Report of the IWC Scientific Committee Workshop on Habitat Degradation[1]

The Workshop was held at Certosa di Pontignano, University of Siena, Siena, Italy, 12-15 November 2004. The list of participants is given as Annex A.

1. CONVENOR'S OPENING REMARKS

Simmonds welcomed the participants to the Workshop, noting that several had travelled great distances. The Workshop was made possible by the financial support of the Government of Austria, the Environmental Investigation Agency, ASMS-Ocean Care and the World Wide Fund for Nature. He also noted that the Convention for Migratory Species had offered financial support, but it had not proved necessary to take up this offer. Simmonds thanked the IWC Secretariat for their efficient and effective support to the Workshop, in particular Helen Sharp, Clare Last and Sue Morley, and he acknowledged the contribution of the Workshop steering group in the run-up to the meeting. He thanked Cristina Fossi and the University of Siena for both arranging for the use of the beautiful Certosa di Pontignano as a venue and, along with her colleague Stefania Ancora, for acting as the local support to the Workshop. Finally, he thanked those who had found funding for themselves, thereby allowing others to attend.

On behalf of the primary sponsor of the Workshop, Stachowitsch noted that Austria was looking forward to defining our current state of knowledge of the issue of cetaceans and habitat degradation and outlining the work that needs to be done in the future. Against the backdrop of a deteriorating marine environment, he believed that habitat degradation was one of the key environmental concerns identified by the IWC, and Austria has supported and participated in the environmental agenda of the IWC since it joined in 1994.

Fossi welcomed all the participants to the University, noting its long history of work on ecotoxicological and marine issues. She hoped that its pristine environment would help the participants in their deliberations!

Simmonds summarised the background to the Workshop. The IWC has been concerned about the influence of environmental changes on cetacean populations for many years, and has passed various resolutions requesting the Scientific Committee (SC) progress understanding of this issue. In response, the SC identified eight environmental priority topics: climate/environment change; physical and biological habitat degradation; chemical pollution, direct and indirect effects of fisheries; impact of noise; disease and mortality events; ozone and UV-B radiation; and Arctic issues. Prior to this Workshop, two special Workshops have been held – the first on chemical pollution, in Bergen, Norway in 1995 (Reijnders *et al.*, 1999) and the second on climate change, in Hawaii, USA in 1996 (IWC, 1997). In IWC Resolution 1998-5, the Commission had commended the SC for the identification of (1) physical and biological habitat degradation; and (2) Arctic issues as its next priorities (IWC, 1999, p.40), and directed the SC to continue to produce proposals for 'non-lethal research to identify and evaluate the impacts of environmental changes on cetaceans in all priority areas.' In Resolution 2000-7, the Commission reiterated its strong support for investigations on the impact of environmental change on cetaceans and endorsed the further development of an IWC Workshop on habitat degradation (IWC, 2001, p.57). The present Workshop had evolved from proposals made by members of the SC at its 1999 and 2000 meetings which had been followed by a small scoping group meeting for the Workshop, held in June 2001 in Rome, Italy (Simmonds *et al.*, 2002). Simmonds noted that almost all of the members of the original Rome Scoping Group were in attendance and stated that the report of that meeting provided a good starting point for the present Workshop.

2. ELECTION OF CHAIR

Reilly was elected Chair.

3. APPOINTMENT OF RAPPORTEURS AND WORKING GROUP LEADERS

Perry agreed to contribute as primary rapporteur. Bjørge and Hall/Reijnders agreed to act as Working Group leaders, with Simmonds and Jepson rapporteuring. Donovan carried out the final editing after the completion of the Workshop.

4. ADOPTION OF AGENDA

The agenda adopted is given as Annex B.

5. REVIEW OF TERMS OF REFERENCE

It is widely recognised that habitat degradation has the potential to cause major individual and/or population level impacts to cetaceans, including, but not limited to, biologically significant disturbance, injury and mortality. The Workshop **agreed** that the terms of reference for the Workshop were broad, and stemmed from the Commission's directive to the SC to further investigate the impact of habitat degradation on cetaceans and the scoping group meeting report (Simmonds *et al.*, 2002).

[1] Presented to the meeting as SC/57/Rep2.

6. REVIEW OF AVAILABLE DOCUMENTS

The following documents were presented to the meeting: SC/N04/HAB1, SC/N04/HAB2 and SC/N04/HAB3 (see Annex C). In addition a number of published and in press/review documents were discussed, which are listed in the references.

7. INTRODUCTORY PRESENTATIONS

Before deciding its final agenda and *modus operandi*, the Workshop considered a number of introductory presentations.

7.1 Report of the Scoping Group

Taylor presented the report of the June 2001 scoping group meeting (Simmonds *et al.*, 2002). The Scoping Group had developed a framework for investigating the significance of habitat degradation and identified several model systems that it believed effort could most fruitfully be directed towards: white whales; gray whales; bottlenose dolphins; *Sousa* spp; right whales; and pinnipeds. The scoping group had identified several levels of responses to habitat degradation and hence levels of significance, ranging from individual health and body condition, to vital rates (i.e. survival and fecundity and other life history parameters), population changes and community-level changes. The principal tools for linking habitat changes to these response variables were thought to be correlative analyses comparing response variables across habitats with very different levels and patterns of impact; analogy from more detailed mechanistic studies on model species; and modelling of population responses to changes in vital rates as a result of habitat degradation. The scoping group had recommended that a Workshop be held that would: (1) consider case studies in relation to the species and populations identified earlier; (2) help assess current understanding of cetacean critical habitat and evaluate issues such as habitat quality indices; and (3) review methodological considerations including modelling approaches. It had proposed that these issues could be examined by Working Groups on: (1) modelling, (2) habitat quality assessment and (3) cetacean population data.

The Workshop took account of the views of the Scoping Group in its future discussions.

7.2 Assessing and managing marine mammal habitat in the USA

Ragen (in press) summarised the existing US framework for the management and conservation of marine mammal habitat, which is based largely on a series of laws passed in the 1960s and 1970s, and discussed ways that this could be improved. The Endangered Species Act requires analysis of potential effects of Federal actions on endangered or threatened species, including effects on their critical habitat. The National Environmental Policy Act requires environmental assessments of proposed major federal actions and environmental impact statements of those actions that may have a significant effect on the environment. Arguably, these and related federal legislation (e.g., the Marine Mammal Protection Act, the Magnuson-Stevens Fisheries Conservation and Management Act) reflect a general intent to sustain marine mammal habitat and marine ecosystems in a healthy state. Scientists contribute to the existing management and conservation framework by describing: (1) marine mammal distributions; (2) the essential features of the associated habitat; (3) baseline data for those features; (4) significant human-related effects and their causes; and (5) the basis of confidence in their information and conclusions.

Nonetheless, marine mammal habitat in the US continues to be degraded by a variety of factors. These include: human population growth and development in coastal regions; the introduction into the marine environment of pathogens, contaminants, and noise; the indirect effects of fishing; and long-term environmental or climate change. This provides evidence that the existing framework, as implemented, is insufficient for its intended purpose. Among other things, it does not provide sufficient information on marine mammal distributions, the essential features and baseline conditions of their habitat and the effects of human activities. It constrains scientific investigations for a variety of reasons, including economic, and it fails to place the burden of proof regarding potential effects of proposed actions on the proponents of those actions. It also fails to investigate human impacts at appropriate temporal and spatial scales and fails to provide adequate mechanisms for feedback and accountability regarding framework efficacy.

To address these and other shortcomings, Ragen (in press) proposed modification of the existing US framework for habitat management to:

(1) translate society's general intent into specific, measurable goals and objectives for habitat conservation;
(2) develop a comprehensive strategy for achieving those goals and objectives;
(3) establish and promote a stronger intellectual foundation based on ecosystem science and community ecology;
(4) define habitat types to use as management units and determine their quantity and quality;
(5) emphasise and require the collection of baseline information for each habitat or habitat type;
(6) identify and provide quantitative measures to evaluate key issues, problems, or threats;
(7) emphasise comprehensive, multivariate, inter-disciplinary research programs;
(8) facilitate comprehensive descriptions of human effects;
(9) provide comprehensive summary statistics that characterise the condition of marine habitat and changes in conditions over time;
(10) provide guidance for restoration efforts where human impacts have adversely modified habitats beyond levels consistent with the goals and objectives of the framework;
(11) incorporate feedback and adaptive mechanisms for assessing management efficacy and modifying the framework as needed;
(12) facilitate international co-operation in managing human activities that affect marine habitats; and
(13) secure the resources needed to develop and implement the framework.

The Workshop **agreed** that the presentation was helpful in outlining the issues, difficulties and uncertainties in dealing with marine habitat management and conservation. It identified a number of political, scientific and legal steps towards improving cetacean habitat in the face of anthropogenic and other factors. In particular it identified a number of scientific issues that were relevant to the present Workshop including the need to: describe distribution and abundance; identify essential features of cetacean habitat; collect baseline data; attempt to link cause and effect (by detecting significant effects and linking them to causes); recognise uncertainty; and describe the level of confidence of any conclusions and recommendations made.

7.3 Health status of marine mammals in relation to habitat quality

Reijnders presented paper SC/N04/HAB2, which outlined two possible approaches to assess the health status of marine mammals in relation to the quality of their habitat:

(1) determine habitat requirements of marine mammals in pristine or near-pristine areas and assess the extent to which the requirements were fulfilled in areas of concern; and
(2) characterise the population condition in demographic and physiological terms.

Given the difficulties in finding a pristine area and thus describing the situation at 'time zero', the author recommended the second approach.

He suggested that an index for population condition should include a measure of the recuperative power (or resilience) of the population. For example, if the immune system of individuals within a population is challenged by contaminants, it will be less likely that additional stressors can be absorbed. He believed that demographic condition can be described by measuring the rate of increase, '*r*', although one drawback of this approach is that 'resilience' will thus be measured over a period of time rather than at a moment in time. He noted that the general sequence of events in mammalian populations with a declining *r* is (1) increase in juvenile mortality, (2) increase in age at first reproduction, (3) decline in fecundity and finally (4) increase in adult mortality. The author therefore suggested that juvenile mortality should be considered a sensitive index of demographic vigour and should be monitored.

Physiological condition in mammalian species is usually described by deposited fat reserves, adrenocortical hypertrophy, haematology and clinical chemistry blood parameters, urinary excretion of hydroxyproline and body growth. To measure fat reserves, three indices are used: kidney fat index (KFI) = perinephric fat weight/total kidney weight; bone marrow fat (BMF) = fat percentage of the marrow; and sequence of fat metabolisation in mammal species – the sequence is rumpfat, subcutaneous fat, visceral fat and marrow fat. More studies on lipokinetics in marine mammals are needed to assess the applicability of these indices. Adrenocortical hypertrophy and hyperplasia are responses of the body to stress (e.g. disease syndrome in Baltic seals). A variety of factors influence adrenocortical hypertrophy and the relationship between adrenal weight and physiological condition in marine mammals needs to be established before adrenal hypertrophy can be used as an indicator. Although haematology and clinical chemistry data are available, these blood parameters are subject to multi-factorial influences. For pragmatic reasons, the author recommended that research should concentrate on those parameters indicative of reproduction/early development, the function of immune system and disease. A proposed starting point could be the list given in Reijnders *et al.* (1999). Urinary excretion of hydroxyproline and body growth are matters which need further investigation in order to assess their value and applicability to marine mammal studies. Body mass has been shown to have a high power to explain life-history variation, fertility and juvenile survival in pinnipeds (e.g. Hall *et al.*, 2001). In conclusion, the author suggested that population condition may best be described by: its rate of increase and juvenile mortality as population parameters; and an examination of body mass, haematology parameters and clinical blood chemistry of individuals in the population.

Reijnders outlined an approach to assess health parameters of marine mammals and environmental variables (i.e. habitat characteristics) by using procedures linking variability in the marine environment to cetacean distribution, abundance, migration and fitness (e.g. Ballance *et al.*, 1997; Reilly *et al.*, 2000). Examining several populations of one species exhibiting different states (gradients of condition) enables investigation of the impact of differences in habitat quality on health parameters. Environmental attributes relevant in this respect could be derived from classifying threats to marine mammals in terms of the immediacy of their effect: immediate threats (e.g. harvest, bycatch); intermediate threats (pollution, effects of fisheries on food availability); and longer-term threats (climate change, genetic diversity). Changes in environmental factors and responses by populations can often not be measured directly because of the latency period between a change and response. The use of the concept of a dose-response curve expressing a set of indices of population condition against a set of indices for habitat quality may facilitate examination of this topic. Applying models such as those designed by Anderson and May (1978) and Harwood *et al.* (1999) may allow us to take account of additive, multiplicative and interactive effects of the different environmental stressors.

In discussion, the Workshop discussed the use of the net rate of increase (*r*) as a measure of demographic condition. It **agreed** that even in good habitats one would not necessarily expect *r* to be positive, except in the special case of populations that had been depleted by past exploitation and are now recovering. For other populations, *r* will fluctuate between positive and negative values, but will be zero on average both in good and in moderately degraded habitats. In severely degraded habitats that are beyond the point where the population can persist, the average value of *r* will become negative until the population disappears, or the habitat is restored.

Another measure of the demographic condition is the resilience, i.e. the ability of the population to recover from perturbations, such as those caused by epizootics or environmental fluctuations. However, because this can only be discerned from time series of data that happen to span such perturbations, it is not always available as a useable measure. The Workshop concluded that no single statistic can capture all the important features of demographic condition.

The Workshop noted the general approach suggested by Reijnders and took this into account in its later discussions.

7.4 Effects of long-term environmental change on marine mammals

Reilly summarised the paper by Moore (2003) on the effects of long-term environmental change on marine mammals. Moore had recommended that research on marine mammal responses to long-term environmental change must extend across a range of spatial and temporal scales. Interdisciplinary research is required to address this issue and it should be guided by a predictive modelling framework. This type of research, and associated adaptive management, can be accomplished only with reliable multi-year financial support. Most urgently, long-term studies should be initiated that capture existing conditions in polar regions, where climate warming is ongoing and is predicted to increase in the near future.

For example, in the Arctic the author recommended that studies be undertaken that: (1) establish baseline data on marine mammal population estimates and trends; (2) investigate the effects of ice retreat and warming on marine mammal prey; and (3) measure underwater noise levels in advance of anticipated commercial vessel traffic and fishing. In the Antarctic, where there are much longer marine mammal time-series, and where commercial fishing and tourism are ongoing, the author believed that attention should focus on development of predictive models to investigate the ecological role of marine mammals in a highly productive ecosystem. Where possible, these polar-focused studies should access historical data and accomplish retrospective analyses to extend temporal assessments as far as possible. Assessment of ambient noise in the Arctic, via analyses of military and industry-held data sets is one example of this approach. Estuaries and coastal regions are also undergoing rapid change due to warming and should receive immediate focus to capture marine mammal responses to habitat alterations, especially since populations in these areas are often very isolated.

She also believed that further development of tools (e.g. passive acoustics, satellite tagging and remote sensing) that extend focal-animal and habitat sampling capability over space and time is essential. Finally, and most importantly, the planning of long-term marine mammal research should begin with integration of purpose among scientific disciplines. The goal of such planning should be the development of testable hypotheses that can guide adaptive management and support species conservation. Predictive models can provide a framework for sampling design and hypothesis testing, at nested scales, from the combined interdisciplinary data. Ultimately, the outcome of any research effort directed at determining marine mammal responses to long-term environmental change will be successful only if clear goals can be agreed upon, the complexities of multiple factors can be integrated and multi-year support made available.

In discussion, the Workshop **agreed** that the issue of habitat degradation should be examined at a number of different temporal and spatial scales, and that a variety of approaches may be applicable. Scientists should take into account the different time scales that are operating at an ecological level and those that interest managers. Management (and particularly funding) time scales are almost always shorter than the environmental processes that affect cetaceans and our ability to measure changes in cetacean life history parameters and abundance.

The Workshop also **agreed** that a better understanding of long-term natural environmental variability is needed in order to distinguish anthropogenic environmental changes from natural changes. For examining these issues, the integration of cetacean studies with broad-scale, interdisciplinary oceanographic and other ecosystem studies is essential.

The Workshop also noted the value of studies that examine only a segment of a population or that focus on certain sensitive species, particularly where time series of data on the abundance and life history are available. One example mentioned concerned possible research priorities for Eastern North Pacific gray whales. Some authors have identified the possibility that the timing of the melt of seasonal ice may impact the probability that existing pregnancies will be carried to term (Perryman *et al.*, 2002a; Perryman *et al.*, 2002b). To examine this further, research could focus on pregnant females returning to the feeding grounds. Other studies have found fluctuations in both eastern and western gray whale reproductive rates that may be related to changes in environmental factors. In this context, the feeding grounds for both populations (the former has recovered and may be at carrying capacity whilst the latter is critically endangered) are limited to specific shallow waters that support large populations of benthic fauna. It has been suggested that these fauna are particularly at risk from environmental change and will likely reflect the impacts of environmental change earlier. Measuring their abundance directly and/or examining the status of the gray whales may provide early warning signals of change.

The Workshop noted that sensitivity to environmental changes will vary between species and within populations. Cetacean populations that are at very low abundance levels may lack the flexibility to respond to changing environmental conditions, whilst generalist feeders may be more able to tolerate change than specialist feeders. Case studies often indicate a complex pattern with often apparently contradictory data. It is important, therefore, that as many relevant data as possible are collected on a variety of biological and chemical characteristics of the environment. The Workshop **agreed** that cetacean field programmes should include measures of biological and chemical parameters wherever possible, provided it is believed that the quantity and level of resolution is sufficient to allow correlations to be determined should they exist.

7.5 Developing a framework for addressing habitat degradation and its effect on cetaceans

Taylor presented SC/N04/HAB3, a concept paper suggesting a framework for dealing with definitions and process to assess the significance of habitat degradation to cetacean populations. Defining cetacean habitat is difficult for a number of reasons, including the changeable nature of cetacean prey distributions. Habitat is an ecological not just physical concept and it may be defined by distributions of distinct resources for example: prey concentrations and the conditions conducive to prey production; migration corridors; refuges from predators and diseases; refuges for breeding; waters of tolerable temperature, chemistry and turbidity; and key physical locations needed for normal behaviour. Temporal considerations must also be considered; even non-persistent impacts such as noise can be considered habitat degrading. Factors such as shark or mariculture nets that may exclude cetaceans from suitable habitat can be considered as degrading habitat, as well as causing direct mortality. Degradation can be considered to be any process or processes that makes a habitat more dangerous, unhealthy, less suitable or less accessible for cetaceans.

Taylor proposed the development of a workplan, based on the development of a checklist of tasks proposed by Ragen (see Item 7.2) and incorporating the proposals of Reijnders (see Item 7.3), which could be applied to model systems such as killer whales, bottlenose dolphins and the other species listed as candidates in the scoping group report (see Item 7.1). He suggested that the process should be to:

(1) describe the distributions of cetaceans;
(2) identify (and quantify) likely important features of the habitat from a cetacean perspective;

(3) identify (and quantify) variation in those features of the habitat that may be due to human actions;
(4) identify (and quantify) whether identified changes in the habitat have had a negative impact on cetaceans; and
(5) communicate results/recommendations for remedial action if necessary to the appropriate persons (managers, legislators and the wider community).

In relation to task (3), Taylor recognised the difficulty in obtaining information on the unperturbed baseline, but noted that it was often possible to identify a range of variation in levels of habitat disturbance which could be related to population responses. He suggested that the main habitat impacts are: (1) seafloor, coastline and/or river modifications; (2) global warming and ozone depletion; (3) noise, chemical and litter pollution; and (4) ecosystem changes due to fisheries. He also drew attention to the critical importance but relative lack of information about synergies among impacts and range shifts caused by climate change.

In relation to task (4), Taylor observed that two principal methods were available to link habitat impacts to population responses: (1) dose-response or correlational comparative studies, such as correlations between military sonar use and beaked whale strandings; and (2) mechanistic studies, usually not on the direct species or populations of interest, but on 'model' species. In relation to sonar and beaked whales, tagging and necropsy studies suggest that a mechanism of sonar-related beaked whale mass strandings may be a behavioural alteration to dive profiles, leading to decompression-related bubble formation and tissue injury (Jepson *et al.*, 2003). The question of the appropriate level of 'certainty' when expressing concern over possible links between anthropogenic habitat degradation and its effects on cetacean populations is important and problematic.

Taylor noted that habitat impacts could be ranked along several axes of significance. The first axis of response variables is divided into the more problematic density independent or r-reducing impacts, those that reduce fecundity and survival to the point that populations will decline to extinction, and into density dependent or K-reducing factors, which diminish in effect when populations decline away from K. However, he also noted that prey or K fluctuations and reductions can also fragment populations putting each subpopulation at risk of extinction or negative density dependent factors such as Allee effects or inbreeding. He also drew attention to the complexities of changes in prey distribution, and loss of primary prey species, which can have density dependent negative impacts by placing an energetic penalty on foraging cetaceans, or force them to consume more contaminated and less nutritious prey. Other axes of importance are the persistence of habitat impacts in time, the susceptibility to management remediation and the basis of confidence in the linkages made.

Finally he turned attention to modelling the 'ultimate' measure of significance: how populations themselves change as a result of degradation. He noted the limitations of modelling methods, in particular how to be explicit about the plausibility of different scenarios of habitat changes from the more to the less speculative. He noted the danger of assigning the 'baseline' scenario more plausibility than it deserves, when in fact it only describes indefinite continuance of the current or some inferred past situation.

In discussion, the Workshop considered the issue of beaked whales and military sonar, particularly in the context of what constitutes sufficient evidence to raise concern and implement remedial action. The beaked whale strandings issue first arose in the 1980s in the Canary Islands where mixed species live strandings of beaked whales started to occur. When compared to reports of strandings of beaked whales from elsewhere in the world (i.e. data held by James Mead at the Smithsonian Institute) these strandings appeared unusual. Investigations in the Canary Islands then showed a correlation between most of the strandings and the presence of naval exercises offshore (Simmonds and Lopez-Jurado, 1991). Simmonds noted that investigations to try to link cause to effect relating to these and other similar strandings had now been ongoing for two decades and only in the last two years have mechanisms been proposed (e.g. Jepson *et al.*, 2003).

Jepson noted that although difficult, determining likely mechanisms underlying cause and effect relationships is important. Using comparative correlations in the case of beaked whale mass strandings related to the use of mid-frequency military sonar, it was evident that some kind of causal relationship existed. This was initially suspected to be mediated by physical damage to the auditory system, but more recent studies have suggested that the mechanism may be a result of a behavioural response to the noise altering dive behaviour, and potentially causing lethal bubble formation in tissues via a 'decompression sickness' type mechanism. Thus, the mechanism in this instance would have a significant impact on mitigation since the received noise level initiating a behavioural response is predicted to be lower (possibly much lower) than that which would cause direct physical damage to tissues.

The Workshop **agreed** that it is usually difficult to characterise mechanisms conclusively and although establishing cause-effect relationships is an ideal, a weight of evidence approach should be sufficient to elicit precautionary management action.

A draft schematic representation of links between habitat degradation and cetacean individual and population parameters (Fig. 1) was discussed by the Workshop, with the suggestion that the issue could be approached from both the top (population) and the bottom (stressor) of the diagram. It is usually very difficult to study the middle region (function) due to lack of data and therefore limited statistical power.

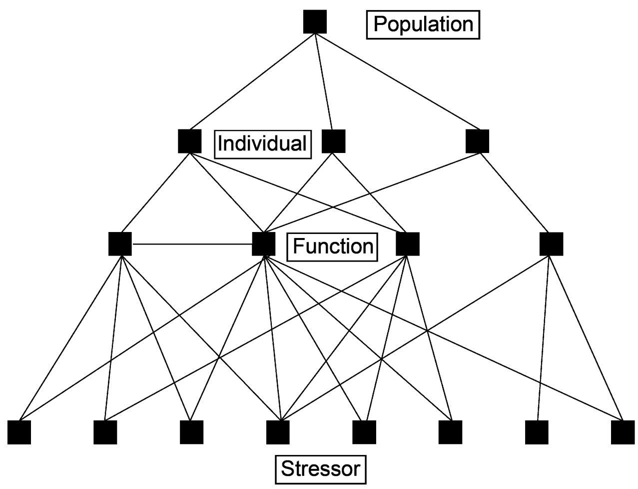

Fig. 1. A schematic representation of links between habitat degradation and cetacean individual and population parameters.

8. WORKING GROUP TASKS

After the initial discussions under Item 7, the Workshop agreed that, particularly given the limited time available, it was sensible to establish two working groups (see Items 8.1 and 8.2). Both Working Groups considered a variety of modelling approaches and how these can be linked into a general framework is discussed under Item 11. The reports of the two groups have been incorporated as Items 9 and 10 of this report. There was insufficient time for a thorough consideration of either report in the Plenary, although the major points were discussed.

8.1 Habitat quality assessment Working Group

The habitat quality assessment Working Group addressed issues external to the animals, including points 1-3 from the five-point checklist described under Item 7.5.

8.2 Population and health Working Group

The population and health data working group addressed items linking cause and effect primarily from the perspective of the individual organism.

9. HABITAT QUALITY ASSESSMENT CONSIDERATIONS

9.1 Definitions

9.1.1 Habitat

The Workshop **agreed** that 'an animal's abiotic (physical and chemical) and biotic environment' (Ragen, in press) was a useful working definition of habitat.

This emphasises the fact that an organism must integrate and adapt to all the features of its surrounding, including those that are living. Ragen also noted that habitat has a temporal dimension 'with a history and a future' and changes diurnally, seasonally, annually, up to an evolutionary scale. Essential habitat features include availability of prey, refuge from predators, areas for reproduction, social behaviour and rest and areas safe from extreme environmental events such as storms.

The issue of critical habitat was explored and it was noted that this term was sometimes used purely in a geographical context, to define important areas for species or populations (e.g. in US law). The Workshop **agreed** that, for its purposes, the concept related to habitat features that are essential to the long-term survival of a population/species at some point in its life cycle. The Workshop decided not to elaborate this matter further.

9.1.2 Habitat degradation

Noting that, for example, natural fluctuations and geological processes also may influence marine mammal habitats, the Workshop adopted 'processes of anthropogenic origin that make habitats less suitable or less available to marine mammals' as a working definition of habitat degradation.

The Workshop identified a wide range of environmental stressors for which there is some evidence of potential or observed significance for marine mammals (Table 1). There was not time to elaborate or evaluate these, although Workshop participants **agreed** that this was *inter alia* a list of some key stressors. Some literature relating to these stressors was also identified (e.g. Simmonds and Hutchinson, 1996; Harwood, 2001; Harwood and Wilson, 2001; Reeves *et al.*, 2004; Markowitz *et al.*, 2004). The importance of these stressors for any particular population/situation will be case specific.

Table 1

Factors that cause or may cause habitat degradation that affect or may affect cetaceans.

Climate change	Storm intensity changes
	Sea ice changes
	Changes in run-off/water circulations
	Ozone depletion
Chemical pollution	Nutrient pollution/eutrophication
	Harmful algal blooms
	Oil spills
Fisheries/related activities	Over-fishing and prey-culling
	Mariculture
	Marine debris, including ghost nets
Noise pollution	Seismic surveys
	Boat traffic
	Military sonar
Pathogens/emergent diseases	
Physical habitat degradation	Bottom trawling
	Dredging
	Other destructive fishing techniques
	Reclamation
	Coastal construction
	Wind farms
	Dams and barrages
	Marine fossil fuel exploration/extraction
Tourism	Whalewatching
	'Swim-with' programmes
War related activities	Mines
	Munitions dumps
Introduced species	

Fig. 2 presents a diagrammatic representation of habitat states ranging from the pristine to the degraded and indicates likely concomitant population states along this spectrum (a colour copy of Fig. 2 is available from the Office of this Journal).

The Workshop **agreed** that the development of appropriate indices to inform managers that action is required is of high priority but difficult to achieve. For example, in practice it is difficult to identify what comprises a pristine environment because most environments are already degraded to some extent, because the range of natural variability in both environmental and cetacean population parameters may be unknown or poorly characterised. Given that instances in which cetacean populations are excluded from portions of their natural range due to habitat degradation are likely to increase in the future, the development and progress of habitat restoration science and technology is seen as worthy of effort.

9.2 Review of recent literature

9.2.1 Spatial modelling and similar approaches to identifying important features of habitats and responses to changes in these

Spatial modelling is a relatively new technique that shows great promise in the quantification and understanding of habitat characteristics and cetacean distribution and abundance.

Cañadas introduced two papers on this subject. Cañadas *et al.* (2005) used habitat preference modelling of a range of species to determine areas to be recommended as Marine Protected Areas in part of the Mediterranean. The spatial modelling approach used a two-stage method: first predicting species occurrence and secondly predicting group size, both as a function of features of the environment. The second study (Cañadas and Hammond, 2004) generated a model-based abundance estimate for bottlenose dolphins again using a two-stage modelling approach to estimate first abundance of groups and then group size as functions of environmental features.

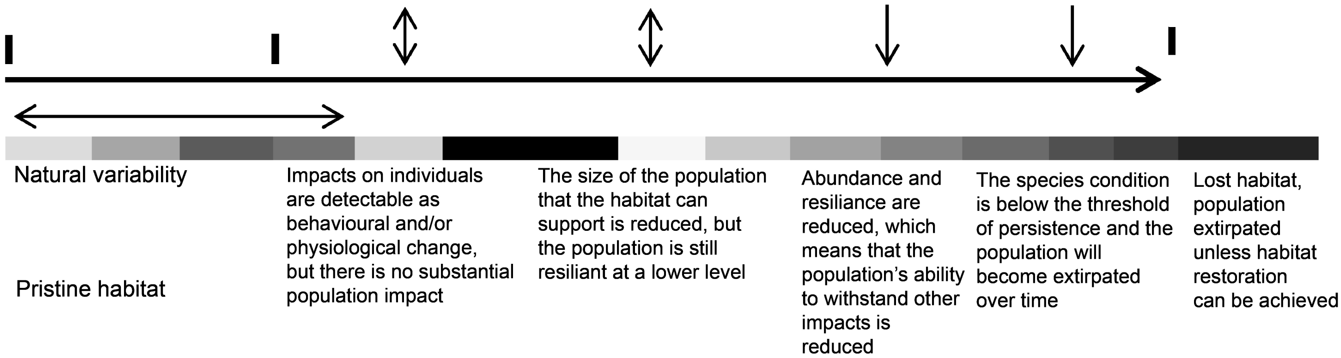

Fig. 2. The shading indicates the gradient from pristine to degraded habitat, vertical two-way arrows indicate states of habitat degradation where population resilience can compensate, downwards arrows indicate habitat states where population resilience cannot compensate and populations therefore are driven to extirpation unless habitat degradation is reversed.

Spatial modelling methods relate distribution and abundance to environmental variables (which may be physical variables such as depth, distance from shore etc, or anthropogenic variables such as distance from disturbance or pollution sources). Predicted distributions are thus more informative than simple distribution maps and estimates of abundance may be more precise. Of course, the correlations observed do not necessarily indicate cause-effect relationships – for example a link between depth and cetacean occurrence may actually be due to a relationship between depth and prey occurrence/abundance. The methods can use data collected through non-systematic surveys as well as from design-based line transect surveys. They also allow for stratification – temporal, geographical and behavioural (e.g. allowing preferred feeding areas to be identified).

Such methods allow trends in abundance and shifts in habitat use to be described, and allow the creation of surface maps of variability. In discussion, it was noted that managers might find this latter approach particularly useful, as results can be presented in a user-friendly graphical format. The question of the reliability of model fits was raised. It was noted that whilst there would always be problems with ground truthing, validation methods had been applied to the habitat preference modelling, with positive results. Cañadas also noted that there are some disadvantages with these methods (at least at present). In particular, spatial modelling is data hungry and requires good coverage of the whole range of the predictive variables. In many cases, only a limited number of variables with adequate data are available. Finally, the use of dynamic variables is still not well implemented.

The authors stressed the importance of the time period being considered for the bottlenose dolphin abundance estimates: at least in this case use of shorter time frames would have given different (and erroneous) impressions of population trends – longer time frames by contrast allow natural variability to be better described. Spatial scale is also important and should reflect, to the extent possible, true population range and the larger the study area, the better understanding of the fluctuations in distribution. Periodic updating of models was also highlighted as desirable, particularly given the rapid improvements in analytical techniques.

The value of combining oceanographic studies with cetacean-focused surveys, where practical, was noted. Interdisciplinary studies would improve matters, allowing incorporation of more dynamic factors into analyses. Whilst relevant data from other studies conducted in the same region have some value, contemporaneous data are the most important. Where possible, therefore, studies where population assessment and environmental data are simultaneously collected are recommended. However, it was agreed that this should not be at the expense of rendering the assessment data unsatisfactory (e.g. where collecting the full suite of environmental data compromises interpretation of the abundance data).

Fortuna described the preliminary results from a similar study in Croatia. Bottlenose dolphin distribution was predicted from physiographical factors (such as depth) and three anthropogenic factors: bottom trawling areas; distance from the three main harbours; and distance from the shipping-lane between them. A relationship was found between occurrence of the dolphins, some natural features (positive) and all anthropogenic factors (positive or negative). Bottlenose dolphins were found to avoid areas with higher anthropogenic activity (entrances to three main harbours), one year after an increase in the number of recreational boats was registered within the archipelago. It is not clear whether this was caused by physical (fast moving objects) or noise disturbance. Studies such as this, as well as highlighting critical features of the habitat with respect to dolphin distribution, also illustrate the fact that animals' responses to habitat degradation can be both immediate and long-term. Following these preliminary results, a study on seasonal variations in local ambient noise was started. The relevance of this work to possible effects of boat traffic on bottlenose dolphins in other areas of the Mediterranean was noted.

SC/N04/HAB3 illustrated how cetacean data collected during abundance surveys can be used to examine cetacean habitat and prey selection. The paper considered data from minke, fin, and sperm whales and from *Lagenorhynchus* dolphins collected during surveys in the Barents Sea 2000-2002. At the same time as the observations were made, data were collected on habitat characteristics (depth, sea surface temperature and temperature gradients) and potential prey (plankton, 0-group fish, capelin and herring. The study found that different species appeared to react differently to annual variation in habitat and prey distributions. Minke whales were associated with cold waters and herring and capelin in years with low herring abundance. Fin whales were mainly associated with northern cold and deep waters, as well as capelin, 0-group fish and plankton. The distributions and abundances of both species remained similar between years within the study area, suggesting that they might be considered generalists, responding to environmental changes by switching between prey species. *Lagenorhynchus* dolphins were associated with capelin and appeared to move northwards over the period, possibly due to tracking the shifting capelin distributions. Finally, sperm whales were associated with deep waters and 0-group fish. The latter probably reflects the fact that 0-group fish are the prey of predatory fish (e.g. *Sebastes* spp.) and squid (e.g. *Gonatus* spp.). The authors discuss their results in light of how such cetacean-habitat and cetacean-prey relationships can be valuable for the proper assessment of population sizes and trends, both through guiding design of sighting surveys and assessing whether changes in abundances within fixed surveyed areas are due to distribution shifts or changes in population sizes. The Workshop thanked the authors for their paper.

The Workshop **agreed** that spatial modelling approaches were of great importance in trying to determine the role of habitat (and anthropogenic changes to habitat) in the population dynamics of cetaceans and it **recommends** that such studies be given high priority, both in the context of case studies and in the context of improving the theoretical framework for incorporating time-dependent variables.

9.2.2 Habitats and habitat use: temporal and geographical scales

Bjørge reviewed the question of the persistence of marine mammal habitats given the varying nature of oceanic environments (Bjørge, 2001). In particular he focussed on the importance of choosing the most appropriate temporal scales to characterise marine mammal foraging habitats. He examined a number of case studies ranging from pilot whales, Risso's dolphins and minke whales to hooded seals, harbour seals and walruses. He provided examples of marine mammal foraging habitats established by fronts and gyres at the temporal scale of days or weeks, and foraging habitats established by bathymetric features that are 'permanent' compared to the lifespan of a marine mammal. In general, marine mammal foraging habitats associated with pelagic systems are more dynamic in space and time than habitats associated with bathymetry or benthic systems. The author stressed the need to collect appropriate baseline data if one is to be able to try to determine whether observed changes in habitat characteristics are affecting marine mammals adversely and if they are the result of human activities or natural fluctuations or oscillations. Bjørge also referred to SC/N04/HAB3 (see Item 9.2.1) and noted that this also illustrated the importance of collecting data over reasonable timeframes and geographical areas by highlighting the transient nature of some habitat features for certain cetacean species as well as illustrating their different responses to changes in habitat (and thus the different potential effects at the population level).

Bjørge also presented Mauritzen *et al.* (2003), which considered habitat use by polar bears. The authors noted that habitat selection includes the concept of trade-off, e.g. between the use of habitats with abundant forage and the use of safer retreat habitats with little forage. The balance in such trade-offs may result in relative habitat use being conditional on the relative availability of the different habitat types. Thus the proportional use of foraging habitat may exceed proportional availability when foraging habitat is scarce, but be less than availability when foraging habitat is abundant. Hence, trade-offs in habitat use may result in functional responses in habitat use (i.e. changes in relative use with changing availability). The satellite-tagged polar bears considered by the authors demonstrated season and population specific functional responses in habitat use, that probably reflected the seasonal and regional variations in use of retreat and foraging habitats. The authors suggested that in seasons with functional responses in habitat use, polar bear space use and population distribution may not be a mere reflection of prey availability, but rather reflect the alternate allocation of time in hunting and retreat habitats.

The Workshop **agreed** that this study also illustrated the importance of using appropriate spatial and temporal scales when trying to identify important habitat characteristics and predict possible effects on marine mammals when these characteristics change. The Workshop **agreed** that further fine-scale work such as that carried out by Mauritzen *et al.* (2003) on polar bears could prove valuable in cetacean studies.

9.2.3 Other issues

Lusseau *et. al*. (2004) investigated the influence of ocean climate variation on the grouping behaviour of two widely separated populations of cetaceans, inhabiting North Atlantic and North Pacific coastal waters. The group size of both bottlenose dolphins in the Moray Firth, UK, and killer whales in Johnstone Strait, Canada, varied from year to year in relation to large-scale ocean climate variation. Local indices of prey abundance were also related both to climate indices and predator group sizes. The cetaceans tended to live in smaller groups when there was less salmon available in both areas which seem to occur two years after a lower phase of the North Atlantic and Pacific Decadal Oscillations. These findings suggest that, even in highly social mammals, climate variation may influence social organisation through changes in prey availability. The Workshop noted that this is a potential monitoring tool although it recognised that observed changes may relate to both natural and anthropogenically induced change.

Lusseau and Higham (2004) identified that resting and socialising dolphins in Doubtful Sound, New Zealand, were particularly sensitive to boat disturbance. Behavioural states – once sensitivity to disturbance is identified – can thus be used as a management tool and an indirect index for habitat quality. A direct index for habitat quality that follows from this could be boat traffic density, particularly in resting and socialising areas.

Parsons summarised a number of studies on Indo-Pacific humpback dolphins (*Sousa* spp.), which have been identified as a potential target species by the habitat scoping meeting. The species occurs in a wide range of areas, from relatively pristine habitats to severely degraded habitats, such as Hong Kong harbour (Parsons, 2004). A number of studies involved the monitoring of various contaminants in a variety of biotic (e.g. potential cetacean prey species) and physical habitat factors, and using this information to predict possible individual and population level effects on the Hong Kong dolphin population. In these studies, high levels of dietary cadmium and mercury intake were suggested that were subsequently borne out by analysis of dolphin tissues. Parsons noted that one advantage of such prey analysis studies was that they were relatively cheap and easy to conduct. The results could be used to provide an indication of habitat degradation by contaminants to inform managers made before the collection of a large dataset of cetacean tissue samples. He noted that this may be especially useful in areas where there are no established cetacean strandings programmes. He also described the results of a further study in which sewage-borne bacteria intake (through the ingestion of contaminated seawater) was predicted. The estimated levels were orders of magnitude higher than those that would trigger health concerns in humans. The study allowed urgent management decisions to be made, with respect to proposed sewage treatment plans in the region.

The Workshop thanked the authors of these papers and **agreed** that there is potential for useful habitat related research from platforms of opportunity, such as fishing and whale watching vessels (e.g. Macleod *et al.*, 2004).

9.3 Lessons from interdisciplinary approaches

Reilly, who has been involved in interdisciplinary field programmes for many years, gave an overview based on his experience. He stressed the value in collecting a broad suite of data as simultaneously as possible with cetacean data. One important result of the lack of environmental data is an inability to evaluate the significance of apparent population trends from survey data, when explanations may include real declines or increases in relation to environmental factors. For example, there is an apparent decline in the abundance of Southern Hemisphere minke whales from the IWC IDCR and SOWER circumpolar surveys. Only very limited environmental data were collected during those cruises and it is now very difficult and perhaps not possible, to determine the extent to which the apparent declines might be due to changes in environmental conditions (which can affect levels of both detection and availability bias) among the three circumpolar (CP) surveys (e.g. see IWC, 2005b).

In the context of the IDCR/SOWER cruises it was noted that consideration had been given to trying to collect detailed environmental data during the cruises. However, the advice received from oceanographers over the scale of data collection (i.e. spatial distribution of stations and time spent collecting data at each station) was such that the surveys themselves could not have been satisfactorily completed from the cetacean abundance estimate perspective. The surveys began in the late 1970s and since that time the ability to collect remotely on a number of oceanographic characteristics (including sea ice, sea temperature and productivity) has improved greatly. The question of sea-ice and the ability to integrate satellite data into the trend analysis will be considered at the 2005 IWC SC meeting. The Committee also considered the question of interdisciplinary studies at the SOWER 2000 Workshop (IWC, 2000) and the IWC has been collaborating with both CCAMLR and SO-GLOBEC in recent years.

Donovan updated the Workshop on the progress of discussions on the future of the IWC SOWER CP programme, which has carried out annual abundance surveys in the Antarctic since the late 1970s, primarily targeting minke whales and more recently blue whales, but providing estimates for a number of species (Branch and Butterworth, 2001; 2002). At the latest planning meeting in Tokyo in 2004, it was agreed to recommend that future surveys will focus on blue, minke and fin whales, with a key focus on the relationship between environmental factors (especially ice) and cetacean distribution and abundance. The programme will use spatial modelling approaches, as well as utilising radio-tracking and satellite techniques where appropriate. It will also attempt to combine acoustic techniques with sightings survey methodology where appropriate. The Workshop welcomed this information, noting that the issue will be discussed at the forthcoming IWC SC meeting.

The Workshop **agreed** that:

(1) at least a basic set of environmental variables should be collected while surveying cetacean abundance to aid in interpreting trends – where possible collaboration should occur with programmes addressing other aspects of the environment in a similar temporal and geographical scale;
(2) valuable cetacean data can be collected during surveys focused on other aspects of the environment, e.g. oceanographic or fisheries surveys, particularly in the context of spatial modelling, provided that certain minimum conditions are met; and
(3) collaboration with experts from other disciplines is essential for progress.

9.4 Identification of habitat quality indices

9.4.1 Habitat and habitat use

As noted earlier (e.g. see Item 9.2), for many reasons it is extremely difficult to determine what habitat and habitat use means for cetacean species and populations. Without a good understanding of the basic ecology of a species, it is extremely difficult to specify appropriate indices of habitat quality. However, the Workshop noted the great value in new spatial modelling approaches in this regard. Generalised Additive Models (GAM) and Generalised Linear Models (GLM) provide new ‘sharper tools’ and models can be developed for the single species/population of management concern. Canonical Correspondence Analyses (CCA) can be used to develop habitat use models that are derived in relation to habitat patterns of other, similar species. While these results may be more interesting in terms of community-level patterns, they are more difficult to interpret for any single species. However, the datasets needed for both approaches are similar and it is recommended that both approaches be developed further and results be compared.

9.4.2 What comprises good habitat quality indices?

Indices of habitat quality may be derived in a number of ways, depending on the use to which they are being put. In discussion, a number of pertinent questions that must be asked of any indices were raised. These included:

(1) What mechanisms exist to examine the potential relationships of potential habitat quality indices to the population of interest?
(2) To what extent are potential indices interpretable with regard to observed population change(s)?
(3) Given probable limits in data availability, can potential indices be used to discriminate among alternative hypotheses regarding observed population changes?
(4) To what extent is the use of any potential indices practical, given the variability in environmental factors and the expense of long-term studies needed to develop reliable indices?
(5) Can potential indices be interpreted with sufficient confidence to be used by managers?

Arising out of these discussions, the Workshop developed a list of potentially desirable features for habitat quality indices, recognising that in the real world it will be difficult if not impossible to develop ideal indices:

(1) they must be related to the animals/populations of interest;
(2) they should be unambiguous[2];
(3) they should be sensitive to changes in habitat quality;
(4) they should be precise i.e. have low variability;
(5) they should exhibit good explanatory power;
(6) they should be consistent over time and space;
(7) they must be verifiable; and
(8) they must be of value to management.

[2] For example, juvenile survival of Steller sea lions proved to be problematic as an indicator of human impacts because of the potential effect of confounding variables, including natural ones.

The Workshop **agreed** that (8) was the most important property of an index.

Habitat quality indices may range from a single variable that is empirically derived and based on minimal knowledge of the habitat, to a composite (or aggregated) variable with known causal relationships to the population of interest. A composite or aggregate index or variable is one that is generated by combining other variables. The combined variables may be qualitative or quantitative and conceptually the simplest method of combining them is by linear addition – i.e. *Z* in the following is a composite of *X*,*Y* and *W*. ($Zi = aX_i + bY_i + cW_i$). Composite indices may be more powerful in detecting significant habitat effects, but can also be more difficult to explain in terms of cause and effect relationships.

It was noted that some environmental indices are already quite widely used, including trophic and benthic indices (see Item 9.4.4). It was **agreed** that these should be examined for their relevance for cetaceans.

9.4.3 Cetacean examples

The Workshop considered the example of east Pacific killer whale populations in the context of appropriate indices. Williams reported that there are three distinct populations: 'transients' (mammal hunters); 'residents' (fish-eaters which have exhibited little or no dispersal from the family group providing a well-known family tree and where there is no evidence of inbreeding); and 'offshores' (highly mobile and poorly known).

The residents comprise northern, southern and Alaskan populations. The southern population in particular has been heavily impacted by removals for captivity and also occurs in the highly populated and industrialised Puget Sound/Georgia Basin ecosystem. It is the most chemically contaminated population of the residents and this probably means that their present abundance is considerably reduced from its historical levels. Over the last few decades, the southern population grew steadily, but went through a period of decline in the 1990s. Existing data suggest that northern and southern residents are dependent largely on Chinook and chum salmon. River damming has probably reduced prey availability for southern residents, perhaps more in the winter than the summer range. To some extent they may be supplementing their diet with bottom fish, but this is not evident from current diet studies.

The winter distribution and diet of both populations are unknown. Whalewatching is one potential stressor for the killer whale population. An emergent potential threat is open-cage farming of Atlantic salmon, which typically occurs close to important wild Pacific salmon habitat. In addition, seismic surveys are scheduled to start in British Columbia coastal waters during September 2005.

Williams provided a list of potential habitat quality indices in this case (Table 2).

All these indices are at an early stage of development. However, the Workshop **agreed** that northeast Pacific resident killer whales would be a good case study as the habitat is reasonably well known for these populations. Both populations have recently gone through a period of decline and this has been more pronounced in the south. Determining the extent to which this may reflect natural variability or anthropogenic influences will be difficult.

Whilst an excellent 30+ year photo-ID data set exists for the northern and southern residents, this is not the case for killer whale populations elsewhere. In addition, good data on Pacific killer whale diet exist and are still being collected in the summer, although information on winter and night-time prey are sparse. Habitat quality indices relating to prey are thought to be useful and the killer whale recovery plan is already proceeding on the basis that salmon availability needs to be addressed. However, there are ongoing and additional concerns over other aspects of the habitat.

9.4.4 Non-cetacean examples

The Workshop also briefly considered whether there are useful examples from other non-cetacean studies. Two major reviews of benthic indicators were considered, Diaz *et al.* (2003) which examined composite indices and focused on habitat quality, and Diaz *et al.* (2004) which examined 64 indicators (largely univariate) and divided them into nine themes, including for example, abundance and biomass. Benthic studies incorporated long-term monitoring at reference sites.

The Workshop briefly considered the value of indices that represented the habitat versus indices that are directly related to the species of interest. It was noted that the former indices may be of more value in providing a warning that effects on cetaceans may be likely to occur, provided that knowledge of the effect of changes in the index on the cetaceans exists, the latter indices clearly will indicate when an effect has occurred. In this context, it was noted that bivalves are considered as good integrators of pollutant levels, although fish may give a more direct link to cetaceans. However, their value as an indicator depends to some extent on the question one is trying to ask. Bivalves represent short-term indicators of contaminants in the environment since their contaminant loads can change in a matter of hours. Levels in cetaceans themselves however, represent a long-term integration of contaminants into the environment and other historical exposure (e.g. via transfer from mothers). As has been shown in the development of the POLLUTION 2000+ project of the IWC (Reijnders *et al.*, 1999) moving from measurements of levels to effects at the individual and population level is not easy. Although the use of human health indicators has been suggested as potentially helpful (e.g. Parsons, 2004), the Workshop recognised that there are great difficulties in extrapolating even within the same genus, let alone across taxa (Reijnders *et al.*, 1999).

Table 2

Examples of potential habitat quality indices for Pacific resident killer whales.

Relative abundance of primary (salmon) and other known (or potential) prey species.
Prey quality (e.g. lipid content).
Contaminant loads in prey.
Ambient noise levels.
Duration of whalewatching season.
Saturation of whale's time by whalewatching (daily and annually).
Access to particular areas – e.g. refuges (places free of human disturbance) or special habitat such as preferred rubbing beaches.

In conclusion, the Workshop **agreed** that existing indices require further examination in the context of their potential value for cetacean situations.

10. POPULATION AND HEALTH DATA CONSIDERATIONS

The major stressors considered by the Workshop in this context were: pollution; noise; prey availability; disturbance, novel and recurring pathogens; and biotoxins. This list is not exhaustive but is considered to represent the key factors (referred to collectively as exposures) that are currently believed to result in habitat degradation. The Workshop did not consider bycatch in static nets or exclusion from areas by pingers on nets and the effect of directed takes (harvest), new and emerging stressors (e.g. electromagnetic fields, pharmaceuticals and personal care products) and overarching stressors (e.g. climate change, effects of temperature changes on thermoregulation).

Whilst recognising that there may be interactions between stressors, it was agreed to initially consider each stressor separately. Discussion centred on two aspects: (i) the measurement of exposure to the stressor in individuals (as indirect measures of habitat degradation); and (ii) the establishment of cause-effect and/or dose-response relationships between exposure and individual responses.

In discussing the general relationship between habitat quality and indicators of individual stress factors, the Workshop stressed that one does not expect animals at or near carrying capacity in undisturbed habitats to be ‘unstressed’. A population of unstressed or low-stressed animals will tend to increase, until stress levels reach the point at which the population can increase no further. It is thus not indicators of overall stress levels *per se* that are important for the assessment of habitat quality, but the linkages between specific human-caused stress factors and individual and population responses. For example, disease can be an important indicator of degraded habitat, especially when the disease can be linked to human-caused factors, such as contact with sewage, or contaminant-induced immunosuppression. However, care is needed in making a general correlation between disease and habitat degradation because theory predicts that in undisturbed habitats, disease is more likely to become the dominant limiting factor for populations when other habitat factors are favourable such that relatively high population densities can be attained.

10.1 Monitoring individuals

A number of approaches to trying to establish whether exposures are important to cetaceans at the population level can be used. These include comparisons of:

(a) exposed and unexposed populations (dichotomous variable);
(b) populations across a gradient of exposures (continuous variable); and
(c) exposure profiles in ‘cases’ compared with ‘controls’.

With all three approaches, confounding variables and effect modifiers must also be investigated and controlled for.

10.1.1 Health/disease indicators and application of biomarkers as indirect measures of habitat degradation

Knowledge of an individual’s body condition (nutritive status) is essential for many aspects of monitoring individual health or exposure. However, there is no universally agreed measure of body condition in cetaceans. For example, although blubber thickness is often used, this is not always the most sensitive indicator of changes in nutritional status because it varies with age and season and is not indicative of phase II of starvation[3]. Other indicators (e.g. residuals around the body weight to length regression relationships) may provide more suitable measures of nutritive condition.

The Workshop **recommended** that a review of the methods used to assess cetacean nutritive status in both live and dead specimens, with a view to future standardisation of techniques, be given high priority (see SC/N04/HAB1).

Table 3 lists a number measures for different target organs or systems that might provide a sensitive response to exposure to different stressors. Table 4 shows that many of these exposures can elicit similar responses and provides background for the discussion of interactive and synergistic effects below.

Table 3

Illustrative list of some possible examples of individual blood parameters and biomarkers used as response indicators by target organs/systems.

Target organ/system	Blood parameters/biomarkers
Immune function	Total WBC
	Differential WBC
	Mitogen proliferation assays
	Immunoglobulin levels
	Retinol
	Cytokines
	Prevalence of disease (e.g. skin lesions)
	Serology
	Viral RNA (PCR/immunoperoxidase etc.)
Reproductive function	Reproductive hormone levels
Endocrine disruption	Hormone levels (e.g. thyroid, cortisol)
Nutrition/body condition	Body mass
	Blubber thickness
	Lipid content of blubber
	Total body fat (e.g. using isotope dilution or ultrasound)
	Morphometric index (e.g. mass/length or mass/length^2)
	Total protein
	Vitamins (Retinoids, vitamin E)
Liver function	Liver enzymes
	Albumin
	Urea
	Bilirubin
Kidney function	Urea
	Creatinine
	Phosphate
	Potassium
	Haematocrit
Biomarkers of exposure to pollutants	CYP450 induction/expression
	Retinoid levels

The Workshop **agreed** that the following individual measures could usefully be considered when investigating the degradation of cetacean habitats.

10.1.1.1 BLOOD PARAMETERS AND CLINICAL CHEMISTRIES

These may be relatively sensitive indirect response variables and it is possible to obtain ‘normal ranges’ for those species or populations that can be studies using live capture release programmes (SC/N04/HAB2 and Table 3). This approach does, however, require standardisation and further investigation of the nature of outliers. Normal ranges must

[3] During the first phase of starvation, blood glucose levels are maintained through the production of glucose from glycogen, proteins and fats. In the second stage, fats are the primary energy source whilst the third stage of starvation begins when the fat reserves are depleted and there is a switch to proteins as the major energy source.

Table 4

Possible interactions between some stressors and the potential for effects on survivorship.

Stressors	Immune	Reproduction		Neuro-behavioural	Metabolic (liver/kidney)	Nutrition	Hormonal	Parasite load	Skin disease occurrence	Mortality
		ASM	Fecundity							
Noise	X	?	?							X
OCs and POPs	X		X	X	X	X	X		X	X
Heavy metals	X	X	X	X	X				X	X
Biotoxins	X	X	X		X				X	X
Disturbance		X				X				
Novel pathogens	X	X						X	X	
Bycatch										X
Prey availability	X	X				X		X	X	

also be considered in relation to season, life history and age stages (e.g. animals of different ages or reproductive status will have different normal ranges).

The use of biomarkers[4] has evolved in recent years, and a number of sensitive and useful markers of contaminant exposure are now available (Peakall, 1999; Fossi *et al.*, 2003; Godard *et al.*, 2004). Different biomarkers are needed for different stressors and their use should be focussed upon tests of specific hypotheses. The disadvantage of integrating biomarkers that focus on several target systems is that large sample sizes are required if many systems are to be investigated simultaneously. Although dependant on the species and the nature of the biomarker, biopsy sampling will probably allow larger data sets to be generated than live capture-release programmes, while fresh strandings may also provide samples of sufficient quality. Bycatches and legal direct catches can also be sources of appropriate samples. As noted in Reijnders *et al.* (1999), where possible, power calculations should be used to determine how many samples will be required, particularly where samples from live individuals are being taken. *In vivo* and *in vitro* studies, for example of cytochrome P450 induction, are now quite advanced, but they need to be verified for use on different species. Future cell culture experiments may also help determine the relative susceptibility of different cetacean species to particular stressors (Fossi *et al.*, 2004).

Genomic and proteomic studies using microarrays are now providing new molecular approaches to monitoring individual responses. These are likely to become more useful once ongoing work to sequence the *Tursiops* genome has been completed. Using these techniques, future studies of skin samples could investigate the expression of many thousands of genes or proteins on ‘chips’ (microarrays), providing opportunities to compare patterns of up- and down-regulated genes or protein expression patterns in exposed and unexposed individuals, giving a quantitative response. The higher quality information obtained from smaller samples of live-capture release studies will be particularly important for verifying these studies, exploring confounding factors and examining the predictability of resultant effect measures to population level measures.

10.1.1.2 SKELETAL AND TOOTH LAYER CHANGES

Skeletons and teeth that have traditionally been obtained from bycaught, harvested, live capture and stranded cetaceans may provide long-term datasets that could be related to environmental change. For example, age at physiological maturity (speed of growth) can be estimated from skull morphology and this may change over time with habitat degradation. Fluctuating asymmetry has been related to contaminant exposure in other marine mammals. In conjunction with contaminant information, such studies may help determine long term changes in individuals from potentially impacted populations. Tooth growth layer groups can be used to estimate ages and may also reflect environmental variation (e.g. Antarctic fur seals and El Niño events), while stable isotopes as well as element deposition in tooth layers may reflect changes in prey choice of distribution related to changes in food availability.

10.1.1.3 CHEMICAL POLLUTANT TISSUE CONCENTRATIONS

Long term monitoring of chemical pollutant levels e.g. organochlorines (OCs) in blubber is continuing in some populations. When identifying exposures in individuals in relation to current habitat degradation, there is the need to ensure lag/latency/generational transfer and age, sex, reproductive status, nutritional condition and other confounding factors are accounted for (Reijnders *et al.*, 1999; Aguilar *et al.*, 1999; Aguilar *et al.*, 2002).

10.1.1.4 NOISE

Pathological abnormalities resulting from loud noise exposures have been recorded but little studied. Pathological indicators (e.g. see Jepson *et al.*, 2003) are now being identified as potential noise-specific effects or lesions. However, knowledge of the physiological or pathological effects of noise exposure is generally lacking for cetaceans and no biomarkers of noise exposure have been identified, so investigating links between health indices and noise exposure will always be difficult in cetaceans. Behavioural responses to noise are also important, particularly where they lead to physiological responses following changes in e.g. foraging behaviour.

10.1.1.5 BIOTOXINS

Harmful algal blooms produce biotoxins of various types and markers of exposure can be measured in individuals. Diagnostic techniques are advancing for the evaluation of exposure and effects for specific biotoxins, although field tests are not yet available and laboratory tests require extremely fresh tissue samples. Such biotoxins may result in mass strandings (particularly in high risk areas) and stranded animals should be examined carefully in such cases.

10.1.1.6 PREY AVAILABILITY

Decreased prey availability weakens body condition of individuals and populations and thus has a potential to enhance the effect of other adverse changes in habitat. In addition, prey availability impinges on many other stressors as it may be the route of exposure, and/or may interact with other stressors (e.g. chemical pollution and quality of prey, skin lesions). The consequences of prey switching by cetaceans needs to be investigated on a population basis

[4] A biological response to a chemical or chemicals that gives a measure of exposure and sometimes, also of toxic effect (Peakall and Walker, 1994).

(e.g. see SC/N04/HAB2). There are a number of ways to measure this response and the most appropriate method will depend on the question being asked and the practicalities for the particular species/population involved. Each method has particular strengths and weaknesses and where practical, use of more than one method may be appropriate. For example, both stomach content and faecal analyses have potential biases but considerable work has been undertaken to try to address these and few workers still use uncorrected proportions. Fatty acid blubber profiles represent an integration of food intake over time but are not quantitative (although models are becoming available to estimate quantity eaten); often only relative differences between groups can be determined (although this in itself may be useful) and it is labour intensive. Stable isotopes (e.g. C, N, S) may allow determination of changes in prey consumed between trophic levels but captive studies and validation experiments are needed because the method may be tissue specific and turnover rates may differ.

10.1.1.7 NOVEL AND RECURRING DISEASES

Exposure to new disease-causing agents (particularly infectious agents and pathogens) may be measured using one or more of (multiplex) PCR/real time (RT)-PCR, microarrays, serology (although this is limited by blood availability), faeces, urine, pathological samples and visual signs of disease (e.g. skin or eye lesions). In order to investigate levels and effects, changes over time within the same population can be monitored when novel diseases are identified or comparison of prevalences between exposed and unexposed populations can be made (e.g. changes in the number of skin lesions in North Atlantic right whales has been correlated with inter-calf interval and nutritive states (Hamilton *et al.*, 1995)). Confounding factors (e.g. natural age-specific changes in the immune system or changes in susceptibility/mortality rates as results of other stressors affecting the immune system) need to be examined. Necropsy of stranded animals is an essential tool to investigate die-offs and to examine whether pathogens were the cause or a contributory factor.

10.1.1.8 CONFOUNDING FACTORS

Confounding factors are those associated with exposure but not effect, that could account for any relationship seen. It is vital that these are monitored in the individuals being studied so they can be controlled for in the final analysis. Examples include:

(1) sex – this can be established directly or indirectly (skin for genetics);
(2) reproductive status – new techniques such as the examination of blood, blubber or faeces for reproductive hormones make this increasingly feasible for many sampling regimes;
(3) age – it is not always possible to obtain age estimates but length or estimate of mature/immature may be available (age class estimates).

10.1.1.9 TISSUE BANKS AND ARCHIVES

There are now a number of long-term tissue collections and data archives for cetaceans which are providing valuable retrospective information for pollutant exposure measurement and to determine changes in diet through the analysis of stable isotopes and fatty acids. Also, this material may be of use in genetic studies.

The Workshop **recommended** careful preservation of tissues from wide ranges of species and populations for retrospective studies. Appropriate sample collection and storage based on new techniques available (e.g. tissues in *RNALater®* for molecular studies) and the maximum use of non-diseased animals as controls are also to be encouraged and made available to the wider scientific community.

10.2 Linking indirect measures of habitat quality (responses) with exposures (cause-effect and/or dose-response relationships)

10.2.1 Chemical pollutants

As discussed in Reijnders *et al.* (1999) determining cause-effect and dose-response relationships for chemical pollutants and cetaceans at the individual and population level is extremely difficult and may turn out to be impossible for some cetaceans. The Workshop **recommended** continuation of the POLLUTION 2000+ initiative and **encouraged** the further development of mark-recapture methods using photo-ID studies and individual covariates (contaminant levels or biomarkers) to provide estimates of dose-response (Hall *et al.*, 2001; Hall *et al.*, 2002). It also **encouraged** work along the lines of Jepson *et. al.* (2005) who examined relationships between polychlorinated biphenyls and health status in harbour porpoises from strandings data[5], for example case-control studies that estimate relative risks (determined from the odds ratio, that is the odds of exposure amongst the cases compared to the odds of exposure amongst the controls) should be encouraged. Using this approach cases might be defined as animals that died of infectious disease and controls as trauma deaths.

In the absence of species or taxon-specific information, the Workshop noted that data from different species (e.g. via laboratory and human studies) have sometimes been used but stresses that this should only be done with extreme care – great differences have been found even between relatively closely related species in other taxa. The use of *in vitro* studies of e.g. Aryl-hydrocarbon (Ah) receptor expression might assist in determining the likelihood that responses to certain exposures are similar, although metabolism may be a problem if metabolites or intermediates are more toxic. There is also a need to develop more robust *in vitro* methods to determine species susceptibilities.

Responses to multiple exposures (synergistic and antagonistic effects) need to be considered, particularly given the relationships that may exist among levels of certain contaminants: cause and effect relationships rather than simple correlations may be required by managers before action is taken.

It was reiterated that there are increasing levels of many pharmaceuticals and personal care products in the environment, for which nothing is known of their potential effects on cetaceans.

10.2.2 Noise

There are at least two categories of noise that might impact cetaceans:

(1) chronic/white noise (e.g. restricting communication range; Fristrup *et al.*, 2003; Foote *et al.*, 2004); and
(2) acute repeat impact noise (e.g. that causes direct physical damage or leads to death e.g. military sonar and beaked whales; Jepson *et al.*, 2003)

The potential adverse effects of noise on cetaceans have been reviewed many times in recent years (e.g. see IWC, 2005a, pp.37-8) and it is not appropriate to include a major

[5] The potential limitations of some strandings data are well documented, particularly with respect to how representative they are of the population and this must always be taken into account.

discussion here. As with other stressors, determining cause and effect relationships is extremely difficult, particularly where the effect may be indirect (e.g. exclusion from preferential foraging areas may result in nutritive stress; impaired hearing may reduce reproductive or foraging success; avoidance of vessels may result in increased energy budgets). Models can be developed that attempt to predict possible effects such as these at the population level but testing these e.g. by measuring changes in body condition will be difficult (e.g. Lusseau *et al.*, 2004). The potential effect on populations will also depend on the overall status of the population concerned and the significance of the area in which the noise occurs – for example, particular concern has been expressed over the noise generated by oil and gas development in the feeding grounds of the critically endangered western gray whale.

In the case of impact noise (blasts e.g. seismic surveys, rig removal, harbour dredging, clearing shipwrecks) there may be a time lag for the detection of effects, and the effects may be cumulative. Controlled exposure experiments have been proposed to help evaluate the significance of noise exposure, but some concerns over their value have been expressed.

10.2.3 Prey availability

Knowledge of the availability, quantity and quality of prey, as well as knowledge of how this is translated into body condition is clearly extremely important in characterising key aspects of cetacean habitat and examining the effects of habitat degradation on cetaceans. As noted earlier, a number of stressors may impact on feeding and body condition in many ways including affecting cetacean prey quantity and quality directly or indirectly, affecting ability to capture prey and/or by affecting ability to transfer food into energy. Alternatively, changes in prey quality and quantity may result in changes in behaviour (e.g. larger schools) that may make cetaceans more susceptible to transmissible diseases.

It was noted that changes in prey availability (e.g. due to fishing) may have beneficial (e.g. by changing the balance such that cetacean prey species become more available) or adverse effects (e.g. Indian River Lagoon bottlenose dolphins changed to a diet of pufferfish which led to saxitoxin exposure and mass mortality.)

Clearly, an understanding of multi-species functional responses is important in order to understand the impact of prey availability on cetacean populations.

10.2.4 Biotoxins

Although the reasons are unclear, Hallegraeff (1993) noted an increase in the intensity and frequency of naturally occurring[6] harmful algal blooms (e.g. domoic acid, saxitoxin, brevetoxin). Some have postulated that the causes may include increased coastal development and regime shifts. Detecting and monitoring the progress of such blooms has usually been attempted through examination of sea surface temperature and chlorophyll levels (via satellite data) but this is not entirely reliable and temporal and spatial correlations with remote sensing data will not always help to detect sources. For example, Mediterranean monk seals (in Mauritania) and bottlenose dolphins (in Florida) were exposed to offshore or subsurface blooms, where it is believed that fish brought the toxins inshore (Hernandez *et al.*, 1998). Toxins may remain in fish from hours to weeks and have been found in fish flesh, which has significant implications for determining appropriate exposure measures. There is some evidence that some populations may have become adapted to certain toxins (e.g. compare the effects on bottlenose dolphins in Charlotte Harbor with those in the Florida Panhandle (Schwacke *et al.*, 2002; 2004)).

[6] Ballast water has caused the introduction of exotic phytoplankton that are not normally toxic but when 'stressed' produce toxins so that when they colonise new areas they are aggressive.

10.2.5 Novel pathogens

New molecular diagnostic tools (e.g. multiplex PCRs/microarrays) are now available to better identify novel pathogens. The primary issue with respect to 'novel' pathogens is that baseline data do not exist. The use of archived tissues from stranded animals (using serology and molecular methods) may allow retrospective studies to be undertaken.

10.2.6 Disturbance

Although noise (from vessels, oils and gas development, wind farms, etc.) is considered the primary disturbing factor (see above), boat collisions, particularly involving fast ferries, may be important in certain regions (e.g. the Mediterranean) and for certain endangered populations (e.g. North Atlantic right whales). In some cases, occurrence can be monitored via strandings networks. If development projects are instigated (e.g. oil platforms and pipelines, wind farms) it is important that responses are recorded before, during and after installation.

10.3 Population response

There are many ways in which responses to habitat degradation may affect population status. Most of these effects are mediated through vital rates and the sensitivity and ease of measurement of each are considered briefly below, although clearly these will often be species and population specific. It should be noted that in many cases, vital rates can not be estimated with great certainty, making detecting significant changes difficult. The question of obtaining a sufficiently representative sample of the population is important (and difficult) whatever methods (photo-ID, biopsy sampling, examination of stranded animals or animals in directed or indirect fisheries) are used. Separating natural variability (and density-dependent responses) from changes due to habitat degradation will also be problematic.

10.3.1 Vital rates

10.3.1.1 JUVENILE MORTALITY

Although often thought to be a sensitive parameter for terrestrial populations, juvenile mortality is a difficult parameter to estimate. For some, if not all cetacean species, it may be necessary to distinguish calf survival from post-weaning to maturity survival (recognising the transition to independence is not just in the first year for cetaceans – weaning might not be abrupt).

In some species where identifying marks develop early in life and resighting probabilities are high, juvenile mortality (calf survival >1 year olds) can be estimated from photo-ID data, although for neonates (<1 year old) it might not be possible. For example, Gaspar (2003) found from photo-ID data that bottlenose dolphins in the Sado estuary in Portugal experience very low juvenile survival such that in many years no cohorts reach maturity; the reasons for this are not clear. It has been suggested that juvenile mortality is sensitive to short-term changes in the environment, and that changes in it might serve as an 'early warning signal'. However, given the difficulties in estimating it (and hence detecting changes in it), alongside the expected variability due to natural causes, it does not seem a promising index of habitat quality for most cetaceans.

10.3.1.2 AGE AT FIRST REPRODUCTION (OR ATTAINMENT OF SEXUAL MATURITY, ASM)

It should be noted that age at attainment of sexual maturity (ASM) and age at first reproduction are not necessarily the same (even allowing for the pregnancy period in females) since animals do not necessarily reproduce immediately on becoming sexually mature. ASM is probably determined by the cumulative effects over an animal's life (including before birth), whereas the decision to reproduce on maturity or delay 1-2 years may be a shorter term decision, based, for example on nutritive status at a particular time of the year.

There are a number of methods for estimating ASM (e.g. see Perrin *et al.*, 1984) including examination of ovaries, testes and transition phases in teeth and earplugs. Age of first reproduction can be observed directly from calf attendance in naturally marked populations (e.g. right, gray, humpback whales), but data series longer than the maximum age at first reproduction are needed. Estimates for ASM can be obtained from examination of stranded animals but the usual caveats about the representativeness of such animals remain. Changes in ASM may reflect density-dependence and habitat heterogeneity rather than habitat degradation, particularly where animals are at the extremes of their range. For example, striped dolphins in Mediterranean and Japan had the same age at physical maturity, but those in Japan reached ASM at six years old, and in the Mediterranean at 10 years old – it was thought that this reflected the fact that the Japanese population was exploited.

10.3.1.3 FECUNDITY

Perrin *et al.* (1984) reviewed methods to estimate pregnancy rates in cetaceans. Usually this involves examination of ovaries from exploited populations. Systematic necropsy of stranded animals might provide data on pregnancy rates for some populations with the usual caveats applying over the representativeness of the samples (some control for biases such as the cause of death can be made by selecting physical trauma cases and removing diseased animals that may have recently aborted); in some species, the natural segregation of the population by reproductive class must be taken into account. In naturally marked animals, calf attendance (reciprocal of intercalf interval) can be used to provide estimates of successful pregnancy rates (e.g. humpback whales in the Gulf of Maine, right whales and killer whales). In some species (e.g. North Atlantic right whales), it has been suggested that increased inter-calf intervals were related to changes in habitat quality.

10.3.1.4 FERTILITY

Fertility is not easy to estimate at the population level. Examination of reproductive hormones from blood spots or blubber biopsies, faeces or urine may be monitored in some populations but it might be difficult to discriminate between normal reproductively inactive females and impacts due to adverse exposures. Immunohistological and histological studies have been conducted on UK-stranded porpoises to derive qualitative and quantitative indices of testicular development and fertility (across all ages and seasons).

10.3.1.5 ADULT MORTALITY

Adult mortality is not easy to estimate but it is easier than for juveniles. In some species there are thought to be sex differences in adult mortality; female survival is likely to be more important in terms of population abundance. For appropriate species, estimates of survivorship from photo-ID studies[7] can be quite robust provided that data are available for an appropriate timescale (e.g. see Hammond *et al.*, 1990; Cooke *et al.*, 2001; Best *et al.*, 2001). Increased adult mortality rates (particularly of females) can have a major effect on population size over time. For example, in harbour seals in the Wadden Sea, high adult mortality prior to the 1988 PDV outbreak was 11-12% and after the PDV outbreak it was 5-6%, this might have been related to selective mortality due to contaminant exposure. If changed estimates of natural mortality are detected, as for other life history parameters, determining whether changes are part of natural variation or are due to indirect anthropogenic causes (e.g. lowered immune systems) will be difficult.

10.3.1.6 DISTRIBUTION CHANGES

Quantifying changes in distribution is not easy. For some species it might be possible to do this by determining temporary and permanent emigration (multistrata or joint live/dead mark recapture models from mark-recapture data can estimate changes in these rates over time e.g. sperm whales, western gray whales, bottlenose dolphins). The data series must be sufficient to separate natural temporary changes in distribution from permanent ones due to habitat degradation.

10.3.1.7 CHANGES IN SEX RATIOS

Determination of the sex of an animal can be achieved from physical examination (from live-captured as well as dead animals), photographs and biopsy samples. Skewed sex ratios may be a consequence of differential survivorship due to exposure to, for example endocrine disrupters or immune suppressive contaminants (see e.g. harbour seals in the Wadden Sea; Reijnders *et al.*, 1997). This may have an effect on vital rates and population dynamics. Care needs to be taken to ensure that segregation by sex is accounted for when estimating sex ratios.

10.3.1.8 TRENDS IN ABUNDANCE

A trend in abundance is the overall result of the many processes and changes in the vital rates discussed above and ultimately the parameter of interest. It is a gross measure but may be monitored in many populations via sighting surveys, photographic mark-recapture methods etc. Given the uncertainty around estimates, detecting trends is not simple and may requires many years of data. In addition, for many populations, long-term monitoring may not be considered practical due to the logistics and costs involved. It is not an especially sensitive measure to habitat degradation *per se*, but may be the first or only indication of changes at the population level. The disappearance of a species from a part of its range may be significant even when no change to overall abundance can be detected.

11. MODELLING AND ANALYSIS TO LINK CETACEAN POPULATION DYNAMICS TO CHANGES IN HABITAT

The Workshop reviewed how the various modelling approaches that have been described and discussed could inform a general framework for modelling the links between environmental stressors that degrade habitat and population effects.

[7] Note that such studies cannot distinguish between permanent emigration and mortality.

The main purpose of modelling the link between cetacean demographics and habitat is to provide a means of incorporating data on distribution, demographics, individual condition and other data such as measures of exposure and contamination, into a quantitative framework that enables the degree of threat posed to different populations by habitat degradation to be assessed. In particular, it will allow consideration of synergistic effects. Initial simulation modelling to look at the sensitivity of the whole system to particular stressors, including the potential to 'rule out' certain stressors as well as to identify potential key stressors is important and can help to direct future research efforts.

The available modelling approaches differ in the kind of information they can make use of. For example, spatial models of distribution use data on occurrence, while demographic models use data relating to vital rates. The proposed framework is illustrated in Fig. 3. Most of these are dynamic models of factors affecting individual health, vital rates and populations, but spatial models relate observed distribution and abundance of populations to features of the habitat and stressors. Approaches to integrate the different kinds of modelling are at a fairly early stage. The Workshop **strongly recommended** that effort be put into further consideration of the framework presented, including the linking of the different types of models, e.g. through data on vital rates. Such a modelling framework will be valuable in focussing studies to model existing data and in directing future analytical and modelling work. It was noted that the Workshop had not discussed ways to model how stressors affected features of the habitat or individuals directly. More work was needed in this area. It was noted that ecosystem models attempt to link all aspects of habitat and populations and thus encompass the whole framework. There was no time to discuss the question of ecosystem models, but reference was made to the Committee's workshop on related issues held in 2003 (IWC, 2004).

11.1 Examples

11.1.1 Common dolphins in the Mediterranean Sea

The model framework was discussed in relation to investigating whether the decline in Mediterranean common dolphins was related to a decline in prey availability. Research could follow the route of data collection and analysis to inform dynamic models linking individual health to prey availability, vital rates to individual health and population dynamics to vital rates. It could also focus on data collection and spatial modelling to relate distribution and abundance to features of the habitat, including prey availability. This example clearly highlights that to investigate such questions will take a large amount of dedicated data collection, analysis and modelling, potentially over a long period of time.

11.1.2 Killer whales on the west coast of the USA and Canada

As another example, Taylor presented summaries of Taylor (2002) and Taylor (2004). Taylor (2002) described attempts to make inferences about the likely impact of a range of environmental stressors on vital rates and the impact of these effects on population dynamics of southern resident killer whales. Taylor (2004) investigated the consistency between the degradation of various features of the environment and observed population features including vital rates for pods of whales from the northern and southern resident communities. In the latter study, no clear picture emerged. It was agreed that it would be valuable in this example to construct an individual based model (see Hall *et al.*, 2005) to investigate whether the observed population features could be explained by demography alone.

11.1.3 Bottlenose dolphins on the eastern coast of the USA

An integrated bottlenose dolphin programme is underway in the US examining individuals from various populations from New Jersey to Texas. The programme is centred around live capture – release activities, but includes data from strandings, biopsies and photo-ID programmes. Evaluations include standardised health, population, community, stressor and environmental parameters. The goal is to evaluate these parameters over a gradient of stressors to obtain information on exposure and dose response relationships to model potential effects on population parameters and more importantly to conduct sensitivity analyses to determine where data is needed.

11.1.4 Harbour porpoises in the North Atlantic

There are relatively good data sets available for North Atlantic harbour porpoises; data from a number of different populations with different levels of habitat degradation. For example, there is a 15-year long-term dataset on UK stranded animals including life history, reproductive, pathological and toxicological data. Other datasets on stranded porpoises exist in Europe using the same standardised necropsy protocols. In UK-stranded harbour porpoises, relationships between polychlorinated biphenyl exposure and infectious disease mortality have been identified which constitute empirical dose-response relationships suitable for modelling. In addition, abundance and distribution data exist for porpoises in European Atlantic waters (SCANS I and II).

12. WORK PLAN, RECOMMENDATIONS AND CONCLUSIONS

12.1 Work plan

The Workshop, whilst unable to develop a formal workplan in the time available to it, **agreed** that a workplan to develop the framework shown in Fig. 3 should include the items given below.

(1) First attempts should be made to apply the framework to specific case studies. Case studies identified as initially promising include bottlenose dolphins from Florida, harbour porpoises from Europe and resident killer whales from the northwest coast of North America. This will enable further development of the framework and give a clearer idea of where data and methodological gaps exist.

(2) Effort should be made to further develop methodological approaches to distinguish the relative effects of different stressors via population and spatial modelling approaches.

(3) Consideration should be given to applying the framework for one area (see (1) above) and then using the results to make predictions for the same species in a different area and comparing this with the actual situation as a type of 'validation'. A similar approach has been successfully used with spatial modelling approaches to try to determine whether it is reasonable to predict cetacean distribution in areas where data are not available.

(4) A follow-up Workshop to take place at an appropriate time to review the progress of this workplan, make specific progress on the analysis of data (e.g. porpoise or *Tursiops* case studies) and make recommendations for future work.

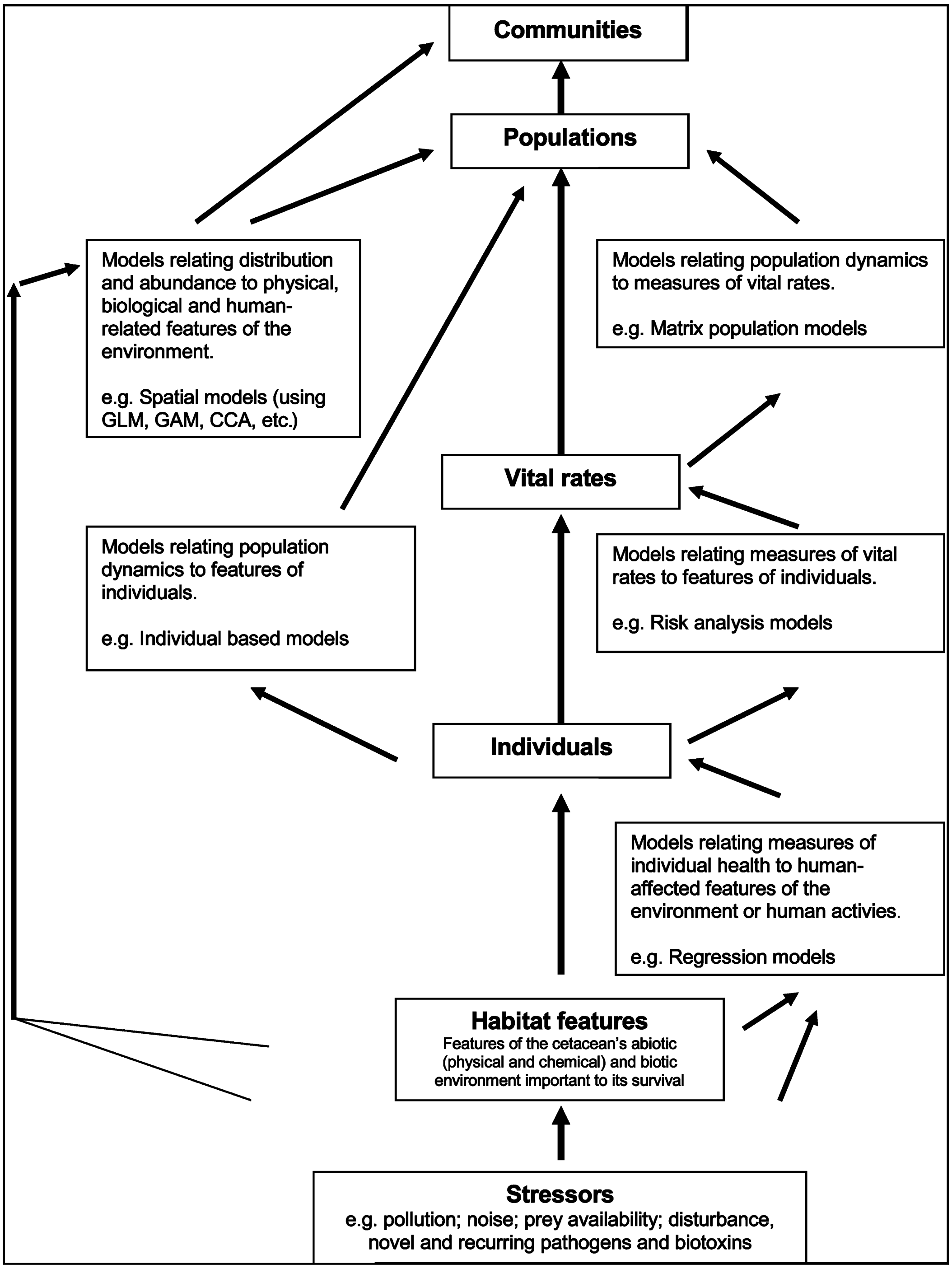

Fig. 3. General framework for modelling the links between environmental stressors that degrade habitat and population effects.

12.2 Recommendations

International interdisciplinary collaboration will be required to address the considerable theoretical and practical work which is needed to reach the goal of being able to explain and predict the effects of habitat changes on cetacean populations.

The Workshop **strongly recommended** that effort be put into further consideration of the framework given in Fig. 3, including (1) the linking of the different types of models, e.g. through data on vital rates; (2) developing ways to model how stressors affect features of the habitat or individuals directly; and (3) developing ways in which spatial modelling approaches can better incorporate dynamic variables. Such a modelling framework will be valuable in focussing studies to model existing data and in directing future analytical and modelling work. Attention must also be given to trying to determine the relative importance of natural versus anthropogenic environmental changes on the dynamics of cetacean populations.

The Workshop recognised the essential role played by long-term monitoring in our understanding of the impact of habitat degradation; key datasets considered during the meeting had been underpinned by long-term research programmes. The Workshop **strongly recommended** the continuation (and where necessary, initiation) of long-term studies both of cetaceans and key biotic and abiotic features of the environment. In this regard, it recognises that this may require a change in emphasis of both management and research agencies. In the present political climate there is often reluctance to invest in long-term programmes. The

Workshop stressed that the issue of cetaceans and habitat degradation will only be resolved by long-term interdisciplinary datasets. This will also require a change in the way many institutes evaluate scientists. At present, this is often on the basis of their number of publications. It is often a feature of long-term monitoring programmes that they do not result in several publications per year despite the fundamental importance of the work. This may discourage high calibre scientists from committing to such programmes, to the detriment of cetacean conservation.

The Workshop also recognised the difficulties in developing (and measuring) suitable indices both of habitat quality and response in cetaceans. It **recommended** that further work be undertaken in this regard, particularly with respect to:

(1) identifying key features of cetacean habitats;
(2) reviewing methods used to assess cetacean nutritive status in both live and dead specimens, with a view to future standardisation of techniques;
(3) developing indices of cetacean response to various stressors.

Both (1) and (3) will require a better understanding of the feeding and reproductive behaviour of cetaceans. The Workshop **recommended** that fine-scale feeding studies such as those recommended by the SOWER 2000 Workshop be undertaken. It also **recommended**, where appropriate, studies using satellite tags that can also record environmental variables. The Workshop also **recommended** further work to develop standardised behavioural sampling techniques and indices that will allow inter-site comparisons, as well as the integration of behavioural indices in the framework.

Addressing (1) will require interdisciplinary research and the Workshop **recommended** the development of collaborative programmes that include cetologists, oceanographers, fishery biologists etc. Where possible, collection of cetacean data and data on their environment should be conducted simultaneously. As noted earlier, spatial modelling approaches are particularly valuable in integrating data on cetacean distribution and abundance with data on their habitat and priority should be given to incorporating dynamic variables in such analyses. Also with respect to (1), the Workshop **recommended** that the suitability of available environmental indices to describe cetacean habitat condition be examined.

Examination of dead animals can provide valuable information on the possible effects of stressors. Standard necropsy procedures exist (and see the recommendations of the POLLUTION 2000+ programme), but the Workshop **recommended** that these be periodically reviewed and in particular that standardised necropsy protocols be devised for examination of cetacean carcasses potentially linked to noise exposure, including the optimisation of sampling techniques to identify gas and fat emboli. The Workshop stressed the importance of considering the representativeness of information collected from strandings programmes (and indeed all programmes where the results are intended to be applied at the population level).

Given the large data demands, the Workshop **recommended** that the SC explores ways to improve collaborative research and data/information sharing and to facilitate the development of mechanisms to achieve such collaborations. The use of web-based metadatabases shows promise in this regard and a number of such projects now include cetaceans.

Baseline data are especially important and the Workshop **recommended** appropriate long-term preservation of tissues from wide ranges of species and populations for retrospective studies. Sample collection and storage should be based on the best techniques available (e.g. include tissues in *RNALater®*, a proprietary preservative solution that stabilises RNA at room temperature, allowing it to be recovered from the tissue for molecular studies) and maximum use should be made of available biological materials and such materials made available to the wider scientific community. The development of a web-based metadatabase, detailing the locations and curators of available tissue banks and sample collections should be encouraged and instigated at the earliest opportunity.

Finally, given the likelihood of increasing cases of cetacean populations being excluded from portions of their natural range due to habitat degradation in the future, the Workshop **encouraged** the continued development of habitat restoration science and technology.

12.3 General conclusions

The Workshop stressed the importance of undertaking work relating habitat condition to cetacean status in the context of conservation and management. This is a particularly complex area of study, requiring both theoretical developments in modelling approaches and a commitment to long-term interdisciplinary data collection programmes.

The framework developed provides the basis of a long-term approach for investigating the significance of habitat degradation for cetaceans. General application of the framework would require a much longer-term view to be taken by management and research bodies. This would allow major improvements in advice to resource managers for the conservation and management of cetaceans with respect to predicting the effects of habitat degradation and the effects of many anthropogenic activities and the development of appropriate mitigation measures. The continuation of the present *ad hoc* and usually unsatisfactory processes (such as ‘Environmental Impact Assessments’ based on short-term limited datasets) would be unsatisfactory. The Workshop recognised the need for indices to be developed that will inform managers when action needs to be taken, but recognises that this will not be a simple task. However, for urgent conservation cases (e.g. the western North Pacific gray whale), the Workshop stressed that more direct and immediate management actions will be required.

In order to facilitate the development process, the Workshop **agreed** that primary focus should be on populations for which it is believed there is most chance of success i.e. those for which good information is available on both cetaceans and their habitat over a reasonable time period. The Workshop recognised that overall there are few cetacean populations studied with sufficiently broad sampling programmes covering sufficiently long time frames. Whilst a broad analysis of key habitat problems globally may help prioritise areas of concern and suggest species or populations that might be candidates for this type of analysis, the Workshop believed that at present the following species/areas seemed most promising: bottlenose dolphins from Florida; harbour porpoises from Europe; and resident killer whales from the northwest coast of North America.

The Workshop stressed the value of long-term monitoring of both cetaceans and key aspects of their habitat at appropriate temporal and geographical scales. Baseline data on natural variability in cetacean populations and their habitat area are prerequisite to determining whether anthropogenic changes in the habitat are important to the conservation of cetacean species. Obtaining suitable information on the biotic and abiotic features of habitat will require interdisciplinary efforts and co-operation, such as that found in the present IWC-CCAMLR and IWC-SO-GLOBEC research efforts. Where possible, collection of cetacean and environmental data should be conducted simultaneously. Spatial modelling approaches are particularly valuable in integrating data on cetacean distribution and abundance with data on their habitat.

The Workshop also stressed the need to better understand the feeding and reproductive behaviour of cetaceans. With respect to the former, this particularly includes the relationship of cetacean distribution with their prey. As suggested in the report of the SOWER 2000 Workshop (IWC, 2000), this will include fine-scale research on feeding strategies and prey selection. It also requires much better knowledge of the distribution, behaviour and abundance of prey species which will require better co-operation with other disciplines, especially physical and biological oceanographers and fisheries scientists. The potential of newer technologies such as satellite tagging (including environmental sensors), remote sensing and new initiatives to develop ocean-based observing systems (e.g. in the USA and Europe) have the potential to provide broad-based data sets on both the cetaceans and their habitat.

13. CLOSING STATEMENTS

Reilly thanked all the participants, Working Group leaders and rapporteurs.

Donovan, on behalf of the IWC, thanked all of the participants for their contributions to this challenging and important Workshop, which he saw as the first stage in a longer process. In particular, he thanked Christina Fossi and Stephania Ancora for their hard work in making all the arrangements and providing such a beautiful working environment, as well as all of the staff who looked after us all so well. Finally, he wished to thank Clare Last from the Secretariat who handled all of the arrangements for the IWC with great patience and good humour, given the eccentricities of the scientists! She has now moved on to pastures new and we all will miss her and wish her well.

The meeting closed at 1pm, Monday 15th November 2004. The report was adopted by e-mail.

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Annex B

Agenda

1. Convenor's opening remarks
2. Election of Chair
3. Appointment of rapporteurs and Working Group leaders
4. Adoption of Agenda
5. Review of terms of reference
6. Review of available documents
7. Introductory presentations
   - 7.1 Report of the Scoping Group
   - 7.2 Assessing and managing marine mammal habitat in the USA
   - 7.3 Health status of marine mammals in relation to habitat quality
   - 7.4 Effects of long-term environmental change on marine mammals
   - 7.5 Developing a framework for addressing habitat degradation and its effect on cetaceans
8. Working Group tasks
   - 8.1 Habitat quality assessment Working Group
   - 8.2 Population and health Working Group
9. Habitat quality assessment considerations
   - 9.1 Definitions
     - 9.1.1 Habitat
     - 9.1.2 Habitat degradation
   - 9.2 Review of recent literature
     - 9.2.1 Spatial modelling and similar approaches to identifying important features of habitats and responses to changes in these
     - 9.2.2 Habitats and habitat use: temporal and geographical scales
     - 9.2.3 Other issues
   - 9.3 Lessons from interdisciplinary approaches
   - 9.4 Identification of habitat quality indices.
     - 9.4.1 Habitat and habitat use
     - 9.4.2 What comprises good habitat quality indices
     - 9.4.3 Cetacean examples
     - 9.4.4 Non-cetacean examples
10. Population and health data considerations
   - 10.1 Monitoring individuals
     - 10.1.1 Health/disease indicators and application of biomarkers as indirect measures of habitat degradation
   - 10.2 Linking indirect measures of habitat quality (responses) with exposures (cause-effect and/or dose-response relationships)
     - 10.2.1 Chemical pollutants
     - 10.2.2 Noise
     - 10.2.3 Prey availability
     - 10.2.4 Biotoxins
     - 10.2.5 Novel pathogens
     - 10.2.6 Disturbance
   - 10.3 Population response
     - 10.3.1 Vital rates

Annex C

List of Documents

SC/N04/HAB1. REIJNDERS, P.J.H. Health status of marine mammals in relation to habitat quality a conceptual framework.

SC/N04/HAB2. TAYLOR, M. What is cetacean habitat degradation and what are the impacts on demography?

SC/N04/HAB3. MAURITZEN, M., SKAUG, H.J. AND ØIEN, N. Combining line transects, environmental data and GIS: cetacean distributions and habitat and prey selection along the Barents Sea shelf edge.