoyt, 2001; Janik and Thompson, 1996; Lusseau and Higham, 2004). They have a sporadic distribution around the Australian coastline and there are at least seven sites (Eden, Merimbula, Jervis Bay, Port Stephens, Forster, Port Macquarie and Coffs Harbour) that offer boat-based tours to observe and interact with Indo-Pacific bottlenose dolphins (*T. aduncus*) along the New South Wales (NSW) coast alone (Gill and Burke, 1999).

Concerns regarding potential impacts on targeted cetacean populations from tourism growth have been raised for many years (e.g. IFAW *et al*., 1995). A number of studies have found that boating around bottlenose dolphins results in short-term changes in their activities, including: swimming speeds; respiration rates; and behavioural states (Allen, 2005; Constantine *et al*., 2004; Nowacek *et al*., 2001). While long-term consequences of repeated disturbance from tourism remain for the most part unproven, research in New Zealand has indicated significantly altered residency patterns and behavioural budgets as a result of tour boat activity (Lusseau, 2003; 2004; 2005). Another recent study using long-term sighting records in Western Australia has detected declines in the number of dolphins using a tourism impacted area (Bejder *et al*., 2006). These studies report on biologically significant impacts that make the sustainability of local eco-tourism questionable (Lusseau *et al*., 2006), with the Scientific Committee of the International Whaling Commission (IWC) agreeing 'there is new compelling evidence that the fitness of individual odontocetes repeatedly exposed to whalewatching vessel traffic can be compromised and that this can lead to population level effects' (IWC, 2006).

The management of cetacean-based tourism around the world currently ranges from government regulation, to a variety of guidelines and codes of conduct, to no management whatsoever. This variability in management regimes has been described as 'haphazard' and 'highly fragmented' (Garrod and Fennell, 2004; Gjerdalen and Williams, 2000). In Australia, State wildlife government agencies are responsible for the protection of marine mammals in State waters (i.e. to 3 n.miles offshore), including the management of any industry or activity that may impact on these animals. Marine mammals are protected in NSW waters under the National Parks and Wildlife Act, 1974. Several draft bills have been formulated in recent years (e.g. National Parks and Wildlife

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Management (Conservation of Marine Mammals) Bill, 2002), with an amended regulation released in 2004 being passed later in 2006 (National Parks and Wildlife Amendment (Marine Mammals) Regulation). Nevertheless, outside marine protected areas there remains no licensing system to monitor commercial cetacean-based tourism activities in NSW waters. Monitoring the effectiveness of new regulations would seem to be a priority given the growth of the industry in NSW, reportedly undergoing a remarkable 37% per annum increase from 1998 to 2003 (IFAW, 2004).

Dolphin watching in Port Stephens is a driving force behind the growth of the industry in NSW. Two boats began conducting dedicated dolphin watching tours in Port Stephens in early 1991 and there have since been up to 17 tour boats, around half of which run multiple, daily tours on a year-round basis. Dolphin watching, and now whalewatching, bring a substantive portion of the tourist influx to the area. Figures from 2001-03 for example, indicated sustained increases in visitation for the purposes of dolphin/whale watching, despite regional and global events making this a difficult period for tourism (Bureau of Tourism Research, 2003; 2004). Over 200,000 dolphin and whalewatching tourists injected more than 55 million Australian dollars in total expenditure to the central and mid-north NSW coast in 2003 (IFAW, 2004). Port Stephens thus represents a typical site at which a multi-million dollar tourism industry has developed around a resident and/or seasonally visiting population of cetaceans, as has occurred in the Canary Islands, Spain; Hervey Bay, Australia; Kaikoura, New Zealand; Provincetown, USA and Tofino, Canada (Hoyt, 2001).

In addition to commercial dolphin watching boats, around 3,000 recreational boats are registered in Port Stephens each year, with general commercial registrations in the wider area rising 30% to almost 500 boats from 1999 to 2003 (Waterways Authority, 2003). Influxes of up to 300 boats also occur during fishing tournaments. Up to 105 boats have been counted at one time in a systematic scan of the *ca*. 30km^2 study area in eastern Port Stephens (Allen, 2005). The cumulative impacts of an intensive dolphin watching industry, combined with other commercial and recreational activity (including aquaculture, fishing, parasailing, jet-boating, water-skiing and sea-planes) remain almost entirely unquantified in Port Stephens. Due to concerns over the industry's impacts on dolphins, the absence of government regulation and increasing competitiveness and hostility between boat captains, dolphin watching operators formed the Port Stephens Commercial Dolphin Watch Association Inc. (PSCDWA) in 1995. A Code of Conduct (CC) was then developed and adopted in 1996 to reduce perceived pressures on dolphins and facilitate better coordination between operators. The majority of operators in Port Stephens were members of the PSCDWA. Their CC was updated in 2000 to conform to the Australian National Guidelines for Cetacean Observation (AG) and to address a number of management and operational issues (outlined in Table 1).

The CC and AG were the only guidelines by which operators in Port Stephens managed their activities until late 2006. In this study, the CC is assessed in terms of compliance by dolphin watch operators and suitability for minimising impacts on dolphins in Port Stephens, quantifying:

(1) the number of dolphin watching boats interacting (see definitions below) with dolphins;
(2) the duration of interactions between dolphin watching boats and dolphins;
(3) the method of approach and boat-handling around dolphins;
(4) the number of dolphin watch cruises conducted per boat per day; and
(5) the number of dolphin schools approached that contained calves (<1/2 the length of an adult).

MATERIALS AND METHODS

Study site

Port Stephens is a *ca*. 140km^2 estuary located 200km north of Sydney, NSW, Australia. The area observed for the purposes of this study (*ca*. 30km^2) is renowned for regular dolphin sightings and hence the vast majority of dolphin watching activity (Fig. 1). It is relatively shallow for the most part (2-8m), and is dominated by marine processes, having sandy substrate, some rocky outcrops, seagrass beds and a strong tidal influx of oceanic water (Manly Hydraulics Laboratory, 1999). There is also a largely unobstructed view of the eastern port from an elevated, land-based vantage point.

Study subjects

A population of Indo-Pacific bottlenose dolphins inhabits Port Stephens. The wider region is estimated to contain up to 160 individuals, around 90 of which are considered 'resident' and the remainder 'transient' or 'occasional visitors' to Port Stephens (Möller *et al*., 2002).

Observations focussed on dolphin watching boats interacting with dolphin schools as they moved through the study area. A total of 15 boats conducted commercial dolphin watching tours during the study. These boats ranged in capacity from 35 to 296 passengers; 9 boats conducted regular tours and an additional 6 conducted occasional or opportunistic tours. A regular operator was defined as one that conducted a minimum of 25 dolphin watch trips during the study (i.e. a mean of one or more trips per day). Data were gathered on all boats conducting dolphin watching, but analyses were carried out only on those defined as regular operators.

Study methods

Observations were conducted from the roof of the Port Stephens Royal Volunteer Coastal Patrol Building on Nelson Head (32°42'37"S, 152°09'40"E) on a near daily basis from 21 December 2002 to 26 January 2003. The observation period coincided with the peak in tourism activity (i.e. summer holidays) and the hours of observation (09:30-17:30, weather permitting) encompassed CC designated dolphin watching hours (10:00-17:00).

Observers used naked eye, 8×30 binoculars and a 30-45× spotting scope to observe interactions between dolphins and dolphin watching boats. Continuous sampling (Altmann, 1974) of dolphin watching boats commenced when a boat left the marina and continued for the duration of the trip. For each trip the following was recorded:

(1) boat name and trip number for the day;
(2) number of interactions with dolphins per trip (an 'interaction' was defined as a boat making a directed approach to one or more dolphins to within 100m for >1min; distance was estimated using number of boat lengths);
(3) whether an interaction was considered a 'continued interaction', i.e. where a dolphin watching boat began

an interaction with a dolphin school <5mins after departure of another boat from that same school;

(4) duration of each interaction;
(5) maximum number of boats interacting with a dolphin school during each interaction;
(6) method of approach and boat-handling around dolphins (Table 2); and
(7) whether or not the dolphin school contained a young calf (individuals <1/2 the length of an adult and closely associated with an adult).

Data analysis

Analyses were carried out in Microsoft *Excel 2000* and *SigmaStat* for Windows (2.03). Non-parametric tests were used where data did not fulfil assumptions of normality or equal variances (determined by Kolmogorov-Smirnov tests). A chi-squared test was used to assess the difference in proportion of breaches of the CC for number of boats interacting with dolphins under two conditions: dolphin watching boats only; and dolphin watching boats plus recreational boats. A chi-squared test was also used to assess the difference in proportion of dolphin schools approached that contained calves against the proportion of schools that were found not to contain calves (comparison made with the proportion of schools found with/without calves during photographic identification work in the summers of 1999 and 2000). A Friedman analysis of variance by ranks test, a nonparametric analysis performed on a randomised block experimental design (Zar, 1996), was used to compare compliance rankings between all regular operators across all aspects of the CC. Boat names were withheld to maintain the anonymity of individual operators.

RESULTS

Observations were conducted on 27 entire days and six partial days for a total of 238.25h. During this period 716 dolphin watching trips were observed and 947 dolphin-boat

Table 1

PSCDWA approved CC 1996 (updated in 2000). Stipulations highlighted in bold are assessed in this study.

Code issue	Code stipulation
Dolphin contact	**Maximum of two boats with a group at any one time.**
	Maximum of 30min to be spent with a dolphin group.
	Minimum approach distance of 30m to dolphin group.*
Method of approach	Slow approach used when within 300m of a dolphin group.
	Approach from behind or at an angle aft of the group's beam when dolphins are travelling.
	Approach from any angle if the group is milling, foraging or otherwise not travelling in any particular direction.
	When two boats are present they should stand off 30m to either side of a travelling group.
Cruise frequency and operating times	**Maximum of three advertised cruises per boat per day.****
	All interactions with dolphins to occur between 10:00 and 17:00h.
Time sharing	Time sharing should be in order of time of arrival.
	When more than one dolphin group is present, boats should move to another group to minimise time sharing.
Communication	Boats will communicate amongst themselves to assist each other in locating dolphin groups, share information on time sharing, dolphins in the area and operational matters.
	Radio VHF Channel 72 will be used whenever possible.
Information provided to passengers	Provide information on local dolphin population, habitat, protection status and general biology.
	Inform passengers that the PSCDWA have a self imposed Code of Ethics and explain reasons for certain limits.
	Published materials should promote realistic expectations of the experience and dolphin behaviour including a description of the limits placed on distance of approach and time spent with dolphins.
Regulations and legislation	Operators will abide by all Government Regulations and Legislation.

*Operators agreed to adopt the 50m minimum approach distance stipulation specified in the AG (Commonwealth of Australia, 2000), but this was not ratified by written amendment to the CC. **Originally the CC stipulated two cruises per day per operator. This was changed to three cruises per day per operator in 2002 to encourage operators who wanted to run more cruises to remain in the PSDCWA. #Whilst not stipulated in the CC, operators also agreed to abide by the AG in avoiding groups containing newborns.

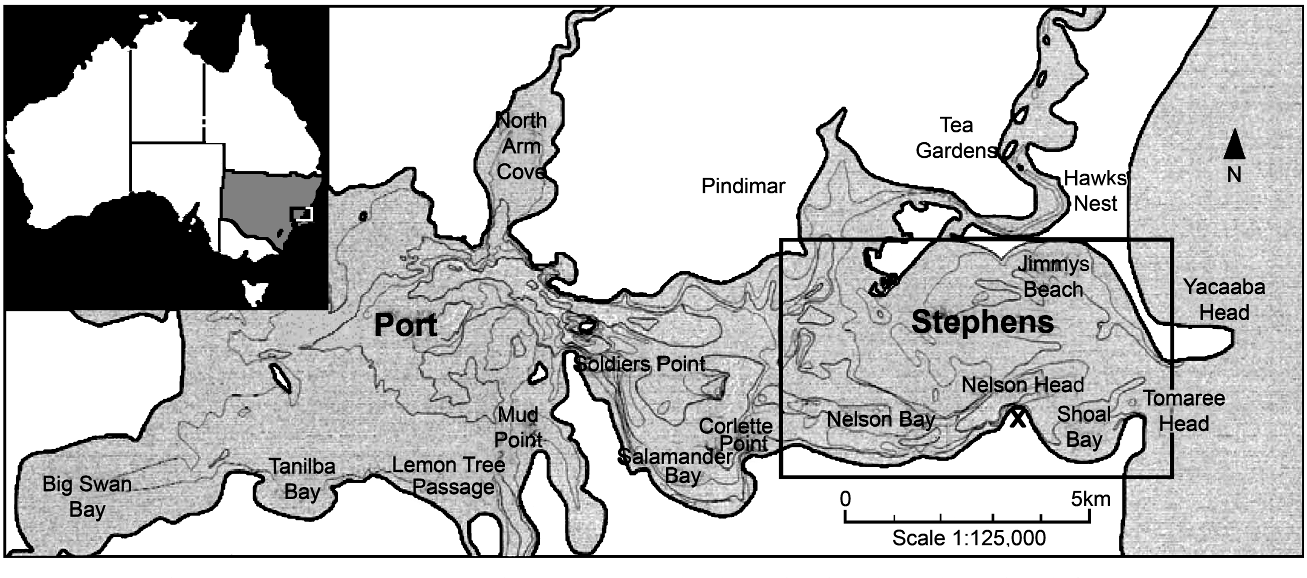

Fig. 1. Port Stephens: on NSW coast (inset map), area under observation (inset box), observation platform (x).

Table 2

Description of methods of approach and boat-handling around dolphins (bold = breach of CC).

Boat activity	Description
Pass-by	Boat steers a straight course, not altering course or stopping to interact with dolphin school.
Stationary	Boat drifts in proximity to dolphin school with motors in neutral or switched off.
Parallel	Boat takes a course parallel to dolphin travel, i.e. maintaining boat abeam of dolphin school.
Follow	Boat follows behind moving dolphin school with dolphins positioned ahead of boat.
Circle	**Boat drives around dolphin school in a circle.**
J-curve	**Boat drives parallel to dolphin school and then arcs in front of dolphin school.**
Through	**Boat drives into and over or through dolphin school.**

interactions were recorded. Boats approached between one and four dolphin schools during each dolphin watching trip (median=1, mean=1.4, SD=0.6) and more than one school was approached on at least 30% of observed trips. The same school was revisited on a single or subsequent trip on at least 19 occasions.

Number of boats in contact with a school

The number of dolphin watching boats within 100m of a particular dolphin school ranged 1-4 at any one time (median=2, mean=1.7, SD=0.7). The number of boats around dolphins ranged 1-10 during interactions that also involved recreational boats (30% of all interactions, median=3, mean=3.6, SD=1.6). The CC limit of two boats within 100m of dolphins was breached during 35% of all interactions (Fig. 2).

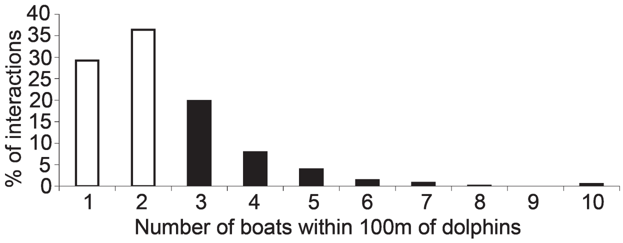

Fig. 2. Number of boats interacting with a dolphin school at any time (all boats pooled; comply with CC limit of 2 boats = no fill, breach CC limit = fill).

During interactions involving dolphin watching boats only (70% of interactions), compliance by individual operators to the CC limit of two boats per dolphin school ranged 71-97%. During interactions involving recreational boats as well as dolphin watching boats, however, compliance by each dolphin watching operator dropped (ranging 6-25%; Fig. 3). For each individual dolphin watching boat, a significantly greater proportion of breaches occurred during interactions involving all boats than during interactions involving dolphin watching boats alone (χ^2 = 42.077, 35.509, 8.514, 51.305, 86.606, 33.726, 45.307, 83.933, 22.047 for b1-b9, respectively, d.f.=1, p<0.001).

Durations of interactions

The durations of 810 complete interactions between regular dolphin watching boats and dolphins were recorded (Fig. 4). 87% of these were within the CC proscribed limit of 30min interaction time with dolphins. Individual dolphin watching operators spent median times of 8-24min with dolphin schools (overall range=1-70min) and compliance levels ranged from 74-98%.

While the issue is not specified in the CC, a total of 91 'continued interactions' were recorded, indicating that a single dolphin school was exposed to at least one dolphin watching boat for periods ranging 10-142min, with a median interaction time of 43min (Fig. 5). Dolphins were continuously exposed to dolphin watching boats for longer than 30min during 76% of recorded continued interactions.

Methods of approach (and boat-handling)

The predominant methods of approach and boat-handling techniques were recorded during 843 dolphin-boat interactions. Methods of approach and boat-handling that breached the CC were observed on 138 (16%) occasions. This represents a minimum count since 'stationary' boats can drift over dolphins, 'parallel' interactions can involve boats approaching to within proscribed limits and 'follow' can constitute an approach from directly behind dolphins (all of which represent breaches of either the CC or AG). Regular operators engaged in boat-handling activity that complied with the CC 88-99% of the time.

Frequency of cruises and hours of interaction

Combined dedicated dolphin watching boats ran a median of 23 trips per day (n=838 total trips, max=47 trips per day). Five boats committed 31 breaches of the CC imposed limit of three trips per day. On 18 occasions dolphin watching boats were observed interacting with dolphins outside the hours recommended by the CC (10:00-17:00). One of these events occurred before 10:00 and 17 after 17:00.

Approaching calves

Newborn animals or young calves were observed in a minimum of 120 (21%) of the 571 interactions in which calf presence or absence was recorded. This is not significantly different from the proportion of schools observed with newborns during boat-based photo-identification surveys at the same time of year in 1999 and 2000 (27 (17%) of 158 schools observed, χ^2 = 3.28, d.f.=1, p=0.07: unpub. data).

Overall compliance

Using all aspects of compliance assessed as 'blocks' and individual boats as 'treatments', the Friedman test revealed a highly significant boat effect (s=5.10, 8 and d.f.=32, p=0.002). Results of multiple pair-wise comparisons at the 5% significance level indicated differences between boats, with three clear groupings: four boats were most compliant; two boats occupied the middle ground; and three boats were consistently least compliant across all aspects of the CC in which compliance was assessed.

DISCUSSION

Is a voluntary Code of Conduct sufficient to ensure compliance in Port Stephens?

In this study, compliance was generally high, but variable between different aspects of the CC and between operators. While operators were informed that compliance would be

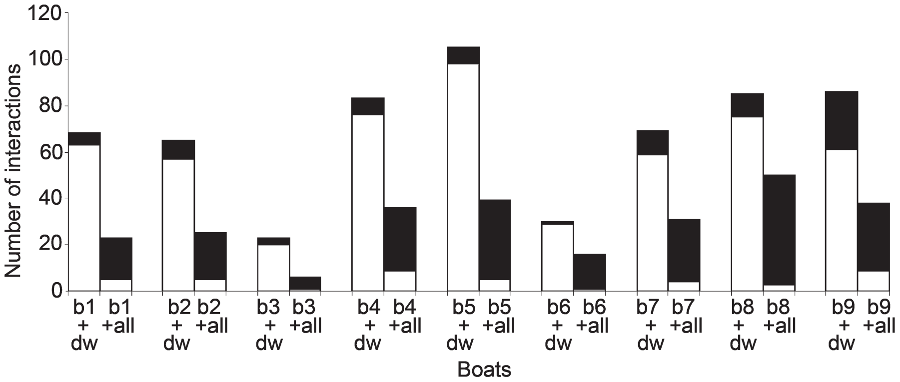

Fig. 3. Number of interactions complying with (no fill) and breaching (fill) the CC limit of 2 boats in contact with a dolphin school at any time under two conditions: dolphin watch boats alone (e.g. b1 + dw) and dolphin watch boats as well as recreational boats and all other boats (e.g. b1 + all).

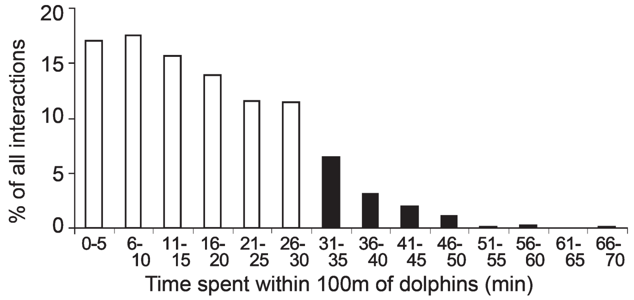

Fig. 4. Compliance with (no fill) and breaches of (fill) the 30min interaction time limit recommended by the CC (n=810).

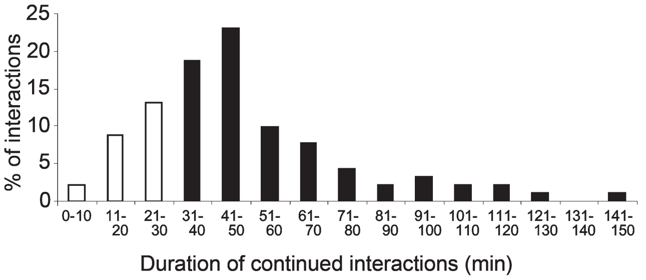

Fig. 5. Duration dolphins were exposed to dolphin watch boats during continued interactions (no fill = comply with CC, fill >30 mins exposure to boats, n=91).

assessed, they were unaware of exactly when they were under observation. Compliance levels reported here are thus likely to represent levels influenced little by the presence of observers, as opposed to assessments made by observers on board tour boats (e.g. Lalime-Bauer, 2000; Scarpaci *et al*., 2003; Scarpaci *et al*., 2004; Whitt and Read, 2006). For the purposes of this discussion, an 'acceptable' threshold of compliance to each particular aspect of the CC is defined as 80% or greater (based on discussions with regional managers of NSW National Parks and Wildlife Service and NSW Maritime Authority regarding realistic targets for a voluntary Code of Conduct; R. Gibbs and M. Dunkley, pers. comm.).

There was a high degree of compliance by most dolphin watching operators with regard to the upper limit of two boats interacting with dolphins at any one time, with eight of the nine regular operators maintaining 'acceptable compliance'. However, the level of compliance dropped significantly during interactions that also involved recreational boats and this occurred for almost a third of interactions. This meant that the efficacy of the CC in limiting crowding of dolphins was compromised by boaters to which the CC did not apply. The AG sets an upper limit of three boats within 150m of cetaceans (Commonwealth of Australia, 2000), so it appears that most recreational boaters were unaware of, or chose to ignore, these guidelines and dolphin watching operators seemed to regard the CC to only apply to the number of dolphin watching boats, not taking into account the presence of recreational vessels.

The mean duration of interactions with dolphins by all individual boats was well below the CC stipulated maximum of 30min per boat, with most dolphin watching operators exceeding this period on relatively few occasions. Seven of the nine regular operators demonstrated above 80% compliance. Nevertheless, staggered departure times, visits to multiple schools, returning to a previously approached school and regular 'continued interactions' involving multiple boats meant dolphins were exposed to boats for protracted periods of up to several hours. Thus, while compliance was acceptable, the CC was not adequate in protecting dolphins from prolonged exposure to boats.

Acceptable levels of compliance were maintained by all dolphin watching operators in methods of approach and boat handling around dolphin schools. However, around one in six interactions involved a breach of the CC (which equates to multiple breaches every day) and three of the nine regular operators committed the majority of these breaches. The frequency of dedicated dolphin watching cruises was also generally within the bounds of the CC limit of three per day. However, two operators regularly breached this limit, placing competitive pressure on other operators and exposing dolphins to a disproportionate amount of boating activity.

Avoiding calves is not specifically referred to in the CC. There was, however, agreement to abide by the AG when they were released, under which there are recommendations to 'exercise additional caution when observing pods containing calves' and to 'not approach very young calves or pods containing very young calves' (Commonwealth of Australia, 2000, p.6). The proportion of interactions involving approaches to dolphin schools containing calves in Port Stephens is a reflection of how many schools actually contain them, rather than a dedicated effort to approach or avoid young animals. This lack of discrimination was not an artefact of calves going unnoticed, since operators regularly communicated as to whether or not calves were present in the schools they approached, and calves were often seen (with the aid of binoculars) from the remote observation point on a headland. The lack of discrimination does not strictly equate to a breach of the CC, but is a violation of the recommendations in the AG by failing to withdraw outside a 150m caution zone and is another inadequacy of the CC in that it does not provide additional protection for these more vulnerable animals to the standard set by the AG.

If all dolphin watching operators as a group were assessed against the individual stipulations of the voluntary CC, compliance could be considered acceptable. However, when individual variation between operators and all aspects of the CC are taken into account, certain themes emerge; some operators were consistently or reasonably compliant but three did not generally abide by the CC. The voluntary CC does not, then, ensure compliance by all operators in this industry and some measures are needed to improve compliance. Education for operators, for example, or legislative adoption and enforcement of a suitably modified CC or AG, seem necessary.

Membership of the PSCDWA and compliance with the CC remain entirely voluntary. Indeed membership has fluctuated considerably throughout the PSCDWA's existence as new operators have joined, or established members have either been requested to leave the association or have withdrawn of their own accord. Two operators were not members of the PSCDWA at the time of this assessment of compliance and they ranked in the 'middle ground' and 'least compliant' groupings. Thus, not all PSCDWA members were more compliant than non-members. This suggests a need for an association (or set of regulations) that all operators are subject to, rather than just those that choose to belong, and that has the capacity to encourage or ensure compliance with its code. There is potential for investigation into the reasons why compliance by some operators was low and the strategies that may be required to improve understanding, acceptance and adoption of a code.

Given the prevalence of whale and dolphin watching industries around Australia and the world and the diversity of methods used to manage them (Carlson, 2001; Hoyt, 2001), there are surprisingly few published assessments of compliance with cetacean-based tourism management regimes with which to make comparisons. The trend in results from this limited literature is, nevertheless, not encouraging. A lack of compliance is highlighted, as is a need for review and standardisation of industry management, as well as the application of better education and enforcement of regulations. For example, a lack of compliance where there is no enforcement is reported from a number of locations in the United States, particularly with regard to recreational boat-handling around dolphins and manatees (Marine Mammal Commission, 2001); frequent breaches of commercial dolphin watching and swim regulations have been reported from Port Phillip Bay, Victoria, where operators breached numerous stipulations of the law (Scarpaci *et al*., 2003) and continued breaching regulations after an industry review (Scarpaci *et al*., 2004); numerous violations of a number of clauses within the US Marine Mammal Protection Act by swimmers and boaters around dolphins at Panama City Beach, Florida, were documented by Samuels and Bejder (2004); and most recently from Florida, Whitt and Read (2006) report just 60% overall adherence to dolphin-watching guidelines by tour operators at Clearwater. Similar to this study, operators complied with interaction time limits, but there was variation between operators, frequent violation of minimum approach distances and inappropriate vessel manoeuvring when near dolphins (Whitt and Read, 2006).

Is a voluntary CC effective in minimising perceived impacts on dolphins in Port Stephens?

While each stipulation should have reduced exposure of dolphins to boats, the results of this study indicate that the CC was rendered ineffective in minimising impacts due to: (1) some operators not adhering to all stipulations of the CC; (2) repeated exposure of dolphins to numerous dolphin watching operators and other boats; and (3) the lack of discrimination between schools containing calves and those that do not. Inadequate or inappropriate controls similar to this exist in the Bay of Islands, New Zealand, where legislation that is designed to protect a dolphin population targeted by tourism is apparently ineffective (Constantine *et al*., 2004). While the legislation provides specific controls over the number of tours conducted per day, time of departure and the number of operators present, exposure of dolphins to boat activity has not been reduced.

More than three continued interactions were recorded every day in Port Stephens, which equates to over 20 occasions per week in which dolphins were exposed to tour boat activity for protracted periods. This is of concern as boat presence in the area has been found to cause similar disruption to resting and socialising behaviour as that observed elsewhere (e.g. New Zealand (Constantine *et al*., 2004; Lusseau, 2003); Port Stephens (Allen, 2005)). Furthermore, Port Stephens represents a busy waterway – a mean of 35 boats (all vessels, including commercial dolphin watching boats, recreational boats, etc.) were recorded per scan in the Port Stephens study area and in excess of 20 dolphin watching tours were conducted per day by up to 15 boats (Allen, 2005). By way of comparison, a mean of 3.7 boats (again, all vessels) were recorded per scan of a similar-sized area in Shark Bay, Western Australia, and a maximum of six dedicated dolphin watching tours were conducted per day by two boats (Bejder *et al*., 2004). The intensity of recreational boating and commercial dolphin watching traffic in Port Stephens is therefore an order of magnitude higher than that which occurs in an area where a decline in relative abundance of bottlenose dolphins has been attributed to an increase in dolphin watching activity from one to two dedicated dolphin watching boats (Bejder *et al*., 2006).

While the greater number of dolphin watching operators in Port Stephens show acceptable levels of compliance to the CC, dolphin-boat interactions need to be viewed in the wider context of an industry involving many operators focussing their activities in a limited area and a busy waterway that is by no means limited to dedicated dolphin watching boats. Large numbers of boats, including those prohibited from interacting with cetaceans under the AG (Commonwealth of Australia, 2000; 2005), use eastern Port Stephens on a daily basis during peak holiday periods. Recreational runabouts are by far the most numerous, followed by dolphin watching boats, sailing boats and jetskis (Allen, 2005; Waterways Authority, 2003). There may be a threshold of boating traffic or tourism industry intensity beyond which a voluntary code becomes ineffective.

Gjerdalen and Williams (2000) highlight that industry-developed whalewatching codes can be useful in empowering local tourism, encouraging stewardship and helping individuals administer their activities with integrity. Nevertheless, operators in the area of their study ranked direct legal sanctions as the most effective method of ensuring compliance (Gjerdalen and Williams, 2000). The voluntary CC in Port Stephens may be useful in some regards, but it requires revision and greater incentive for compliance by all operators in order to be effective in reducing the exposure of dolphins to boats. The CC's efficacy is compromised by the total number of operators and the lack of compliance by all operators (those belonging and those not belonging to the PSCDWA) and other boaters in the area. This voluntary code is thus of limited value without revision, education and enforcement.

Evidence from this study indicates that conditions within the CC requiring revision include: (1) the CC should be made applicable to all operators; (2) recreational boaters need to be made aware of the AG and the CC and their responsibilities on the water to ensure the safety of wildlife; (3) a general limit needs to be set for the total number of all vessels within a certain distance of dolphins; (4) the hours of commercial dolphin watching activities should include a cessation of dolphin watching in the middle of the day in order to limit consecutive dolphin watches targeting the same school for prolonged periods (a mechanism to reduce continued interactions); and (5) a directive (again similar to the AG) should be included to withdraw outside a 150m caution zone when small calves are observed in a school.

The issue of cumulative impacts from combined commercial and recreational boating activities needs to be addressed in Port Stephens. If minimising potential impacts on dolphins is the goal of managing cetacean-tourism interactions, the challenge lies in improving the effectiveness of management, rather than simply improving compliance. Both compliance to, and efficacy of, stipulations within the CC for industry and rules that govern how recreational users operate might be improved with educational programmes designed to target dolphin watching operators, recreational boaters and the tourists that drive the industry. Rules need to be enforced when breaches occur in order to serve any function in minimising impacts on dolphins.

In 2006, the NSW government introduced the National Parks and Wildlife Amendment (Marine Mammals) Regulation and, furthermore, Port Stephens was declared a Marine Protected Area. The new Regulation adopted all aspects of the updated AG (Commonwealth of Australia, 2005) including proscribing minimum approach distances, number of vessels permitted within this distance and the operation of vessels around marine mammals. Thus, most stipulations within the CC are now enforceable and it is up to the NSW government to ensure that the public and dolphin watching operators are aware of the regulations and that compliance with them is enforced. It is therefore also critical that monitoring of dolphin-boat interactions continues, including compliance monitoring, to identify impacts as they arise and assess the validity and effectiveness of education programmes and the new legislation. The designation of Port Stephens as a Marine Protected Area also means that commercial tour operators will require licenses to use the area, under which any stipulations of the CC that are not already addressed in the amended Regulation could be adopted and later enforced (e.g. dolphins may be afforded additional protection from over-exposure to boating activity through the application of spatial and temporal dolphin watching zones).

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REFERENCES

Allen, S.J. 2005. Management of bottlenose dolphins (*Tursiops aduncus*) exposed to tourism in Port Stephens, NSW, Australia. MSc thesis, Macquarie University, NSW, 2109, Australia. 95pp.

Altmann, J. 1974. Observational study of behavior: sampling methods. *Behaviour* 49: 227-67.

Bejder, L., Dawson, S.M. and Harraway, J.A. 1999. Responses by Hector's dolphins to boats and swimmers in Porpoise Bay, New Zealand. *Mar. Mammal Sci.* 15(3): 738-50.

Bejder, L., Samuels, A., Whitehead, H., Gales, N., Mann, J., Connor, R. and Heithaus, M. 2004. Habitat use and reproductive success of bottlenose dolphins exposed to tourism. Abstracts of the Workshop on the Science for Sustainable Whale Watching, Capetown, South Africa, April 2004.

Bejder, L., Samuels, A., Whitehead, H., Gales, N., Mann, J., Connor, R., Heithaus, M., Watson-Capps, J. and Flaherty, C. 2006. Decline in relative abundance of bottlenose dolphins exposed to long-term disturbance. *Conserv. Biol.* 20(6): 1,791-98.

Bureau of Tourism Research. 2003. National visitor survey and international visitor survey.

Bureau of Tourism Research. 2004. National visitor survey and international visitor survey.

Carlson, C.A. 2001. A review of whale watching guidelines and regulations around the world version 2001. Paper SC/53/WW4 presented to the IWC Scientific Committee, July 2001, London (unpublished). 119pp. [Paper available from the Office of this Journal]

Commonwealth of Australia. 2000. *ANZECC Australian National Guidelines for Cetacean Observation and Areas of Special Interest for Cetacean Observation*. Environment Australia. 20pp.

Commonwealth of Australia. 2005. *Australian National Guidelines for Whale and Dolphin Watching*. Department of Environment and Heritage. 20pp.

Constantine, R., Brunton, D.H. and Dennis, T. 2004. Dolphin-watching tour boats change bottlenose dolphin (*Tursiops truncatus*) behaviour. *Biol. Conserv.* 117: 299-307.

Garrod, B. and Fennell, D.A. 2004. An analysis of whalewatching codes of conduct. *Annals of Tourism Research* 31(2): 334-52.

Gill, P. and Burke, C. 1999. *Whale Watching in Australian and New Zealand Waters*. New Holland, Sydney.

Gjerdalen, G. and Williams, P. 2000. An evaluation of the utility of a whale watching code of conduct. *Tourism Recreation Research* 25(2): 27-37.

Hoyt, E. 2001. Whale watching 2001 – worldwide tourism, numbers, expenditures and expanding socioeconomic benefits. Report to IFAW, Crowborough, Sussex, UK. 157pp. [Available from IFAW].

IFAW. 2004. *From Whalers to Whale Watchers – the Growth of Whale Watching Tourism in Australia*. IFAW Asia Pacific, Surrey Hills, NSW. 34pp.

IFAW, Tethys Research Institute and Europe Conservation. 1995. Report of the Workshop on Scientific Aspects of Managing Whalewatching, Montecastello Di Vibio, Italy, March 1995. [Available from: *info@ifaw.org*].

International Whaling Commission. 2006. Report of the Scientific Committee. *J. Cetacean Res. Manage. (Suppl.)* 8:1-65.

Janik, V.M. and Thompson, P.M. 1996. Changes in surfacing patterns of bottlenose dolphins in response to boat traffic. *Mar. Mammal Sci.* 12(4): 597-602.

Lalime-Bauer, J.M. 2000. Operator compliance to Australian whale-watch regulations and guidelines. Paper SC/52/WW4 presented to the IWC Scientific Committee, June 2000, in Adelaide, Australia (unpublished). 8pp. [Paper available from the Office of this Journal].

Lusseau, D. 2003. Effects of tour boats on the behaviour of bottlenose dolphins: using Markov chains to model anthropogenic impacts. *Conserv. Biol.* 17(6): 1785-93.

Lusseau, D. 2004. The hidden cost of tourism: detecting long-term effects of tourism using behavioural information. *Ecology and Society* 9(1): 2.

Lusseau, D. 2005. The residency pattern of bottlenose dolphin (*Tursiops* sp.) in Milford Sound, New Zealand, is related to boat traffic. *Mar. Ecol. Prog. Ser.* 295: 265-72.

Lusseau, D. and Higham, J.E.S. 2004. Managing the impacts of dolphin-based tourism through the definition of critical habitats: the case of bottlenose dolphins (*Tursiops* sp.) in Doubtful Sound, New Zealand. *Tour. Mar. Environ.* 25: 657-67.

Lusseau, D., Slooten, E. and Currey, R. 2006. Unsustainable dolphin watching activities in Fiordland, New Zealand. *Tour. Mar. Environ.* 3(2): 173-78.

Manly Hydraulics Laboratory. 1999. Port Stephens/Myall Lakes Estuary Processes Study. Unpublished report to Port Stephens and Great Lakes Councils, MHL913.

Marine Mammal Commission. 2001. *Annual Report to Congress, 2000*. Marine Mammal Commission, 4340 East-West Highway, Room 905, Bethesda, Maryland 20814. 163pp.

Möller, L.M., Allen, S.J. and Harcourt, R.G. 2002. Group characteristics, site fidelity and seasonal abundance of bottlenose dolphins (*Tursiops aduncus*) in Jervis Bay and Port Stephens, southeastern Australia. *Aust. Mammal.* 24(1): 11-21.

Nowacek, S.M., Wells, R.S. and Solow, A.R. 2001. Short-term effects of boat traffic on bottlenose dolphins, *Tursiops truncatus*, in Sarasota Bay, Florida. *Mar. Mammal Sci.* 17: 673-88.

Samuels, A. and Bejder, L. 2004. Chronic interaction between humans and free-ranging bottlenose dolphins near Panama City Beach, Florida, USA. *J. Cetacean Res. Manage.* 6(1): 69-78.

Scarpaci, C., Dayanthi, N. and Corkeron, P.J. 2003. Compliance with regulations by 'Swim-with-dolphins' operations in Port Phillip Bay, Victoria, Australia. *Environ. Manage.* 31(3): 342-47.

Scarpaci, C., Nugegoda, D. and Corkeron, P.J. 2004. No detectable improvement in compliance to regulations by 'swim-with-dolphin' operators in Port Philip Bay, Victoria, Australia. *Tour. Mar. Environ.* 1: 41-48.

Waterways Authority. 2003. Recreational register and commercial boat statistics, Hunter region. [Available from: *www.waterways.nsw.gov.au*].

Whitt, A. and Read, A. 2006. Assessing compliance to guidelines by dolphin-watching operators in Clearwater, Florida, USA. *Tour. Mar. Environ.* 3(2): 117-30.

Williams, R.M., Trites, A.W. and Bain, D.E. 2002. Behavioural responses of killer whales to whale-watching traffic: opportunistic observations and experimental approaches. *J. Zool. (Lond.)* 256: 255-70.

Zar, J.H. 1996. *Biostatistical Analysis, 3rd Edition*. Prentice-Hall, Inc., New Jersey. 662pp.

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