Report of the International Cachalot Assessment Research Planning Workshop, Woods Hole, Massachusetts, 1-3 March 2005

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U. S. DEPARTMENT OF COMMERCE
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CONTENTS

TABLES

ANNEXES

1. WELCOME

Smith welcomed participants on behalf of the conveners (Smith and Reeves). Despite a major snowstorm in the New England region, nearly everyone was able to arrive safely and on time. The list of participants is given in Annex 1.

Clapham spoke briefly about the life of Bill Watkins, an esteemed scientist at the Woods Hole Oceanographic Institution and pioneer of research on sperm whale behavior. For many workshop participants, Bill's death in late September 2004 meant the loss of a valued and generous colleague. He was an innovative and influential force in the fields of marine bioacoustics and telemetry, a great editor, a unique resource, and a remarkable man. As such, he will be missed by many of us in the marine mammal community. Kerr and Godard spoke briefly about Rebecca Clark, a young scientist killed by the tsunami in December 2004 while working on a sea turtle project in Thailand. She had been associated with the voyage of the *Odyssey* since 1999. Kerr recalled that after sailing from the Galápagos to the Marquesas (54 days at sea) and spending only four days on shore in "paradise," Rebecca had been eager to resume the voyage. She is remembered as an enthusiastic, meticulous, hardworking, and good-humored colleague. Bannister noted that the Australian Government and its Department of the Environment and Heritage had asked to be associated with the remembrance of Rebecca Clark at this workshop.

2. REVIEW TERMS OF REFERENCE, AGENDA, AVAILABLE DOCUMENTATION, AND MEETING ARRANGEMENTS

The terms of reference for the workshop, developed by a steering group within the International Whaling Commission's Scientific Committee, were as follows:

- Identify and evaluate new methods, identify critical tests of such methods, and describe how these might be conducted, especially using combinations of new methods simultaneously.
- Identify relevant spatial scales and formulate plans for regional field studies to address key uncertainties relevant to an eventual In-depth Assessment.
- Develop a research program that would be necessary and sufficient as the basis for an In-depth Assessment of sperm whales, including research coordination and funding mechanisms.

Smith placed the workshop and its terms of reference in a wider context, citing contributory rationales, as follows:

- Since the early 1980s when the IWC Scientific Committee last attempted to assess sperm whale stocks, individual researchers and a few independent programs have made steady progress toward a better understanding of sperm whale biology, behavior, ecology, and population dynamics. This has required development of novel methods for studying live, free-ranging sperm whales, and the availability of such methods offers new possibilities for research planning.
- Sperm whales are no longer high on the IWC Scientific Committee's agenda, given that commercial whaling on the species stopped with the moratorium that took effect in the Antarctic in 1983 and elsewhere in 1987. Nevertheless, the Committee has accepted the recent initiative, led by Smith and a small group of colleagues, to at least begin preparing the background for an eventual in-depth assessment of sperm whale populations.
- There is interest within the U.S. Federal Government in reassessing the sperm whale's status under the Endangered Species Act. The sperm whale is one of several species of large whales (also the humpback whale and fin whale) that are listed as Endangered but for which credible supporting documentation is lacking. There is interest in determining whether this listing is warranted and in completing a long-delayed recovery plan.
- The sperm whale is classified in the IUCN Red List as Vulnerable, but again, the documentation to justify that status has not been provided. A global assessment of the species and a regional assessment of the Mediterranean population have been underway for some time within the Cetacean Specialist Group of the IUCN (World Conservation Union) Species Survival Commission, and both have proven controversial.
- Sperm whales are subject to an array of threats from human activities. Sperm whales are hunted today only on a very limited scale (e.g., in Indonesia – Barnes 1996; the western North Pacific – CARP/FP/6), and they are killed occasionally by gillnets and ship collisions. Their depredation on demersal longlines has put them in conflict with fisheries in the Gulf of Alaska (black cod) and the Southern Ocean (toothfish). Further, like other cetaceans, sperm whales are contaminated by a variety of potentially toxic manmade chemicals, and there is increasing concern about the potential effects of underwater noise on sperm whales (e.g., from offshore oil and gas development).
- A subproject of the Alfred E. Sloan Foundation's Census of Marine Life, called History of Marine Animal Populations or HMAP, has sparked interest in studying the history of whaling in order to better understand the impacts on whale populations and, in turn, marine ecosystems. An HMAP-sponsored workshop in 2002 (Smith and Reeves 2003; CARP/HI/5, CARP/HI/12) cited the need for a workshop "on sperm whale population biology, ecology and abundance to determine regional population structure."

All of the factors listed above helped lay the groundwork and provided impetus for the workshop. The conveners envisaged that the results would be of interest to a range of parties, including the IWC Scientific Committee, agencies of the U.S. Federal Government (e.g., the National Marine Fisheries Service, the Marine Mammal Commission, and the Minerals Management Service), IUCN, fishery management and advocacy bodies, the oil and gas industry, the world's navies, the Census of Marine Life, and nongovernmental organizations.

The draft agenda was reviewed briefly, modified slightly, and adopted (Annex 2).

Smith explained the scheme for classifying and numbering workshop documents, which are listed in Annex 3. Throughout this report, documents that were prepared explicitly for the workshop are cited as CARP/…. These documents are summarized and discussed within the report, but with no intention to distribute them (e.g., through a proceedings volume). Readers wishing to obtain copies of any of the papers are encouraged to contact the author(s) (see Annex 1 for contact details). Documents labeled as For Information (FI) are cited within the report in the standard manner – author(s) and publication date/status – with full citations in the References Cited section.

3. INTRODUCTION OF WORKSHOP CHAIR AND RAPPORTEUR

Bannister chaired the meeting and Reeves was rapporteur. The task of drafting the workshop report was delegated to Reeves and Smith, and all participants were offered an opportunity to review the draft before the report was finalized.

4. OVERVIEWS (CARP/INT)

Whitehead presented a summary and critique of his published analysis of the global status of sperm whales (Whitehead 2002). For that analysis, he used the available (published) results of modern abundance surveys (mainly shipboard line-transect) from various regions to produce a global abundance estimate for the species. He did this by first correcting the estimates for whales missed on the trackline ($g(0) = 0.87$) and then scaling up, assuming that about 24% of the sperm whale's global habitat had been adequately surveyed. He employed three different scaling approaches – by area, assuming that all ocean areas >1000m deep and at <70º of latitude have the same average density of sperm whales; by Townsend's (1935) plotted catch positions from 19th century whaling (citing Jaquet et al. 1996 as partial justification); and by primary productivity, using surface chlorophyll data from NOAA. A simple population model was used to examine possible trajectories from 1999 back to 1712 when commercial sperm whaling began. He used "best estimates" and "reasonable ranges" for input parameters including: percentage of sperm whales in the Atlantic (as opposed to Indo-Pacific) before modern whaling (best 33%, range 25-40%); extent of depletion in Atlantic 1712-1799 (best 33%, range 10-55%); maximum rate of increase (best 1.1%, range 0.7-1.5%); density-dependent exponent (best 1.4, range chosen randomly); correction factor for open-boat catch (best 1.5, range 1.1-3.0); correction for modern catch (best taken as given, range 0.9-1.2); 1999 population size (best 360,000, range chosen from normal distribution of 360,000 and CV = 0.36). Each model run calculated central values, along with 95% confidence intervals, for the pre-exploitation population level (1712) and the relative levels in 1880 (when open-boat whaling was greatly in decline) and 1999. The results suggested that there were some 1,110,000 sperm whales (95%CI: 672,000 to 1,512,000) in 1712, reduced by open-boat whaling to about 71% of that (95% CI: 52 to 100%) in 1880, and further reduced by modern whaling to about 32% (95% CI: 19 to 62%) in 1999.

In his published paper, Whitehead (2002) acknowledged that there were "some potential biases and errors which were not fully considered" in his model and therefore that the resulting estimates could be even less precise than indicated. He nevertheless concluded that other authors had substantially over-estimated pre-exploitation abundance (by a factor of two or three) and under-estimated the present extent of depletion (by a factor of at least two). He also acknowledged the difficulty of reconciling his modeling results showing relatively modest depletion by the early open-boat fishery with the findings by Tillman and Breiwick (1983) and Whitehead (1995), which indicated severe drops in encounter rates (about 60%) on the Japan and Galápagos sperm whaling grounds during the first half of the 19th century (also see Bannister et al. 1981). Whitehead (2002) concluded in this regard that the discrepancy "may be at least partially explained if the whales changed their schooling behavior or distribution as exploitation progressed, or if there were refuges, such as unavailable or undiscovered grounds, where the whales were fairly free from the whalers."

Barlow (2003a) described the IWC Scientific Committee's models of sperm whale population dynamics as "among the most complex models that have ever been used to manage any living resource" (see Annex 4). He distinguished two types of population models for sperm whales, each with a different purpose. Demographic models can be used to estimate current, historical, or potential rates of population growth. Assessment models can be used to determine the present status of populations relative to historical population sizes. His conclusion regarding previous demographic models, estimated from whaling statistics, was that they did not have "a sufficiently solid foundation to be trusted without independent verification using alternative methods." Regarding assessment models, Barlow considered that of Whitehead (2002) to be "exemplary" because it took full advantage of the two "most dependably estimable parameters that affect status" – (1) current abundance from line-transect surveys and (2) numbers of whales removed by whaling over time. Barlow identified four steps needed to elaborate and improve upon Whitehead's assessment, as follows: (1) a fundamental understanding of population structure; (2) accurate estimates of numbers of whales of each sex removed from each population; (3) increased survey coverage so that abundance estimates are available for a greater proportion of the species' range; and (4) better understanding of sperm whale demography, particularly in relation to the maximum rate of population growth. He also suggested that a Bayesian population dynamics model would provide a better way to deal with missing and uncertain data.

During the discussion of Whitehead's presentation, participants emphasized the desirability of using a sex-structured population model to account for the effects of the male bias in 20th century catches. Whitehead agreed on the desirability of such an approach, which could be expected to show extreme depletion of adult males and less severe depletion of females, especially post-World War II. In addition, Dawson expressed concerns about methodological differences underlying the estimates of current abundance, not all of which were accounted for in Whitehead's analysis. Gunnlaugsson expressed several reservations, including his view that the abundance estimates used in the model were negatively biased (i.e., g(0) was overestimated) and that the "best" estimate of maximum rate of increase of 1.1% was too low. Best observed that the data stream from whaling had stopped approximately 20 years ago and that studies of live sperm whales had, to date, provided little basis for improving estimation of fecundity or survival. He also pointed out that most of the field research with living sperm whales had taken place in tropical regions, which may not be representative of the species overall. Best emphasized that improving certain parameter estimates would be infeasible without reference to "old" whaling data.

Further suggestions on how sperm whale assessment models could be improved are given in section 11.5, below.

5. POPULATION STRUCTURE AND MOVEMENTS (CARP/PS&M)

As noted above, and as reflected in the previous call for a workshop "to determine regional population structure" (Smith and Reeves 2003), progress in assessing the status of sperm whales requires an improved understanding of population structure.

Mesnick presented CARP/PS&M/3, in which she and Whitehead reviewed the various methods that have been used to study population structure and movements in sperm whales. Existing methods include: morphology, morphometrics, parasite analysis, distribution of catch or sightings data, patterns of change in catch-per-unit-effort (CPUE) or sightings rates, mark-recapture, photo-identification, contaminant analyses, allozymes, mitochondrial DNA (mtDNA) sequencing, and distributions of microsatellites. Newer methods being developed include: satellite tagging, vocal (coda) analysis, trace analysis of tooth sections, single nucleotide polymorphisms (SNPs), and Y-chromosome sequence variation. CARP/S&M/3 identified three specific sites where applications of one or more of the approaches listed are underway. These are the *Odyssey* voyage based at the Ocean Alliance in Weston, Massachusetts (CARP/FP/4, CARP/FP/9; and see 10.8, below), Whitehead's laboratory at Dalhousie University in Halifax, Nova Scotia, and Mesnick's laboratory at the Southwest Fisheries Science Center in La Jolla, California.

5.1 Tagging

Firing steel markers into the muscles of large whales, including sperm whales, in the expectation that they would be recovered when the same whales were killed and processed by the whaling industry, was a method used to study long-range movements, migrations, and "stock identity" before the emergence during the 1970s and 1980s of new "non-invasive" methods such as photo-identification and biopsy sampling (Brown 1977). Returns of these "Discovery marks" have been used only to a limited extent to inform hypotheses concerning sperm whale population structure (see Donovan 1991 for a review). Best pointed out that Discovery marking was largely opportunistic and was generally not designed to answer specific questions or test hypotheses.

In the North Pacific, Discovery marking was conducted by Canada, Japan, United States, and USSR. Japanese marking began in 1949 and continued until 1979 when commercial pelagic whaling ceased. The results of Japanese Discovery marking were reported to the IWC Scientific Committee every year through the Japan Progress Reports on Whale Research. In addition, two reviews of Japanese whale marking results have been published (Omura and Ohsumi 1964; Ohsumi and Masaki 1975). The analysis by Kasuya and Miyashita (1988) explicitly integrated mark-recapture data from all four countries (as of 1987) as well as Japanese and Soviet catch and sightings data with oceanography, concluding that there were likely at least three sperm whale stocks in the North Pacific – northern and southern stocks in the west and a single stock in the east. Also, the tagging data showed trans-equatorial movement by sperm whales in the Pacific.

Discovery marking in the North Atlantic was not reviewed for the workshop. However, a male marked off Nova Scotia, Canada, was later taken off northwestern Spain, some 6000km away (Mitchell 1975). Another killed off Iceland had previously been struck by a hand harpoon in the Azores, approximately 3000km to the south (Martin 1982). A male Discovery-marked off Mauritania was later taken off Cape Town, South Africa (Ivashin 1967), demonstrating trans-equatorial movement in the Atlantic. Mark returns have also indicated links between the Antarctic and waters off Durban (South Africa), and substantial latitudinal movements along the west coast of southern Africa by both sexes (Best and Ross 1989). Finally, Discovery mark returns have been used to suggest that females have smaller "home ranges" (straight-line distances between marking and recapture) than males (averages of 372 and 850 n. miles, respectively) (Best 1979).

Bannister commented that returns of Discovery marks from sperm whales in the Southern Hemisphere were fewer than expected and that this could have been a result of the fact that the USSR program was not fully integrated with those of other whaling nations. It could also be related to the strategic misreporting of whale catches by the Soviet fleet (cf. Zemsky et al. 1995).

Substantial progress has been made since 2002 on satellite tracking sperm whales, mainly in the northern Gulf of Mexico under the direction of Bruce Mate. Animals there have been tracked for more than a year, and battery longevity rather than tag retention is currently the main limiting factor. Miller reported that a method was being developed to extend battery life by generating energy from the instrumented whale's own movement through the water. Ohsumi noted that a sperm whale tag was being developed in Japan by Hayashi.

After some discussion of the pros and cons of satellite tagging, it was generally agreed that the main value is that it provides unequivocal data on the movements of a very small set of animals (relative to the entire population). It shows where the animals go when they are not being monitored by direct observation. The northern Gulf of Mexico provides an ideal context in which to approach and instrument sperm whales, but the sampling there may be biased. For example, researchers there have not yet succeeded in approaching and tagging large, solitary ("roving") males, which are likely the most wide-ranging individuals. While satellite tagging is properly regarded as a valuable tool for investigating population structure, it is best seen as complementary to other methods, rather than as definitive by itself.

With implantable tags, a pronounced swelling is often observed for several months at the tagging site (for up to 11 months in one instance according to Miller). In most instances the swelling is gone and the site is "clean" thereafter. Participants with direct experience generally did not feel that satellite tagging had any harmful long-term effects on the whales.

There was brief discussion of VHF radio tagging of sperm whales using suction-cup attachment. Miller explained that these tags provided detailed information on movements and behavioral ecology for only brief periods (up to two days). The method was, therefore, not considered relevant for investigation of population structure.

5.2 Individual Identification

Much of the discussion of this agenda item alternated between the use of photo-identification for studying population structure and its use for abundance estimation. In addition, the discussion often considered simultaneously the two main types of individual identification – photographic matching and genotyping from biopsies. These two methods were compared, with a view to evaluating their relative strengths and weaknesses (see Annex 5).

Photo-identification has been used widely since the 1980s to trace movements (Dufault and Whitehead 1995) and develop movement models (Whitehead 2001). Photographs of the flukes (and to some extent the back and dorsal fin) allow sperm whales to be identified individually. As a rule of thumb, a sperm whale can be expected to raise its flukes above the surface about once every hour (Gordon, pers. comm.). Gordon, Jaquet, and Whitehead have acquired extensive experience with photo-identification of sperm whales in the northern Gulf of Mexico and Caribbean Sea, various parts of the North Atlantic, the northern Indian Ocean, the Gulf of California, the Galápagos, and Chile; they have conducted their work from both large and small vessels (e.g., CARP/PS&M/5).

Whitehead and Mesnick (CARP/PS&M/3) identified strengths of photo-identification to include that: (1) it is non-lethal and largely non-invasive; (2) it can be applied inexpensively and by diverse, small-scale research operations; and (3) analytical models are already well developed for using the data. Digital photographic technology has greatly improved the feasibility and affordability of photo-identification. Weaknesses include: (1) marks used to identify animals can change; (2) there is a need to correct for unevenness of effort, which reduces model precision; (3) accuracy of identification is a function of quality of the photograph; and (4) it can be difficult to coordinate input from a large variety of researchers. Photo-identification is limited as a tool for studying population structure because each photo-identification event provides information on the animal's location at only a single point in time, and data can be obtained only from areas (often near shore) where research is being conducted.

Some participants argued that photo-identification was impractical on the high seas far from coastlines, and for a species so abundant and wide-ranging as the sperm whale. This depends partly, of course, on the question being addressed and the amount of effort invested in the research. However, participants with extensive first-hand experience approaching and photographing sperm whales reported that they had no difficulty obtaining fluke photographs in offshore ("pelagic") conditions.

It was also noted that the problem of false positives, a particular concern when applying photo-identification methods to large populations, is already addressed to some extent by the computer-assisted matching procedures that are being used (see below). Further, all methods of assessing numerically large and wide-ranging populations have their limitations, so those that rely on individual identification and "recapture" should not necessarily be discounted.

With regard to concerns about mark change, Dawson (CARP/FP/1; also see item 10.7) noted that during his eight years of photo-identification work in Kaikoura, New Zealand, there had not been a single case where changes in markings were sufficient to cause difficulty with matching. He also emphasized that all of the sperm whales in his study area (maturing and mature males) had proven to be well enough marked for individual photo-identification. Participants with experience in tropical waters pointed out that mixed groups tend to be more difficult to approach than maturing and mature males. Discussion of the relative importance of incorporating effort to photograph the back and dorsal fin, rather than just the flukes, was inconclusive.

Photo-identification images for the North Atlantic and adjoining waters are coordinated within the North Atlantic and Mediterranean Sperm Whale Catalogue (NAMSC). NAMSC holds images from the Mediterranean and Caribbean Seas and the Gulf of Mexico. The catalog is curated by the International Fund for Animal Welfare (contact Tim Lewis at tlewis@ifaw.org).

Another photo-identification initiative, which to date has been focused mainly within the eastern Atlantic and Mediterranean areas but could be extended globally, is Europhlukes (http://www.europhlukes.net/). Europhlukes was a 3-year project funded by the European Community to create a coordinated database and matching tools for cetacean photo-identification images. Sperm whales have been a particular focus for Europhlukes, probably because of the existence of NAMSC. Europhlukes has developed structures and tools for field databases from which subsets of data and images can be exported to a main online database. Automated matching tools have also been developed as part of Europhlukes, and these are most developed for sperm whales. Development work on automated matching is being continued by Eric Pauwels at the Centre for Mathematics and Computer Science, Amsterdam. Another initiative from Europhlukes has been to establish a web page to allow experience and "best practices" on photo-identification to be exchanged among fieldworkers.

The present systems used by both Europhlukes and Whitehead's laboratory to compare and match photographs of sperm whales can be characterized as semi-automated. They still require judgments concerning the suitability of photographs for inclusion in the catalogs, i.e., a grading system to classify photographs according to quality and information content. They also require a human observer to make final decisions; perhaps this is not only unavoidable but also desirable. Participants agreed that techniques involving a probabilistic approach to matching are both attainable and desirable, and therefore should be encouraged.

5.3 Acoustic

Mesnick introduced CARP/PS&M/2, representing an attempt to integrate acoustic data on "vocal clans" (groups of sperm whales that are distinguished by distinctive coda repertoires) with genetic data. The concept of using acoustic differences as markers for population structure has been developed previously by Weilgart and Whitehead (1997) and Rendell and Whitehead (2003). Social codas are produced only in mixed schools of sperm whales (none by adult males, although Gordon pointed out that the term "coda" was first applied to patterns heard at the end of dives by males) and therefore the vocal clans are directly relevant only to female population structure. Drouot noted that the coda repertoire of sperm whales in the Mediterranean Sea is different from the repertoires of Atlantic animals. Madsen stated that codas have not been recorded from the large males off Norway, and Dawson that the maturing and mature males off Kaikoura, N.Z., rarely make coda sounds. Barlow observed that in the Pacific, it can take 12-24 hours of recording to obtain coda sounds; the whales seem to produce them only when they are socializing. Watwood, based on her experience in the North Atlantic, Mediterranean, and Gulf of Mexico, stated that some animals produce codas at depth, and these would not necessarily be picked up by a surface hydrophone.

Some vocal clans have been found to be sympatric, which raises the question of social philopatry and how clan structure might relate to genetic population structure. Are sperm whale populations structured more according to language than to geography? Rendell et al. (CARP/PS&M/2) found statistically significant mtDNA genetic differentiation among the three vocal clans that they compared, but none of those clans was strictly matrilineal (i.e., each clan contained more than one haplotype). The authors concluded that more work was needed to ascertain the influence of group structure on acoustic and population structure. They identified four specific approaches to be pursued in future studies: (1) investigating group effects by expanding sampling to include more groups within each clan, and more clans, across a broader geographic range; (2) investigating the relative importance of area effects (if any) by a combined (hierarchical) group, geographical, and clan analysis; (3) ensuring that relatedness of individuals within groups does not violate the basic assumption that samples are random and independent; and (4) ascertaining whether coda dialects are more likely transmitted genetically or culturally (i.e., by learning).

Diverse views were expressed on the question of whether codas are, in fact, appropriate markers for population structure. Groups that share coda repertoires seem to interact preferentially, if not exclusively, with one another. Thus, they are in some sense functional units. It is crucial to know how codas are transmitted and whether, for example, groups of whales might just converge on a given coda repertoire. A problem in evaluating what kind of marker the coda might be is that when one records a coda, it usually is not possible to determine which individual in a group has produced it.

5.4 Morphology

Rice (1989, 1998) reviewed, and dismissed as inconclusive, the evidence of population structure from morphological variation and biochemical differences in sperm whales at a global scale. Recognizing that a number of studies of geographical variation had been published since, the workshop concluded that there would be value in a review and synthesis of such information.

Ohsumi referred to his own analyses of tooth counts in sperm whales from the Antarctic, South Georgia, Japan, and other areas. He found no statistically significant difference in counts across regions and therefore concluded that this was not a promising approach for distinguishing populations.

It was suggested that the pattern of body scarring by cookie-cutter sharks (*Isistius* spp.) might hold promise as a population marker in sperm whales (as it has in killer whales). Participants agreed that an investigation of scarring in general (e.g., from killer whales, lampreys, or cookie-cutter sharks) might contribute to the formulation of hypotheses concerning sperm whale population structure.

5.5 Genetics

Biopsy sampling and genetic analyses have become standard tools for assessing population structure in whales. Mesnick summarized CARP/PS&M/1, which describes progress to date by "Cachalote Consortium," a collaboration among researchers who hold genetic data on sperm whales for the purposes of planning and carrying out investigations of global population structure in sperm whales. Mitochondrial DNA markers (maternally inherited) and nuclear DNA markers (biparentally inherited; e.g., microsatellites) are currently used widely. SNPs and Y-chromosome markers (paternally inherited) are viewed as the most promising new tools for the immediate future.

The combined collection of material currently includes more than 2400 tissue samples from areas including the Gulf of California, Chile, the Galápagos, the Gulf of Mexico, the Azores, and Tasmania. Significant gaps remain in the North Atlantic, western Pacific, and Southern Hemisphere. A remarkable feature of preliminary analyses is the low diversity of mitochondrial DNA in sperm whales: 24 variable sites have defined only 28 haplotypes worldwide thus far. No fixed genetic differences have been found to differentiate populations.

The problem of defining strata for analysis represents a major challenge, and some of the new approaches for integrating acoustic data (coda repertoire) and genetic data (mtDNA) were discussed in CARP/PS&M/2 (see Item 5.3, above). Stratification by geographic and group differences may be confounded by group vs. clan effects. An integrated approach is needed to determine whether, and to what extent, sperm whale populations are structured socially or geographically. To this end, understanding the function and context of codas may be key.

There was extensive discussion of the relative merits of photo-identification and genotyping, and a working group was formed to summarize that discussion (Annex 5).

In addition to biopsies from living sperm whales, a potentially important source of sperm whale DNA is material in museum collections, e.g., teeth (cf. CARP/FP/2 and see Item 10.9, below).

5.6 Historical Evidence

Hypotheses on population structure can be informed by spatial discontinuities among concentrations of sperm whales ("grounds") where the species was observed or hunted in the past (CARP/PS&M/3). A weakness of making definitive inferences about population boundaries from such evidence, however, is that sperm whales clearly move between grounds (e.g., photo-identified individuals from the Galápagos were later seen in the Gulf of California; CARP/FP/8). Differences in catch or sighting rates between regions can be interpreted as suggesting incomplete mixing, and therefore contribute to hypotheses that can be tested using other, more nearly definitive markers (e.g., genetics). The temporal scales of available catch or sighting rate datasets range from about five to 50 years, and large amounts of such data are available for some areas and periods (e.g., Bannister et al. 1981; Hope and Whitehead 1991).

5.7 Other

Chemical analysis of trace elements in teeth might be used for retrospective inference of habitat use. Such an analysis may elucidate temporal patterns of movement between high- and low-latitude feeding grounds. An advantage of this approach is that it can be conducted using archived material. Isotopic analysis of blubber, skin, or teeth may provide insights into dietary preferences and, in turn, population structure.

Best called attention to the possible use of differences in breeding season to distinguish sperm whale stocks (Tormosov et al. 2003).

6. ABUNDANCE AND DISTRIBUTION

6.1 Whaling Records

The geographic location of whaling can provide basic, albeit potentially biased, information on spatial distribution patterns. For example, Bannister summarized CARP/HI/3, in which he attempted to characterize the 19th century sperm whaling grounds as identified and described in the literature. Relying principally on the works of five major authors (Beale, Wilkes, Scammon, Clark, and Townsend), he identified 64 locations worldwide: 17 each in the North Atlantic and South Pacific and ten each in the South Atlantic, North Pacific, and Indian Ocean. Relatively few of these were "mixed grounds" where other whale species were also regularly hunted. Josephson and Smith illustrated the location of these grounds in CARP/HI/6.

Year-round grounds were mainly in the tropical belt between 30ºS and 30ºN whereas those south of 25ºS or north of 25ºN were visited primarily in summer. While American whalers dominated the industry, the British and French fleets were also prominent for at least a few decades, and there were some differences in the grounds used by American and British whalers.

In discussion, Bannister confirmed that the Mediterranean Sea was not a major whaling ground, at least not for the American fishery. It is also of interest that some areas where sperm whales are present in relatively large numbers today (e.g., the lee shores of Tasmania and Kangaroo Island, Australia; the northern coast of Chile; waters southeast of Sri Lanka) were not always identified as whaling grounds. Bannister observed that problems inherent using sailing vessels, e.g., the need to avoid lee shores, could help explain at least some of what appear to be anomalies of this kind.

Smith and Josephson described the distribution of 20th century whaling activity in CARP/HI/15, noting that whaling was generally distributed more poleward, with relatively little overlap with 19th century whaling grounds except in the western North Pacific. The shifts in the grounds in the 19th century and the differences in the grounds used in the 20th century make it difficult to draw inferences about distribution patterns, especially over time and in areas where whalers did not operate.

Changes in catch and sighting rates in the 19th century suggest marked changes in abundance over decades on the Japan Ground in the western North Pacific (Bannister et al. 1981) and around the Galápagos in the eastern Pacific (Hope and Whitehead 1991). Bannister et al.'s data were used to estimate pre-whaling abundance of sperm whales on the Japan Ground (Tillman and Breiwick 1983), although the lack of clarity about population structure made it unclear whether the analysis should have taken into account whaling results from other regions where this same whale population might have been hunted (Smith and Reeves 2003). In the 20th century, studies of sperm whales by the IWC Scientific Committee also considered decreases in the numbers of whales caught per unit of effort (CPUE), although the rapid evolution of whaling equipment and techniques as well as the mixed-species character of many operations often confounded the interpretation of such change (see Appendix 5).

6.2 Genetic Diversity

Methods of estimating population size before whaling that do not rely on catch data could be useful, especially where the catch history and population models have large uncertainty. The potential for using genetic diversity to estimate historical population size (e.g., Roman and Palumbi 2003) was discussed within the IWC Scientific Committee in 2004 (IWC 2005). The low mtDNA genetic diversity in sperm whales represents a different situation than that of the humpback whale, fin whale, and common minke whale considered by Roman and Palumbi (2003). Given the low mtDNA genetic diversity observed in sperm whales, direct application of the Roman and Palumbi approach would be problematic, and indeed it has not been applied to sperm whale populations. However, Lyrholm et al. (1996) used a novel genetic method, quite different from that of Roman and Palumbi, to estimate time since common ancestry and explain the low mtDNA genetic diversity in sperm whales.

The IWC Scientific Committee's critique of Roman and Palumbi's paper (IWC 2005) stated, "A key concern regarding the use and interpretation of genetic-based estimates of historic abundance is that these cannot be assigned to a point in time narrow enough to assure that the estimates apply to the time period just prior to the onset of whaling that has been the reference point for management…." A number of additional sampling, molecular, and analytical biases and uncertainties require further investigation, as outlined in the Scientific Committee's report. Uncertainties include the effect of unsampled populations on estimated genetic diversity, the bias due to deviations from mutation-drift equilibrium, the ratio of effective population size to survey population size, the mode and rate of changes in mtDNA control regions, the genetic diversity in nuclear loci, and methods of determining statistical reliability. Substantial further work would need to be completed before genetically derived abundance estimates for sperm whales could be deemed useful for assessment purposes.

6.3 Sightings and Acoustics Surveys, Including Dive Cycle

Gillespie introduced CARP/A&D/1, which reviewed and compared acoustic methods of assessing sperm whale abundance. There are three basic types of surveys that incorporate an acoustic component: the "Cartwheels" method, "Distance"-type line-transect methods, and the "hybrid" method. The Cartwheels method involves sampling at discrete stations along a transect and uses a statistical approach developed by Hiby and Lovell (1989) to estimate detection range based on numbers of whales in 45º sectors at each station. Its advantages are that individuals do not have to be tracked for extended periods and that it only requires point sampling. Among its disadvantages are that it requires relatively large samples to narrow confidence limits for estimation of effective detection range, and it only works robustly when the separation between sampling stations is 50-130% of the detection range, thus requiring some prior knowledge of detection range to ensure this. Bias in abundance estimates derived from the Cartwheels method will be directly proportional to any bias in estimates of the proportion of time spent vocalizing. Distance-type line-transect methods can be used effectively in areas, such as the Southern Ocean (Leaper et al. 2000), where densities are relatively low and individuals are separated by at least a few hundred meters. They require the ability to track individuals or small groups long enough to establish their positions by intersecting bearings from many points along the trackline. Hybrid surveys use acoustic detection to locate groups and then require the vessel to close on them to obtain visual estimates of group size.

Barlow and Taylor (2005) applied the hybrid method for an extensive survey of the northeastern temperate Pacific, resulting in an estimate of 20,000-30,000 sperm whales in the study area. In presenting the paper, Barlow noted that slow clicks were detected at ranges up to 37km whereas usual sperm whale clicks were typically heard at less than 9km. In a separate study (Barlow and Rankin 2004) independent teams of observers searched for sperm whales visually and acoustically during surveys in the eastern tropical Pacific. The percentages of missed groups on the trackline were 38% for visual and 21% for acoustic. Assuming that the two methods are independent, the percentage missed by both teams was 8%. Although acoustic detection methods greatly reduced the fraction of missed animals, they cannot reliably estimate group sizes and some groups are still missed. Therefore, the authors recommended that a hybrid approach be used for sperm whale surveys.

Most of the "groups" (= aggregations) included in the study of Barlow and Taylor (in press) consisted of asynchronously diving "clusters," which they defined as subgroups of 2-10 whales in close proximity to one another. Such clusters were often spread over several square kilometers. Typically, the vessel would spend 90 minutes in the area, with at least five observers maintaining a 360º watch, before deciding on a final group size estimate. According to Barlow, group size estimates made 10 minutes following initial detection were about half those made after the 90-minute closing mode watch. During workshop discussion, it was noted that in some circumstances (e.g., off Peru), clusters of whales can be so numerous and geographically extensive that it leads to "system overload" on the part of survey observers.

The sperm whale's proclivity for deep, prolonged diving has generated concerns about availability bias (g(0)). Those concerns are summarized below:

6.3.1 Visual

Better methods of estimating g(0), the probability of detecting sperm whales on the trackline in visual line-transect surveys, are needed both to improve future density and abundance estimates and to "correct" the results of past surveys. Whitehead (2002) used a single estimate of g(0) to correct for missed animals for a wide variety of survey types in a wide variety of habitats. Better estimates of density and abundance from past surveys could be obtained if g(0) estimates were more specific to the survey method, region, and average group size.

Simultaneous use of towed hydrophones is likely to be the best approach to improve g(0) estimates for visual sightings surveys, as it is probably the only way to deal adequately with the problem of estimating g(0) for groups of asynchronously diving individuals. Estimates of g(0) can also be derived from dive data for visual survey methods that are based only on detecting individuals (e.g., cue counting). The usual methods of estimating g(0) using two independent teams of visual observers on ship surveys are not likely to be effective for sperm whales because they only account for perception bias (from animals that surface within the visual range of observers but are not seen) and do not include the likely greater contribution from availability bias (from animals that are submerged and not available to be seen).

6.3.2 Acoustic

Simultaneous use of visual and acoustic survey methods is also an effective way to estimate g(0) for acoustic surveys, particularly those that treat groups as the units of observation. Acoustic methods based on detection of individuals can be corrected using information on dive times and surface times. Information on long periods of acoustic silence ("resting" or "sleeping" behavior) is also important for developing correction factors for acoustic surveys. Whitehead pointed out that, in his experience, sperm whales form spatially tighter groups in the Pacific than in the Atlantic. If this is true more generally, acoustic methods that depend on detection of individuals might be more effective in the Atlantic and methods based on detection of groups might be more effective in the Pacific.

6.3.3 Group vs. Individual Detections

It is important to appreciate that in the line-transect method described in CARP/A&D/1, the units of detection are individual animals (albeit individuals that are aggregated) while for the hybrid methods described by Barlow and Taylor (in press), the units of detection are groups. Detailed information on vocal behavior, which can be obtained from long recordings made while following individuals ("focal follows", e.g., see CARP/FP/1; Drouot et al. 2004a), may be useful in calculating a value of g(0) for individuals in the Distance-type method, although very detailed data – at the level of the time of each click – may be required to model this for different detection scenarios. It is unlikely that such data can provide a realistic g(0) for "group" detection. This will depend, however, on a host of factors, including spatial distribution of the group, the precise definition of "group," and the degree of synchronicity of vocal behavior of individuals within the group. Further, it may be the vocal output of a small number of animals that determines a group's detection probability. Barlow noted (and see Barlow and

Taylor in press) that in North Pacific surveys, aggregations typically were not detected by the vocal output of most of their members but, rather, by the characteristic calls ("clangs" or "slow clicks") of mature males within them.

6.3.3.1 Cost and Equipment

An advantage of passive acoustic monitoring is that it can reduce survey costs by allowing the use of either small, relatively inexpensive vessels (such as motor sailers) which, because of their small size and hull shape, are often ideal acoustic monitoring vessels, or platforms of opportunity. In several instances, simple towed arrays and semi-automated analysis and recording systems have been used by small teams of one or two researchers to conduct large-scale quantitative acoustic surveys, incurring little or no additional vessel costs. Oceanographic research vessels, which often follow a predetermined survey design and collect useful ancillary oceanographic data, have proven to be particularly suitable platforms. The hydrophone arrays used for both the small-vessel surveys and the platform-of-opportunity surveys were very simple. Most, in fact, were less sophisticated than the array described by Leaper et al. (1992). Simple, low-cost equipment was appropriate for those early trials and remains so for surveys from low-cost platforms or platforms of opportunity. However, for dedicated surveys, investment in larger two- or three-dimensional arrays offers opportunities for greater spatial resolution. The continuing advances in acoustic digital processing and the development of more powerful analysis software should make the real-time analysis of data from such arrays feasible and affordable. In addition, groups such as the Centre for Research into Ecological and Environmental Modelling at the University of St. Andrews, UK, are working on improved analysis methods tailored to acoustic survey capabilities and limitations.

6.3.3.2 Click Rate and Time Spent Vocalizing

Dawson summarized his experience in studying click rate and the proportion of time individual sperm whales spend silent (CARP/FP/1). For acoustic surveys, it is important to know what proportion of time whales spend vocalizing. For approaches based on click counting, it is important to know usual click rate. Usual click rates measured over complete dive cycles of photographically identified individuals at Kaikoura, NZ, showed that five-minute averages of mean usual click rate did not differ significantly within dives, among dives of the same whale, or among whales (Douglas 2000). On average, individual sperm whales at Kaikoura spent 60% of their time usual clicking in winter and in summer. There was no evidence that whale identity or stage of the dive recorded affects significantly the percentage of time spent usual clicking.

For acoustic surveys at Kaikoura, it is probably reasonable to assume that the probability of detection on the trackline is unity – at least for foraging individuals. This is because silent individuals generally recommence clicking while the ship is still within acoustic range. For example, the dive cycle generally lasts about 54 minutes, and the longest average continuous period of silence is around 14 minutes. During 14 minutes, an acoustic survey vessel traveling at 8 knots will travel less than 2nmi, far less than the typical range over which usual clicks are detectable.

6.3.3.3 Cue Counting

Abundance estimates for the central and eastern North Atlantic from the NASS-2001 survey are based on a cue-count-transect method that corrects for availability bias (Gunnlaugsson et al. 2002). This method critically relies on information about the dive cycle (frequency of dives and proportion of time spent at the surface between dives), and it is preferable that the dive data come from the area being surveyed. It is anticipated that the same method will be used to analyze data from the NASS-2007 survey (Gunnlaugsson, pers. comm.). The method has only been applied in high-latitude regions of the North Atlantic where most sperm whales are solitary males. It is uncertain whether it would be practical in areas where whales occur in large groups.

6.4 Individual Identification

Mark-recapture estimates (using photo-identification) are available for sperm whales only in a few local areas (Leaper et al. 2003). Assumptions concerning random sampling, population closure, and immigration/emigration apply to sperm whales as they do to other cetacean populations, although particular complications may arise from "social organization within mixed groups" of sperm whales. Additional discussion of mark-recapture estimation appears under Items 5.2 and 5.5 and in Annex 5.

7. LIFE HISTORY (CARP/LH)

7.1 Age Determination

Bannister drew attention to a study of growth layer groups (GLGs) in 92 teeth collected from three sperm whale strandings on the Tasmanian coast (Evans et al. 2002). The large inter-reader variability suggested that age estimates based on GLG counts in sperm whales are subjective and can only be regarded as relative. Photographs increased definition of growth structures and decreased variation between counts. High-quality photographs should be used to verify GLG counts with other readers, resulting in "consensus counts," ensuring interpretation of the same structures and confidence in comparing GLG counts.

7.2 Vital Rates

In introducing a review of sperm whale vital rates (CARP/LH/1), Best pointed out that these were an important component of past management attempts to set catch limits. Their current significance, however, at least in the context of this workshop, is probably limited to providing input to models used to explore the effects of past whaling on population trajectories and estimate initial population sizes.

Twentieth-century sperm whaling featured the differential exploitation of males because of their larger size (and proximity to summer whaling grounds for baleen whales in higher latitudes). The effective sex ratio (or the proportions of mature animals of each sex needed to maintain the fertilization rate) was therefore a major issue in assessments of sperm whales. In the absence of information on the mating system, the Scientific Committee of the IWC used a model based essentially on the premise that males tend to join groups of females that then travel together for extended periods. Thus, based on observed group sizes, the Committee assumed that 2 mature (at least 25 years old) males were needed per 15 mature females in the population, and that if the ratio fell below that level, the pregnancy rate would decline accordingly. To test whether greater relative male depletion indeed resulted in reduced female breeding success, the Committee examined the observed pregnancy rate in the catch. Results were equivocal, with observed declines possibly confounded by temporal shifts in the whaling grounds or in the degree of selection against lactating females. Also, the male depletion models that were used tended to fail to match the observed trends in pregnancy rate, either qualitatively or quantitatively. Recent observations of living sperm whales suggest that large males associate only very briefly with a school of mature females during the breeding season. In Best's view, this observation suggests that the Committee's analyses were biased toward under-estimating resilience. Whitehead pointed out that results from different kinds of analysis suggest that the breeding success of male sperm whales is highly skewed (see Whitehead 2003:282-83) and thus that pregnancy rates are not resilient to changes in the abundance of large males.

Identification of socially mature males as individuals at least 25 years old was based on a rapid increase in testis growth and density of spermatozoa in the seminal fluid at this age, as well as observations of the size of males accompanying females in the breeding season. However, physiological maturity (the stage at which spermatozoa are first present in the testes) occurs much earlier, even in males as young as 10-12 years. Moreover, there is a secondary acceleration in growth in body length at around 18-20 years of age, possibly associated with the commencement of migrations to higher latitudes than those normally visited by females. Whether any of these younger males manage to participate successfully in breeding is unknown, but some investigators consider it possible that they could do so in the absence of competition from larger males (Best 1979).

Modeling the effects of whaling also requires estimates of natural mortality rate. These were obtained in the past from the age composition of the catch, and were therefore likely confounded to some degree by fishing mortality. Thus, while population theory would suggest that male sperm whales should have higher natural mortality rates than females, and that natural mortality should increase in older mature individuals of both sexes, the appearance of such features in the age-composition data could equally be attributed to the effects of exploitation. In spite of these uncertainties, the IWC Scientific Committee adopted a higher natural mortality rate for males than females. Juvenile mortality has remained unmeasured in either sex.

7.3 Social Structure

Mesnick presented CARP/PS&M/1, CARP/PS&M/2, and CARP/LH/4 on behalf of herself and her various coauthors. All three papers are relevant to this agenda item as well as to Item 5 (Population Structure and Movements), above. Sperm whales have a complex social structure. The observed "group" of females and immature whales is a temporary association between more stable social "units." Breeding males rove between female groups, but important elements of the mating system remain unknown. Male-biased exploitation and the possible disturbance of the groups of females and immature whales by whaling may have lowered the fecundity of surviving females, although evidence and mechanisms for such reduction have not been clearly identified. The social structure and mating system of sperm whales are being studied principally using photo-identification and genetic analyses. These types of studies are augmented by studies of vocalizations, observed behavior, and information from short- and long-term tags, and through inferences from other aspects of sperm whale biology. Genetic research is under rapid development. Research on paternity and the relationship between fecundity and social integrity is particularly important.

At present, no genetic evidence of a strictly or largely matrilineal unit or group of sperm whales is available. Rather, genetic results suggest that groups of female and immature sperm whales generally contain more than one matriline (a matriline being a set of animals with the same oldest living female ancestor), as indicated by the presence of multiple mtDNA haploytpes. Both "groups" and "units" contain clusters of closely related animals, but some individuals have no close relations. These results are consistent across 50+ groups sampled at sea and in strandings in four different ocean basins (Richard et al. 1996; Christal et al.1998; Bond1999; Lyrholm et al. 1999; Mesnick 2001; Mesnick et al. 2003; Engelhaupt 2004). The view of female sperm whale social structure that is emerging is one of kith (close, but not genetically related companions) and kin. Observations of groups in areas without a significant modern whaling history are currently being collected in the western Atlantic (Whitehead, pers. comm.) and may be particularly valuable in addressing whether the non-matrilineal structure is an artifact of removals by commercial whaling.

There was considerable discussion of whether the low observed proportions of calves (about 1% in the Galápagos; Whitehead et al. 1997) are indicative of low calving rates, and if they are, whether this is an intrinsic and "normal" feature of the species or instead reflective of the differential depletion of large males by commercial whaling that ended more than 20 years ago. An alternative explanation would be that low observed proportions of calves is an expression of the extreme environmental variability of the region. The observed proportions of calves in various low-latitude areas seem to differ markedly today, suggesting that rates of increase can vary according to population history and/or other factors. The workshop recognized that some inconsistencies in the available data could not easily be reconciled, but concluded that it would be useful for field researchers in different geographic areas to compare their observations of proportions of calves. In view of the difficulties of detecting calves (or identifying individuals as calves) at sea, hormonal sampling of females from biopsies might be worth considering as an approach for estimating calf production (pending a demonstration of feasibility).

Stranded groups of subadult males have been found to be composed predominantly of unrelated individuals, although there were cases of half-siblings within each of the groups (Bond 1999; Engelhaupt 2004).

Kato introduced CARP/LH/2, which examined the age- and body-length structure of a sperm whale school composed of 14 males that stranded on the Ohura coast, Kagoshima, Japan, on 22 January 2002. The authors succeeded in obtaining body lengths for all animals and ages for 12 of the 14. Although one exceptionally large male (15.5 m, 41 yr) was involved, the lengths (mean 12.81, range 12.1 – 13.7 m) and ages of the remaining animals were consistent with those for medium-sized bachelors as defined by Best (1979). Thus, these data were interpreted as supporting the existence and definition of a male social unit. The authors gave two alternate interpretations for the presence of the large male: either this animal was socially still immature, or large males do not always segregate permanently from other social units.

Dawson summarized the results of his work on body size distribution of male sperm whales in the Kaikoura area of New Zealand (CARP/FP/1). Norris and Harvey (1972) proposed that multiple pulses present in clicks result from reflections within the head, and thus that inter-pulse interval (IPI) is an indicator of head length, and by extrapolation, total body length. While several previous studies have generated acoustic estimates of whale length, only one (Gordon 1990) was validated by independent measures of length (for 11 individuals). Research at Kaikoura, NZ, on individually identified, photogrammetrically measured whales showed that, measured over short periods within the same dives, IPIs were highly stable within individuals. Further, the relationship between IPI and photogrammetrically measured length was non-linear (a second-order polynomial had a highly significant fit; Rhinelander and Dawson 2004). Most individuals showed significant increases in IPIs over several years, suggesting growth.

Dawson considered that IPIs provide more precise estimates than photogrammetry and thus are more suitable for sampling the size, age, and sex distribution of whales in a given area or group. He recognized, however, that more IPI data and more independent photogrammetric data will be needed to further develop the relationship. Other participants cited the difficulty of applying Dawson's methods to sperm whales in areas where they occur in large groups. It was agreed that there should be a standard procedure for recording IPIs that takes account of the animal's orientation with respect to the receiver. The small but measurable effects of pressure and temperature need to be incorporated and accounted for. Also, Best called attention to the possibility that post-mortem stretching may help explain the difficulty of reconciling carcass lengths measured on whale processing platforms with lengths derived from photographs of living animals.

8. POPULATION ECOLOGY

8.1 Feeding

In introducing his review of sperm whale feeding Best noted that feeding success might be a key factor in interpreting sperm whale movements and population dynamics. The nature of sperm whale food has been fairly well established through the examination of stomach contents and (more recently) the collection of feces at sea (CARP/PE/1). Both methods have various biases, many of them in common. In the case of stomach contents, some bias can be circumvented through the use of prey items with flesh still attached. Fecal sampling has the additional problem of the differential sinking rates of beaks of different sizes. Most studies to date have demonstrated the predominance of cephalopods, especially mesopelagic and bathypelagic squids, in the diet, although fish are of considerable importance in some areas. There is some evidence of prey partitioning by sex (and in males by size), with larger males tending to feed on larger species of squid and to take larger individuals of a particular species than females and small males. Also, males in general feed more frequently on benthic fishes and crabs.

Rates of feeding have historically been examined through the incidence of fresh remains in the stomach, but analyses have largely been confined to estimates of diurnal or intra-annual variation, rather than inter-annual trends. Data on blubber thickness have been used as a proxy for feeding success, but such data are sensitive to the measurement techniques employed. More recently, defecation rates in living animals have been used as a measure of feeding success. Differential feeding rates between larger males and females and/or smaller males have been found in a number of studies, using data on both stomach contents and defecation. It has also been suggested that large males are out-competed by females when they occur sympatrically.

There was some disagreement among participants concerning the value, and indeed the feasibility, of using defecation as an index of feeding success or rate. Jaquet pointed out that detection of feces on the surface can be influenced by lighting conditions and height of observation platform. Madsen stated that a strict study protocol is needed to avoid startling the whales and inadvertently "forcing" them to defecate. Drouot noted that sperm whales in the Mediterranean are rarely observed to defecate. Moreover, it is difficult to see how to calibrate defecation to feeding rates, even if it were possible to observe whales constantly over a full feeding cycle, and if there were no heterogeneity in digestibility and pass-through rates of different prey types.

Bando summarized the analyses of stomach contents from 28 sperm whales taken from May to September under the 2000-2003 JARPN II program in the western North Pacific (CARP/PE/03). Thirty-two prey species were identified, consisting of 28 squids, one octopus, and three fishes. Weight of stomach contents was measured for each individual and mean weight was ca. 0.2-0.5% of total body weight in each subarea. Intestine contents were sampled from some of the whales. Numerous beaks were found in the large intestine. Species identification of these beaks and comparisons with stomach contents are ongoing. Bando expressed the view that these types of analyses are important for future elucidation of feeding ecology of sperm whales and that they can contribute to improvement of non-lethal sampling methods, such as fecal sampling. In response to a question, Ohsumi stated that these data coming from animals killed in offshore waters supplement previous studies of stomach contents from animals killed in coastal waters.

Madsen suggested that oxygen uptake and biomass turnover might be estimated from ventilation rates (obtained from D-tags) and that this could provide a more accurate assessment of the sperm whale's role in the ecosystem than simply additional data on stomach contents from killed whales. In fact, understanding the species' role in the ecosystem requires information on both metabolic needs and what is consumed.

Drouot presented CARP/PE/2 on investigations of sperm whale feeding in the Mediterranean. In the past, feeding success has been assessed by measuring the fatness or blubber thickness of stranded animals (i.e., average success over a few weeks or months) and by analyzing stomach contents (i.e., evidence of feeding over a few hours prior to death). Another method that has been used recently is to count "creaks," which are vocalizations (increased click rate of up to 220/sec, persisting for 10-25sec, followed by silence) thought to be produced by sperm whales investigating targets at close range, and therefore indicative of feeding attempts (cf. Miller et al. 2004a). This method was applied in the northern Mediterranean, where single sperm whales made an average of 25 creaks per dive (Drouot et al. 2004b). However, the method is difficult to apply when several whales are diving within range of the hydrophone, as it becomes difficult to discriminate the creaks of individual whales by ear. Further methodological development is needed before feeding attempts can be reliably detected and counted in such conditions. Other issues that need to be resolved are how to enumerate the number of prey items taken per creak (e.g., proportion of missed prey, catches of single or multiple prey) and the meaning of pauses in the click sequence (e.g., visual approaches of bioluminescent prey?). Timing of the first creak of a dive (consistently about 6 minutes following flukes-up in the Mediterranean study by Drouot and Gannier) is believed to provide a rough estimate of the depth of the feeding layer. In addition to providing insights on sperm whale feeding ecology, the creak rate and the foraging depth may be useful parameters for helping to assess the effects of anthropogenic disturbances.

In discussion, participants cited the difficulty of distinguishing creaks from interruptions in clicking (pauses) that may be unrelated to foraging (cf. Jaquet et al. 2001). Also, there is the problem of knowing whether any given foraging attempt was or was not successful (cf. Miller et al. 2004a). There is very high within-region variability in creak rates. Generally, it was agreed that analyses of creak rates to assess foraging patterns, while promising, are problematic in some respects and need further development.

Other possible approaches to assess foraging success might include ultrasonic measurement of blubber thickness (cf. Moore et al. 2001) and using high-resolution archival tags (so-called D-tags) to infer blubber content from buoyancy and gliding patterns during ascent and descent (cf. Miller et al. 2004b).

8.2 Diving Physiology

During an average dive, a sperm whale spends about 45min at depth and about 10min at the surface recovering. Scaling from the Weddell seal, it has been estimated that a 45min dive is within a sperm whale's aerobic dive limit. Miller inferred, based on D-tag data, that female sperm whales approach their predicted aerobic diving limits more often than males. However, Whitehead expressed his impression that in a given area, females and males seem to dive approximately for the same length of time, while on a global scale, males exhibit more variable diving behavior than females, the latter being relatively stereotyped in this regard.

Attention was drawn to the recent paper by Moore and Early (2004) where they document progressive bone damage in sperm whales, which they speculate could be related to trauma from nitrogen sickness (the bends). This hypothesis, if true (but see Rothschild [2005] and Moore and Early [2005]), indicates that sperm whales pay a physiological price for their deep-diving behavior.

Diving physiology is relevant to estimation of g(0) (see Item 6.3), and therefore actual dive times, when measured, should be published and, if at all possible, stratified by sex. In relation to this point, Whitehead noted that the percentage of time spent socializing by sperm whales differs considerably by area (e.g., Caribbean vs. tropical Pacific), and that because much of this behavior is at the surface, this could have a large effect on g(0).

Thode presented CARP/A&D/2 (and see Thode et al. 2002; Thode 2004), which was relevant to a number of agenda items involving the underwater acoustic tracking of sperm whales. Sperm whale clicks generate enough energy to reverberate, or echo, off the ocean surface and bottom. Under certain circumstances, these echoes can be used to track a sperm whale in range and depth using a single hydrophone deployed from the surface. This technique has been used to measure sperm whale dive profiles and foraging depths in the Gulf of Alaska and Mexico. The foraging behavior of sperm whales around longlines in Alaska has also been investigated. If a second hydrophone can be deployed with sufficient horizontal separation, a 3-dimensional dive track can be derived under more general circumstances, because then only a single surface-reflected echo is needed. Automated systems using this method are currently being developed as part of a study in the northern Gulf of Mexico (Sperm Whale Seismic Study, Texas A&M), where potential correlations are being investigated between sperm whale foraging and the presence of prey concentrations signaled by acoustic backscattering. These techniques are currently being incorporated into standard acoustic tracking software.

9. HUMAN INTERACTIONS

9.1 20th Century Whaling

Smith drew attention to Allison and Smith (2004), which described and classified whaling operations around the world, drawing on Reeves and Smith (in press). Five types of operation were responsible for most of the sperm whale hunting in the 20th century. Of these, the most important were Norwegian-style land stations and factory ships. The magnitude of whaling in the 20th century is remarkably well known, although an integrated database representing the complete catch data has only recently been assembled. Catch records for many whaling operations were reported to and assembled by the Bureau of International Whaling Statistics (BIWS) between 1930 and 1986, and reported to the IWC subsequently. However, catches for some whaling operations were not reported to, or otherwise did not come to the attention of, either of these bodies.

The 20th century catch data have been assembled in a single database, seasonally and by expedition or land station for the entire century. The database shows that 20th century catches are relatively well documented. It provides a better understanding of the completeness and reliability of some data sources, and it has resulted in improved allocation of catches to species and area. In the process of assembling the database, whaling operations with substantial remaining uncertainties have been identified, and this affords guidance on where additional archival research would be most valuable.

Reports of total catches are available at quite detailed levels (Allison and Smith 2004: their Table 2). Decadal summaries by ocean basin, nation, and type of operation reveal the major whaling operations and how catches shifted over the century (Allison and Smith 2004: their Table 3.)

In addition to the total catch data, information has been reported on individual whales taken, including location, sex, and length, in some cases with additional biological observations. Reports on individual whales are available for a large fraction of the total whales caught, and include locations. These data show that 20th century catches were generally at higher latitudes than pre-20th century catches, and there was limited spatial overlap with the earlier whaling grounds (CARP/HI/15).

A number of whaling operations have been identified for which submitted data were either incomplete or falsified (e.g., Zemsky et al. 1995; Kasuya 1999; Yablokov and Zemsky 2000). While these data have been improved in many cases, major uncertainties remain concerning catches of sperm whales in the North Pacific by Soviet pelagic operations and some Japanese shore stations. Because of the likely degree of falsification, there is a need to address these uncertainties in order to determine the biological impact of sperm whaling in this ocean basin. One approach that has proven useful is to search for archival data that were collected during whaling operations but were not reported. In the absence of such archival material, various statistical approaches exist that would allow estimation of missing catches from similar whaling operations where more nearly complete data are available. Such approaches are currently being applied to Antarctic catch data and should be applied to North Pacific data. Kasuya (2003) outlined an approach for dealing with some of the Soviet and Japanese records and called for an expansion of coverage to include additional geographic and seasonal strata in the North Pacific. There was no known falsification of sperm whale catches by modern whaling in the North Atlantic.

In both the North Pacific and the Southern Hemisphere, sperm whale catches were routinely under-reported by the USSR (Soviet Union) beginning in about 1948 and continuing until the early 1970s when the International Observer Scheme came into effect (Yablokov et al. 1998; Brownell et al. 2000). In the North Pacific, true catch data are available for only two floating factory fleets: the *Dalnij Vostok* and the *Vladivostock*. Catches were misreported both in total and by sex, with the overall true catch total for these two fleets being 106,053 (reported = 86,741). Totals for the two fleets by sex were as follows: males 73,173 (reported 72,532), females 32,880 (reported 14,209). True catch data are not available for three other floating factory fleets. However, using correction factors derived from the *Dalnij Vostok* and *Vladivostock* data, Brownell et al. (2000) estimated total Soviet North Pacific takes for 1949-71 at *ca.* 180,000 sperm whales. If one adds to this the 1972-79 total catch (32,338), the grand total of Soviet sperm whale catches in the North Pacific (known + estimated, 1949-79) is approximately 212,338 whales. Also in the North Pacific, the reliability of Japanese catch statistics is in doubt, especially for post-World War II operations (Kasuya 1999).

Southern Hemisphere catch records have been largely rectified. The total true Soviet catch of sperm whales in the Southern Hemisphere was 89,493 (reported = 74,834; Yablokov et al. 1998, Clapham and Baker 2002). The total estimated 20th century catch for the Southern Hemisphere (all nations, including the revised Soviet data) was estimated by Clapham and Baker (2002) at 395,000 sperm whales.

9.2 Pre-20th Century Whaling

In a previous workshop (July 2002), a detailed research program was outlined to improve understanding of the effects of whaling on sperm whale populations worldwide and on regional scales (Smith and Reeves 2003). The emphasis was on refinement of catch history for pre-modern ("open-boat") sperm whaling. Smith provided an overview of progress since 2002 on that research agenda (CARP/HI/5).

One area of progress was improved estimation of open-boat removals on a global basis from aggregate and voyage-based sperm oil returns, following earlier work by Best (1983). Improved estimates for the 19th century and new estimates for the 18th century are being developed by Best (CARP/HI/16 and CARP/HI/17). For the 19th century, the overall approach had been to compile sperm oil production figures from the US and other whaling operations, either using declared landings from that fishery (US, Britain, France) or oil imported into the UK from other fisheries (Germany, Australia, New Zealand, Chile, etc.). Where possible, the latter imports were checked against declared exports from the nation concerned. A correction factor for vessels lost was applied to the US production figures (and will be applied to the British figures; Best, pers. comm.). The adjusted production figures were then used as an index of the total catch, and were divided by a barrel-per-whale figure to obtain an estimate of the number of whales processed. Where possible, barrel-per-whale figures were used that were from that contemporary fishery. In the case of the US fishery, such figures were obtained by dividing the declared returns of a particular voyage, as listed by Starbuck (1878) or Hegarty (1959), by the number of sperm whales listed for the same voyage by Townsend (1935). These yields were in turn stratified by vessel-type, as smaller vessels (brigs, schooners, and sloops) tended to have lower mean oil yields than larger vessels. For other nations, oil yields were obtained either from information on the given nation's own fishery (e.g. France, Azores) or by analogy with the US fishery (e.g. Britain). The total landed catch for the 19th century (adjusted for vessel loss rates) was estimated to be 271,900 sperm whales, of which 69.1% were taken by US whalers. At its peak (ca 1840), the fishery may have been landing between 6,000 and 7,000 sperm whales annually.

For the 18th century the overall approach was much the same, but adequate series of production indices were only available after 1762, and then often only as "train oil" without any indication as to type (whale or sperm). Some separation was attempted using whalebone (baleen) landings to determine the proportion of whale oil, although the retention of whalebone seemed to be strongly affected by market forces. Production figures for the US from 1790 from Starbuck (1878) were pro-rated upward to account for missing voyages (using Lund 2001). Adequate barrel yield per whale data were only available from the French fishery, and an average value from this source was applied to all production figures. The estimated total landed catch from 1762 to 1799 from the US, British, and French fisheries, combined (adjusted for vessel loss rates), was 27,600 sperm whales, of which 74% were taken by US whalers. The estimates from both CARP/HI/16 and CARP/HI/17 refer to landed catch only, and still need to be adjusted for whales struck and lost that died and were not recovered.

Smith presented CARP/HI/1 in which he and his colleagues summarized other progress since the 2002 workshop. A "voyage database" contains summary information for roughly 15,000 individual voyages by American whaling vessels. This includes information on rigging, announced destination, and amount of sperm oil (and other products) obtained during the voyage. A second database contains daily information from a sample of whaling logbooks, including numbers of whales sighted and taken, and in some cases volumes of oil obtained from individual whales. Pierce and Smith (CARP/HI/11) described the specific data being extracted and the data entry program being used. Smith and Josephson illustrated selected voyage tracklines in CARP/HI/7, and illustrated the location of catches as individual points and as numbers per area in CARP/HI/8.

Taken together, these two databases allow estimation of total catches using two approaches. One is that used by Best (CARP/HI/16 and CARP/HI/17) – volume of oil landed divided by average volume of oil obtained from individual whales. The second approach estimates the catch as the product of the numbers of voyages and the average numbers of whales per voyage. CARP/HI/2 addressed the characteristics of these two approaches. The oil yield per animal was most affected by latitude, as would be expected from the known sex and size segregation, and the apparent differences in average oil yield per whale from vessels with different rigging was not significant once latitude and year had been accounted for. It is known that vessels with different rigging were used in different regions (e.g., Atlantic versus Pacific), and likely in different latitudes, so assigning a single average yield per whale may be inappropriate. Further, CARP/HI/2 demonstrated greater average numbers of whales per voyage for the generally larger barks and ships than for the usually smaller schooners and brigs, as well as higher average catches per voyage after 1875. The authors plan to explore further the implications of using the catch-per-voyage estimator for different time periods and areas.

Smith's presentation prompted a discussion of whether sperm whales in different areas differ in body size (= oil yield). No conclusion could be reached, but this is a question that deserves closer investigation through a variety of methods. In response to a question as to whether spermaceti was ever registered separately from sperm oil, Chatwin and Best said that the distinction was generally not made except sometimes early in the fishery when "head matter" was listed as such. There was also a brief discussion of how large sperm whales could get. Best stated that yields in excess of 100 barrels were not infrequently recorded (there being 31 whales with this yield or greater in the Townsend "abstracts") and that a 100bbl sperm whale would be about 63 ft long.

Lund called attention to the availability of a collection of ship manifests for New Bedford covering the years 1818-1919, noting that a small sample examined by her had revealed a number of discrepancies with the product data in Starbuck (1878). Further investigation of these manifests subsequent to the workshop revealed that the discrepancies primarily occurred in the earlier years (Lund, pers. comm.).

During discussion, attention was drawn to what has been described as a paradox. Regional historical studies by Bannister et al. (1981) and Hope and Whitehead (1991) appeared to confirm that whaling pressure in the 19th century caused declines in sperm whale encounter rates on both the Japan and Galápagos Grounds, yet this would imply much smaller pre-exploitation whale numbers than are plausible, given the magnitude of the catches by the modern whaling industry in the 20th century (for further elaboration, see Whitehead 1995). Among possible explanations (from Smith and Reeves 2003) are that: (1) analyses of encounter rates have been confounded by changes in whale behavior (i.e., they learned to avoid the whaling ships), (2) catches by the open-boat fisheries have been greatly underestimated, or (3) environmental carrying capacity for sperm whales increased substantially between the 19th and early or mid-20th century.

9.3 Interactions with Fisheries and Shipping

9.3.1 Longline Depredation

Straley summarized CARP/HI/9, noting that there is evidence of depredation by sperm whales on longline gear, defined as observation of damaged or lost fish, reduction in expected catch, or damaged hooks, from many locations in the Southern Hemisphere, the Gulf of Alaska (see CARP/HI/10), and the North Atlantic off Greenland and Newfoundland. Most observations have involved solitary or small groups of male sperm whales. Target fishes have included sablefish (*Anoplopoma fimbria*), grenadier, and Pacific halibut in the North Pacific, Greenland halibut (turbot) in the North Atlantic, and Patagonian toothfish in the Southern Ocean. In all reported instances, depredation has occurred on fishing grounds that are also recognized as natural feeding grounds for sperm whales, and the authors of CARP/HI/9 concluded that longlining has simply made it "easier" for sperm whales to obtain their natural prey. A better understanding of the nature and magnitude of interactions between sperm whales and longline fisheries will depend on the systematic collection of data. In the toothfish fishery, explosives are used, at least to some extent, to deter whales. Unfortunately, a large part of this fishery is illegal and uncontrolled, which effectively precludes monitoring and mitigation for that component.

9.3.2 Longline Depredation in Alaska

Straley summarized CARP/HI/10 on the longstanding problem of sperm whale depredation on demersal longlines in the Gulf of Alaska. Depredation on gear set for sablefish, also called black cod or butterfish, has been occurring since at least the mid-1970s when the phenomenon was first observed. The fishery, one of the most lucrative in Alaska, was year-round until the early 1980s when fleet expansion resulted in a regulatory shortening of the season. In 1995 individual fishing quotas were implemented, reducing overall effort with an 8 month open season.

In 2003 and 2004, the North Pacific Research Board funded the first phase of a collaborative study between fishermen, scientists, and managers to collect quantitative data on longline depredation. Off the port of Sitka, in the eastern Gulf of Alaska, the shelf edge is 10-20nmi offshore. This makes Sitka an ideal study base because, within 2 hours of departure, a researcher in a fast boat can be following fishing vessels hauling longline gear off the shelf. The eventual goal is to develop deterrents or changes in fishing practice that will reduce depredation and hence decrease the economic loss to fishermen. Fishermen collect data on fishing activity and whale behavior, and they provide photographic documentation. Also, they assist in the deployment of acoustic equipment (hydrophone arrays) on their longline anchoring gear. The initial phase of the study has been successful in finding sperm whales near fishing vessels and evaluating the magnitude of the depredation.

Results indicated that whales were present near the fishing vessels about a third of the time. Of those sets with whales present during the haul, 65% had evidence of depredation. Depredation was determined by the presence of shredded fish bodies or lips remaining on hooks. From 1 to 7 whales were found near the fishing vessels. Also, lone sperm whales were observed to dive repeatedly along the shelf edge with no vessel in close proximity. Preliminary genetic results determined that the six whales biopsy-sampled in 2003 were all males. A total of 34 individual sperm whales were photo-identified across both years.

The conflict between fishermen and sperm whales arises from the spatial and temporal overlap in their efforts to take advantage of the same resource. Fishing vessels may function as magnets for whales that would not otherwise associate with one another. This may create opportunities for researchers to learn about feeding and social behavior, individual movements, and population structure. Mark-recapture methods can be used to estimate the number of whales in the region. Future plans include (a) placing cameras on or near longlines to discover how fish are removed from lines and (b) expanding the acoustic component. This latter would involve using a towed passive array for 3-dimensional tracking to estimate how far away a sperm whale can hear a fishing vessel and how far away the vessel (fisherman) can hear the whale.

In discussion, it was noted that although pots can be used to catch at least some of the demersal target fish species, longlines are currently the most common gear used . Thode listed three basic approaches for addressing the depredation problem: (1) not fishing in certain areas (avoidance), (2) active deterrence, and (3) passive deterrence. The last of these may involve reduction in acoustic cues (e.g., quieter winches) or "flashing a mirror" (acoustically) back at the whale as it homes in on its target. He cited rockfish bladders, which make the line "light up" acoustically as it is being hauled, and bird activity as among the cues that might attract whales. Mesnick pointed out that one of the best strategies is to prevent the problem from starting. She noted that in the past, Alaskan longliners would spend 45 minutes hauling the line very loudly and then effectively "chum" the whales and various scavengers as they processed the catch.

Cornish called the workshop's attention to the International Fisheries Observer Conference in Sydney, Australia, in November 2004, and specifically to the pre-conference workshop on "Developing Best Practices for the Collection of Longline Data to Facilitate Research and Analysis to Reduce Bycatch." Although sperm whales do not appear to be killed or injured often as a result of their interactions with longline gear, it was clear that observers on longline vessels represent a potentially valuable resource for collecting systematic data on sperm whales observed in the vicinity of fishing operations. A data form developed by Straley in collaboration with Alaskan fishermen provides a standard format for documenting interactions with sperm whales. Among the important elements to include are target species of the fishery, bycaught species, presence of offal, where whales occur in relation to the vessel and currents, and behavior of the whales around the vessel.

9.3.3 Bycatch

Although it was not discussed in any detail, participants wished to record the fact that sperm whales are, like other cetaceans, susceptible to entanglement in gillnets. The frequency of entanglement has been noted as a particular problem in the Mediterranean Sea (Notarbartolo di Sciara 1990) and along the west coast of South America (Haase and Félix 1994).

9.3.4 Ship Strikes

Sperm whales are also susceptible to ship strikes (Laist et al. 2001) although the frequency of collisions appears to be low off North American coasts. Collision risk is regarded as a more significant conservation concern for sperm whales in the Mediterranean Sea and around the Canary Islands.

9.3.5 Competition with Fisheries

The neon flying squid (*Ommastrephes bartrami*), which is one of the major target species for fisheries in Japan, was found in the stomachs of sperm whales sampled during the 2000-2003 JARPN II surveys in the western North Pacific. Preliminary estimates indicate that 800,000 tons of neon flying squid are consumed by sperm whales, equivalent to roughly eight times the total estimated catch of this species by fisheries in the western North Pacific (Tamura et al. 2004; CARP/PE/3). Ohsumi suggested that these estimates indicate the possibility of competition with fisheries.

The Gulf of California is another area where sperm whales might feed on a commercially fished species of squid, in this instance jumbo squid (*Dosidicus gigas*), which is a major food source for sperm whales off Peru and Chile. A pilot study of sperm whale diving behavior in relation to squid distribution and behavior was conducted off Santa Rosalia (Gulf of California) (CARP/FP/8). Five sperm whales were tagged with satellite-linked time-depth recorders and several large *D. gigas* were tagged with archival tags. Preliminary analyses showed that sperm whales spent most of their time at depths of around 300m, but comparisons with squid data have not yet been completed. This was the first time that both sperm whales and their potential prey were tagged simultaneously in the same area, and further research is planned. See also Item 10.3.

Deep-sea fishing operations have often targeted species that are long-lived, slow-growing, and poorly known (e.g., rockfish, *Sebastodes*), with predictable results of over-exploitation and stock collapse. In some cases, fishes that form part of the diet of sperm whales in some areas have been fished more generally, potentially resulting in a perturbation to part of the food supply of sperm whales.

9.4 Environmental Issues

9.4.1 Contaminants

There is widespread and growing concern about the effects of chemical contamination on high-order marine consumers, such as the sperm whale. This topic was not reviewed for the workshop or discussed in depth. However, Godard and her colleagues with Ocean Alliance summarized their biopsy sampling program and their plans for conducting a variety of contaminant analyses (see Item 10.8, below).

Godard presented a summary of Godard et al (2004), which demonstrated *in vitro* cytochrome P450 1A1 induction in sperm whale tissues after exposure to ß-Naphthoflavone. The study demonstrated a causal relationship between chemical exposure and CYP1A1 induction and therefore validated the use of CYP1A1 expression in skin biopsies as a biomarker in sperm whales (and other cetaceans).

9.4.2 Underwater Noise

Sperm whales are acoustically oriented animals. The extent to which they use sound in all aspects of their lives is still being elucidated, and new technologies such as archival telemetry are providing new insights in this area. One indication of the importance of acoustics for this species is the extraordinary investment in specialized energy-rich fats and oils found in the spermaceti, junk, and other associated bodies within the head. Together, these elements comprise an organ that is easily the largest natural sound-producing structure on the planet. The evident importance of acoustics to sperm whales is an *a priori* reason to suspect that they are sensitive to manmade sound, including shipping noise, especially because of their deep-diving habit. Deep diving may constrain a sperm whale's behavior, making any forced change in response to disturbance costly. For example, the large fixed investment in time traveling to and from feeding depth during a typical sperm whale foraging dive means that any reduction in overall dive duration would have a proportionally large effect on time spent foraging. In addition, the one group of cetaceans (Ziphiidae, beaked whales) for which there appears to be good evidence of mortality resulting from exposure to anthropogenic sound (as suggested by Frantzis 1998 and subsequent authors)) are also deep divers. While the mechanism leading to the deaths of beaked whales remains uncertain, recent work by Jepson et al. (2003) suggests that they suffer decompression sickness, perhaps as a result of surfacing too quickly or remaining too long at the surface between dives in the presence of noise. Bone damage recently observed in sperm whales is morphologically similar to bone necrosis, a condition associated with saturation diving in humans. Moore and Early (2004) suggested that the tissues of sperm whales also become supersaturated with nitrogen, the effects of which may be exacerbated by exposure to noise.

In summary, there are reasons for concern, but the evidence for serious impacts of anthropogenic sound (noise) on sperm whales is equivocal. Few studies have been conducted, and published reports, many based on opportunistic observations, give contradictory results.

9.4.3 Oil and Gas Industry

Within the oil and gas industry, techniques have recently been developed to allow oil and gas to be exploited seaward of the continental shelf. Rigs are currently operating at depths greater than 2000m and that limit continues to be extended. This means that oil- and gas-related activities are being pursued on a large scale in sperm whale habitat for the first time. Seismic surveys, which use large arrays of airguns to make intense sound pulses, have been the activity of most immediate concern. Large-scale seismic surveys are employed during the exploration phase and there is an increasing trend within the industry for smaller-scale seismic surveys to be repeated to monitor how oil reserves are being exploited (so called four-dimensional surveys). During the exploitation phase of an oil field, there is increased noise production and disturbance involved with drilling, rig construction and operation, and the vessel traffic involved in servicing an oil field.

Workshop participants involved in field experiments in the northern Gulf of Mexico (see Item 10.1, below) reported preliminary results suggesting that sperm whales there, even after many years of frequent exposure to seismic airgun noise, exhibit at least subtle behavioral responses (e.g., Miller noted some indication of declines in creak rates at distances as much as 5-10km from the sound source). Despite the difficulty of determining if and how these responses might translate into biologically significant effects (e.g., changes in vital rates), the very fact that sperm whales are such deep-diving, acoustically oriented animals is cause for concern about the potential impacts of noise pollution on them.

10. FIELD PROGRAMS

10.1 Gulf of Mexico

During 2000-2002 the Southeast Fisheries Science Center (SEFSC) participated in a multifaceted, collaborative sperm whale research program with funding from the Minerals Management Service (Mullin et al. 2003). These studies focused primarily on photo-identification, behavior, and tagging of sperm whales in the northern Gulf of Mexico and have been continued in the ongoing Sperm Whale Seismic Study. Prior to those studies, SEFSC marine mammal assessment surveys were conducted as "piggy-backed" visual sighting surveys between 1996-2001. In addition, small-scale photo-identification studies in the northern Gulf of Mexico have been conducted aboard small vessels during the last two years.

In summer 2003 and spring 2004 the SEFSC conducted dedicated marine mammal assessment surveys in oceanic waters of the Gulf of Mexico between the continental shelf break and the limit of the U.S. EEZ. These were combined visual line-transect and passive acoustic surveys, employing the 90min count approach of Barlow and Taylor (2001). In addition, nighttime small-scale acoustic surveys were conducted to provide fine-scale information on sperm whale presence/absence throughout the Gulf and for comparison to daytime encounter rates. Biopsy samples were collected opportunistically by deploying a small inflatable boat. These studies are expected to result in substantially higher abundance estimates for sperm whales in the Gulf than those presently available due to the improved estimates of group size and correction for visibility bias, or g(0). The SEFSC plans to conduct its next large-scale vessel survey in the Gulf of Mexico during summer 2007. That survey will likely include two independent visual teams, passive acoustics, dedicated biopsy sampling, and deployment of bottom-mounted recorders.

Gordon presented CARP/FP/7, an overview of the Sperm Whale Seismic Study (SWSS). This study in the northern Gulf of Mexico is sponsored and administered jointly by the U.S. Minerals Management Service and the Texas A&M Research Foundation, with additional partnerships (e.g., Office of Naval Research, National Science Foundation, and National Marine Fisheries Service). The potential vulnerability of sperm whales to offshore petroleum exploration and development operations, and especially to airgun noise, has become a major concern as oil and gas activities have expanded offshore into waters deeper than 200m. The fundamental goals of SWSS are to define "normal" behavior and habitat use by sperm whales in the study area and determine how these are altered as a result of seismic survey operations. SWSS includes the following technical components: satellite imagery and limited physical oceanography input, a visual watch team, a passive acoustics monitoring team, a satellite tag team (long-range tracking), a D-tag team (controlled exposure studies), a DNA team, a photo-identification and behavior team, and a "meso-scale" team that conducts "classical" observational research from a sailboat (see below). Thode called attention to a parallel study sponsored by industry that involves passive acoustic monitoring to supplement onboard visual observation as part of seismic survey mitigation protocols (www.pamguard.org). The idea is to ensure that whales within visual or acoustic range of a seismic vessel are detected and located in time to allow the operator to take appropriate action (e.g., temporarily shutdown the airguns) and reduce the likelihood of an impact.

In discussion, Gordon indicated that there was little prospect in the immediate future of extending the satellite tagging operation into waters outside the northern Gulf of Mexico study area. Thus far, one tagged whale traveled to the Gulf of Campeche (Mexico) and at least one male moved into the North Atlantic and then returned. For the most part, however, the population in the region appears to be fairly stationary.

Gordon also presented CARP/PS&M/5, which described the initial results of work by the SWSS "meso-scale" team, consisting mainly of photo-identification, acoustic recording, biopsy sampling, and observations of behavior. In the first year they worked from a large vessel with a team of 15 (depending on a small rigid-hulled inflatable for close approaches to the whales), and in the second year from a smaller boat with a team of seven. Results demonstrated that the sailboat with a small research team was much more cost-effective than the large vessel and larger team of researchers.

In response to a question concerning the relative merits of large vs. small platforms for observing calves and obtaining data to estimate calving rates, Whitehead stated that, using the same platform and crew, he had observed a very dramatic contrast in proportions of calves between the eastern tropical Pacific on one hand and the Caribbean Sea and Indian Ocean on the other.

10.2 Mediterranean Sea

A central question for the Mediterranean Sea, where abundance and movements through the Strait of Gibraltar are poorly known, is the extent to which sperm whales there are isolated from those in the North Atlantic. Drouot et al. (2004b) found frequency differences in mtDNA haplotypes between sperm whales in the Mediterranean Sea and those in the eastern North Atlantic.

Comprehensive assessment of sperm whale abundance in the Mediterranean is precluded by the uneven distribution of effort and the complete lack of effort in the southeastern part (CARP/FP/11). More than 20 institutes and research groups are active in the Mediterranean, although the sperm whale is a focal study subject for only a few of them. Most of those primarily collect photo-identification and acoustic data in their local areas. Recent acoustic surveys conducted by the International Fund for Animal Welfare in the Ionian Sea (between southern Italy and Greece) and in the southwestern Mediterranean (along the North African coast from Morocco to Tunisia) should provide abundance estimates for those areas in the near future.

The sperm whale is one of the priority species for broad-scale abundance surveys being planned under the Agreement on the Conservation of Cetaceans of the Black Sea, Mediterranean Sea and Contiguous Atlantic Area (ACCOBAMS). The earliest that any such survey is likely to take place is 2007. It is anticipated that the surveys will employ ships operating in double-platform mode (Buckland Turnock method), which is considered the most effective method for most of the species of interest. The primary data for assessing sperm whale abundance, however, will be acoustic (CARP/FP/11).

10.3 Eastern North Pacific

NOAA's Southwest Fisheries Science Center in La Jolla, California, has conducted multi-species cetacean line-transect surveys annually in the eastern North Pacific since 1986, and intermittently prior to that. Annual field effort is typically 240 sea days on NOAA research ships. Study areas vary from year to year, but have covered the eastern tropical Pacific (1986-90, 1992, 1998-2000, and 2003), the U.S. West Coast (1991, 1993, 1996, 2001), the U.S. EEZ of Hawaii (2002), the Aleutian Islands, Gulf of Alaska and Bering Sea (1996, 2004), and western Baja California and the Gulf of California (1993). These are visual line-transect surveys using 25X binoculars as the primary searching method, but the surveys also include collecting a full suite of oceanographic measures of cetacean habitats. In addition to these multi-species surveys, a dedicated sperm whale survey was conducted in the eastern temperate Pacific in 1997 (Barlow and Taylor 2005). Towed arrays were added to collect acoustic data on vocalizing dolphins and sperm whales in 1997 and in most subsequent years. Sperm whale density estimates from visual line-transect methods have been made for the eastern tropical Pacific (Wade and Gerrodette 1993), West Coast (Barlow 1995, Barlow 2003b), eastern temperate Pacific (Barlow and Taylor 2005), and Hawaii (Barlow 2003c) study areas. An acoustic line-transect estimate of sperm whale density was also made for the eastern temperate Pacific (Barlow and Taylor 2005). Multi-species line-transect surveys by the SWFSC are expected to continue into the foreseeable future, with 120-240 sea days per year on NOAA research vessels. In summer/fall of 2005, survey areas will include two distinct regions: (1) U.S. EEZ waters around Johnston and Palmyra Atolls and surrounding international waters between those islands and Hawaii, and (2) the U.S. West Coast. In summer/fall of 2006, survey efforts will return to the eastern tropical Pacific.

Clapham reported that the National Marine Mammal Laboratory in Seattle holds some fluke photographs and biopsies from the vicinity of the Aleutian Islands, but there are no concrete plans for research on sperm whales in that laboratory. The autonomous listening devices deployed by Sue Moore and colleagues may have generated some useful data on sperm whales. Although the U.S. Navy's bottom-mounted hydrophone arrays (Sound Surveillance System, or SOSUS) remain active in the North Pacific, Barlow pointed out that the archived components generally do not go above about 100Hz, which means they have little to offer regarding sperm whales.

The ongoing sperm whale depredation study in the Gulf of Alaska will continue to collect data on sperm whale behavior, acoustics, genetics, and photo-identification (see CARP/A&D/2, Thode, Scripps Institution of Oceanography; and CARP/HI/10, Straley, University of Alaska Southeast).

Jaquet summarized CARP/FP/8, describing sperm whale studies in the Gulf of California, Mexico, since 1998. The six field seasons to date have spanned an average of one month each, 564 individual sperm whales have been identified, and further research is planned. Traditional methods (developed by Whitehead and colleagues in the 1980s) have been used to assess distribution, abundance, residency, social organization, habitat use, patterns of small-scale movement, large-scale movements, genetics, and coda repertoires of the whales in the Gulf. The use of similar methods in different study areas allows comparisons between regions and consideration of spatial variation in social organization, mating behavior, habitat use, etc. Preliminary analyses suggest that social organization, group size, and mating strategy are similar in the Gulf of California, the Galápagos, and Chile, but differ substantially between these areas and the northern Gulf of Mexico, where similar techniques were used in summer 2004 (see CARP/PS&M/5). Differences have been observed in habitat use and site fidelity between sperm whales in the Gulf of California and those off the Galápagos and Chile, with the whales using mainly relatively shallow habitat (600-1000m) in the Gulf of California and showing high site fidelity for a small area of the central Gulf. Eleven individuals first identified in the Galápagos were resighted in the Gulf of California, a straight-line distance of about 3800km.

10.4 Western North Pacific

Kato noted the large-scale Japanese sighting survey program in the western North Pacific since the mid-1970s and introduced CARP/FP/5 and CARP/FP/10. These papers examined monthly changes in spatial distribution and yearly changes in encounter rates of sperm whales. Preliminary estimates of abundance were also produced. The large-scale program is expected to continue. Kato also drew attention to specific research projects in Japan on sperm whale acoustics and to data-logger experiments with sperm whales. CARP/FP/6 provided an overview of Japan's whale research program in the western and central North Pacific (JARPN, 1994-1999, and JARPN-II, 2000 and ongoing), and CARP/A&D/6 analyzed sperm whale distribution in the western North Pacific from sightings surveys between 1994 and 2004.

10.5 Western North Atlantic and Caribbean

The Southeast Fisheries Science Center conducts large-scale vessel surveys in Atlantic waters of the U.S. EEZ between Florida and Maryland on a two- to three-year cycle. The last large-scale assessment survey was conducted in summer 2004. It involved two independent visual sighting teams and passive acoustic monitoring. High densities of sperm whales were encountered along the continental shelf break north of Cape Hatteras, and a survey is planned for summer 2005 to collect biopsies from sperm whales and other species in that area. Further, a "process-oriented" ecosystem survey is being planned for summer 2006, to include intensive hydrographic sampling, active fishery acoustics to assess biomass of food species, mid-water trawling, intensive biopsy sampling, and visual marine mammal sightings (Garrison, pers. comm.). The goal will be to evaluate habitat features that account for the observed high densities of sperm whales and other marine mammals in this region.

The Northeast Fisheries Science Center will continue to conduct summer multispecies line-transect (ship and aircraft) surveys in shelf and offshore waters between Maryland (38ºN) and the Gulf of St. Lawrence. Surveys are conducted at 3- to 5-year intervals. An aircraft is used to survey shelf (0-200m) waters in the entire survey region. Shelf edge (200m) and oceanic waters between Maryland and the U.S./ Canada EEZ border are surveyed by ship. Ship surveys include visual (two independent teams) and acoustic components. Further, in summer 2006 or 2007 a dedicated biopsy sampling survey will be conducted throughout the survey region (Waring, pers. comm.).

Whitehead reported that the Canadian Department of Fisheries and Oceans conducts marine mammal surveys sporadically, mainly off Newfoundland. His own shipboard work recently involved a visit to the Sargasso Sea, mainly to test equipment. Very high densities of sperm whales were found there. Whitehead noted that the western North Atlantic may be of particular interest because it is one of very few areas of the world where sperm whales were not subjected to modern industrial whaling.

Whitehead also reported that he and his group at Dalhousie University have an ongoing field program at Dominica in the West Indies. Kato called attention to a Caribbean FAO "ecosystem" study that began in 2002. Several participating countries have an interest in the sperm whale and are compiling sightings.

10.6 Eastern and Central North Atlantic (including Iceland)

A long-term study in the Azores, principally involving acoustic monitoring and photo-identification, was funded by the International Fund for Animal Welfare from 1987-1995 (Leaper et al. 1992; Matthews et al. 2001). This study has been continued to some extent by the University of the Azores and by some of the whalewatching operators (Gordon, pers. comm.).

From 4 June to 2 July 2004 the Norwegian R/V *G.O. Sars* conducted a multidisciplinary survey along the northern portion of the Mid-Atlantic Ridge (Reykjanes Ridge to the Azores). Sperm whales were the most frequently sighted cetaceans. Data analyses will be available in summer 2005 (Waring, pers. comm.).

A photo-identification study ran for many years (1987-1990s) along the west coast of Norway, based on a whalewatching operation (Lettevall et al. 1993; Hastie et al.. 2003). Madsen reported that he and Mark Johnson have a continuing collaboration with B. Møhl to study sperm whale acoustics off Norway.

A regular series of quantitative acoustic surveys of the Shetland Faeroes channel and waters to the northwest of Scotland have been conducted since 2000 by researchers from Aberdeen University and the Sea Mammal Research Unit (SMRU) using the Fisheries Research Vessel *Scotia*. Two to three surveys are carried out each year and this series is currently being continued (Hastie et al. 2003).

Norwegian NASS surveys and serial yearly partial-coverage surveys, primarily aimed at minke whales, have been combined to produce two estimates of abundance for sperm whales in the northeastern Atlantic. These estimates are not corrected for availability bias (Øien 2005). An estimate for the NASS-2001 survey area – East Greenland to the Faroe Shelf and Jan Mayen – is corrected for availability bias (Gunnlaugsson et al. 2002). A comparison of sperm whale sighting rates from the series of NASS surveys 1987-2001 and observations from O-group surveys around Iceland, 1982-1995, shows a decline in both cases. This is contrary to increases in sighting rates of other species (Gunnlaugsson 2004).

The Norwegian minke whale surveys are expected to continue. The next large-scale NASS survey is scheduled for 2007 and will be coordinated by NAMMCO in collaboration with the IWC.

10.7 South Pacific

Dawson provided a summary of the Otago University project at Kaikoura, NZ (CARP/FP/1). The sperm whales there are comprised of (a) "residents" that remain in the study area for several weeks or months, and return to it regularly, and (b) "transients" that appear to be passing through. Several residents have been seen six years in a row, and two that were first identified in 1991 were still visiting Kaikoura in 2002. Mark-recapture analysis of photo-identification data collected from 1990-2001 suggested that an average of 79 (CV = 23%) whales were present in any one summer or winter season (Childerhouse et al. 1995; Gormley 2002). There is no evidence of a trend, and no evidence of seasonal differences in abundance. The photo-identification catalog contains 202 individuals. To date, all well-photographed individuals have been uniquely identifiable. Mark change has been observed, but over a period of 4.5 years has been insufficient to cause misidentification (Childerhouse et al. 1996). Both whaling records (Grady 1982) and stereophotogrammetry (Dawson et al. 1995) indicate that, except for rare visits by mixed groups, the sperm whales routinely present off Kaikoura are males. Age-length data (Ohsumi 1977) suggest that about two thirds are between 10-20 years old, and thus pubertal (Chessum 1992; Dawson et al. 1995). The remaining third are aged 25 years or older.

Abundance is similar between summer and winter, but distribution differs significantly; whales are found closer inshore in winter. Fish (especially grouper) become more important in the winter diet (Gaskin and Cawthorn 1967). It seems likely that this dietary change causes of the shift in distribution. Dives and surface intervals were significantly longer in summer (mean dive time 43.9 vs. 38.7 min; mean surface interval 9.3 vs. 8.8 min). Whales covered, on average, 0.86nmi (CV = 50%) between consecutive flukes-up

(Jaquet et al. 2000). Large whales did not dive for longer than small whales, and dive time and surface recovery period were only very weakly correlated. Unlike sperm whales in nursery groups, males at Kaikoura very seldom spent extended periods (>15min) at the surface. These males spent about 83% of their total time underwater.

Off Kaikoura, sperm whales are the focus of whalewatching, which involves the use of boats and aircraft to view the animals year-round. Richter et al. (2003) made boat-based and shore-based observations to quantify the responses of whales to the whalewatching activities. Shore-based observations showed that blow interval decreased significantly in the presence of the research vessel and/or whalewatching platforms. Data collected from the research vessel showed that both whalewatching boats and planes, individually or together, caused significant increases in time spent at the surface and in the frequency and number of heading changes. In the case of boats, there was also a significant decrease in the time to first click. Aerial behavior was significantly more frequent when only the research vessel was present, which is likely due to its closer positioning to surfacing whales after acoustic tracking. Transients react more frequently and more strongly to vessels than do residents. For this reason, and because of their more inshore distribution, residents receive the majority of whalewatching attention. Reactions to whalewatching vessels vary significantly among different individuals, some of which are very tolerant. Reactions also vary with season, for reasons that are not understood. On balance, effects on resident whales, while statistically detectable, appear not to be of any serious biological consequence. However, current whalewatching effort on residents is high, such that individuals are likely to spend approximately half of their surfacing time during the busy summer season in the company of one or more vessels.

Dawson described an acoustic and photo-identification survey of sperm whales conducted in Tongan waters from May to September 2003, focusing on the area around Vava'u and between Vava'u and the Ha'apai island groups. This was a collaboration between scientists at Otago University in Dunedin, New Zealand, and the Southwest Fisheries Sciences Center in La Jolla, California. In addition to the survey in Tonga, a hydrophone array was towed on the voyage from New Zealand's east cape to Tonga. Despite poor weather that restricted array deployment, sperm whales were heard on six days of this 9-day passage. In Tongan waters, mixed groups including calves were found most often along the 1000m contour between the Vava'u and Ha'apai island groups. Groups of males were occasionally seen to the east and west of Vava'u. In one case, these whales were silent for extended periods. Detection distances under sail at slow speeds (<6 knots) were around 10nmi for usual clicks. Under good conditions, slow clicks could be heard considerably farther away (ca. 20nmi).

Whitehead expressed interest in resuming work in the South Pacific, having carried out extensive studies there (Chile to the Gulf of California) from 1985-2000. Future efforts by his group would focus on, among other things, estimating survival rates.

10.8 *Odyssey*

Ocean Alliance's "Voyage of the *Odyssey*" program is a five-year (2000-2005) global effort designed to gather baseline data on levels and potential effects of synthetic contaminants in the world's oceans. Detailed information on methods and synopses of the data collected thus far were presented in CARP/FP/4 and CARP/FP/9. The ship is expected to return to the U.S. east coast in autumn 2005. A new voyage is expected to begin in 2007 (Godard, pers. comm.).

Persistent lipophilic contaminants accumulate and biomagnify in marine mammals because of their high body fat content, their relatively long life span, and their high trophic position within marine food webs. Of all marine mammals, the sperm whale was chosen as the study species for the program because of its global distribution and because it can be identified and tracked acoustically. The *Odyssey*'s route was designed to include regions historically known as sperm whale grounds as well as regions little or poorly surveyed.

Close to 1000 biopsies had been collected to the time of the workshop; a final sample size of about 1200 is expected by the program's end. Whenever possible, each biopsy collected by the *Odyssey* team is divided into subsamples that can provide material for the following analyses: contaminant burden, biomarkers of exposure to and effects of contaminants, genetics, stable isotopes, and fatty acids. Godard recommended that biopsy efforts from other platforms follow similar subsampling protocols in order to maximize the information obtained from each individual sperm whale sampled. According to Godard, analyses of contaminant burdens can be expected to provide information on the overall level of environmental contaminants in sperm whale tissues. In addition, differences in contaminant patterns may be useful as markers for population or stock differentiation. Studies of the potential effects of environmental contaminants on the health of sperm whales (cf. Godard et al. 2004) are ongoing.

Godard acknowledged that contaminant analyses can be costly and that many samples have yet to be analyzed. Arrangements have been made to have some of the material analyzed in Christina Fossi's laboratory at the Universitá di Siena, Italy. Godard acknowledged that zonation of contaminant concentrations in skin and blubber can be a confounding factor in some analyses. She noted that sex would be determined for each biopsy and that a gross estimate of the individual's body size (as a proxy for age) was also available in each case.

In addition to the toxicology component, the Ocean Alliance program includes genetics and acoustics components. The initial genetic analyses will provide information on sex distribution, sex ratio, and the relationship between sex and contaminant burden. Acoustic recordings associated with the program also may provide information that is useful for sperm whale population assessment. After a brief discussion of this latter point, the workshop concluded that it was unlikely the acoustics data could be used retrospectively to generate meaningful density estimates. It was agreed that, at a minimum, the acoustics data should be archived at Cornell University.

10.9 Indian Ocean

Bannister briefly described a proposal to develop methods to determine sperm whale distribution, population size and trend, habitat, and conservation status in Australian waters, particularly off southwestern Australia where the commercial sperm whale fishery operated from 1956 to 1978 (CARP/FP/2). A pilot study has been funded for 2005, with two main elements: (a) to review an earlier proposal for aerial surveys off Albany, Western Australia, and (b) to review methods of DNA extraction and to sequence mtDNA from sperm whale teeth. The first element would provide a proposal for surveys of relative abundance to be compared against data from the earlier whaling aerial spotter operation. The second element would consist of an analysis of mtDNA diversity based on teeth collected from the commercial catch.

10.10 Antarctic

Kato summarized the current status of the IWC's IDCR/ SOWER project, which began in 1978/79 with the primary objective of stock assessment of Antarctic minke whales. The project has now completed its third set of circumpolar surveys. Future planning is ongoing through a special working group. Further detailed planning will take place at the upcoming (2005) meeting of the Scientific Committee. The sperm whale is a potential priority, but it is important to consider that the program's Antarctic focus means that only large males can be investigated. Kato emphasized that these cruises were sampling only the large-male component of the Southern Ocean population and therefore could not be expected to provide estimates of the whole population. Best added that, in fact, they sample only that part of the large-male component that is south of 60ºS, and that sampling the whole adult male component would require redesign of the surveys and extending the northern boundary of the study area northward.

CARP/FP/6 provided an overview of Japan's Antarctic whale research program (JARPA), and CARP/A&D/7 presented new information on sperm whale abundance and distribution in Antarctic Areas IIIE, IV, V, and VIW (35ºE to 145ºW). Ohsumi stated that there is interest in estimating the biomass of sperm whales as input to ecosystem models.

11. FUTURE WORK

Participants recognized that the overarching theme of the workshop was population assessment. Development of such an assessment will require the following (not necessarily in order of priority):

11.1 Need to Understand the True, Underlying Structure of Populations

The need for an improved understanding of population structure in sperm whales was a frequent theme of the workshop, and indeed a significant part of the rationale for convening it. "Structure" can be interpreted variously as applying to, or being driven by, differences in sex, age, behavior, geography, genetics, or culture. In the context of this workshop, population structure was essentially considered the same as stock structure, with "stock" interpreted to mean that the *internal dynamics* of a group of animals are more important than *external exchange* with other groups.

Given that the overarching theme of the workshop was population assessment, it is important to consider whether such assessment is likely to be sensitive to a range of scales of population structure. For example, a reasonable initial step might be to establish a series of possible scales ranging, say, from ocean basins to 5-degree squares. If depletion levels appear similar across that range and at the extremes, there may be little need to worry about getting things exactly right. Additional work on population structure may not then be a high priority, at least from the perspective of assessment.

Although genetics is often invoked as a key factor in determining population structure, it was considered more appropriate here to consider genetics a *consequence of*, not a *driving factor for*, the structure. In other words, genetics provides a way of assessing structure but does not necessarily cause it, and therefore genetic difference constitutes a *marker* for other structuring forces. A global review of sperm whale genetics is clearly a priority. This will require, as a first step, an inventory of what material is available for genetic analyses, including where and how it was collected, by whom, etc. Such a process has already begun and should be encouraged and supported (see CARP/ PS&M/1). The next steps would be to analyze the available material, and then to conduct directed sampling based on the initial results and working hypotheses.

Participants struggled with the problem of how to define hypothetical population units (i.e., strata), recognizing that the traditional concept of geographic boundaries may not adequately reflect cultural aspects of sperm whale population structure (cf. Whitehead et al. 2004). A non-traditional view requires the integration of genetics with finer-scale "cultural" markers such as coda dialects (CARP/PS&M/ 2), as well as basic data on modal and extreme movements of individuals (e.g., from satellite tagging and photo-identification), morphology (e.g., scarring), and knowledge about mating systems and foraging ecology (e.g., from historical whaling data). CARP/PS&M/1 and CARP/PS&M/3, together, provided an initial basis for such an integrative approach.

Using a hierarchical model, one might begin by asking: Are there multiple distinct units within the global sperm whale population or not? In addressing that question, one can choose between a deductive process of assembling the available data and looking for patterns, and a more inductive process using a predictive ecological framework.

Another way of approaching the issue of population structure might be with the following series of questions:

1. Is there a single global population, or is meaningful structure present within that population?
2. If there are distinct groups of sperm whales, are they or are they not geographically overlapping?
3. What markers, in addition to or instead of genetic markers, can be used to define sperm whale populations (e.g., differences in behavior or "culture")?

The following alternatives for establishing strata to compare and test were agreed:

1. Use as an initial working hypothesis that the sperm whales in each ocean basin represent separate units (stocks).
2. Use strata alternatively based on: oceanography, geography, ecology (prey distribution), or social or cultural variables (coda repertoires), as well as a "no structure" hypothesis.

Among the tools that might be used for the above analyses are: tagging (movement data), photo-identification, acoustics, and biopsies (DNA, contaminants, stable isotopes).

As a way of trying to rank various methods of addressing population structure, a straw poll of workshop participants, on a scale of 1 to 3 (low to high), had the following results:

- High – parasite and predator (scarring inflicted by killer whales) analyses, Discovery mark returns, photo-identification, mtDNA sequencing, nuclear DNA markers (microsatellites and single nucleotide polymorphisms), satellite tagging, vocal (coda) analyses, trace analysis of tooth sections, Y-chromosome sequence variation, and breeding-area studies (seasons out of phase).
- Medium – patterns of change in catch or sightings per unit of effort, contaminant analyses.
- Low – morphometrics, morphology, distribution of catch or sightings data, allozymes.

11.2 Need to Obtain Accurate Estimates of the Numbers of Whales (Preferably by Sex and Size Class) Removed by Whaling from Each Population

Although ideally catch and associated data (including some kind of effort index) should be collected at a fine scale, limitations of time and cost are unavoidable in practical terms. Particularly in regard to historical (pre-20th century) whaling where there is substantial uncertainty, information on the statistical properties (e.g., ideally confidence limits, but at least some indication of lower and upper bounds) of catch estimates should be provided. Also when possible, it is preferable to explore a range of mortality factors to "correct" catch data for hunting loss (struck/lost) in different areas and times. While corrections to account for hunting loss and allocation of catches to sex should be straightforward for much of the era of modern whaling (with exceptions as noted under Item 9.1), this is not the case for the open-boat era.

At what point is further pursuit of improved catch data no longer cost-effective? The workshop was unable to answer this question conclusively. However, participants agreed that the answer depends in large part on the scale of analysis and the size of the area inhabited by the "population" of interest. It was further noted that there was likely a strong temporal effect, such that efforts to collect better information from the early days of sperm whaling (especially the 18th century) are likely to be more worthwhile than efforts to improve the more recent catch history.

The workshop emphasized the importance of reaching closure on the revised modern catch data for the North Pacific, and the need to specify sex to the maximum extent possible in the case of sperm whales. It was agreed, for example, that the sex composition of the validated sample of catches in the North Pacific could be extrapolated in the manner outlined by Kasuya (2003).

11.3 Need to Estimate Abundance for a High Proportion of Waters Worldwide

Whitehead (2002) extrapolated densities from a heterogeneous set of abundance surveys to estimate current sperm whale numbers worldwide. Additional areas of the world's oceans need to be surveyed to validate those density estimates. Special emphasis should be given to waters of the Atlantic and Indian Oceans because only small proportions of them have been surveyed systematically for sperm whales.

11.3.1 Line-Transect Surveys: Visual and Acoustic

Combined visual and acoustic (hybrid) surveys need to be continued for the immediate future, but it is reasonable to expect acoustic-only surveys to become the norm eventually, given their relative efficiency. As explained more fully under Item 10.1 (and see CARP/PS&M/5), the current state of acoustic survey methodology allows for the use of small boats and platforms of opportunity, which obviates the need for large field teams and costly ship charters.

There was some disagreement on the question of how much further development is necessary for acoustic surveys, but it was agreed that unprocessed ("raw") acoustic data should be carefully organized and archived so that as methods of analysis improve, those data can be reanalyzed. A particular need for acoustic methods is to determine how to estimate group size when surveying areas where sperm whales occur in large groups.

Further refinement of g(0) is needed for visual surveys. This will require more dive data (e.g., from data loggers), more parallel visual and acoustic surveys for calibration, and more modeling. A caveat for telemetry data is that they are useful for estimating g(0) for individuals but not necessarily for groups. It was also noted that the proportions of time spent by whales resting vs. socializing are critical to g(0), yet these patterns vary a great deal between ocean areas. Whitehead indicated that groups of sperm whales tend to be larger and more compact in the Pacific than in the Atlantic. As better estimates of g(0) become available, they can be used to reanalyze data from past surveys as well as to analyze data from future surveys, recognizing the potential variability among surveys.

Kato stated that Japan has been carrying out shipboard sighting surveys to obtain abundance estimates for most species because this methodology is reliable and realistic. However, because of the necessity to have appropriate g(0) values, acoustic surveys are also useful for sperm whales or long-diving cetaceans. As a consequence, the National Research Institute of Far Seas Fisheries has started simultaneous visual and acoustic surveys for sperm whales. Furthermore, the Institute has succeeded in obtaining dive-profile data by attaching data loggers to sperm whales and Baird's beaked whales. These data can be used to improve estimates of g(0) for sperm whales.

The workshop discussed whether the effort and observations (visual and/or acoustic) from the *Odyssey* voyage could be used retrospectively to generate useful density estimates *ex post facto*. Also, Kerr noted that the ship would be visiting the Twelve-Forty (12ºN by 40ºW) Ground in the North Atlantic in summer 2005, and wondered whether plans could incorporate the necessary protocols for obtaining useful data for density estimation. More generally, platforms of opportunity (e.g., seismic survey vessels, transoceanic shipping, and oceanographic research) offer the possibility of obtaining useful data at little cost but also the risk of biases of various sorts. Some platforms carry sophisticated oceanographic equipment or operate year-round in all conditions. The best platforms are those that follow a systematic or grid design and that travel at low or moderate speed. Acoustic survey techniques are particularly amenable to use on platforms of opportunity.

11.3.2 Mark-Recapture Studies

Photographic mark-recapture methods of estimating abundance are useful and have been applied successfully over relatively small spatial scales. They are likely to be most useful for population assessment in fairly closed areas such as the Mediterranean Sea, Gulf of Mexico, and Gulf of California. However, the large spatial scales over which most sperm whale populations occur mean that photo-identification is unlikely to be a generally useful technique for population estimation. For further elaboration of the relative merits of this and other techniques, see Items 5.2 and 5.5.

11.3.3 Methods of Extrapolation

Several suggestions were offered on ways to validate or improve the extrapolation procedures used by Whitehead (2002) to estimate global sperm whale abundance. With access to unprocessed (and not just summarized) data from surveys, it should be possible to extrapolate to additional areas using multivariate approaches. Kato reported that the Worldwide Map of Cetacean Distribution based on Japanese sightings data (Miyashita et al. 1995) is being updated. When available (possibly 2006), it may be of use in decisions about extrapolation. Finally, collation of data from various platforms of opportunity (see 11.7.2, below) might also provide insights about presence, absence, and relative densities of sperm whales in unsurveyed areas.

11.4 Need to Improve Understanding of the Demographics of Population Growth

Among the important parameters to estimate are individual growth rate, average age at sexual maturity, pregnancy rate, and survival rate (by age and sex).

Whitehead's (2002) model is very sensitive to r_{max}. Therefore, validation or improvement of the values used for that parameter must be a high priority. Knowing the survival rate of adult female sperm whales in their prime would substantially improve population modeling. Because of the great difficulty of obtaining an unbiased sample from the data presently available, obtaining estimates from a "closed" population (e.g., Caribbean Sea or Gulf of Mexico) using fishery-independent data (e.g., photo-identification) is an option to consider (cf. Barlow and Clapham 1997). It is uncertain, however, whether any isolated or relatively isolated population would be representative of the species overall.

Best pointed out that survival rates calculated in this manner (i.e., using photo-identification for a specific ocean area) would require a substantial time series to acquire sufficient precision, and that the longer the time span, the more likely that the estimates would be confounded by emigration and by the likely age-specific nature of sperm whale survival. Because of the time-consuming nature of such studies, it is important to capitalize on data already available and on programs that are in place and continuing. For example, approximately 20 years of data are available for the eastern Pacific and the Caribbean (Whitehead, pers. comm.).

Although there might be some merit in re-analyzing the whaling-derived data (Best et al. 1984), this was not considered particularly promising, as the same problems of heterogeneity would remain. Another suggestion was that r_{max} be estimated independently for females, and that modeling be limited to the female component of the population. A drawback, of course, is that male survival is likely critical to maintaining high pregnancy rates. Regarding the relevance of male survival to rate of increase, Whitehead suggested that integration of photo-identification and genetics data could provide a means of establishing paternity, and therefore assessing "social" maturity in males. Incorporation of acoustic or photogrammetric measurements would also help to generate estimates of body size at "social" maturity.

Besides better estimates of survival rate, estimates of gross reproductive rate are needed. These are currently determined from the ratios of calves to other animals in the school, but problems with field determination of "calves" (and the identification of the component of the population represented by the other animals in the school) indicate that more rigorous methods are needed to assess reproductive rate.

Potential methods to investigate reproductive status of individuals include: (1) fecal steroid hormone analysis to assess pregnancy and sexual maturity, (2) hormone assays of biopsies, (3) hormone assays of blow expirate, (4) longitudinal photo-identification studies of calves to determine age at sexual or social maturity (assuming that calves are well enough marked for photo-identification), and (5) long-term photogrammetric studies to track individual growth. More use might also be made of tooth sections in large samples from the whaling industry (assuming that such teeth are linked to biological data on the specimens from which they were extracted), and data from satellite tracking could be informative for some aspects of life history.

Ohsumi and Gunnlaugsson suggested that research catches of sperm whales, under present-day environmental conditions, would be a valuable supplement to other kinds of life history data. Workshop participants noted, however, that the value of such data would depend on the extent to which the samples duplicate existing samples and on the number of individuals sampled. Unless many individuals were sampled, which would necessitate large-scale whaling, the value of data from research catches will be low. Strandings, especially mass strandings, might be investigated as a source of relevant data, but the same qualification as mentioned for research catches applies – i.e., inevitably small sample size and thus inadequate statistical power.

11.5 Need to Develop Sperm Whale Population Models

There was general agreement that modeling of sperm whale populations should move as quickly as possible into a Bayesian, and preferably an age-structured, framework.

Population models for sperm whales need to be compatible with (i.e., more closely matched to) the quality of available data. As is always true of models, it is important that the uncertainty associated with data and rates used as input be explicitly represented.

Best considered that development of a more appropriate model of the effects of relative male depletion is essential for proper assessment of the current status of sperm whales. During the major 20th century episode of exploitation, many more males than females were taken, and inevitably a population model incorporating catches by sex would show that males (and particularly large males) have been depleted substantially more than females. This is true even after allowing for the substantial under-reporting of females in the Soviet (pelagic; Brownell et al. 2000) and Japanese (shore station; Kasuya 1999) catches. The implications for the population trajectory would depend critically on whether such depletion was sufficient to adversely affect female reproductive success. One assumption of the previous male depletion model used by the IWC Scientific Committee has been shown by recent field studies to be inappropriate (although probably risk-averse), and there is an ongoing need to establish: (a) the threshold size of breeding males and (b) the effective sex ratio of breeding males to mature females. Addressing these questions adequately will require carefully planned field experiments, as well as further simulation modeling. Lengthy tracking of individual roving males, if feasible, could prove informative.

Gunnlaugsson noted that although some stable CPUE series from modern whaling operations may not be of any significance, observations of historic depletion and trend should be reflected in the output of population models if such models are to be considered realistic. Alternatively, priors on depletion levels and trends can be used as input to the models to estimate population growth rate. With an age-structured model, the observed mortality rates from "age readings" (GLGs in teeth) could be compared to the mortalities predicted by the model, or even fitted in the model. Gunnlaugsson urged that estimates of effort should be collected wherever feasible. In his view, a decline in CPUE in a fishery that is unrestricted in range is generally believed to reflect a decline in the stock, and possibly a disproportionately severe decline (i.e., non-linearity).

The issue of how, and to what degree, CPUE data should be incorporated into any sperm whale model was controversial. On one side, there was a view that all CPUE data are suspect and that inherent biases confound virtually any analysis that uses such data. On the other side, it was noted that in some cases of “pure” sperm whale fisheries (i.e., with no other whale species as alternate targets), the relatively “clean” CPUE data would be informative for a sufficiently resolved model. Examples might be the 19th century sperm whale fisheries on the Japan Ground (Bannister et al. 1981) and around the Galápagos (Hope and Whitehead 1991) and the 20th century fisheries off South Africa (Best 1974 and pers. comm.) and Western Australia (Kirkwood and Bannister 1980).

Additional suggestions to improve Whitehead’s model included: (1) further exploration of the density dependent response using additional simulations and perhaps incorporating lessons from work with other species (e.g., seals in the UK) and (2) incorporating a variable, time-dependent carrying capacity (K) to reflect possible changes in global primary productivity over time.

11.6 Biological Significance of Present-Day “Changes”

11.6.1 Climate Change

Whitehead reported that the two main sperm whale “clans” around the Galápagos were strongly affected by El Niño. If the incidence of such events increases, as expected as a result of climate change, this could significantly influence the balance among sperm whale clans according to their different adaptive characteristics. Some of the implications of climate change for sperm whale populations were addressed by Whitehead et al. (2004), who concluded that “cultural diversity” in sperm whales may need to be preserved as a way of minimizing the risks to the species from climate change.

Participants discussed briefly whether sperm whales, as oceanic animals that forage at great depths, might be less vulnerable to the effects of climate change than animals that depend more directly on surface plankton. The balance of opinion was that in most models, primary production near the surface is closely linked to deep-ocean conditions, and therefore it is reasonable to assume that effects on the former can be extrapolated to the latter.

11.6.2 Chemical Pollutants

In some other taxa (studied in the laboratory or the wild), high levels of some of the pollutants detected in sperm whales have been implicated in reproductive or immunological problems. Too little is known to assess whether pollutants cause or contribute to such disorders in sperm whales; however, if problems do exist, or could arise in the future, they would potentially compromise already-low rates of population growth and recovery in this species.

The workshop agreed on the value of continuing to collect, analyze, and archive sperm whale tissues for contaminant analyses. Understanding the effects of the various chemicals, and dose:response relationships, requires long-term effort, but reporting of tissue levels in the meantime should continue. In addition, collection and analyses of contaminant levels in known prey of sperm whales would be informative. According to Godard, the standards and protocols for tissue collections and archives, as outlined in CARP/FP/9, are in conformity with those of the National Institute of Standards and Technology, which serves as the long-term storage site for archived tissues. Ocean Alliance was encouraged to explore collaboration with the IWC’s Pollution 2000+ project.

Godard and Mesnick provided a table to guide biopsy collection and storage (Table 1).

11.6.3 Changing Prey Base

This topic was recognized as an important one, and the workshop agreed that methods for monitoring feeding success (e.g., creak rates, defecation rates, blubber thickness measurements; see Item 8.1) should be integrated as fully as possible into field studies of sperm whales.

11.6.4 Increased Underwater Sound

There has been growing concern about the impacts of manmade sound on cetaceans, including sperm whales (see Item 9.4). These concerns range from the discrete effects of activities with limited duration over limited time periods to the more generalized (chronic, cumulative) effects of such things as ship traffic.

The most sensitive technique for evaluating short-term effects on behavior involves monitoring the behavior of a whale before, during, and after a controlled exposure to sound (Tyack et al. 2003). Such experiments can be used to define a dose:response relationship between a sound exposure and a behavioral response. If the experiment is designed to measure an important type of behavior whose function is understood, then it can address the question of how much sound prevents an animal from meeting a need such as foraging, maintaining contact between mother and calf, or finding a mate. The area of greatest uncertainty is predicting how such disruption affects growth, survival, or reproduction of the individual (National Research Council 2005). Larger spatial scales and longer time series are clearly needed to address this uncertainty.

It was noted that the subject of underwater sound and its effects on marine mammals has been or is being addressed in a comprehensive manner by a number of U.S. agencies, notably the Ocean Commission, the Marine Mammal Commission, and the National Research Council (2005).

Table 1. Analyses facilitated by biopsies, with handling and storage procedures.

Analysis	**Tissue**	**Storage solution**	**Storage container**	**Storage temperature**
Genetics	epidermis	30% DMSO saturated with NaCl or 90% ethanol	Glass or polypropylene vial	Room temperature for up to 3 months or frozen at –20°C. (Frozen at –20°C without preservative is best)
Cell culture	Epidermis	1)Culture media or 2)Freezing culture media	polypropylene tube or cryotube	1) -4°C for up to 1 week or 2)-20°C, -80°C or liquid nitrogen, according to freezing media requirements.
Stress responsive proteins (SRP)	Epidermis	None	Glass or polypropylene vial	Frozen -80°C
SRP expression	Epidermis	None	polypropylene vial	Liquid nitrogen (or -80°C for short-term storage)
Stable isotope	epidermis or blubber	None	Glass or polypropylene vial	Frozen -20°C
Cytochrome P450 – *enzymatic activities*	epidermis and blubber interface	None	polypropylene vial	Liquid nitrogen (or -80°C for short-term storage)
Cytochrome P450 – *Gene expression*	epidermis and blubber interface	1)None or 2)©RNA*later* solution	polypropylene vial	1)Liquid nitrogen (or -80°C for short-term storage) or 2)-4°C for 24hr followed by -80°C to -20C
Cytochrome P450 – *Immunohistochemistry*	epidermis and blubber interface	10% neutral buffered formalin	Glass or polypropylene vial	Room temperature
Chemistry – *Contaminant burden*	Blubber	None	Ultraclean glass vial	Frozen -80°C to -20°C
Fatty acids	Blubber	None	Glass or polypropylene vial	Frozen -20°C
Hormones	Blubber	None	Glass vial	Frozen -80°C to -20°C

11.6.5 Other Factors

The ongoing human-caused mortality from entanglements and ship strikes was noted. Reportedly high rates of driftnet mortality in the Mediterranean Sea have been a conservation issue for a considerable time and were discussed at the annual IWC Scientific Committee meeting in 2004 (IWC 2005). At the present workshop, it was agreed that the IWC should be encouraged to continue compiling data on incidental catches of cetaceans, and that special attention be given to sperm whales in the Mediterranean and in other areas where driftnetting overlaps the occurrence of sperm whales. Also, it was suggested that analyses of scarring on the bodies of living sperm whales (particularly in the region of the tail peduncle) could help elucidate the incidence of entanglement.

Sperm whale interactions with longline fisheries have become a major management issue in some regions (Gulf of Alaska, Southern Ocean), and they also represent a significant scientific challenge in determining their ecological significance and in finding ways of solving or mitigating the problem. The workshop recommended that data be collected in longline fisheries to determine the nature and extent of interactions with sperm whales and to improve knowledge of the whales' foraging patterns. Standard data collection protocols are essential for trend analyses.

11.6.6 Implications for Changes in Vital Rates

No attempt was made to investigate this issue in detail. The workshop simply noted the difficulty of inferring changes in vital rates from potential effects of such things as exposure to chemical contaminants or noise, reduced availability of prey, or climate change.

11.7 Implementing Components of Needed Research

11.7.1 Agencies with Interest

Some of the agencies with an ongoing interest in sperm whale assessment were mentioned under agenda Item 2 – the U.S. National Marine Fisheries Service (need to evaluate classification as Endangered, need to complete a Recovery Plan), IUCN (need for global Red List assessment, regional assessment of Mediterranean population), the IWC (not an immediate priority, but some interest in the medium to long term), and the HMAP project of the Census of Marine Life. The Department of the Environment and Heritage in Australia has signaled its interest by commissioning a pilot study of sperm whales in 2005 (Item 10.9). Japan has an ongoing interest in sperm whale research in the North Pacific and Antarctic, the former through JARPN-II (Item 10.4), the latter through JARPA and the IWC's IDCR/SOWER project (Item 10.10). The Mediterranean population of sperm whales is a high priority of ACCOBAMS (Item 10.2). The U.S. Minerals Management Service has a strong present interest and likely will have an even stronger interest in the future as oil and gas development moves into deeper water off the continental shelf (Item 10.1). There is interest in New Zealand, mainly related to whalewatching at Kaikoura (Item 10.7). As mentioned in Item 9.3, Alaskan longline fishermen and the North Pacific Fisheries Management Council have a strong interest in sperm whale status and behavior on a local or regional level, as does the North Pacific Research Board.

11.7.2 Cooperative Projects

A number of specific proposals for collaboration were identified and discussed. Ohsumi observed that because each country has its own policies regarding EEZ access, cooperative programs are needed to carry out research on an appropriate scale for a wide-ranging species like the sperm whale. Abundance surveys conducted under the auspices of the IWC and the North Atlantic Marine Mammal Commission provide examples.

11.7.2.1 Global Inventory of Photo-Identification Data

A global inventory of photo-identification data is needed. It is important that formal collaborations be established that include licensing agreements. The linking of catalogs greatly enhances their value.

Existing catalogs of sperm whale photographs and data include the following:

- International Fund for Animal Welfare, NAMSC (see Item 5.2) (contact: Tim Lewis); MS-Access based; covers Mediterranean Sea and North Atlantic
- Dalhousie University (contact: Hal Whitehead); covers eastern Pacific from Baja California to central Chile; has own matching routine for digital photographs; being consolidated with NAMSC catalog
- R. Hucke-Gaete in Chile
- Center for Coastal Studies (contact: Nathalie Jaquet); Gulf of California
- Southwest Fisheries Science Center (contacts: Jay Barlow); eastern North Pacific
- Ocean Alliance, *Odyssey* catalog (contact: Iain Kerr); numerous regions
- University of Otago (contact: Steve Dawson); Kaikoura, N.Z., region and Tonga
- University of Alaska Southeast (contact: Jan Straley); Gulf of Alaska
- Southeast Fisheries Science Center (contact: Lance Garrison); a small regional catalog
- Europhlukes (see Item 5.2) (contact: Jonathan Gordon); currently looking for a home base; online database and catalogs; other tools developed or under development; has useful structure for linking programs
- Cascadia (contact: *www.cascadiaresearch.org/*); North Pacific
- National Marine Mammal Laboratory in Seattle (contact: Sally Mizroch); a small catalog
- Jonathan Gordon holds some old collections from Sri Lanka
- Benjamin Kahn of APEX Environmental in Cairns, Queensland, has a South Pacific/Indian Ocean collection.

11.7.2.2 Global Inventory of Tissue Collections

A similar global inventory of tissue collections, essentially a continuation and elaboration of what was described in CARP/PS&M/1, is also needed. Again, it is important to emphasize the value of formal collaborations. Moreover, it is important to recognize that many tissue samples potentially have multiple research uses beyond genetic analyses (e.g., contaminants, isotopes). Also, teeth (including those in museum collections, with associated locality data) are an under-recognized potential source of DNA.

Existing tissue collections include the following:

- Southwest Fisheries Science Center (contact: Sarah Mesnick); North Pacific emphasis but global
- Cambridge University, UK (contact: Bill Amos); Azores
- University of Durham, UK (contact: Rus Hoelzel); northern Gulf of Mexico
- Centro Interdisciplinario de Ciencias Marinas – Instituto Politécnico Nacional (contact: Diane Gendron); Gulf of California
- Dalhousie University (contact: H. Whitehead): mainly Pacific
- Ocean Alliance (contact: Celine Godard); numerous regions
- University of Auckland (contact: Scott Baker); small collection mainly South Pacific
- Groupe de Recherche sur les Cétacés, Antibes, France (contact: Violaine Drouot); Mediterranean
- National Research Institute of Far Seas Fisheries, Shizuoka, Japan (contact: Hidehiro Kato); large num-

bers of tissues (including teeth) from commercial whaling, Antarctic and North Pacific
- Institute of Cetacean Research, Tokyo (contact: Seiji Ohsumi); large numbers of tissues (including teeth) from commercial whaling, Antarctic and North Pacific
- University of Uppsala, Sweden

11.7.2.3 Global Inventory of Coda Repertoires

Another area of potential collaboration is in consolidating and sharing coda recordings. An initiative is already underway, coordinated by the University of St. Andrews (Gordon) and Dalhousie University (Whitehead), to examine dialect differences in relation to population structure. Additional collections of coda recordings are know to be held by Ocean Alliance, Groupe de Recherche sur les Cétacés, University of Otago, and Woods Hole Oceanographic Institution. Garrison also noted that there may be some useful coda repertoires, unrecognized and unused, in the more general audio recordings held by the Southeast Fisheries Science Center.

11.7.2.4 National or International Database of Dive Profiles

Miller called the workshop's attention to the fact that a consolidated database of pinniped dive profiles is being developed, and he suggested that a similar initiative be considered for sperm whales.

11.7.2.5 Strandings

There are many networks around the world engaged in responding to whale strandings, and it was agreed that at a minimum, stranded (or bycaught) sperm whales represented a potential source of teeth, other hard parts, and at least some soft-tissue samples. Costly responses to sperm whale stranding events, however, require a coherent and well-justified research need. The workshop encouraged relevant agencies to collect and distribute tissues to appropriate researchers. Mass strandings of fresh animals, especially any that involve female sperm whales, are of exceptional interest and potential importance from a scientific perspective.

A tentative list of items that should be collected from a stranded sperm whale would include (most important items are in boldface):

- **Sex**
- Lengths (**total body**, dorsal fin to blowhole, fluke width)
- **Skin sample**
- **Tooth (as unworn as possible, e.g., front mandibular)**
- Stomach contents
- **Ovaries**
- **Photograph of flukes**
- **Blubber sample**
- Sample of liver
- **Check if lactating**
- **Check if pregnant**
- An eyeball
- Skin and/or internal tissue for cell culture (fresh animals only)
- Note any evidence of human interactions (e.g., scars, peduncle photograph).

11.7.2.6 Sharing of Tools and Technology

The workshop encouraged the sharing of research tools and technology and noted that the International Fund for Animal Welfare had set an exemplary standard in this regard, particularly with respect to acoustic survey equipment and techniques.

11.7.2.7 Platforms of Opportunity

In a general way, oceanographic and fishery research cruises offer potential for collecting data on sperm whales and their prey. The workshop encouraged this type of collaboration whenever and wherever possible. Gunnlaugsson provided an example from the North Atlantic, where redfish surveys are carried out regularly in a wide area southwest of Iceland, including the Mid-Atlantic Ridge south to 55ºN. Cetacean observers operated with good success on the two Icelandic vessels participating in these surveys in 2001. No observers were onboard the other two participating vessels. The value of observations on these platforms is enhanced by the collection of data on multiple ecological variables. This work is conducted under the ICES Planning Group on Redfish Stocks, which includes Germany, Norway, Russia, and Iceland.

Similarly, Waring pointed out that the MARECO project of the Census of Marine Life included marine mammal observers aboard recent oceanographic and fishery exploratory studies on the Mid-Atlantic Ridge. Sperm whales were the most frequently sighted cetaceans.

Straley pointed out the value of forging collaborations with coastal fishing fleets and fishery observer programs. This has been demonstrated to some extent in southeastern Alaska, where fishery interactions with sperm whales have provided a strong motivation on the fishermen's part. She stressed the importance of standard forms and protocols for data collection, and this applies to all platform-of-opportunity programs.

Whalewatching operations also offer potential for data collection of various kinds. The workshop encouraged sperm whale scientists to explore the possibilities of cooperating with such operations, e.g., in Dominica, the Azores, Norway, and Kaikoura (some of this potential has already been realized in the Azores and Norway).

11.7.2.8 Population Modeling Working Group

Given the importance, and the difficulties, of modeling sperm whale populations, it was recommended that a working group of experts be formed to develop, test, and refine appropriate models in a collaborative manner.

11.7.3 Research Coordination Mechanisms

It was agreed that a follow-up workshop to the present one should be convened in approximately two years. Also, it was agreed that an e-mail consultation should be organized among participants approximately in one year's time, to check progress on items discussed and recommended by the workshop.

12. TOP PRIORITIES FOR FUTURE WORK

The workshop agreed that the following areas of research should be given highest priority:

- Subdivide the global sperm whale population into a series of provisional units for analyses (hypothesis-testing) and initial management.
- Obtain and analyze additional data on female survival for at least several small populations.
- Facilitate more detailed exploration of differential depletion (male vs. female) by stratifying catch data by sex and investigating the breeding system more closely (to evaluate the role of large "roving" males), e.g., through behavior studies in semi-enclosed areas.
- Improve catch history by accounting for 18th century removals, resolving the problem of misreporting in the North Pacific post-World War II, and increasing spatial resolution.
- Carry out abundance surveys in additional areas, especially in the Atlantic and Indian Oceans.
- Continue to refine estimates of g(0).
- Use existing data to refine modeling approaches (e.g., extrapolation methods), investigate alternative values of r_{max} (rate of increase), and test sensitivity to different input parameters (e.g., density dependence).

Ideally, in the course of that research, there should be regular and substantive interaction between modelers and the field researchers involved in data collection.

Following the workshop, the conveners and chairman prepared a list of research tasks identified by workshop participants (Table 2). These tasks were regarded as desirable steps to be taken in advance of, or as part of, an in-depth assessment of sperm whale populations. The tasks were grouped by topic, roughly consistent with the various subjects covered in the workshop agenda. Numbering of the tasks was arbitrary and not meant to reflect order of priority. Nevertheless, those tasks of highest priority (as the editors interpreted the discussion) are highlighted. It was intended that priorities should be determined by the needs of modeling, as indicated earlier under this agenda item. It was recognized that completion of some of the tasks in Table 2 could be achieved by discrete, one-time efforts, while others would require more general, ongoing efforts by several different researchers or research teams.

Table 2. Research tasks by general category to be addressed in preparation for in-depth assessment of sperm whale populations. Those in boldface type should be given highest priority and initiated as soon as possible. See text for elaboration.

Category	Number	Description
Pop. Structure	1	**Provisionally identify units to test for discreteness.**
Pop. Structure	2	Continue and expand genetic analyses, integrated with data on vocal clans as possible.
Pop. Structure	3	Conduct comprehensive analysis and synthesis of Discovery mark program, including USSR data.
Pop. Structure	4	Conduct global inventory of photo-identification data, linking catalogs to the maximal extent possible. (Also applies to Abundance)
Pop. Structure	5	Conduct global inventory of tissue collections.
Pop. Structure	6	Conduct global inventory of coda repertoires.
Pop. Structure	7	Establish unified, comprehensive database on sperm whale morphometrics.
Pop. Structure	8	**Refine provisional population units**.
Abundance	1	Conduct global inventory of dive profiles.
Abundance	2	**Refine estimates of g(0).**
Abundance	3	Improve automation of photograph matching; evaluate use of dorsal fins and other features besides the flukes in photo-identification of individuals.
Abundance	4	**Improve methods for estimating group size acoustically, especially for large groups (up to 30 individuals).**
Abundance	5	Develop consensus on relative merits of acoustic and visual surveys.
Abundance	6	Evaluate methods of extrapolating densities to unsurveyed areas.
Abundance	7	Conduct additional surveys in selected areas.
Human Interactions	1	**Improve estimates of whaling removals in 18th and 19th centuries, by region and sex, including estimates of statistical precision.**
Human Interactions	2	**Resolve problems surrounding misreported and under-reported catches in North Pacific during 20th century: USSR, Japan.**
Human Interactions	3	Improve reporting and estimation of incidental mortality of sperm whales in fisheries, especially drift gillnets.
Human Interactions	4	Obtain additional measures of chemical contaminants in sperm whale tissues and improve understanding of effects, including dose-response relationships whenever possible.
Human Interactions	5	Get more and better data (both qualitative and quantitative) on sperm whale interactions with longline fisheries.
Human Interactions	6	Determine effects of human-induced noise on behavior and ecology of sperm whales, especially in relation to oil and gas industry.
Life History	1	Compare observed calf proportions in different study areas and refine understanding of calving rate and maximal potential rate of increase.
Life History	2	Determine function of codas.
Life History	3	**Determine population effects of differential depletion by sex.**
Life History	4	**Obtain more precise estimates of adult female survival.**
Modeling	1	**Establish population modeling working group to ensure interaction among researchers.**
Modeling	2	**Refine modeling approaches – e.g., alternative values of r_{max}, sensitivity to input parameters.**
Coordination	1	**Organize e-mail consultation**.
Coordination	2	**Conduct follow-up workshop in two years to review progress.**
Coordination	3	Determine when sufficient information is available to allow in-depth assessment of sperm whales.

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ANNEX 2: AGENDA

1. Welcome
2. Review terms of reference, agenda, available documentation, and workshop logistics
3. Introduction of workshop chair and rapporteur
4. Overviews (INT)
    - 4.1 Overview of sperm whale assessments
    - 4.2. Overview of population models
5. Population structure and movements (PS&M)
    - 5.1. Tagging
    - 5.2. Individual identification
    - 5.3. Acoustic
    - 5.4. Morphology
    - 5.5. Genetics
    - 5.6. Historical evidence
6. Abundance and distribution (A&D)
    - 6.1. Whaling records
    - 6.2. Genetic diversity
    - 6.3. Sighting and acoustic surveys, including dive cycle
    - 6.4. Individual identification
7. Life history (LH)
    - 7.1. Age determination
    - 7.2. Vital rates
    - 7.3. Social structure
8. Population ecology (PE)
    - 8.1. Feeding
    - 8.2. Diving physiology
9. Human interactions (HI)
    - 9.1. 20th Century whaling
    - 9.2. Pre-20th Century whaling
    - 9.3. Interactions with fisheries and shipping
    - 9.4. Environmental issues
10. Field Programs (FP)
    - 10.1. Gulf of Mexico
    - 10.2. Mediterranean
    - 10.3. E North Pacific
    - 10.4. W North Pacific
    - 10.5. Western North Atlantic and Caribbean
    - 10.6. Eastern and Central North Atlantic
    - 10.7. South Pacific
    - 10.8. *Odyssey*
    - 10.9. Indian
    - 10.10. Antarctic
11. Future Work
    - 11.1. Need to understand true, underlying structure of populations
    - 11.2. Need to obtain accurate estimates of the numbers of whales removed by whaling from each population
    - 11.3. Need to estimate abundance for a high proportion of waters worldwide
    - 11.4. Need to improve understanding of the demographics of population growth
    - 11.5. Need to develop sperm whale population models
    - 11.6. Biological significance of present-day ‘changes’
    - 11.7. Implementing components of needed research
12. Top priorities for future work

ANNEX 3: LIST OF DOCUMENTS

A&D	**1**		Gillespie D., Leaper, R., Gordon, J.	Acoustic Surveys for Sperm Whales - Theory and Practice
A&D	**2**		Thode, A.	Three-dimensional Underwater Tracking of Sperm Whales Using Passive Acoustics
A&D	**3**	**FI**	Barlow, J., Rankin, S.	Estimates of the Percentage of Sperm Whales Missed on Combined Visual and Acoustic Surveys in the Eastern Pacific Ocean
A&D	**4**	**FI**	Barlow, J., Taylor, B.L.	Estimates of Sperm Whale Abundance in the Northeastern Temperate Pacific from a Combined Acoustic and Visual Survey
A&D	**5**	**FI**	Leaper, R., Gillespie, J., Matthews, J.	Abundance Assessment of Sperm Whales
A&D	**6**		Matsuoka, K., Kiwada, H., Fujise, Y. and Ohsumi, S.	Distribution Pattern of Sperm Whales in the Western North Pacific Based on Sighting Survey Data of the JARPN/ JARPN II between 1994 and 2004.
A&D	**7**		Matsuoka, K., Kiwada, H., Hakamada, T., Nishiwaki, S., Ohsumi, S.	Distribution and Abundance of Large Male Sperm Whales in the Antarctic Areas: IIIE, IV, V and VIW (35 E-145 W).
FP	**1**		Dawson, S.	Acoustic and Ecological Research on Sperm Whales at Kaikoura, New Zealand
FP	**2**		Bannister, J., Harcourt, R., Moller, L.	The Status of Sperm Whales in Australian Waters: Developing Methods to Determine their Distribution, Population Size/Trend, Habitat and Conservation Status
FP	**3**		Mullin, K., Engelhaupt, D., Cates, C., Barros, N.	Sperm Whale Research in the Gulf of Mexico
FP	**4**		Godard, C., Clark, R., Kerr, I., Teglberg-Madsen, P., Payne, R.	Preliminary Report on the Sperm Whale Data Collected During the Voyage of the Odyssey
FP	**5**		Miyashita, T., Kato, H.	Sightings of sperm whales in the western North Pacific for the past twenty years.
FP	**6**		Institute of Cetacean Research	Sperm whale research by the Institute of Cetacean Research.
FP	**7**		Minerals Management Service	The Sperm Whale Seismic Study (SWSS) – An Overview of the Research Administration and Goals
FP	**8**		Jaquet, Gendron, Davis	Population Characteristics and dive behavior of sperm whales in the Gulf of California, Mexico (FP) based on an ongoing project using both new and old techniques
FP	**9**		Clark, R., Godard, C., Kerr, I., Fleming, A., Solomon, P., Payne, R.	Data Collection Methodologies of Ocean Alliance's Voyage of the Odyssey Program

FP	**10**		Kato, H., Miyashita, T.	Current status of the North Pacific Sperm Whales and its Preliminary Abundance Estimates
FP	**11**		Gillespie, D.	Mediterranean - Status of field programmes
HI	**1**		Smith, T., Josephson, E., Reeves, R., Lund, J.	Linking Historical Whaling Data for Voyages and from Logbooks for American Open-Boat Sperm Whaling
HI	**2**		Smith, T., Reeves, R.	Numbers of sperm whales per voyage and barrels of sperm oil per voyage in 19th century American open-boat whaling.
HI	**3**		Bannister, J.	Pre-20th century sperm whaling grounds
HI	**4**		Smith, T., Allison, C.	Preliminary Summaries of 20th Century Sperm Whale Catches
HI	**5**		Smith, T., Reeves, R.	Overview of Research to Date on the Effects of Sperm Whaling
HI	**6**		Smith, T., Josephson, E (Poster)	Locations of Sperm Whale Catches by American Open-boat Whaling
HI	**7**		Smith, T., Josephson, E. (Poster)	Tracks of American Open-boat Whaling From Logbooks
HI	**8**		Smith, T., Josephson, E. (Poster)	Locations of Sperm Whale Catches by American Open-boat Whalers by Vessel Rigging
HI	**9**		Warner, N., Mesnick, S., Straley, J.	Sperm Whale Depredation on Longlines Worldwide
HI	**10**		Straley, J.	Using Longline Fishing Vessels as Research Platforms to Assess the Population Structure and Feeding Ecology of Sperm Whales in the Gulf of Alaska
HI	**11**		Pierce, N., Smith, T.	Procedures for Whaling Logbook Data Entry
HI	**12**	**FI**	Smith, T., Reeves, R.	Design of a Program of Research on Sperm Whale Catch History: Results of a Workshop
HI	**13**	**FI**	Kasuya, T.	Potential For Improvement of 20th Century Sperm Whale Catch Data
HI	**14**	**FI**	Allison, C., Smith, T.	Progress on the Construction of a Comprehensive Database of Twentieth Century Whaling Catches
HI	**15**		Smith, T., Josephson, E. (Poster)	Locations of Sperm Whale Catches in the 20th Century
HI	**16**	**FI**	Best, P.	Estimating the Landed Catch of Sperm Whales in the 19^{th} Century
HI	**17**	**FI**	Best, P.	Estimating the Landed Catch of Sperm Whales in the 18^{th} Century
INT	**1**	**FI**	Whitehead, H.	Estimates of the Current Global Population Size and Historical Trajectory for Sperm Whales
INT	**2**	**FI**	Smith, T., Bannister, J., Best, P., Childerhouse, S., Gunnlaugsson, T., Kasuya, T., Reeves, R.	Cachalot (*Physeter catodon*): The Need to Improve Our Understanding of Status of Populations

INT	**3**	**FI**	Barlow, J.	Perspectives on Models of Sperm Whale Population Dynamics
LH	**1**	**Rev**	Best, P.	A Summary Review of Sperm Whale Vital Rates
LH	**2**		Kato, H., Kishiro, T., Bando, T., Ohata, K., Tamai, K.	Age and Body Length Structure of a Male Sperm Whale School Stranded at Ohura Coast, Kagoshima, Japan in January 2004
LH	**3**		Not a paper	
LH	**4**	**FI**	Whitehead, H., Mesnick, S.	Social Structure and Effects of Differential Removals by Sex in Sperm Whales: Methodology
PE	**1**	**Rev**	Best, P.	Summary Review of Sperm Whale Feeding
PE	**2**		Drouot, V., Gannier, A.	Assessing Sperm Whale Feeding Rate
PE	**3**		Tamura, T., Kubodera, T., Ohizumi, H., Konishi, K., Isoda, T., Fujise, Y.	Food habits of sperm whales based on JARPN II (2000-03)
PS&M	**1**		Mesnick, S., Engelhaupt, D., Lyrholm, T., Taylor, B., Escorza-Trevino, S.	Population Structure and the Social Animal: Global Genetic Differentiation in Sperm Whales
PS&M	**2**		Rendell, L., Mesnick, S., Burtenshaw, J., Whitehead, H., Dalebout, M.	Assessing Genetic Differentiation among Vocal Clans of Sperm Whales
PS&M	**3**	**FI**	Whitehead, H., Mesnick, S.	Population Structure and Movements of Sperm Whales: Methodology
PS&M	**4**		Not a paper	
PS&M	**5**		Gordon, J., Jaquet, N., Würsig, B.	A comparison of sperm whale photo-id research techniques using large and small vessels in the Gulf of Mexico

ANNEX 4: A BRIEF HISTORY OF THE IWC SCIENTIFIC COMMITTEE'S ASSESSMENTS OF SPERM WHALES

The IWC Scientific Committee conducted extensive data analysis and population modeling of sperm whales from the early 1960s. In November 1963 the Committee held the first of a series of scientific meetings to review information on sperm whales worldwide. Then it was noted that "with the present decline of baleen whale stocks, increasing attention is being devoted to the capture of sperm whales in many parts of the world" (IWC 1966, p51). Several recommendations came from that meeting, including use of marking and blood typing to identify population structure and collection of both catch and effort data for determining population status. This meeting was followed in 1968 by a more extensive review organized by the UN Food and Agriculture Organization, where several key issues were addressed. Substantial declines were noted in catch per effort rates for several regions and the implications of the sperm whale's sexual dimorphism and polygynous breeding system were of concern: "Because of the polygynous nature of the sperm whales, the sustainable yield of males might be much larger than that of females, for all males surplus to breeding may be exploited without harm to the stock" (IWC 1969 p43).

Several regional assessments were attempted, and among other things, it was concluded that the estimated fishing mortality of sperm whales off the South American Pacific coast was on the order of 11% per annum, and that the population was declining. P. Best concluded at the next Scientific Committee meeting that "the present level of exploitation of male sperm whales in the south-east Atlantic, and particularly of mature males, must be viewed with concern" (IWC 1970, p37)..

The Committee gained momentum on sperm whale matters, continuing with a major review meeting in 1970 (IWC 1971, p40-50). In 1972 the Committee recommended "that records of 19th Century Whaling be analyzed to attempt to reconstruct the original sperm whale stock status in the North Atlantic" (IWC 1973 p. 37). This concern gave impetus to the idea of organizing an international workshop on historical whaling records, which was held in 1977 (IWC 1983). Smith (1981) summarized the Committee's sperm whale assessments from 1963 to 1977. Subsequently, the Committee conducted three more special meetings and discussed sperm whales at several annual meetings. An important subsequent development was the identification of differential depletion by sex (IWC 1980). However, with the moratorium on commercial whaling, the Scientific Committee began to focus on developing management approaches for baleen whales that continued to be whaled, precluding any significant consideration of sperm whales. Commercial sperm whaling and sperm whale assessments had ended by the late 1980s.

At its 1998 meeting the Scientific Committee discussed the possibility of conducting a "comprehensive assessment" of sperm whales (IWC 1999, pp 22-24). Five key studies that had been developed intersessionally were discussed, including (1) genetic mark-recapture methods, (2) sighting survey estimates of abundance, (3) population models of past abundance, (4) review of historical catch data, (5) review of sperm whale dynamics and (6) biological and ecological topics such as life history, social behavior, ecosystem configurations and current anthropogenic mortality. The Committee discussed 11 papers on sperm whales that year, and concluded that "many difficult tasks … must be completed before a Comprehensive Assessment …" would be possible. However, it agreed to consider two of these topics at its 2000 and 2001 meetings. Despite that promising discussion, little further progress was made until 2003, when the Committee agreed to begin planning an assessment of sperm whale populations, and established a steering group to conduct a research planning workshop (IWC 2004, p 26).

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ANNEX 5: COMPARISON OF PHOTO-IDENTIFICATION AND BIOPSY SAMPLING

A working group led by Gordon and Clapham reviewed this subject and prepared a table comparing the two methods of study for sperm whales (Table A5-1). Photographs and biopsies can both be used to identify individual sperm whales as well as provide other useful data. The two types of samples are complementary and often a research project will aim to collect both from the same platform (see, for example, CARP/PS&M/5). To minimize interference and maximize the amount of data collected in an encounter, it is useful to consider the pros and cons of both types of sampling. Photographs and biopsies differ in various ways, including in the extent to which they can be collected from a representative sample of the population and whether collecting them is likely to be complementary to, or interfere with, other data collection activities. Multiple factors need to be taken into account when setting priorities for the collection of one type of sample over another.

Feeding sperm whales behave very predictably. Provided it isn't disturbed, a whale will almost always fluke-up after no longer than about 12min at the surface (Whitehead 2003 reported mean, modal, and median surface times from nine studies to have been between 7.5-9.5 minutes). Little variability between individuals has been experienced in researchers' ability to collect standard photographs, provided that the animals are not frightened. Thus, there is a high and consistent probability of being able to collect a photograph or biopsy if the boat stays behind the whale and does not scare it. Coming alongside a sperm whale to obtain a biopsy before it flukes up will usually disturb the animal significantly. This makes it unlikely that a photo-identification image will be obtained on that surfacing, and disturbance may even affect the animal's approachability on subsequent surfacings. Different individuals and components of the population seem to differ in their susceptibility to being disturbed in this way, a factor that introduces heterogeneity in capture probability for both biopsy and photo-identification. Biopsies can be collected from the tail when a whale flukes up. Collecting both samples (photograph and biopsy) at the same time in this way avoids interference and ensures that the two samples are unambiguously linked. It is often the case that samples of sloughed skin can be collected from the whale's wake. If such samples can be collected and unambiguously assigned to an individual, a biopsy may not be required. Mesnick noted that although sloughed skin is a reliable source of mtDNA, difficulties can arise when trying to extract microsatellites from this source.

In terms of their adequacy for individual identification, biopsies analyzed using microsatellite techniques have some advantages. For example, every animal sampled can be identified, and comparisons with other samples analyzed in exactly the same way are probably more accurate than photographic comparisons. However, it is important to recognize that comparisons between different laboratories, and even within a single laboratory over time, as equipment is changed, are not necessarily reliable. This limits the extent to which different groups of researchers can collaborate and pool identification material. In addition, it may be impossible to make comparisons with data that have already been collected, and some groups will not collect biopsy material on principle, making collaboration essentially infeasible.

By contrast, photographic data can be shared readily, and such sharing is made easier by online databases and digital imaging. With a species as wide-ranging as the sperm whale, there are great potential benefits of being able to collaborate and share identification images with other teams. Matching errors may become a more serious issue as photographic collections become larger. Provided that error rates can be quantified in some way, however, there may be analytical solutions to this problem. Another consideration is the incremental cost of analysis for individual identification as the sample size becomes larger. The genetic laboratory costs are substantial but constant with increasing numbers of individuals, while the photo-identification costs are low but increasing due to the number of comparisons to be made. Obtaining biopsies in situations where it is necessary to make multiple identifications over a short period of time, e.g., to establish the nature of social units as part of a population analysis, could present ethical, financial, and practical (because whales become sensitized) difficulties. Potentially, biopsies can be used to identify young animals, which may not fluke-up (calves) and/or that may be much less well marked. However, sampling calves is often specifically excluded in field protocols.

It is the complementary nature of biopsies and photographs that is most striking, and usually it will be desirable to collect both. When biopsies are collected at flukes-up, this can be done with little conflict.

Whitehead (pers. comm.) noted that a large proportion of the sperm whale genetic samples used and analyzed to date have come from sloughed skin rather than biopsies. In his view, collection of sloughed skin has advantages over biopsy sampling ethically, and in some respects also in terms of efficiency (his group seems to have been able to obtain more sloughed skin samples per day at sea with the whales than other research groups, e.g. the *Odyssey*, have been able to obtain biopsies). He acknowledged that sloughed skin sampling also has disadvantages. For example, one cannot as easily target sloughed skin collection from a particular individual or class (e.g., calf, large male) and the DNA obtained is lower quality, which limits some molecular genetic analyses.

Table A5-1. Comparison of biopsy and photographic sampling for individual identification. (Note that for completeness, this table also should have included a column for sloughed skin.)

Information	**Biopsy**	**Photograph**
Reliability of matching	Good within one lab. All animals can be identified.	Dependent on image quality and degree of marking. Not all animals are adequately marked.
Ease of matching	Greater potential for automation.	Automation is being developed.
Sex determination	Yes	Partial (body size, callus, calves)
Hormone analysis	Yes (blubber sample)	No
Contaminant analysis	Yes (blubber sample)	No
Length	No	Yes (although depends on image content and quality)
Stable isotopes	Yes	No
Practical considerations		
Cost	High	Lower
Ability to share data	Poor	Good
Potential for capture heterogeneity	High (?)	Low (?)
Compatibility with other data collection		
Representative behavior	No	Yes
Defecation rate	Incompatible	Compatible
Acoustically derived length	Incompatible	Compatible
Short-term repeated identifications for movement, social organization, etc.	Difficult	Compatible
Proportion of calves	Incompatible	Compatible
Coda collection	Incompatible	Compatible