HABITAT DEGRADATION IN THE CONTEXT OF CLIMATE CHANGE: A REVIEW OF RECENT WORK

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ABSTRACT: Recent work showing largely synergistic effects between ongoing climate change and decline in quality or loss of cetacean habitats is discussed. Recommendations for further work are made.

KEYWORDS: HABITAT, TRENDS, CLIMATE CHANGE.

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Cetacean habitats - feeding and breeding and other special purpose (e.g., rubbing beaches) areas and the routes that connect them - may be variable in time and space and subject to multi-year climate oscillations and regime shifts that can turn suitable into unsuitable habitat by altering the balance of favourable and unfavourable habitat characteristics (Bjørge, 2002). Climate change has potential to shift or degrade suitable habitat, or to amplify other sources of degradation (Scavia et al., 2002).

There are significant challenges in linking habitat degradation to changes in cetacean health, survival and reproduction (Simmonds et al., 2001; IWC/SC/54/Annex J, sect. 7.2). In many cases there are intractable limits to available methods.

An additional problem is that habitats may already be shifting and will continue to shift as a result of climate change. These changes must be taken into account when assessing habitat degradation and its impacts, while conservation planning must also be adapted accordingly (Soto, 2002).

Evans (2002) suggests five general classes of habitat degradation: physical damage, contamination (chemical pollutants, to which biotoxins and exotic pathogens may be added), reduction of prey (fishing, pollution or oceanographic change), disturbance (noise, shipstrikes, bycatch, entanglements) and climate change.

Recent progress in the published literature on cetacean habitat degradation and recent relevant reviews are communicated here, along similar lines to those of Evans (2002), and methodological priorities discussed, with emphasis on synergies with climate change.

PHYSICAL DAMAGE

Physical degradation of cetacean habitat is thought to affect mostly coastal and riverine species (Crespo and Hall 2002). For example Mendes et al., (2002) show bottlenose dolphin association with a specific tidal front, a fragile association easily disrupted by changed river flow or physiography. The impacts are potentially profound when rivers are dammed or channelized, when sediment load is increased by eroding watersheds, or coastal habitats modified by dredging, dumping and construction
of channels, ports and sea walls. Numerous studies attempt to define physiography of cetacean habitats (e.g. Heimlich Boran, 1988; Gregr and Trites, 2001). Methods are likely limited to comparative studies of cetacean use of coastal habitats that are highly modified vs those that are not, in the same climatic and hydrologic regions, or before and after modifications. Such comparative studies are presently lacking.

With global warming, accelerated physical change in coastal habitats is expected from sea level rise and increasing storm energy and/or frequency, which may also trigger further coastal modification to protect human settlements. Although models predict increased storm activity due to global warming, empirical evidence is still only suggestive and difficult to distinguish from natural variation (Goldenberg et al., 2001, Emanuel, 2003, Noren et al., 2002).

**CONTAMINANTS**

Cetacean habitats in riverine and populated coastlines are commonly polluted to varying degrees with persistent organic pollutants (POPs), heavy metals, sediments and nutrients in nearshore waters. Cetacean contamination by organochlorines (OCs) is ubiquitous along Asian coastlines and at very high levels that show no sign of decline since the 1980s (Tanabe, 2002).

Aerial, water and biological transport can carry labile pollutants such as HCHs far afield (review by Hall, 2002).

Despite considerable corroborative evidence, great uncertainty remains over the extent to which cetacean health, reproduction and survival are impaired by organohalogen. Manipulative experiments have proven reproductive impairment for pinnipeds fed PCB contaminated fish (Reijnders, 1986).

More commonly used correlative approaches compare health parameters and ‘biomarkers’ of individuals between polluted and unpolluted habitats, or compare body burdens of POPs of stranded and living individuals in the same habitat. Confounding factors often inhibit inference of causation, however (Hall, 2002).

Cetaceans in polluted habitats may manifest more diseases and mass mortalities (e.g. tattoo disease Van Bressem et al., 1999; Rose et al., 2003). Wilson et al., (1999) found no correlation of skin lesions with pollutant loads, however. Belugas in the polluted St Lawrence estuary suffer high cancer rates (Martineau et al., 1999).

Dead striped dolphins had higher body burdens of organochlorines than the survivors of a mass stranding (Aguilar, 2000). However, stranded animals also tend to have less body fat and fat soluble POPs could be more concentrated in their fat merely due to starvation (Soto, 2002).

For such correlative studies, confounding factors are a structural problem, that may be mitigated by sampling from the broadest array of habitat conditions to capture the widest ranges of possible causative factors (Geraci and Lounsbury, 2002). Pollution 2000+ is pursuing such methods focusing on model species, to establish firmer links between pollutant loads and cetacean health.

Radionuclide contamination of ocean sediments is prevalent in the Arctic and
sub-Arctic coastal regions from dumping and weapons testing (Crane et al., 2000). Hunted marine mammals in Alaska, northern Canada and Barents and Norwegian seas had low $^{137}$Cesium contamination. Health effects are unknown but believed to be minor due to the low levels typically found in tissues (Heldal et al., 2003; Cooper et al., 2000).

Oil spills may poison cetaceans or contaminate their food webs (Geraci, 1990). Synergy with organochlorine contamination is suspected but not proven (Matkin et al., 1998). Although oil spills have significant direct and indirect impacts, oil is less pervasive and persistent than POPs and heavy metals in cetacean environments. Stricter regulation of shipping in response to recent disasters may reduce risk (Rose et al., 2003). Of added concern is continuous low level exposure to petroleum residues for cetaceans whose habitats contain offshore oilwells, a subject that has not received much recent attention (Geraci, 1990).

Fertilizers, nitrous oxides and organic pollution is increasing in coastal ecosystems worldwide (Paerl and Whitall, 1999; Cloern, 2001; George et al., 2001). Among the major problems of resulting eutrophication is hypoxia, which can lead to mass mortalities and drastic changes in community composition, particularly in the benthos. Hypoxia is expected to worsen with increased stratification of coastal waters from global warming (Wu, 2002).

The concept of ‘biological pollutants’ is reviewed by Elliott (2003), referring to pathogens spread by human agency such as shipping bilge, aqua- and mari-culture, runoff and sewage.

A spatial-correlation study by (Miller et al., 2002) found that *Toxoplasma gondii* seropositivity of southern sea otters (*Enhydra lutris nereis*), for which domestic cats (*Felis catus*) form the major known reservoir, was associated with freshwater outfalls. Although this study did not deal with cetaceans it did raise instructive methodological issues of confoundment and study design. The authors found no net correlation between seroprevalence and human density or sewage outfalls. However, they noted that both were negatively associated with freshwater outflows. Sewage outfalls tend to be further out to sea, outside sea otter habitat. In the only case where sewage outfalls occurred inshore, however, seroprevalence was high.

Harm algal blooms (HABs) seem to be increasing, with possible connection to climate change, coastal eutrophication and shipping (Donaghay and Osborn, 1997; Hallegraeff, 1998; Babaran et al., 1998; Cloern, 2001; Kononen, 2001). HABs have been connected to mortality of humpbacks eating contaminated fish (Geraci et al., 1989), but this does not seem to be a widespread phenomenon for cetaceans. Algal blooms or other plankton changes may serve as indicators of regime shifts that impact food supply for cetaceans (Brodeur et al., 1999).

The complexity of natural ecosystems prevents easy analysis of the causes of outbreaks and mass mortalities involving biological ‘pollutants.’ Methods involve painstaking identification of pathogens, linking pathogens to observed pathologies and further work to ascertain whether pathogens are natural or imported, or whether an outbreak is largely due to human agency.
Mass mortality events provide opportunities to identify habitat degradation factors. However proximate causes of deaths (morbillivirus, HABs) are more readily identified than ultimate causes such as prey depletion and POPs (Domingo et al., 2002). In many cases a disease outbreak may be an outcome of declining health in a population due to starvation, in combination with contamination or other habitat degradation. Simmonds and Mayer (1997) discussed the synergistic pathway from starvation to POP mobilisation, immune dysfunction and disease outbreaks in the case of a major epizootic event in Mediterranean striped dolphin populations.

A broader correlative approach was taken by Sherman (2000) to characterise marine ecosystem health by principal components analysis of a large database of marine ‘events.’ Marine mammal events (strandings, mass mortalities) and climatic/oceanographic anomalies were correlated. However many of those events likely involved pinnipeds which are less flexible than cetaceans, tied to land and thus more readily affected by loss of prey as a result of climate anomalies (Harwood, 2001). Le Boeuf et al., (2000) suggested that eastern north Pacific gray whale mortalities in 1999 were based on food shortages, in turn a possible result of both food depletion by whales themselves and elevated surface temperatures (see also Gulland et al., 2002).

Rising sea levels and increased storms and river flows that may result from global warming, may mobilise contaminated sediments, or expose onshore dumps of POPs by flooding, potentially increasing contaminants in coastal waters. Such impacts must be studied on a site by site basis.

Higher temperatures from global warming and excess UV exposure from ozone depletion may weaken cetacean immune systems, adding to starvation, pollutant and noise stress (Würsig et al., 2002). The retreat of Arctic sea-ice is may open the Arctic ocean to shipping, development and oil exploitation increasing contaminant exposure risk (Tynan and Demaster, 1997b; Kerr, 2002).

**DISTURBANCE AND BYCATCH**

**Noise pollution**

Noise pollution may disrupt and inhibit feeding and reproduction, may exclude animals from suitable habitat, or in the extreme may cause direct auditory damage and death. Noise pollution includes ship and boat propeller noise, drilling blasting and dredging, Acoustic Deterrent Devices used by fish farms and fishing vessels, sonar and airguns used in seismic exploration (Simmonds and Dolman, 1999; Würsig and Evans, 2002). A mass stranding of beaked whales in the Bahamas in 2000, during U.S. Navy operations, confirmed that cetaceans are seriously injured by loud sonar under certain circumstances (Balcomb and Claridge, 2001). Although acute episodes of mortality related to loud noise are established, an as-important question is how noise contributes as a *chronic* stressor of cetacean health against a growing background of habitat degradation stressors such as temperature, starvation and contaminants. Whalewatching disturbance has been shown to impose
chronic energetic costs on orcas (Kriete, 1995).

Noise pollution also results in effective habitat loss by deterrence such as by Acoustic Deterrent Devices (Morton and Symonds, 2002).

The impacts of noise on cetaceans are manifold with many different methods being applied and great progress being made in recent years.

Little association is expected between noise pollution and climate change other than possible expansion of shipping, fishing and industrial activity into areas currently protected by ice cover.

**Shipstrikes, debris, entanglements and bycatch**

Marine debris, shipping and fishing gear all represent potential risks of death and injury to cetaceans and as such represent some of the most unfavorable factors contributing to habitat degradation (Bjørge, 2002). Large whales are particularly susceptible to ship-strikes and fishing gear entanglements. For western north Atlantic right whales this may be a primary reason for endangerment (Knowlton and Kraus, 2001; Caswell et al., 1999).

The north Pacific gyre (Moore et al., 2001) has been found to harbour large concentrations of plastic debris that could physically impair digestion (Geraci and Lounsbury, 2002), debris that could be swept further north with climate change.

Such sources of mortality or injury are more readily quantified. Quantification is largely a matter of observational effort. Physical injuries are readily discerned, while shipstrikes and entanglements are often observed directly.

Any increases in shipping, boating and fishing activities increases the likelihood of collision and entanglement for cetaceans. Key cetacean habitats are often also key fishing grounds for the same reason of high marine productivity. Fishing practices can be reformed to greatly reduce bycatch and entanglements (Hall and Donovan, 2002), however this mitigating factor must be considered against the background of the alarming expansion of fishing pressure worldwide (Myers and Worm, 2003).

Sea-ice retreat under global warming may open the Arctic to increased shipping, fishing and development. Kerr (2002) cites a U.S. Arctic Research Commission report that predicts the transpolar and northwest passage sea routes opening to unassisted cargo ship passage in summer by 2050-2080.

**TROPHIC CHANGE**

Cetaceans are embedded within marine food webs. Human impacts on marine food webs go beyond fisheries competition. Of all sources of habitat degradation, trophic change is the most difficult to study, as food webs may respond to disturbance counter-intuitively. However, considering just the enormous scale of removal of marine production by fisheries, there is no doubt that impacts on cetaceans must occur at some level (Crespo and Hall, 2002). A recent meta-analysis concluded that worldwide predatory fish stocks are at about 10% of pre-industrial levels due to over-fishing (Myers and Worm, 2003).
Trawling can modify benthic habitats drastically and reduce production of benthic prey for gray whales or other species connected indirectly to cetaceans (Wolff, 2000; Jennings et al., 2001; Callaway et al., 2002).

Removal of habitat for prey species can have a profound influence on dependent cetaceans. This is most clearly seen in the case of salmon stocks in the northeast Pacific, many of which are now endangered due to river damming, fishing and contamination (National Marine Fisheries Service, 2002).

Geraci and Lounsbury (2002) present a general model of the ‘cascading’ effects of starvation on marine mammals. Starvation may result not only from reduced food supply, but also from other forms of habitat degradation, injuries, illnesses and social disruption.

The most profound modification of food webs may come from climate change.

**CLIMATE CHANGE**

Several keys reviews have discussed the likely impacts of global climate change on cetaceans or marine mammals more generally (MacGarvin and Simmonds, 1996; Tynan and Demaster, 1997a; Tynan and Demaster, 1997b; Harwood, 2001; Moore, 2002; Würsig et al., 2002). There are also a large number of recent reviews of marine ecosystem impacts of climate change (Anisimov and Fitzharris, 2001; McCarthy et al., 2001; Boyd and Doney, 2002; Croxall et al., 2002; Legendre and Rivkin, 2002; Mantua and Mote, 2002; Scavia et al., 2002; Soto, 2002; Wu, 2002). This discussion is not exhaustive but rather highlights major issues for cetaceans.

**Ozone depletion**

Far from receding, ozone depletion may worsen in coming decades (Clark, 2002). Lesions on right whales may be linked to higher UV exposure. (Wilson et al., 1999) did not find such an association for bottlenose dolphins perhaps due to a limited range of observed UV conditions. Direct UV effects on cetaceans clearly need more study with a focus on health of conspecific populations that experience very different UV levels (eg Antarctic vs temperate resident orcas).

Quantification of ecosystem effects of ozone depletion remain elusive (Karentz and Bosch, 2001). Depression of primary productivity by increased UV radiation, has been shown in Antarctic waters during the austral spring (Boucher and Prezelin, 1996). However, phytoplankton can acclimate and community composition shift to UV tolerant taxa (Neale et al., 1998). Protective ice cover, low solar angle and timing of the spring bloom all act to reduce the overall impact of ozone holes which occur in winter over both poles (McMinn et al., 1994). Key prey species for baleen whales suffer increased mortality with increased UV, an effect diminished by the dissolved organic carbon that results from plankton mortality (Rautio and Korhola, 2002). Shifts in trophic structure are nevertheless likely as a result of increased UV and in the long term could exacerbate global warming by affecting carbon fixation rates (Davidson and Belbin, 2002).
Other synergy with global warming is possible. Retreat of sea-ice and increased stratification from surface warming could enhance UV penetration and worsen harm to plankton and other organisms in polar waters (Haeder et al., 1998). A recent strengthening of the Arctic stratospheric vortex has strengthened stratospheric cooling and enhanced ozone depletion (Shindell, 2003).

**Sea-ice retreat**

Retreat of Arctic sea-ice has been going on for decades. The northern summer of 2002 saw the biggest contraction of sea-ice yet recorded (Clarke, 2002). An ice-free summer Arctic is expected by end of this century (Holloway and Sou, 2002; Tynan and Demaster, 1997b). However sea-ice retreat also is concurrent with a peak in the Arctic Oscillation (Rigor et al., 2002). In contrast, Antarctic sea-ice has not undergone and is not predicted by models to undergo retraction (Zwally et al., 2002).

The key questions are to what extent loss of Arctic sea-ice may depress marine productivity, represent a net loss of habitat for some species, or facilitate further habitat degradation.

The unique characteristics of sea-ice in retaining phytoplankton at the top of the water column, enhancing production and the spring bloom, may be lost, resulting in lower productivity (Tynan and Demaster, 1997b). However, whether surface warming of ice-free waters will result in a general increase or decline in net production remains unsettled as discussed below.

For cetaceans like bowheads that associate with sea-ice even in winter, retreat of sea-ice may represent loss of habitat and exposure to future habitat degradation that may limit recovery of this species (Taylor, 2003). However, for other species such as gray whales sea-ice retreat may have beneficial aspects in opening up more areas to benthic feeding (Gulland et al., 2002; but see Moore et al., 2000).

Bowheads like other cetaceans have persisted through great climatic change; alternating glacial maxima and minima with dramatic changes in sea-ice extent, sea-levels and currents which were sometimes both rapid and global (Alley, 2000). Major episodes of evolutionary change in cetaceans including extinctions, have been associated with major climate shifts (Fordyce, 2002). To what extent does the present trends in warming combined with many other forms of habitat degradation represent just such a major shift that could lead to extinctions?

Paleoclimatic evidence suggests that past changes have been abrupt and that during the earliest of the many Holocene climatic peaks, was warmer than at present. Unlike past changes in sea-ice extent, however, the present losses are likely to open relatively protected polar areas to habitat degradation from increased human activities, as discussed.

**Altered temperature/salinity**

Wilson et al., (1999) found a correlation of skin lesions in bottlenose dolphins with salinity and temperature. Changes in surface temperature have already been observed and near-shore salinities can be expected to change with increased freshwater inputs (Tynan and Demaster, 1997b).
Food supply and availability

Habitat shifts

Meta-analyses of many studies have shown clear ‘fingerprints’ of global warming as range and phenological shifts (Parmesan and Yohe 2003; Root et al., 2003). Walther et al., (2002) summarize the known shifts of marine communities toward warm water species. It seems likely therefore that most cetaceans will experience roughly poleward shifts in prey distributions with a great deal of locally complex distributional shifts.

Productivity

Primary production is dependent on correct timing and balancing of mixing and stratification processes which respectively bring in fresh nutrients and concentrate nutrients and plankton (Soto, 2002; Scavia et al., 2002).

Greater surface warming and increased freshwater inputs encourages excessive stratification, which depresses productivity, and potentially also cetacean food supply, depending on food web dynamics. This has been observed for several systems such as for humpbacks around the Galapagos islands during ENSO events (Whitehead, 1997).

Much depends if wind-forced upwelling systems will generally be enhanced (Bakun, 1990) or depressed with global warming (Hsien and Boer, 1992), an issue that remains unsettled. Excessive upwelling could also depress productivity. As discussed, disappearance of sea-ice may depress productivity. Shifts in strength and location of currents may impact prey species that have life histories adapted to larval retention and concentration (Soto, 2002).

Biological change with anomalies such as ENSO, give some indication of how climate change could alter cetacean food supply and provide a kind of natural ‘experiment’ in warming. Such anomalies may also be increasing in duration and intensity as a result of global warming (Wilkinson et al., 1999; Kenney et al., 2001; Fiedler, 2002; Walther et al., 2002; Wu, 2002).

A warming-based regime shift appears to have occurred in the Bering Sea, resulting in reduced carrying capacity for gray, right and bowhead whales (Brodeur et al., 1999; Le Boeuf et al., 2000; Schell, 2000; Stockwell et al., 2001; Hunt et al., 2002; Hunt and Stabeno, 2002; Napp et al., 2002).

Migration issues

Davis et al., (1998) caution that climate change driven range shifts do not occur in a vacuum but within the constraints of the web of species interactions. Nevertheless, many cetaceans especially mysticetes, are highly mobile and may use currents, salinity and temperature cues to locate regions of high prey abundance and thus may be less affected by climatic shifts than by general reduction in marine productivity, compared with cetaceans in confined riverine and coastal habitats (Kenney et al., 2001). However, even mysticetes may have barriers to range expansion. The Okhotsk sea bowheads for example have no space to expand their summer feeding range poleward unlike the Bering-Chukchi-Beaufort seas bowheads.
Baleen whales undertake annual migration from food-rich high to food-poor low latitudes for breeding purposes. Whatever the adaptive purpose of migration (Kshatriya and Blake, 1988; Lavigne et al., 1990; Corkeron and Connor, 1999), any general depression of high latitude production and any poleward shift of feeding grounds, could place excessive energetic costs on migrating whales. Nevertheless, baleens have considerable flexibility. Some females may actually reproduce short of traditional breeding grounds and non-breeding females may skip migration altogether (Craig and Herman, 1997).

CONCLUSIONS

The IWC scoping group on habitats degradation developed a framework for assessing the significance of habitat degradation, by integrating empirical studies and modeling to provide a comprehensive picture of degradation of habitats (Simmonds et al., 2001).

This framework has been explicitly used in a some cases (Taylor, 2002a,b and Pollution 2000+ program). Concerted application and further development of the framework is recommended.

The study of cetacean habitat degradation cannot readily employ manipulative experiments. Correlative studies such as that of Wilson et al., (1999) are likely to remain the mainstay of research into cetacean habitat degradation.

The design of such studies, to ensure sufficient power to detect potentially subtle correlations, while also eliminating confoundment among potential factors, is of critical concern.

Population models can also assist in identifying habitat impacts of greatest concern, and focus research into more fruitful areas.

The framework must also be developed further to take into account the shifts and changes in habitat expected from climate change.

The investigation of climate change impacts remains a largely theoretical exercise. However paleoclimate studies and studies of climate anomalies are important empirical analogues for present and future climate change. Considerable progress is occurring on all three fronts: model refinements to improve realism, studies of biological impacts of climate anomalies and reconstructions of past climates. Study of ‘anomalies’ is critical to our ability to separate cyclic behaviour from secular trends of climate change.

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