Design of a Program of Research on Sperm Whale Catch History: Results of a Workshop[1]

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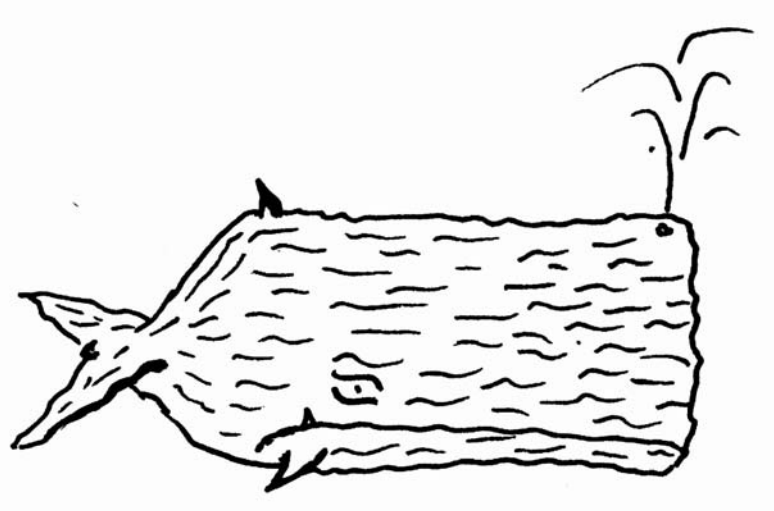

[1] **This report is in a file named Cachalot.pdf. The six appendices are in a file named Cachapp.pdf. These files are on the History of Marine Animal Populations website: http://www.cmrh.dk/hmapindx.html at Southern Denmark University.**

1 Introduction

Participants in a meeting at the Kendall Institute, New Bedford Whaling Museum, in New Bedford, MA, 9-12 July 2002, developed the program of research on sperm whale catch history outlined in this document. This workshop, called the Cachalot Workshop, was co-sponsored by NOAA and the Alfred E. Sloan Foundation's Census of Marine Life (History of Marine Animal Populations), and was convened and chaired by Tim Smith. Randall Reeves served as rapporteur. Thanks to Mark Bravington for providing the logo – a stylized sperm whale doodle.

The overall aim of the research program is to improve understanding of the impact of whaling on the world's sperm whale populations. The specific objective of the research initiatives set forth in the present document is to estimate the number of sperm whales removed by open-boat whaling, by area and time. Catch data are basic to population assessment.

2 Background

In many respects, the present suite of research initiatives is an outgrowth of a workshop held in 1977 at the Kendall Whaling Museum in Sharon, MA, the purpose of which was to establish the relevance of historical whaling records in addressing problems related to the management and conservation of whale populations at that time (IWC 1983). At that time (the late 1970s), it was deemed important. Thus, the intent was to explore ways in which research into historical whaling might serve the interests and priorities of the International Whaling Commission (IWC) and its Scientific Committee. A proposed pilot study of sperm whale catch history in a portion of the North Pacific Ocean was implemented soon after the Sharon workshop (Bannister et al. 1981), followed by a population analysis of the resulting data (Tillman and Breiwick 1983), and eventually by several other investigations incorporating 19th century catch data for another area of the Pacific (Hope and Whitehead 1991; and see Appendix 1). The global moratorium on commercial whaling implemented by the IWC during the 1980s, and the relatively recent shift in emphasis within the whaling industry away from sperm whales and toward the smaller baleen whales (minke and Bryde's whales), have meant that population assessments for sperm whales are lower on the IWC's list of priorities than was true during the 1970s and earlier. Throughout the 1980s and 1990s the IWC's Scientific Committee considered sperm whales intermittently at a low level of effort. In 2002, however, the Scientific Committee agreed to undertake over the next few years a new assessment of the effect of whaling on sperm whale populations worldwide (IWC 2002).

In addition to the IWC's concern, there is a wider scientific and popular interest in knowing more about the impacts of past human use of living natural resources. As one of many examples, a recent article in *Science* describes changes in ecosystem structure and function related to historical overexploitation of large marine animals (Jackson et al. 2001). It is only by reconstructing historical patterns of resource extraction that one can make reasonable inferences about "baseline" conditions, and work toward the restoration and responsible management of marine ecosystems. The Census of Marine Life, a program initiated by the Alfred E. Sloan Foundation in 2000 (see Malakoff 2000), includes within its broad and ambitious agenda a component called History of Marine Animal Populations (HMAP, http://www.cmrh.dk/hmapindx.html). One element of the HMAP program is a "world whaling" project, the ultimate goal of which is to provide an authoritative, comprehensive compilation of whaling catch data. One of many potential uses envisioned for such a compilation is to provide input on the abundance of high-trophic-level organisms for regional or ecosystem-level models. As a cosmopolitan species with large body size, high mobility, deep-diving behavior, and an aggregate pre-exploitation abundance that almost certainly exceeded a million individuals, the sperm whale is assumed to have played a significant role in the ecology of the world's oceans, especially in little-studied pelagic ecosystems. Moreover, the great economic importance of sperm whales during more than two and a half centuries of human history means that an improved understanding of magnitude and trends in the sperm whale populations, i.e., the "supply" side of whaling, will contribute to analyses by economists and historians, as well as biologists and ecologists.

A note concerning whaling museum consolidation: the entire collection of the Kendall Whaling Museum was donated to the New Bedford Whaling Museum in 2001, and in 2002 the Kendall library, including all logbooks, journals, and other manuscript material, was transferred to the Kendall Institute of the New Bedford Whaling Museum. With this consolidation, nearly half of the extant logbooks from the American whale fishery is now held by this single institution. Another 15% is held by the Providence Public Library and most of the balance by the New

Bedford Free Public Library, Mystic Seaport, and Nantucket Historical Association (5-9% each) (J. Lund, pers. comm.). Importantly, the National Archives (Washington, D.C., and branches) also has a very large collection of primary materials in the form of Customs House records (*Ibid*.).

3 Rationale

Davis *et al.* (1997), in a microeconomic study of the New Bedford whaling industry, relied upon selected indices of sperm whale abundance and trends from the literature, allowing them to conclude that open-boat whaling during the 18th and 19th centuries had little or no effect on the whale stocks. They therefore surmised that development of the industry hinged almost entirely upon individual or corporate decisions based on investment strategy, manpower, etc., rather than upon sperm whale population resilience or depletion. In the biological realm, Whitehead (2002) recently produced an analysis of sperm whale global abundance and trends, using a catch series from 1800-1999 based mainly upon Best (1983) for the open-boat fishery and an FAO compilation for modern catches. He concluded that the 19th century whalers reduced the overall abundance of sperm whales by less than 50% and perhaps by no more than about 30% by 1880, and therefore that severe depletion did not occur until modern whaling on sperm whales became intensive beginning in the middle of the 20th century (i.e., post-World War II). Although informative, Whitehead's trajectories are premised upon data that are acknowledged to be far from complete. Hunting loss is not incorporated into removal estimates, for instance, nor are any pre-1800 catch data included, and non-American catches in the 19th century are substantially under-estimated (according to Best 1983). Whitehead also acknowledged the desirability of better data on removals for the entire period of sperm whale exploitation, from the early/mid 1700s to the 1980s.

In contrast to both Davis *et al.* (1997) and Whitehead (2002), Whitehead and Weilgart (2000:171) concluded, based on Tillman and Breiwick (1983) and Whitehead (1995), that by the 1860s "the open-boat whaling industry had probably reduced most sperm whale populations to less than 25% of their pre-exploitation size." Indeed, this conclusion appears to have been supported by the two intensive regional studies of 19th century sperm whaling published to date, both involving Pacific Ocean grounds (Bannister et al. 1981; Hope and Whitehead 1991).

Our present understanding of sperm whale catch history and population status is based on a patchwork of studies that provides conflicting evidence. In two studies of the rates of encounters with sperm whales by 19th century whalers on major Pacific grounds, open-boat whaling appears to have caused substantial stock depletion (Bannister et al. 1981; Hope and Whitehead 1991). However, the sizes of the sperm whale populations at the beginning of the open-boat fishery implied by these studies seem far too low, given the very large catches of sperm whales by modern whaling in the 20th century. Thus, the "paradox" first described by Tillman and Breiwick (1983) and later elaborated upon by Whitehead (1995) remains: "… if open-boat whaling so reduced sperm whale numbers, why were modern whalers able to take more whales over a shorter period (Best, 1983) from smaller initial stocks and not drive the populations to extinction" (Whitehead 1995:411). Among the possible answers are that encounter-rate analyses have been confounded by changes in whale behavior (they avoided the whaling vessels – however the encounter rates are based on sightings, not catches), the open-boat catches have been greatly underestimated, or for some unknown reason, the environmental carrying capacity for sperm whales increased considerably between the early 19th and early 20th centuries (see Appendix 2).

The program of research outlined in this document is intended to resolve at least some of the uncertainties associated with assessments of historical sperm whale population abundance and trends, particularly if removal data are allocated to appropriate biological populations or ecosystems. It should therefore serve the interests of both the IWC Scientific Committee and the Census of Marine Life HMAP project, and contribute significantly to the developing fields of historical ecology and marine environmental history. The initial studies by Bannister et al. (1981), Best (1983), and Hope and Whitehead (1991) have illuminated numerous gaps in knowledge, while at the same time demonstrating the great potential for using the treasure trove of archival documentation in libraries and museums to grapple with questions of immediate relevance to modern resource management and conservation.

The program of research is structured into four major components – estimating open-boat whaling catches, estimating regional open-boat whaling catches, estimating modern whaling catches, and estimating population changes over time, as summarized in Table 1. The emphasis here is on estimating the open-boat catches, and the

discussions of modern catches and population trends are relatively brief – intended simply to illustrate how the various components might contribute to an overall understanding of sperm whale population history.

Table 1. Tasks to develop an understanding of the effects of whaling on sperm whale populations, organized into four projects.	
Project	**Task**
4.1 Global Open-Boat Catch Estimates: Aggregate sperm oil production	Compile available shore whaling catches in all regions
	Incorporate additional British, German & S. American pelagic whaling data
	Evaluate potential double- and under-counting of colonial oil production
	Cross-check Starbuck for bias in aggregate oil production
	Evaluate Townsend data and adjust estimate of average oil yield (bbl/whale) to account for bias
	Compile global aggregate production based estimates of sperm whale catches
4.2 Global Open-Boat Catch Estimates: Based on voyage sperm oil returns	Develop integrated database of American voyages.
	Develop method to estimate American catches 1760-1810
	Cross-checking experiments for bias in various data sources
	Extract and compile additional data on catches for S. American whaling.
	Extract and compile on catches for British, German, and other non-American pelagic whaling (e.g., New Brunswick, Bermuda, Hawaii)
	Develop improved methods to stratify oil yield estimates (bbls/whale) from logbook data
	Compile global voyage-based estimates of sperm whale catches
5.0 Regional Open-Boat Catch Estimates: Based on data from voyage logbooks	5.1.1 Compile and review published information on spatial and temporal patterns in world open boat sperm whale fisheries, including voyage tracks and itineraries (circuits).
	5.1.2 Determine movement patterns of the whaling fleet
	5.2.1 Augment integrated database of American open-boat voyages with more precise locations of whaling catches from published and museum sources (e.g. Sherman, museum docent records, Townsend)
	5.2.2 Assign as possible non-American pelagic whaling voyages from Project 4.2 to region
	5.3.1 Develop gazetteer database structure to receive data as logbooks are read.
	5.3.2 Computerize previously extracted open-boat logbook data (Bannister et al. 1981, others)
	5.3.3 Refine 1977 logbook data extraction scheme, based on data previously extracted from logbooks.
	5.3.4 Evaluate statistical properties of voyage productivity data previously extracted from logbooks.
	5.4Conduct workshop on sperm whale population biology, ecology and abundance to determine regional population structure.
	5.5.1 Design logbook sampling scheme for oceanic region in priority order, including stratification of logbook selection, evaluation of log quality and completeness, and effect of sample size on statistical precision of catch estimates
	5.5.2 Extract data from stratified random sample(s) of logbooks
	5.6.1 Use extracted logbook data to estimate regional catches
	5.6.2 Estimate size and sex compsition of catches for regions
	5.6.3 Compute voyage productivity indices for regions
6.0 Modern Catches	Assemble 20th century individual animal data from BIWS
	Estimate modern whaling catches using the IWC data files, accounting for misreporting.
7.0 Estimation of Population Changes Over Time	7.0 Combine regional and global catch estimates for areas corresponding to specific populations or stocks of sperm whales.
	7.1 Estimate population abundance over time based on estimated catches and contemporary abundance utilizing population back calculation models.

4 Estimation of global sperm whale catches in the open-boat fishery

There are two approaches to estimating global sperm whale catches. One, pursued by Best (1983), is based on aggregate reported sperm oil statistics. The other, which has not yet been attempted, would be based on statistics for each voyage, including oil production. Best (1983) thoroughly reviewed the data available in published sources for a preliminary assessment of the magnitude of catches from the early 1800s to about 1970. He compiled sperm oil production figures for U.S. and other whaling fleets in the 19th century and reviewed factors affecting them. In addition, he considered various aspects of the open-boat fishery, such as average yields, loss rates, geographical distribution of the catches, and trends in these through time.

In a draft paper prepared for the Cachalot Workshop now two decades later, Best (2002) applied some of the lessons learned from his earlier effort and estimated landed catches of sperm whales worldwide for the period 1800-1925. Although he included an adjustment for vessels that were lost, he did not attempt to estimate total removals by adjusting for struck/lost or killed/lost (unprocessed) whales, nor did he attempt to allocate catches to ocean basins or other geographical areas. Reported oil production, by country and by time interval (decade or year), was the basis for all catch estimates. Voyage data (from Townsend (1935) and Starbuck (1878)/Hegarty (1959)) were used to calculate mean yields of sperm oil per whale landed. While this revision is an improvement on his earlier work, Best was well aware of the limitations of his studies, and these are summarized in Appendix 3.

Global estimates of sperm whale removals should be derived from both voyage data and aggregate (fleet-wide) production data. Whenever and wherever possible, estimates of statistical uncertainty should be included (e.g., for conversions of oil amounts to numbers of whales, struck/lost factors). More generally, systematic exploration of the sources of uncertainty in all of the data should make it possible to determine, at least crudely, the degree of uncertainty in the improved global estimates.

4.1 Global Catch Estimates: aggregate oil production

The goal of this project is to produce an improved (i.e., more accurate) series of global catch estimates. This will require the incorporation of data and analyses in addition to those used by Best (1983), but essentially not go beyond revising and expanding the approach of Best (2002). Many of the elements are described in Appendix 3. It is expected that Best will take the lead in carrying out this work, with assistance from Smith and others as appropriate. Among the key factors that will need to be taken into account are:

- Shore whaling catches at the Azores (and Madeira?), Japan, and any other shore sites where sperm whales were hunted during the 18th-19th centuries.
- Inclusion of new and better data on British sperm whaling, particularly for 1840-56 (e.g., from Chatwin 1997; possibly search of Public Record Office after consultation with Sidney Brown and/or Anne Savours/Shirlee, and checking materials by A.G.E. Jones, although these latter have little data on oil production, *fide* P. Best, pers. comm.).
- Inclusion of new and better data on German sperm whaling, to the extent that such data are available (with help from S. Frank).
- Evaluation of "colonial" production (Best 1983: his Table 3) to confirm that it includes all imports to Great Britain from present-day Canada (e.g., New Brunswick, Nova Scotia, Newfoundland) and Bermuda.
- Evaluation of production attributed to New Zealand, Australia, and Tasmania (Best 1983: his Table 3) to ensure that values are complete and not duplicative with "colonial" production.
- Incorporation of data from Brazil, Chile, and Peru (see 4.2, below).
- Investigation of Hawaii-based voyages (see Hegarty 1959) and their possible contribution to U.S. (and British) production, with any appropriate adjustments.
- Application of appropriate loss-rate factors to account for whales struck but not processed (using data from logbooks, including those already available from completed studies by Bannister et al. 1981; Wray and Martin 1983; Hope and Whitehead 1991)
- Inclusion of available data (however incomplete) going back to at least 1760.
- Evaluation of completeness of American production data (from Starbuck and Hegarty) and appropriate compensation if found to be incomplete. This could involve, at a minimum, a spot-check of the aggregate oil importation figures in the tables at the back of Starbuck (1878) with the summed landings per vessel

listed as returning in a particular year (see Appendix 3).
- Partial correction of Townsend's (1935) catch tabulation by reference to Townsend Abstracts[1] (per Best 1987).

4.2 Global Catch Estimates: voyage oil production

Statistics on sperm oil returned for a large fraction of American open-boat voyages have been reported (e.g. Starbuck 1878), and a definitive list of American voyages has recently been published (Lund 2001). The goal of this project is to develop global estimates based on these and other voyage lists.

To accomplish this project, voyage lists will need to be compiled and computerized, and a suite of relevant smaller tasks and studies related to those identified under section 4.1 will need to be completed. It is expected that this project will be led by Smith in collaboration with Best, Bannister, Lund, Frank, Reeves, and others as appropriate (hopefully including H. Whitehead).

The specific tasks to be addressed are:

- Compile a comprehensive database of sperm oil production, by voyage, including "new" voyages listed by Lund (2001) that were not listed by Starbuck (1878) or Hegarty (1959) (see Appendix 4). This will mean integration of data from not only those sources, but also from Davis et al. (1997), Wood (no date), the Whalemen's Shipping List, and possibly other sources. These data should extend back in time to at least 1760.
- For early years of the American, British, and other sperm whale fisheries, a rationale and procedure need to be developed to account for undocumented or poorly documented catches. For example, there are years in the 1700s for which it is known that a certain number of voyages were undertaken (Starbuck (1878) refers to 80 Nantucket vessels sailing in 1756, 118 in 1766, etc.), yet there is little or no information on the activities or catches of individual vessels, and all too often the aggregate product returns do not distinguish between whale oil and sperm oil. The range of uncertainty in any estimates for these years will be large, but it is nevertheless important to account, somehow, for the fact that removals were taking place (e.g. Starbuck describes takes of sperm whales from as early as the 1720s; also see Reeves and Mitchell (1986: their Table 1) and Little (1988)).
- Comparison(s) of voyage production data in various sources (e.g., inbound customs-house manifests, Whalemen's Shipping List, Dias, Wood, Starbuck/Hegarty), with the goal of determining directions and magnitudes of bias. (Note that this is essentially an extension of the cross-checking of data within Starbuck, as described under 4.1.)
- Inquiries need to be made concerning sperm whaling by vessels from Brazil (see book), Chile (A. Aguayo; Codero-Oddo, J. 1984. Whale fisheries on the coasts of Chile, between 1825 and 1840 – typed notes in Alexander Turnbull Library, Wellington, NZ, fide R. Richards MS, 1998), and Peru (R. Clarke, K. Van Waerebeek).
- Further refinements of yield estimates (bbl/whale). Best (2002) used a combination of proportions of the two vessel-types (brig/schooner and bark/ship) in the U.S. fleet at the beginning of each decade (from Starbuck and Hegarty (see Best 1983: his Table 7)) and the mean yield estimates for these types (again, from his 1983 paper) for his estimation of catches. The various logbook extractions already completed (e.g., by Bannister et al., Hope and Whitehead, Wray and Martin, Reeves) provide some data on oil yields of individual sperm whales, and reliable aggregate voyage production totals. These data should be compiled and analyzed to identify the principal factors affecting yield, and to obtain more reliable average values, with measures of statistical uncertainty. This may allow further stratification of estimates of numbers of animals. It is important to be clear and careful about how these oil yields are used, however. Presumably, they will be used in conjunction with estimates or reported quantities of total oil production to produce estimates of numbers of whales landed. If the oil production is an independently measured quantity (i.e., not just the sum of barrel quantities reported for individual whales or voyages), the results could be

[1] The abstracts of voyage logbooks used by Townsend (1935) for vessels beginning with the letters A through J have been located, and are referred to here as Townsend A-J. The other abstracts have not been located.

erroneous.

- Development of a more nearly comprehensive method of stratifying voyage-based records by vessel rigging, which was shown by Best (1983) to correlate with the average yield of oil per whale.
- In addition to checking the Townsend A-J sheets, as described under 4.1, it should be noted that the data extraction sheets for vessels K-Z have yet to be located (and may be permanently lost). It would be useful to compare the full list of "Townsend voyages" (see his published 1935 table – 1,665 voyages by 744 vessels) with the annotations in Lund (2001) to determine which of the logbooks checked by Townsend and his assistants are extant in public collections. This assessment will provide an idea of how great a "loss" is represented by the unavailability of the K-Z data sheets, and therefore how "urgent" it is to find them. In this regard, it should be noted that Arthur C. Watson, who is credited by Townsend (1935:16) as having carried out most of the logbook data extractions, was employed at the Massachusetts Institute of Technology as of 1935. This may provide a useful searching lead.

5.0 Estimation of sperm whale catches by the open-boat fishery on a regional basis

No physical barriers, apart from landmasses, appear to obstruct the dispersal of sperm whales (Berzin 1972; Jaquet 1996). There is some evidence that individual sperm whales inhabit and move across entire pelagic marine ecosystems (*sensu* Longhurst 1998) and indeed ocean basins during the course of their lives, although this roaming behavior is more characteristic of males than of females (e.g., Ohsumi 1966; Ivashin 1967; Mitchell 1975; Best 1979; Martin 1982; Aguilar 1985; Whitehead and Weilgart 2000). Rice (1989) suggested that some inter-basin movement round the Cape of Good Hope (Atlantic Ocean-Indian Ocean) and through the passages between the Lesser Sunda Islands or round the south coast of Tasmania (Indian Ocean-Pacific Ocean) was likely. However, he considered exchange via Cape Horn (Pacific Ocean-Atlantic Ocean) to be "almost entirely restricted, except possibly for a few males." A principal feature of sperm whale biology is the difference in migratory behavior between adult males and females. Only adult males move into high latitudes, while all age classes and both sexes range throughout tropical and temperate seas. An initial examination of global matrilineal population structure suggested that inter-oceanic dispersal of female lineages was limited (Lyrholm and Gyllensten 1998).

Estimation of sperm whale removals on a global basis fails to satisfy the need for regional analyses. Most discussions of sperm whale science and management focus on spatially defined units much smaller than the world, so there is a need to accommodate interest in analyses at a less than global scale. The aggregate distribution of sperm whales is influenced not only by the tendency of females to remain in tropical to cold temperate latitudes, but also by the patchiness of global marine productivity (Jaquet and Whitehead 1996; Longhurst 1998). Quite apart from the influence of physical barriers to dispersal, differences in productivity likely cause some degree of population partitioning within the ocean basins and possibly within pelagic marine ecosystems. For example, Whitehead and Weilgart (2000) indicate that in the South Pacific, female sperm whales are generally found in concentrations spanning approximately 1000km, separated by a few thousand kilometers. Even though research to date has failed to identify genetically distinct sperm whale populations, there is ample justification to insist, *a priori*, that management for conservation of sperm whales should be pursued at the level of an ocean basin or, if possible, at smaller spatial scales that reflect the discontinuous nature of concentrations of breeding groups or the differential productivity of pelagic marine ecosystems. This assumes that the goal of management is to ensure that the species occupies its entire historical range (see Taylor and Dizon 1999).

From an ecological point of view, the concepts of coastal "Large Marine Ecosystems" (Sherman and Duda 2001) and pelagic marine ecosystems (Longhurst 1998), as well as the spatial scales of projects being pursued as parts of the Census of Marine Life, suggest that catch histories for areas smaller than ocean basins will be required. In practical terms, allocating catches to ocean basins is a logical step because of the nature of many of the data sources. For the 18th and 19th centuries, destinations of voyages generally were announced in terms of ocean basin, i.e., bound for the Atlantic, or the Pacific, or the Indian Ocean. Moreover, many of the existing summaries of logbooks, museum cataloging records, and other statistical compilations are organized or indexed by ocean basin.

Regardless of their announced destinations, the majority of the roughly 15,000 voyages in the US open-boat fishery from the late 1700s to early 1920s (Lund 2001) originated in the Atlantic, and the transiting of vessels through the North and South Atlantic *en route* to the Indian and Pacific oceans was a predominant feature of the fishery once the grounds in these latter oceans were discovered. Therefore, it is important to consider that a Pacific or Indian Ocean

destination would not preclude that some whaling effort and catches occurred in the North and/or South Atlantic during the outbound or inbound portions of a voyage. In fact, many voyages likely caught whales in two or more ocean basins. Even though vessels are known to have whaled in regions different from what was indicated on their customs declaration at the time of sailing, those announced destinations may provide a reasonable indication of temporal trends in whaling effort in the Atlantic, Pacific, and Indian Oceans.

Charts of the locations of whaling activity (e.g., Townsend 1935) reveal that while whaling in the Atlantic can readily be allocated to either north or south of the Equator, a significant amount of whaling in the Pacific occurred on grounds along the Equator. Thus, the practical difficulty arises of having to assign effort and catches in the Pacific on an essentially arbitrary basis. Provisionally, it is suggested that the initial regional breakdown of effort and catch data be organized according to ocean basin, as follows: Atlantic, Pacific, and Indian. Further subdivision of the Atlantic (North and South) and Indian (western and Indo-Pacific) may prove desirable.

Although whaling voyages bound to Arctic destinations would most likely have targeted bowhead whales, sperm whales were taken at least occasionally as well. For example, of about 200 voyages from Honolulu to the Western Arctic, 28 returned some sperm oil, usually only small amounts equivalent to one or two whales (total 5390bbl; Hegarty 1959).

There was agreement among workshop participants that a voyage-based approach would be necessary for any reconstruction of sperm whale catch history attempting to allocate catches to regional levels. This means that methods need to be developed to ascertain where whaling was conducted on a given voyage, and therefore where sperm whale catches were made and sperm whale products obtained. Numerous tasks were identified that would contribute to the development of such methods, and these are described in the following sections.

5.1 Synthesis of spatial and temporal patterns in pre-1925 sperm whaling

A critical review of information from the literature, summarizing patterns in the development of world sperm whale fisheries (pelagic and shore-based), would be a useful foundation for the proposed regional analyses. Such a review could be organized on an ocean-basin, national, or chronological basis, depending upon the judgment of its author(s).

5.1.1 Spatial and Temporal Patterns

Within ocean basins, 18th and 19th century whalers distinguished whaling "grounds," and the location and spatial extent of these areas appear to have shifted over time, with the discovery and periods of peak usage usually fairly well defined.

Specifically, this synthesis should describe for each sperm whaling ground the following: (a) its geography (e.g., boundaries, size, seasonal differences, and variability through time); (b) the sequence and timing of discovery; (c) trends in exploitation (e.g., timing of peak catches, increase/decrease in profitability, and degrees of "abandonment"), with associated explanations of driving factors; and (d) the national identities of the whaling fleets operating there, by time.

In addition to the useful overviews already provided by Best (1983, 2002), the American pelagic component can be characterized by reference to authors such as Starbuck, Clark, Townsend, Scammon, Beale, Colby, Decker, and Richards; the French pelagic component from the work of Du Pasquier; and the British component from Jones and Chatwin. Shore-based sperm whaling in the Azores and Madeira has been well summarized by Clarke (1954), that in Indonesia by Barnes (1996), and that in the West Indies by Price (1985). The British, German, and other pelagic sperm whale fisheries (e.g., Chile, Hawaii, Canada, Peru, Japan, etc.) will be more challenging than the American and French components, in terms of identifying and obtaining adequate source material. Another challenging, but key, part of the synthesis will be reconciling differences between sources. For example, the summaries of grounds by Townsend, Clark, and Wilkes (in Clark 1887) are not always consistent.

The synthesis may include a table showing the relevant dates (years) for each milestone (opening, peak catch, "abandonment," etc.), by ground and nation. A chart or charts showing, at least crudely, the various named grounds would be a useful part of the synthesis.

5.1.2 Determining movement patterns in the whaling voyages
Whaling voyages from various regions followed typical routes or itineraries. These were influenced, *inter alia*, by wind and current patterns; strategic access to sources of water, wood, supplemental crew members, and victuals; seasonal weather cycles; and of course the locations of productive whaling grounds. The aspects of the synthesis outlined above (5.1.1) would be expected to provide insights about the standard routing and timing of whaling voyages and how these relate to the whaling grounds A separate effort is needed, however, to identify and characterize the movement patterns of the various pelagic whaling fleets. This could initially involve collation of existing published depictions of cruise tracks (e.g., Shapiro and Stackpole 1959; Hayford and Parker 1967:xix; Dahl 1971; Mitchell 1983) and any working sketches of cruise tracks available in whaling museum libraries and other archives. The materials will vary widely in their degree of detail and probably in their reliability and usefulness. Some tracks are only partial and therefore of limited use (e.g., see Ross 1975, pp. 41, 58, 130; Bockstoce 1986, pp. 23, 99, 123, and 145).

Given the general scarcity of completely charted voyage tracks, a separate follow-up activity would be to supplement those sketches that are already available with a series derived directly from logbook data. The intention would be to have a representative sample depicting central tendencies of various fleets, periods, etc. Data sources might include the Maury abstracts (see Appendix 4), data sheets prepared by Reeves from logbooks examined for humpback whale studies, and voyage abstracts contained in the indices and working files of whaling museums (e.g., Kendall Institute).

This "mapping" component of the synthesis would provide a resource of potential use to various other elements of the overall research program. For example, it would help to answer questions concerning announced voyage destinations (see 5.2) and grounds actually whaled. Did whaleships (whether from New England, France, or England) usually approach the New Holland Ground (western Australia) or the Sulu Sea (eastern Indonesia/Philippines) via the South Pacific or the Indian Ocean? The question of how, or whether, to divide the Indian Ocean into two separate "basins" may hinge in large part upon the itineraries of the whalers. Did virtually all voyages to the western Indian Ocean (see Wray and Martin 1983) enter and leave via the Cape of Good Hope? If so, the split as Western Indian Ocean/Indo-Pacific Ocean may have practical utility. Further, to what extent might one be able to predict which whaling grounds were visited on a particular voyage simply by knowing the date of departure and the announced destination? Better knowledge of typical whaling circuits followed by the whalers would inform the design of studies that involve stratification of data or of sampling effort, especially in the selection of stratified random samples of logbooks (see 5.5.1).

5.2 Determination of the geographic locations of pelagic whaling
Determining whale catches by oceanic region is straightforward for shore stations, but requires information on the specific locations for pelagic whaling. The nature of the problem is different for US and non-US vessels.

Any effort to estimate catches on a regional basis, using sperm oil production as the fundamental proxy for number of whales killed and processed, must involve a method of allocating oil quantities to the regional units of interest, whether these are ocean basins or smaller areas such as large marine ecosystems or whaling grounds. The data on announced and actual destinations provide a useful means of stratifying voyages. For example, if one were interested in estimating catches in the Pacific or Indian Ocean, or in a part or parts of these basins, the first-order distinction between voyages that remained in the Atlantic and those that rounded Cape Horn or Cape of Good Hope would be extremely useful. It would not, however, resolve the question of how much, or what proportion, of the total sperm oil obtained on a given voyage was obtained on Atlantic grounds while the vessel was *en route* to or from its Pacific or Indian Ocean destination. Knowing the destination of a voyage does not necessarily mean that all, or even most, of the whales were taken in that ocean basin or ground. In fact, there are numerous instances in which much of the whaling and most or all of the catch was made in an area outside the voyage "destination." P. Best (pers. comm.) mentioned one "Indian Ocean" voyage which, although it went round Cape of Good Hope and as far east as Western Australia, ended up catching nearly all of its whales off southern Angola in the South Atlantic.

Knowing which whaling grounds were visited would be useful, but not necessarily definitive, in deciding, for example, how to pro-rate the total amount of sperm oil to ocean basin or to ground. Therefore, the use of sources that provide within-voyage data on where catches were actually made (i.e., sperm oil was obtained) is unavoidable. (Similarly, if the intention is to use indices (e.g., encounter rates) to calculate relative or absolute abundance, it is necessary to know how whaling effort was distributed spatially and temporally within a voyage.)

As shown in the table of Appendix 5, information on where the sperm oil of a given voyage was obtained can most reliably be obtained from logbooks and logbook-derived sources. Useful data can include both direct records of where the principal vessel whaled and took whales, and indirect records in that vessel's logbook describing the locations, (interim) returns, and activities of spoken vessels.

Short of mounting a full-scale study incorporating new logbook data extractions, much relevant voyage-based data on numbers of whales and/or amounts of sperm oil taken in different ocean basins or on different whaling grounds may be obtainable in other ways or from other sources. For example, Wray and Martin (1983) appear to have extracted all of the data on sperm whale catches (and strikes) within the western Indian Ocean from the logbooks of 27 voyages. It would be informative to compare returns for those voyages in Starbuck and Hegarty, and attempt to make inferences about the likely numbers of sperm whales taken outside the western Indian Ocean, e.g., on South or North Atlantic grounds during the outbound or inbound legs of the voyages. Similar exercises using published data from studies of Pacific whaling grounds (e.g., Bannister et al. 1981; Hope and Whitehead 1991) and unpublished data from North Atlantic studies (Reeves, unpubl. data) may yield useful insights. Although the voyage-by-voyage tables in Townsend (1935) do not break down sperm whale catches by ocean basin, data from the Townsend abstracts (A-J), the Maury abstracts, the Wood abstracts, and docent data sheets may prove sufficiently consistent and detailed for catch/product allocations. Depending upon the research question being addressed and the sampling strategy selected, further direct examinations of logbooks may or may not be required.

5.2.1 US pelagic whaling voyage destinations

An initial assessment is needed to determine the temporal and spatial distribution of voyages for which logbook-level data exist. In addition to the extant logbooks in public collections (Sherman et al. 1986; Lund 2001), the Maury and Townsend (A-J) abstracts provide relatively detailed data extractions from more than 250 logbooks that are no longer available (the Maury set alone includes somewhat more than 570 abstracts; J. Lund, pers. comm.). Much of the necessary background work of establishing the existence and whereabouts of logbook materials, announced and actual voyage destinations, and total sperm oil returns (landings) by voyage will have been completed in the course of generating global estimates (above).

A basic feature of most statistical compilations of voyages (e.g., Starbuck 1878; Hegarty 1959; Sherman et al. 1986) is announced destination, that is, the ocean basin (or sometimes a more specific region, such as Hudson Bay or Greenland) to which a vessel was said to be bound as it left its port of origin. The information on voyage destination provides an obvious way of stratifying fleet effort and thus, potentially, beginning to break down product returns or whale catches by region. However, it has been noted that the information on destination provided by Starbuck (1878) and Hegarty (1959) is not always reliable and that it is frequently inconsistent with the information on destination provided by Sherman et al. (1986) for voyages represented by extant logbooks. Moreover, the updated, more nearly complete compilation of American voyages by Lund (2001) does not include any information on destination.

There are several sources of reliable information on where voyages actually went, among these the various published studies based on logbook examinations (e.g., Bannister et al. 1981; Mitchell and Reeves 1983; Wray and Martin 1983; Reeves and Mitchell 1986; Hope and Whitehead 1991; Reeves et al. 2001, in press), the published index compiled by Langdon (1978), the Townsend (A-J) and Maury abstracts, the Dennis Wood abstracts, and the voyage data sheets prepared by docents from logbooks held in whaling museum libraries.[1] Some unpublished data are also available on work sheets prepared by Reeves while examining logbooks for previous studies.

[1] The readers, often volunteers, who prepare data sheets for museum files are not always referred to as docents, but this term has been adopted herein for convenience.

It should be possible to ascertain the actual destinations of a large percentage of American voyages by reference to the sources listed above, particularly if all "spoken" voyages are taken into account. It would be useful to have reliable destinations of as many voyages as possible entered into a master database that includes all voyages listed by Lund (2001) and any additional voyages identified subsequent to her compilation.

Appendix 5 was developed during the workshop as a derivation of J.G. Mead's appendix to the 1977 Sharon workshop report (IWC 1983, p. 11, Appendix F). It provides a stepwise procedure for establishing voyage destinations (and product information).

5.2.2 Non-US pelagic whaling voyage destinations

The same need for information on voyage destinations applies to the non-US fleets, although the process that could be used to list the voyages and verify their destinations was not as clear (to participants in the Cachalot Workshop) as it was for American voyages.

There is clearly a need to assess the existence and availability of logbooks, and logbook-like materials, covering non-U.S. voyages (especially French and British). Reports prepared by ship captains for many 19th century French voyages apparently exist in French archives (T. Du Pasquier via P.B. Best, pers. comm.), and logbooks of a small fraction of the British and German "South Seas" voyages are available in public institutions in North America (e.g., Sherman et al. 1986). There is reason to believe that there may be a substantial collection of British logbooks in the Public Record Office, hitherto unexamined (*fide* S. Frank).

It was recognized that accounting for non-US voyages would be a major weakness of the catch history studies as presently envisaged. All readily available logbooks for such voyages should be examined, and information from the synthesis described in section 5.1 should be used to develop rationales for approximating the destinations, and indeed whaling areas, of non-US voyages.

5.3 Logbook Data Extraction Procedures

5.3.1 Gazetteer

An important aspect of any effort to extract spatially referenced data from archival sources (logbooks in particular) is associating place names with geographic coordinates. As observed by Reeves et al. (2001), "The whalemen who kept logbooks or journals present the reader with an often bewildering array of place names." Their own vernacular terms often varied greatly from the modern, formally accepted place names found in standard atlases. Their spelling (and handwriting) was uneven, and their corruptions or attempts at literal translation of non-English words further complicate interpretation. Special care is needed for names that are/were applied to more than one location – e.g. Trinidad Island in the South Atlantic and Trinidad in the southeastern Caribbean Sea, the island of São Tomé off equatorial western Africa and St. Thomas in the Antilles.

The notion of compiling a special gazetteer relevant to a particular area of whaling research is not new (see Bockstoce and Batchelder 1978). Compilation of a gazetteer specifically for the sperm whale fishery is particularly challenging because of the enormous geographic range involved. Nevertheless, such a compilation should be integral to any regionally focused study that involves the extraction of data from logbooks and other archival documents. There should be a consistent protocol for accumulating geographic coordinates and variations in spelling for the place names encountered in the archival materials. A readily accessible gazetteer database, or series of databases, should be established to facilitate the development of a definitive toponymy for the sperm whale fishery.

5.3.2 Assemble and computerize previously extracted data

Based on the recommendations of the whaling history workshop in 1977 (IWC 1983), substantial amounts of data have been extracted from voyage logbooks, principally those kept aboard US vessels. The experience gained in extracting those data, as well as the extracted data, is potentially valuable to the present project. Previously published studies involving logbook data extractions include those by Bannister *et al.* (1981), Bockstoce and Botkin (1983), Mitchell and Reeves (1983), Wray and Martin (1983), Reeves and Mitchell (1986), Hope and Whitehead (1991), Reeves et al. (2001, 2002), and Smith and Reeves (2002). While not all of these studies pertained directly to sperm whaling, even those that focused on other species often yielded some data on sperm whales. Moreover, all of

them addressed the question of where whaling took place on a given voyage, and on other voyages recorded in the logbooks as "spoken" on a given whaling ground.

Participants in the Cachalot Workshop agreed to make the data from projects with which they had been involved available for computerization and integration into a large database for this project. It was also agreed that invitations to collaborate should be extended to individuals holding other data sets, so that the full value of those data sets could be realized.

Where possible, previously computerized data sets should be transferred into relational database formats and linked to the voyage database described in section 4.2. Those data sets that have not been computerized, and those that have been incompletely computerized, should be entered into modern relational database formats. In this work, care should be taken to include information on geographic locations using the gazetteer database structure described in section 5.3.1.

5.3.3 Review of protocols for logbook data extraction

The previously extracted logbook data described in section 5.3.2 provide the basis for evaluating the data extraction protocols that were used, and refining them for future similar work.

Logbooks normally contain daily information on movements and activities during the course of lengthy, often multi-year voyages. Therefore, to achieve consistent data extraction from such sources, which were intended to be industrial, not scientific, records, requires carefully developed protocols. Previous studies (e.g., Bannister et al. 1981; Bockstoce and Botkin 1983; Hope and Whitehead 1991; Smith and Reeves 2002) have involved particular protocols for extracting biological and other data from whaling logbooks and related documents. Development of data-extraction protocols was a major feature of the Sharon 1977 workshop (IWC 1983), and these were used to good effect in the ensuing studies by Bannister et al. (1981) and Bockstoce and Botkin (1983).

Previously used protocols need to be reviewed, with the goal of identifying additional types of data that should be extracted as well as data that were collected in previous studies but found to be superfluous. This will require that already-extracted data be organized to make them accessible and facilitate evaluation. It may involve the computerization of handwritten data-extraction sheets (e.g., from Bannister et al. 1981; Reeves, unpubl.) or attempting to gain access to computerized data sets (e.g., from Bockstoce and Botkin 1983; Hope and Whitehead 1991).

Several issues have already been identified. One is how to consistently record information on the condition (or fate) of struck whales that are not secured (to standardize the process of assigning probabilities of survival). It is unlikely that the only struck/lost whales that died from their wounds were those recorded as either killed outright and lost, or lost spouting blood. For example, it could be relevant to know whether the escaped whale was towing gear (e.g., the harpoon line was cut) or not (e.g., iron "drew") and whether it had or had not been struck with a bomb lance (see Mitchell and Reeves 1983).

Records of "spoken" vessels proved key to catch estimation in the regional studies by Bannister et al. (1981; and see Tillman and Breiwick 1983) and Hope and Whitehead (1991). Although it will be necessary to reconcile differences in the ways these data were interpreted and analyzed in previous studies (e.g., see Appendix 1), what is important here is to ensure that all entries related to spoken vessels are extracted in detail from "read" logbooks, or "read" portions of logbooks. This must include recording the vessel's presence in an area as well as its reported amount of whale products on board, etc. (e.g., references to trans-shipment, numbers of whales taken or struck/lost, any indication as to when or where catches were/were not made).

Another issue is whether and how to record weather data. For example, although Bannister et al. (1981) classified days with "thick" weather conditions to be non-whaling days on the Japan Grounds, Hope and Whitehead (1991) found that whales were sometimes taken on such days off the Galápagos. The weather issue might be addressed by comparing indices of abundance that do and do not involve weather judgments. Such a comparison would make it possible to decide whether the improvement in statistical properties is sufficient to warrant the expenditure of time to continue extracting weather data in future studies.

5.3.4 Voyage Productivity Indices

In addition to catch history, *per se*, there is interest in developing various "performance indices" for voyages, e.g., numbers of sightings (whale encounters) or catches per whaling day. Such indices can be useful for evaluating changes in abundance/availability of whales in the study area, and also for estimating abundance (see Tillman and Breiwick 1983; Appendix 6). Both Bannister et al. (1981) and Hope and Whitehead (1991) found significant (downward) trends over time in at least some of these indices in their analyses of American whaling on the Japan Grounds and Galápagos Grounds, respectively. The "paradox" discussed above and in Appendix 2 hinges in part on how such indices are interpreted. For example, while Bannister et al. (1981) and Tillman and Breiwick (1983) interpreted them as reflecting changes in whale abundance on the Japan Grounds, Davis et al. (1997) and Chatwin (1997) considered vessel productivity to be affected at least as much by economic and capital investment as by whale abundance.

Further analyses of previously extracted data (see 5.3.2) should be pursued to better characterize these indices. This part of the overall program of research would involve an integrated statistical analysis of both logbook data and economic/industrial data, such as product prices and vessel rigs or tonnages. Initial exploratory analyses would be needed to establish the statistical properties of these data, followed by comparisons among the various indices to evaluate whether they are or are not likely to be proportional to whale abundance.

Definitive determination of the relationship between voyage productivity indices and whale density or abundance would, of course, require independent data on whale abundance, which are unavailable (and will remain so) for the period of the fishery. In this regard, it may be instructive to consider the arduous and ultimately unproductive discussions about the validity of CPUE in modern whale population assessments, and evaluate whether the CPUE-type data that can be obtained from the historical open-boat fisheries are likely to fare any better. Measures of "searching time," "chasing time," and "handling time" derived from 19th century logbooks are bound to be at least as crude and fraught with ambiguity as those from modern whaling operations. For example, the logbook reader has no idea of the number of whales seen, just that sightings were either "single" or "plural" (see Bannister et al. 1981). Further, we do not have unambiguous evidence of how the whalers' searching strategies changed in the face of declining whale availability (or increased competition among vessels). Nonetheless, the indices examined by Bannister et al. (1981) and Hope and Whitehead (1991) clearly showed marked changes over time and therefore may include significant information about the fishery and the whale populations.

Issues that would be worth examining systematically using logbook data include: (1) whether the frequency of whale observations recorded in logbooks varies with fishing success, (2) how to account for time spent processing whales that have been brought alongside a vessel, and (3) the effects of various economic/industrial variables on fishing success (see Best 1983 for a summary of many of the possibilities). An issue that always arises with fishery-based performance data is the possibility that the behavior of the fishermen (whalers in this case) and/or the target organisms (whales) changed over the course of the fishery. For example, Bannister et al. (1981) demonstrated that the spatial distribution of whaling on the Japan Grounds shifted eastward over time, but the cause of this shift was unclear. Was it related to better intelligence on the part of the whalers about where to find whale concentrations (see Whitehead and Hope 1991), or to some change in fleet characteristics? Did it reflect the tendency of whales to avoid the heavily fished western parts of the ground? Or was it because the whale population(s) occupying the western areas was (were) becoming progressively depleted? Whaling logbooks and other documents are replete with references to the whales being more difficult to approach in some areas and in some years, and to various "coalitions" of whaling vessels that may have affected searching efficiency.

More generally, attempts should be made to identify situations where such effects can be isolated and subjected to statistical testing. For example, it may be instructive to compare both the spatial changes in the fishery (and the indices) within grounds and between the two Japan and the Galapagos grounds over time. Further, the potential magnitude of changes in whale behavior might be estimated by comparing sighting and capture rates on these grounds when they were first exploited and after the fishery had developed, to see if the indices change in parallel or differentially.

5.4 Workshop on sperm whale population structure and ecology

Regional studies of sperm whale catch history and trends in abundance will be most meaningful if they are designed with a firm understanding of population structure, including spatial distributions, migratory movements, social behavior, and population dynamics (see Appendix 6). To this end, there is an explicit need within the context of the research program proposed herein, to bring together experts on sperm whale behavior, ecology, population dynamics, and genetic population structure and experts on whaling history and methods of compiling and analyzing historical whaling data. A workshop-type meeting should be organized with the clear goal of providing guidance on population structure essential for the design of regional historical studies of sperm whale catch history. While it may be unrealistic, given the state of knowledge, to expect unambiguous advice on this subject, assistance is needed in defining and delineating geographical/biological populations of sperm whales, however provisionally. Attention also needs to be given to identifying ecosystems, or at least ecosystem characteristics (cf. Longhurst 1999), that might serve as the basis for designing regional studies of sperm whale catch history.

5.5 Extraction of new data from logbooks

While the data previously extracted from logbooks will be valuable for addressing certain methodological issues, they will need to be augmented by data extracted from additional logbooks to estimate catches in other areas. Aspects of study design and implementation are discussed below.

5.5.1 Design of logbook reading

The nature and availability of logbooks and journals (both generically referred to herein as logbooks) varies widely. Most American whaling logbooks are held in public collections (museums and libraries) in the northeastern United States. A large fraction of them has been microfilmed, which makes interlibrary loan feasible, but with several provisos. At least one major collection (New Bedford Free Public Library) no longer sends out logbook microfilms on interlibrary loan. Those institutions that continue to participate in this service will send only small numbers of reels (1-3) per request, which obviously affects the pace at which remote-site data extraction can be conducted. Moreover, the uneven quality of microfilms means that in some instances, a microfilmed logbook is effectively unreadable, whereas it would be possible to extract the needed data by examination of the original document.

In previous studies using logbook data, researchers have developed their own criteria and procedures for defining logbooks that are acceptable for sampling, e.g., on the basis of legibility, level of detail in the logbook entries, completeness with respect to the study area, etc. Relevant information about logbook "quality" is not currently available to researchers via standard reference sources. The inventory by Sherman et al. (1986) provides the start and end dates of listed documents, so it is possible to make a provisional judgment as to whether, for example, a given document is likely to cover an entire voyage or only a portion of it. Lund's (2001) compilation only identifies the institutions where logbooks are held; it provides no information about completeness. Neither of these sources provides any insight as to legibility or level of detail in the logbook entries.

As identification and selection of logbooks for data extraction will be a crucial element of any regional catch-history study, the collation of information on logbook quality is a potentially useful task. Considerable information of this kind is available from published studies in which the quality of the logbooks that were handled is recorded (cf., Bannister et al. 1981; Hope and Whitehead 1991; possibly Bockstoce and Botkin 1983). Museum cataloging records (e.g., index cards, docent data sheets) frequently provide sufficient information for making judgments about quality and completeness of logbooks. In addition, Reeves (and perhaps other researchers?), during the course of his own logbook research, has compiled relatively extensive notes on whether or not certain logbooks are legible, complete, detailed, etc. with respect to sperm whale catch and effort. There is considerable uncertainty, however, whether any of those previous studies will have provided sufficient information of this kind. Moreover, knowing logbook quality in advance may introduce unwanted bias. It may be preferable to stratify the sampling on an objective basis, e.g., percentage of fleet or percentage of available logbooks, with the logbooks to be examined chosen at random and only rejected and replaced if uninformative (cf. Smith and Reeves 2002).

An important consideration is whether data should be extracted in a consistent fashion from entire logbooks, or alternatively, the pattern of most previous studies should be continued, that is, extracting data only from those portions of logbooks that pertain to a discrete research topic, e.g., a whaling ground (Bannister et al. 1981; Hope and Whitehead (1991), an ocean "basin" (Wray and Martin 1983), a whale population (Bockstoce and Botkin 1983), or a

species within a particular region (Mitchell and Reeves 1983; Reeves and Mitchell 1986). Previous regional studies of American open-boat whaling have focused on specific whaling grounds, and the data extracted from logbooks have been limited to the periods while the vessels were on or near the target ground (i.e., the "study area"). Obviously, such selectivity constrains the interpretive context and may lead to misinterpretations of various kinds.

While it is generally agreed that the ideal arrangement would be to have all of the desired data extracted from each logbook that is examined (or "read"), the labor-intensive nature of the data-extraction process may mean that such a comprehensive approach is infeasible from a cost or time perspective. If this proves to be the case, the information to be collated under sections 5.1 and 5.2 on patterns in the use of the various whaling grounds would help to determine the portions of voyage logbooks that should be read. The choice must depend, at least to some extent, on the strategy of sampling: if the intent is to sample the fishery as a whole, then data from the entire voyage should be extracted; if only a whaling ground, then data only from that part of the voyage.

Other tasks related to logbook selection are to examine: (1) the representativeness of the voyages for which logbooks are presently extant, and (2) systematic differences in the nature of the logbooks held by different institutions. In relation to (1), for example, logbooks from especially successful voyages or to particular regions may be more likely to have been retained and deposited in public collections. In relation to (2), it is plausible that the various logbook collections have different emphases. For example, New Bedford-based collections may have a higher proportion of logbooks of voyages sailing from New Bedford, Dartmouth, and other nearby ports, whereas the library at Mystic may have an exceptionally high proportion of logbooks from Connecticut-based voyages, etc.

Sample sizes

Previous studies have used somewhat arbitrary rules-of-thumb in deciding how many logbooks to consult. For example, the 1977 Sharon workshop recommended that 100 logbooks be used for the Bannister et al. (1981) study. In contrast, Bockstoce and Botkin (1983) extracted data from all relevant logbooks that met their requirements of quality and completeness, regardless of statistical considerations. Mitchell and Reeves (1983) and Reeves and Mitchell (1986) similarly attempted to identify and examine all available logbooks of voyages that they had reason to believe might contain catch data on West Indies humpback whales and North Atlantic right whales, respectively. Smith and Reeves (2002) designed a sampling scheme, stratified by port and voyage returns, to distribute their logbook data-extraction effort efficiently.

To better understand the relationships between sample size and statistical precision, we propose to analyze samples of the data collected by Bannister et al. (1981), and possibly data from other researchers. Based on the results of these exploratory analyses, in combination with data on the numbers and distribution of extant logbooks, it should be possible to improve study designs to allow incorporation of some measures of statistical bias and sampling error.

Regional Priorities

The priorities for undertaking regional studies will depend, at least in part, on the number and quality of logbooks for voyages to the various regions, as well as on the nature of research questions to be addressed. Higher priority might be given to regions where a suitably large sample of "good" logbooks is available covering the peak years of whaling activity. The data that will have been compiled and analyzed while completing many of the foregoing tasks should help refine the priorities for regional studies. Provisionally, it has been agreed that regional studies in the Indian Ocean should be given the highest priority simply because the proportion of voyages covered by logbooks, during the peak years of the fishery there, is thought to be relatively high. Indian Ocean regional studies might therefore be expected to yield relatively clean results.

Other issues in setting priorities will clearly depend upon management concerns and the priorities of potential collaborators or sponsors. For example, within the IWC the Pacific Ocean, and particularly the North Pacific, has been a major focus of prior discussions concerning sperm whale science and conservation (e.g., IWC 1980). Also, given that two regional studies have already been completed for two major Pacific whaling grounds (Bannister et al. 1981; Hope and Whitehead 1991), a strong argument might be made for building upon that work in the hopes of producing a more nearly definitive catch history for the Pacific Ocean. Alternatively, or as well, the emphasis of the Census of Marine Life on specific marine regions (e.g., North Pacific and Bering Sea) might give reason to focus on one or more areas that would be of direct relevance to that program's ecological modeling and other priorities.

Priorities might also be driven, or at least strongly influenced, by hypotheses concerning, and evidence of, stock structure (see 5.4).

5.5.2 Implementation of data extraction

Implementation of logbook-based regional studies will require large commitments of time from individuals with specialized skills. The intention would be to hire/contract people to carry out the data-extraction tasks. They would need to be trained to ensure that data are recorded accurately and consistently, and their work would need to be checked regularly for quality control. A goal would be to minimize turnover in personnel and thus to maintain methodological consistency and take full advantage of accumulated experience. Logbooks that have not been microfilmed, or that are judged to be illegible on microfilm, will present special problems. It will be necessary to make judgments on an *ad hoc* basis as to whether efforts to gain access to the original documents are necessary and cost-effective. This may not be a trivial matter. For example, access to the collections in Mystic, Nantucket, and Martha's Vineyard may prove costly, and they may include key documents for particular regions or periods requiring coverage beyond what is available in the more readily accessible collections in New Bedford and Providence.

It is strongly preferred that the work of data extraction should take place in facilities where consultation and collaboration among researchers can be facilitated and encouraged. This was a major benefit during the study by Bockstoce and Botkin (1983), where all of the data extraction was conducted at the New Bedford Whaling Museum. Such an arrangement would give the data extractors access to reference materials and expertise (e.g., librarians and curators), so that as uncertainties and novelties arose, they could be handled in an appropriate (and hopefully consistent) manner. Data extractors should be provided with relevant maps and gazetteers (see 5.3.1).

The extracted data would be entered into relational databases linked to the master list of voyages prepared for the global component of the research program (see Section 4). All databases should be designed to allow the data to be archived once analyses are complete. Web-based archiving is planned through the Census of Marine Life, and data would become publicly available after analyses are completed.

5.6 Analysis of extracted logbook data

The methodologies used to estimate catches of sperm whales in the previous studies by Bannister et al. (1981), Tillman and Breiwick (1983), and Hope and Whitehead (1991) were essentially sound. It is expected that further regional studies, as proposed herein, would adopt similar methodologies for catch estimation, but also incorporate any improvements, as outlined above. Moreover, accuracy should be improved by integrating data from a more nearly complete and up-to-date list of voyages, including insofar as possible all participating non-U.S. fleets and any shore-based operations that might have affected the whale population or ecosystem under study. The data on spoken vessels should be more carefully and thoughtfully managed, both in terms of how they are extracted from logbooks and how they are interpreted and analyzed. Probabilistic analyses of the rate at which vessels were encountered ("spoken") on a whaling ground were used by Hope and Whitehead (1991), and more sophisticated analyses of such data in a "mark-recapture" context may be possible.

5.6.1 Regional Catch Estimation

Estimates of sperm whale catches in an ocean basin or other geographical area (W_i) over time could be derived from the voyage-based data described and discussed above under 5.5, using a stratified random sampling approach similar to that of Smith and Reeves (2002). The basic form of the estimates would be the product of the number of voyages to that basin or area (V), average amount of sperm oil (bbl) produced per voyage (B), average proportion of a voyage's sperm oil production obtained in that basin or area (P), and ratio of sperm whales struck to those caught (S_L), divided by the average oil yield (bbl) per whale (B_w), thus:

$$W_i = V_i B_i P_i S_{L,i} / B_{w,i}$$

While this basic formula could be applied for each time period and each ocean basin or other region, denoted by i, certain of the factors could be further stratified (for example, by vessel rig or tonnage; see Best 1983, 2002), or pooled, depending upon the extent and quality of the information available. Sample sizes needed for meaningful results would, at least in part, dictate which of, and how many of, the potential sources of "logbook" data (see 5.3

and 5.5) are consulted.

Statistical uncertainty (variance) could be computed for these estimates by accounting for the statistical distribution of sperm oil production by "unsampled" voyages, proportions of sperm oil attributed to each ocean basin or area, sperm oil yields per whale, and struck/ lost rates In most cases, the number of voyages would be negatively biased to some unknown extent, but the expected major effort to account for all voyages, at least in the American fishery (see Appendix 4), should mean that this bias is fairly small.

5.6.2 Catch size and sex composition
An important step in assessing the impacts of whaling on sperm whale populations is to estimate the catch composition, especially male:female ratios. After reviewing much of the literature, Best (1983) concluded, "it does not seem possible to establish whether any size selectivity [e.g., a preference for, or indeed avoidance of, large bulls] definitely operated in the fishery." There are a number of approaches that might be used to obtain relevant data from logbooks. Bannister et al. (1981) found from their logbook data that the catch composition on the "Japan" ground changed in the late 1830s, from primarily females and small males plus some large males before 1835, to mostly medium-sized males in "bachelor schools" away from the breeding schools between 1840-55. This change appeared to be correlated with a spatial shift in whaling effort.

Examination of a carefully selected sample of logbooks, explicitly to investigate how the whalers responded to encounters with schools and individuals, could prove informative. This would include not only the data on strikes and catches, *per se*, but also entries concerning the relative desirability of catching different size, sex, or social classes of sperm whales. Such an examination would be particularly useful if it was stratified by area and time period, if not also by fleet (e.g., American, British, French, and German whalemen may have had different selectivity patterns). Alternatively, large samples of logbook records of oil yields for individual whales could be analyzed for patterns suggestive of size (and thus sex) selectivity. In the absence of logbook data, some inferences or assumptions can be made about the likely catch composition in different regions, given the ontogenetic and sexually determined social and spatial grouping patterns of sperm whales (cf. Best 1979).

5.6.3 Computing Voyage Productivity Indices
Various voyage productivity indices will be calculated for the logbook data to be extracted under sections 5.3.2 and 5.5.2. The methods of computing indices will be based on the work described in section 5.3.4. These indices will be calculated for various combinations of oceanic regions, using the results of the sperm whale workshop (5.4), to insure ease of input to section 7.1.

6.0 Modern Whaling Catches
Collation of 20th century catch data should be relatively straightforward, as most modern whaling operations reported their catch data to the Bureau of International Whaling Statistics, and later the IWC. These records have been used in previous analyses (e.g., see IWC 1980 and associated papers in that volume).

Recent work by the Secretariat of the IWC has focused on entering all available data into simple computer files for each whaling operation, including extensive evaluation and cross-checking of the data. While the vast majority of the data has proven reliable, there are questions about the accuracy and completeness of some reported catches. These include recent revelations of misreporting by the USSR (Yablokov 1994; Zemsky et al. 1995a, 1995b) and Japan (Kasuya 1999). Those revelations have included the presentation of more accurate data to the IWC by nationals from the countries of the whaling operations implicated.

The Census of Marine Life has undertaken to integrate the data files created by the IWC Secretariat into a modern relational database, and that task should be completed early in 2003. The IWC Scientific Committee has agreed to pursue the problem of estimating catches where the reports were incomplete or falsified. Work on that task will proceed over the next few years (IWC 2002).

7.0 Estimation of population changes over time
Sperm whale abundance over time can be estimated using models similar to those used by Tillman and Breiwick (1983), incorporating extensions developed during the past two decades. In addition to information on population

rates of increase (to be developed in the sperm whale biology workshop, 5.4) and voyage productivity indices (see 5.6.3), data requirements include complete regional catch histories and present-day abundance estimates.

It is important for such analyses that the catch history and abundance estimates pertain to the entire range of the sperm whale stock or biological population. This is necessary to avoid one problem with the studies by Bannister et al. (1981) and Tillman and Breiwick (1983), namely that the same sperm whale population hunted on the Coast of Japan and Japan Grounds during the 19th century may also have been hunted during the same period in other parts of its range, e.g., the On the Line Ground. Uncertainty with regard to the spatial boundaries of a population makes analysis especially difficult and generally requires multiple analyses under a range of alternative hypotheses. For each hypothesis, a different catch-history and abundance configuration is required.

7.1 Estimation of absolute abundance of sperm whales over time

The population-estimation models referred to above (and see Appendix 6) will be applied to the entire suite of data compiled under this program of research. That task will be pursued in consultation and collaboration with the IWC Scientific Committee as a part of its assessment of sperm whale status.

Present-day estimates of sperm whale abundance will be used as they become available. A variety of approaches have been suggested for improving information on sperm whale abundance, including the use of acoustic surveys to complement visual sighting surveys (Whitehead 2002). The novel approaches to spatial extrapolation developed by Whitehead (2002) should be explored further, refined as necessary, and supplemented if possible with fresh ideas. The IWC SC is expected to pursue these matters over the next few years.

Further development of population back-calculation methods is also expected to occur within the IWC SC. This work should address uncertainties in the data and in the assumptions about population spatial structure and population dynamics. Several of the specific studies outlined above will provide useful information in such that regard. For example, the synthesis of the spatial and temporal patterns of whaling operations on each whaling ground (see 5.1) would be useful in interpreting changes in indices of abundance. In addition, a summary of prevailing economic and other non-biological factors that might have influenced whaling effort would be useful. A good understanding of the statistical properties of various fishery productivity factors, e.g., catch or sightings per unit of effort (see 5.3.4), would also facilitate interpretation. Data extracted previously from logbooks could be analyzed to better understand the statistical properties of such potential indices of abundance. Another useful input will be knowledge about the historical age and sex composition of the catches (see 5.6.2).

A workshop of historians, economists, and biologists may be useful for interpreting the results of the studies outlined here, especially those related to economic factor productivity (e.g., Davis et al. 1997) and those used to infer voyage productivity indices. While the latter are undoubtedly correlated to some degree with sperm whale abundance, they are also likely influenced by changes in technology, market effects, whaling practices, or possibly even whale behavior (e.g., avoidance of whaling vessels). A multidisciplinary workshop of this kind would improve the likelihood that all relevant factors have been taken into account in analyses of fishery (and sperm whale population) trends.

8. Conclusions

The research program outlined here and summarized in Table 1 should substantially improve our understanding of the effects of whaling on sperm whale populations worldwide and on regional scales. Our intention has been to design the projects and related tasks so that they would form a natural progression, with the results from each step being useful in their own right, but also contributing to the design and implementation of subsequent steps. The tasks are nonetheless uneven, in part due the nature of the historical source material and in part due to the nature of previous studies.

At the completion of the entire research program, including the aspects that involve integration and use of the data on whaling catch and effort (the focus of the present report), we should have a much greater understanding of the past, present, and possibly even future role of sperm whales in pelagic marine ecosystems.

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LIST OF APPENDICES[1]

Appendix 1. Studies of catch levels in the American ("Yankee") pelagic whale fishery: a methodological review, by R.R. Reeves and T.D. Smith.

Appendix 2. Elaboration of the "paradox" relating to 19th century vs. 20th century abundance estimates, by T.D. Smith.

Appendix 3. Assessing the overall catch of sperm whales in the international open-boat fishery. Possible improvements to, and means of assessing accuracy of, the approach attempted by Best (2002), by Peter B. Best.

Appendix 4. Whaling masters and whaling voyages: a review of historical sources, by Judith N. Lund.

Appendix 5. Stepwise procedure for establishing where voyages went and what they caught.

Appendix 6. Estimation of global sperm whale pre-exploitation population size, by M.F. Tillman and J.M. Breiwick.

Report continues here with appendixes.

[1] **Appendices in file Cachapp.pdf at http://www.cmrh.dk/hmapindx.html at Southern Denmark University.**