

OCS Study
MMS 2008-002

*Bowhead Whale Abundance Through Photographic Analysis:
Data Analysis Supported by Minerals Management Service*

Final Report

National Marine Mammal Laboratory
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This study was funded by the U.S. Department of the Interior, Minerals Management Service (MMS), Alaska Outer Continental Shelf Region, Anchorage Alaska, through an Inter-agency Agreement between MMS and the National Marine Mammal Laboratory (0104RU36560; NMFS Control # AKC=041), as part of the MMS Alaska Environmental Studies Program.

August 2008

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REPORT AVAILABILITY

This document is available to the public through:

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5285 Port Royal Road
Springfield, Virginia 22161
FAX: (703) 605-6900
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CITATION

May be cited as: Rugh, D. (ed.) 2008. Bowhead whale abundance through photographic analysis: data analysis supported by Minerals Management Service; Final Report of OCS Study MMS 2008-002. National Marine Mammal Laboratory, Alaska Fisheries Science Center, NMFS, NOAA, 7600 Sand Point Way, NE Seattle, WA 98115-6349.

Project Organization

David Rugh¹ – Program Coordinator; delivered the original proposal to MMS; provided contracts to the respective institutions and individuals; guided program development; managed the budget; and wrote reports for MMS.

Bill Koski² – Provided oversight for the catalog of bowhead photographs; managed the database; assisted with proposals and budgets; provided updates on contract progress and reports on field activity.

Judy Zeh³ – Provided statistical analysis of results from reviews of photo data and assisted with reporting methods and results.

Gilbert Hillman⁴ – Developed a computer program to increase the efficiency of finding matches between images (resightings).

John Brandon⁵ – Evaluated technical aspects of statistical methods used to assess abundance of bowhead whales.

Julie Mocklin¹ – Categorized aerial photographs of bowhead whales relative to image quality and whale identifiability, searched for matches between images (within-year and between-years), and assisted with data requests.

Andrew Davis² – Searched for matches between images (within-year and between-years) and assisted with data requests.

Kelly Trask² – Digitized whale images and mapped the images to apply them to the computer-assisted matching program.

Katie Sweeney¹ – Digitized whale images and mapped the images to apply them to the computer-assisted matching program.

Craig George⁶ – Provided insights and support for developing the research program, and served as a co-PI on aerial surveys in the Barrow area.

Robert Suydam⁶ – Provided insights and support for developing the research program.

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APPENDIX III: Identifying individual bowhead whales through aerial photography.

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APPENDIX VII: Review of bowhead whale aerial photographic studies in 2003-06.

APPENDIX VIII: Constructing a coherent joint prior while respecting biological realism: application to marine mammal stock assessments.

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PROGRAM OVERVIEW

Introduction

The primary goal of this study was to provide joint funding support to the study titled *Bowhead Whale Abundance Through Photographic Analysis*. Specifically the intent was to support laboratory and reporting portions of this research program to estimate the abundance of bowhead whales in the Bering-Chukchi-Beaufort population. Bowhead whale abundance has been analyzed through aerial photographs in prior studies (e.g., Rugh 1990, Da-Silva et al. 2000, Schweder 2003), but all previous work was applied to photographs collected in only 1985 and 1986. With the documented change in the population size (George et al. 2004), and the potential that ice-based counts of whales migrating past Point Barrow might not be a good option in the future because of a warming climate, the process of conducting mark/recapture type analysis on images of bowhead whales increases in importance. In 2003 and 2004, bowheads were again photographed during their spring migration past Point Barrow (Koski et al. 2005). Accordingly, funds were sought to examine these images and conduct an abundance analysis based on rates of resightings of whales.

Objectives

1. Analyze aerial photographs taken of bowhead whales in 2004 to identify the recurrence of individual whales previously photographed in 2003.
2. Use mark-recapture methods and calculations to estimate the population size of the Bering-Chukchi-Beaufort stock of bowhead whales.
3. Prepare progress and comprehensive draft and final reports of all research activities, analyses, and conclusions.
4. Develop and test a computer program that will increase the efficiency of the search for matches among whale images collected in different years.

Funding history

The history of this project began on 20 January 2004 when discussions were initiated between MMS and NMML regarding funds needed to conduct an analysis of available photographs of bowhead whales. In particular, an analysis was needed that would result in an abundance estimate of the Bering-Chukchi-Beaufort (B-C-B) stock of bowhead whales, also known as the Western Arctic stock of bowheads. On 4 March, a draft proposal was circulated, and an Interagency Agreement (IA) to transfer \$70,200 was signed on 17 August 2004. The MMS money delivered to NMML under this IA was directed into two contracts: to LGL, Ltd. to process, duplicate, and archive photographs of bowhead whales that they collected in 2003 (1,561 images) and 2004 (2,098 images); and to the University of Washington (UW) to continue a program there related to abundance analyses. The UW received funds in early November 2004, and LGL received their contract in early January 2005.

Additional funds (\$96,100) were acquired through an IA signed on 3 May 2006. These funds were for developing a computer program to expedite the search for resightings of bowhead whales in the photographic collection and for scanning photographic images collected from 1976-2000. Digitizing the images made it possible to use a computer-assisted matching

program. Accordingly, in January 2007, contracts were let to: 1) LGL to scan photographs and work with Gil Hillman on development of the computer program; 2) to Gil Hillman to develop the computer program; 3) to the University of Washington to supplement funds for analysis of the results; and 4) to the North Slope Borough (NSB) for archiving the photographic database.

Photo analysis

With receipt of the contract in January 2005, LGL was able to continue analyses of aerial photographs, a process which had been underway through funding from other sources in the past, such as NMML and NSB. LGL proceeded by first scanning and printing images, and then by searching for resightings of individual whales. Funds provided to LGL were used to scan (duplicate) the 2,098 images from 2004 and prepare them for printing and to update the bowhead photography database. (Images collected in 2003 were previously scanned using personnel and funds provided by NSB.)

Search for resightings

NMML and the NSB provided additional funding to conduct searches for resightings (i.e., matches) within the 2003, 2004, and 2005 datasets, including an independent search by two observers looking for matches within 2004. This search provided information on how many times individual whales were photographed in the respective season. As multiple images are included in a composite, there are better chances that a whale will be recognized when it is photographed again in another year. Searches for matches between 2003 and 2004, 2003 and 2005, 2004 and 2005 have been completed independently by biologists at NMML and LGL. Results from the independent efforts have been compared, and the final matches have been confirmed by a panel that included David Rugh and Bill Koski, who have verified all previous bowhead matches that have been made.

Categorization of images

All bowhead images from 2003, 2004, and 2005 have been categorized according to a standardized system that rates photo quality and degree of identifiability of each whale image (detailed in Rugh et al. 1998). This work has been conducted by Julie Mocklin at NMML through NOAA funds directed at stock structure analysis. Abundance analyses incorporate this information on image quality and the degree of marking in various zones on the whale, and the analyses will include allowance for differential recapture rates depending on image quality and the degree of marking.

Scanning of images from 1976-2005

There are a total of 16,740 images in the bowhead photographic database at this time from the years 1976-2005. LGL is the source for 11,125 of these images, and NMML is the source of 5,615 images. Kelly Trask at LGL and Katie Sweeney at NMML have scanned essentially all bowhead images in photographs of adequate quality and whales with sufficient markings to be useable in future resighting efforts.

Statistical analysis

The original contract directed to the UW was initially applied as partial support for a doctoral student, John Brandon, who developed models for analyzing the population dynamics of large whales, including bowheads. During the reporting period, Mr Brandon focused on evaluating

technical aspects of the statistical techniques used to assess the Bering-Chukchi-Beaufort bowhead stock. These analyses were conducted to ensure that the results of recent bowhead stock assessments, in particular those quantities related to management, are robust to certain alternative methods employed in the current stock assessment framework. The results of this aspect of the project were submitted as a report to the Scientific Committee of the International Whaling Commission (IWC) (Brandon et al. 2005). Subsequently, this work was given as an oral presentation ("Alternative resampling schemes used in Bayesian stock assessments of bowhead whales", with Dr Breiwick as coauthor) at the theme session on 'Applications of Bayesian Statistical Methods to Fisheries' at the American Fisheries Society conference in Anchorage, September 2005. This work was subsequently published in the *ICES Journal of Marine Science* (Brandon et al. 2007) under funding supplemented by NMML. In addition, Mr Brandon's earlier work (with Dr Wade as coauthor), on the application of Bayesian model averaging techniques in bowhead stock assessments, has been published in the *Journal of Cetacean Research and Management* (Brandon and Wade 2006).

The remaining funds from the original contract to UW were used to support Dr Judy Zeh to apply the 2003 and 2004 photographic database for making an estimate of abundance. These statistical analyses are ongoing but preliminary results are available in Appendix I. Resighting rates of sufficiently marked whales in adequate photographs were used to make an abundance estimate through mark/recapture-type techniques, as was done by DaSilva et al. (2000). This abundance estimate for bowheads photographed in 2003 and 2004 is comparable to an abundance estimate resulting from the ice-based census conducted by the NSB in 2001 (George et al. 2004).

Computer assisted matching

A computer program has been developed by Dr Gil Hillman for increasing the efficiency of searching for matches (resightings) of bowhead whales in aerial photographs (Appendix II). All images in the available collection are ranked with regard to similarity to a query image. The program is undergoing tests and modifications and is still in active development.

Presentations, reports, and publications

International Whaling Commission

Presentations were made to the Scientific Committee of the IWC in 2005, 2006, and 2007 on aspects of the photography studies that were funded by these MMS projects (Koski et al. 2005, 2006, 2007). Especially the meeting in May 2007 was critical to the assessment of the bowhead whale annual quota as taken by Eskimo hunters. This meeting was attended with considerable international interest. Results of photographic analyses contributed to the conclusion that the Bering-Chukchi-Beaufort stock of bowhead whales is still growing and that there was no stock structure issues that would prevent issuing a quota for the next five-year period (Taylor et al. 2007; George et al. 2007).

American Fisheries Society Conference

Results by Brandon et al. (2005) were presented at the Symposium for the Application of Bayesian Statistical Methods in Fisheries at the 135th Annual American Fisheries Society Conference, Anchorage, Alaska, 11-15 September 2005.

Alaska Marine Science Symposium

As a part of the MMS-funded photographic analysis, a scientific presentation (both a formal talk and poster) was made at the Alaska Marine Science Symposium on 22 January 2007 in Anchorage (Rugh and Koski 2007). The presentation covered scientific benefits and results from using aerial photography for studying bowhead whales (see Appendix III).

Reports and publications

- 1) Koski et al. (2008): this is a working document on applying mark-recapture techniques to estimate bowhead abundance based on photography data from 2003 and 2004. (See Appendix I).
- 2) Hillman et al. (2008): this is the documentation of a new computer-assisted matching program. (See Appendix II).
- 3) Brandon and Wade (2006): this is an extension of previous bowhead stock assessment framework (Brandon and Wade, 2004) to include Bayesian model averaging. (See Appendix IX).
- 4) Koski et al. (2005): this was an IWC report on aerial photography of bowhead whales conducted during the 2003-2005 spring migrations. (See Appendix V).
- 5) Koski et al. (2006): this report was submitted to the IWC SC to provide results from analyses of aerial photography from 2003-2005. (See Appendix VI).
- 6) Koski et al. (2007): this review of bowhead whale aerial photographic studies conducted in 2003-2006 was presented to the IWC. (See Appendix VII).
- 7) Brandon et al. (2007): this publication was a statistical investigation of alternative resampling schemes for obtaining realistic joint prior distribution, applying bowhead and walrus data. (See Appendix VIII).
- 8) Brandon and Wade (2006): this publication in the *Journal of Cetacean Research and Management* uses Bayesian modeling to assess the BCB bowhead population.

Conclusions

The products of this study can be summarized and organized as a function of the stated objectives:

1. Analyze aerial photographs taken of bowhead whales in 2004 to identify the recurrence of individual whales previously photographed in 2003.

The first objective was met by scanning (digitizing) bowhead images found in aerial photographs from the 2003 and 2004 migrations. This was done using MMS funds directed specifically for this study in addition to funds from NOAA and NSB. All images within each of these years were compared to each other to establish how many times each whale might have been photographed. This provided composites of images for the respective whales. Then whale images from the two years were compared independently by two researchers. The number of images of adequate quality showing whales that had marks determined the sample size. Resighting rates provided an estimate of abundance (Appendix I).

2. Use mark-recapture methods and calculations to estimate the population size of the Bering-Chukchi-Beaufort stock of bowhead whales.

Based on a sample of 150 marked whales in 2003 and 210 in 2004, with 9 whales captured in both years, mark-recapture techniques provided an estimate of 3,185 whales in the sample (SE = 3,420). Using an estimate of the proportion of the population that is marked (0.2691) from an examination of all available images in the photographic collection from 2003, the bowhead abundance in 2003 and 2004 was calculated to be 11,836 (SE 3,420; 95% CI = 6,795 to 20,618). This abundance estimate is consistent with results from the completely independent counts made from the sea ice during the bowhead spring migration in 2001 (George et al. 2004), allowing that the bowhead population continued to grow at 3.4% between 2001 and 2003/2004. This study is described in Appendix I.

3. Prepare progress and comprehensive draft and final reports of all research activities, analyses, and conclusions.

This objective was met through routine quarterly reports (25 Jan 2005, 29 Apr 2005, 4 Aug 2005, 26 Oct 2005, 26 Jan 2006, 12 May 2006, 21 July 2006, 31 Oct 2006, 30 Jan 2007, and 26 Apr 2007). A draft final report was submitted to MMS on 30 Aug 2007, and after receiving a review on 26 Jan 2008 and final approval on 15 July 2008, the completed final report is hereby submitted. Research papers, conference, abstracts, and publications that have applied information from the current project (OCS Study MMS 2008- 002) are presented in the Appendices.

4. Develop and test a computer program that will increase the efficiency of the search for matches among whale images collected in different years.

The process of finding resightings (i.e. making matches) between bowhead images is a tedious and time-consuming process. In order to expedite searches through a photographic collection that is gradually increasing in size, a computer-assisted matching program was developed by Dr Hillman (Appendix II). After images are fully prepared for application to the program protocol, they will be available for searches through a system that prioritizes the most likely matches. This program has been through preliminary tests, and modifications and refinements are being designed for future use. Eventually, all workable bowhead images will be available for examination through this computer program, and finding matches will become far more efficient.

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Mission Statements

The Department of the Interior Mission



As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

The Minerals Management Service Mission



As a bureau of the Department of the Interior, the Minerals Management Service's (MMS) primary responsibilities are to manage the mineral resources located on the Nation's Outer Continental Shelf (OCS), collect revenue from the Federal OCS and onshore Federal and Indian lands, and distribute those revenues. Moreover, in working to meet its responsibilities, the **Offshore Minerals Management Program** administers the OCS competitive leasing program and oversees the safe and environmentally sound exploration and production of our Nation's offshore natural gas, oil and other mineral resources. The MMS **Royalty Management Program** meets its responsibilities by ensuring the efficient, timely and accurate collection and disbursement of revenue from mineral leasing and production due to Indian tribes and allottees, States and the U.S. Treasury.

The MMS strives to fulfill its responsibilities through the general guiding principles of: (1) being responsive to the public's concerns and interests by maintaining a dialogue with all potentially affected parties and (2) carrying out its programs with an emphasis on working to enhance the quality of life for all Americans by lending MMS assistance and expertise to economic development and environmental protection.



The National Marine Fisheries Service, NOAA, Mission Statement

NOAA Fisheries Service (also known as the National Marine Fisheries Service, or NMFS) is dedicated to the stewardship of living marine resources through science-based conservation and management, and the promotion of healthy ecosystems. As a steward, NOAA Fisheries Service conserves, protects, and manages living marine resources in a way that ensures their continuation as functioning components of marine ecosystems, affords economic opportunities, and enhances the quality of life for the American public.

The National Marine Mammal Laboratory Mission

The National Marine Mammal Laboratory (NMML) is responsible for conducting research on marine mammals important to the mission of the National Marine Fisheries Service (NMFS) and the National Oceanic and Atmospheric Administration (NOAA), with particular attention to issues related to marine mammals off the coasts of California, Oregon, Washington, and Alaska. This work includes stock assessments, life history determinations, and status and trends. Information is provided to various U.S. governmental and international organizations to assist in developing rational and appropriate management regimes for marine resources under NOAA's jurisdiction. Research programs are carried out cooperatively with other Federal, state, and private sector agencies.