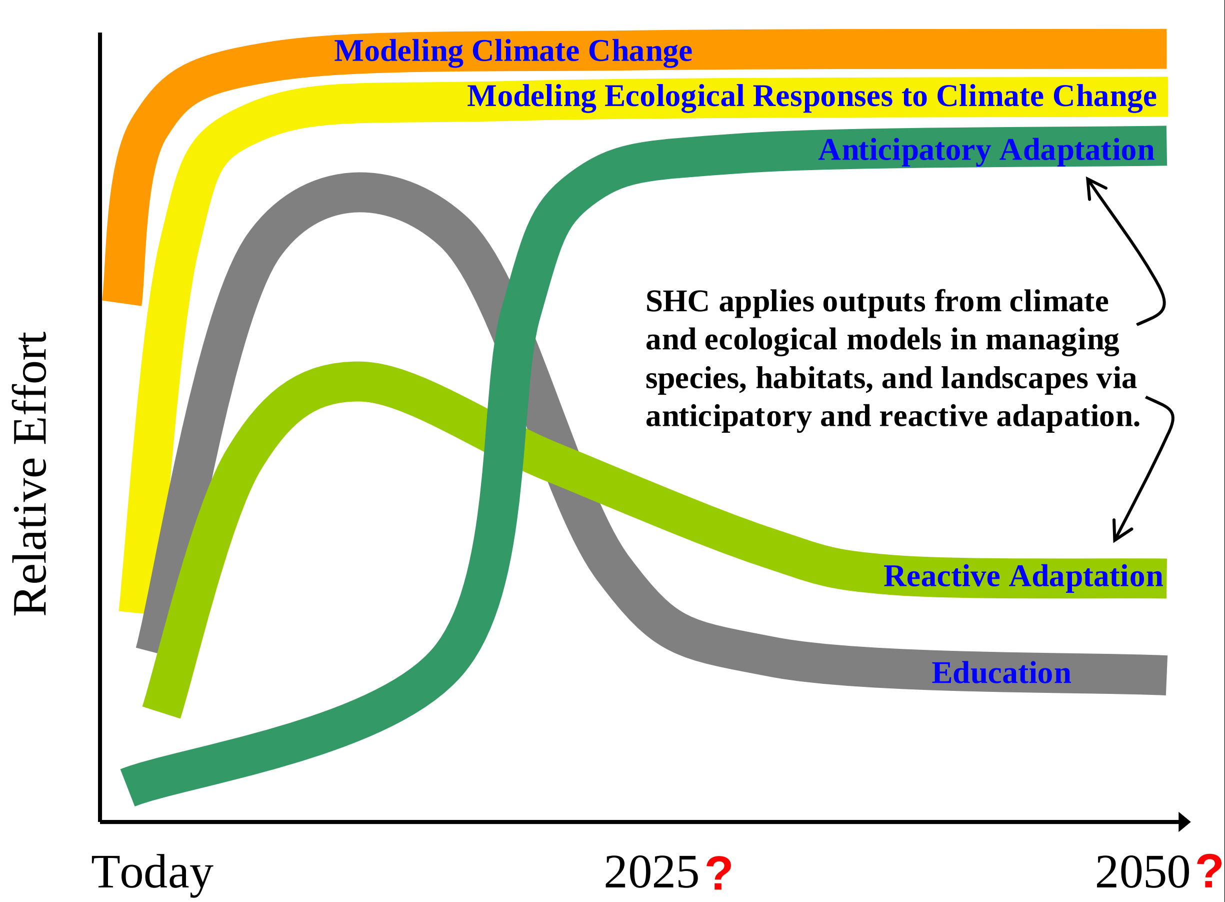
Climate Change and Adaptive Management: the intersection of dynamic natural and anthropogenic processes with the practical needs of conservation management.

A landscape perspective will become an essential part of addressing the effects of global warming on populations, species, habitats, and landscapes and the ecosystem services that they provide. SHC is perhaps the best way to actively and directly address the effects of climate change as these effects become apparent on the landscape and in habitats. Possible time lines for five features that should be considered in a SHC-Climate Change Strategy are presented in Figure 1 and discussed below.

Figure 1: SHC and Climate Change Strategy



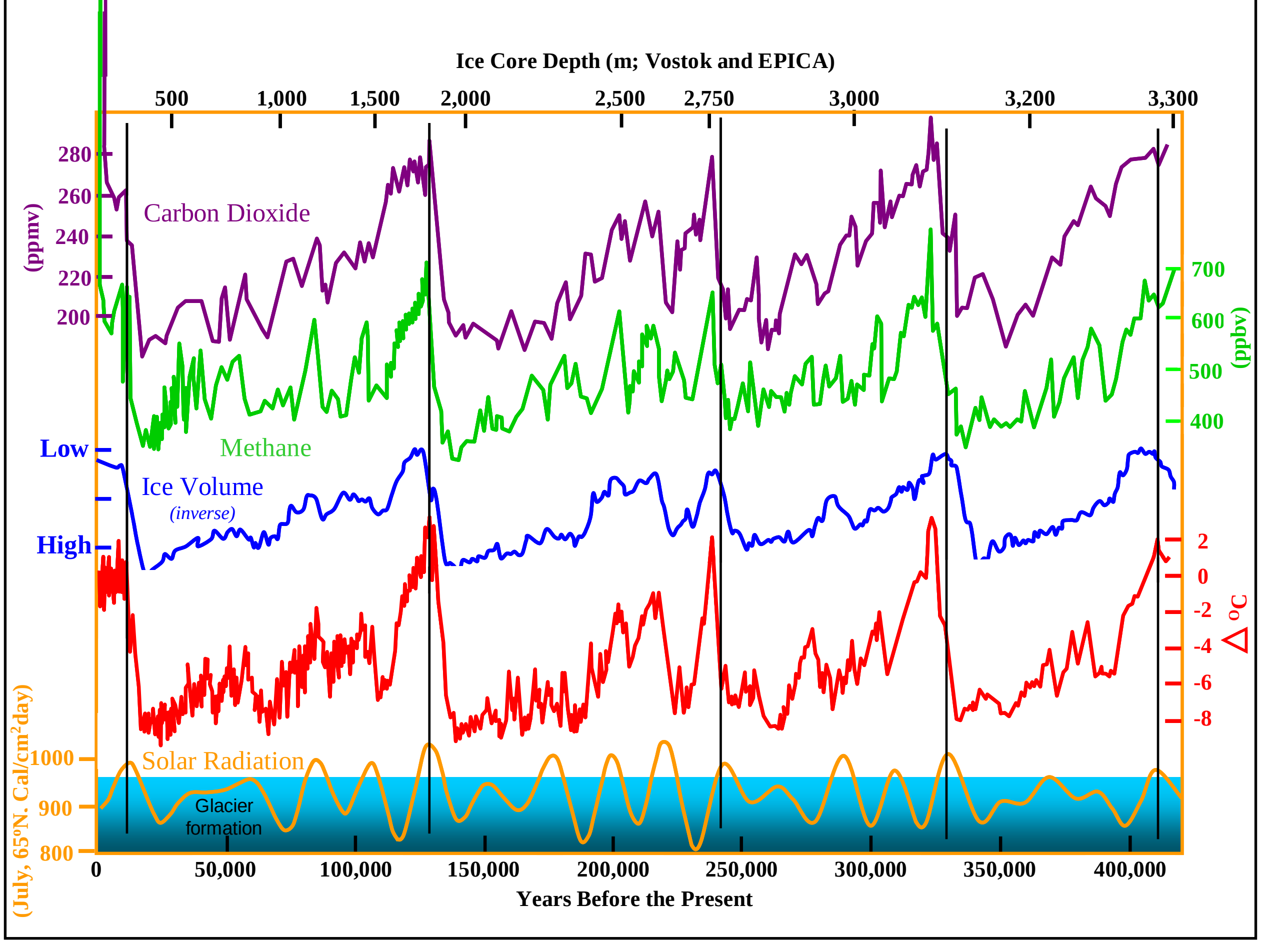
1. Education

Educate individuals, groups, local, national, and world leaders on the coming effects of Global Warming and the urgent action needed to minimize these effects -- **Namely, *reduce greenhouse gases to very low levels within 10 to 15 years***. Note: The Education curve in Figure 3 declines to a low level only when climate change becomes unavoidably apparent to the general public.

- The necessity for the reduction of greenhouse gasses is apparent in Figure 2.

- These two most important anthropogenic greenhouse gasses are carbon dioxide (CO^2) and methane(CH^4).
  - Carbon dioxide is 400 times more common in the pre-industrial atmosphere and has an atmospheric residency time of several thousand years.
  - Methane occurs at much lower level that CO^2, but it is 22 times more effective as a greenhouse gas. It has an atmospheric residency time of only 12 or so years, but has a very large potential for increase due to:
    - Melting of tundra and permafrost, which will release a large amount of CH^4 from decaying vegetation.
    - Potential release of methane hydrate (methane ; methane ice) from deep continental shelf ocean areas, although this seems less likely to occur in the near future.

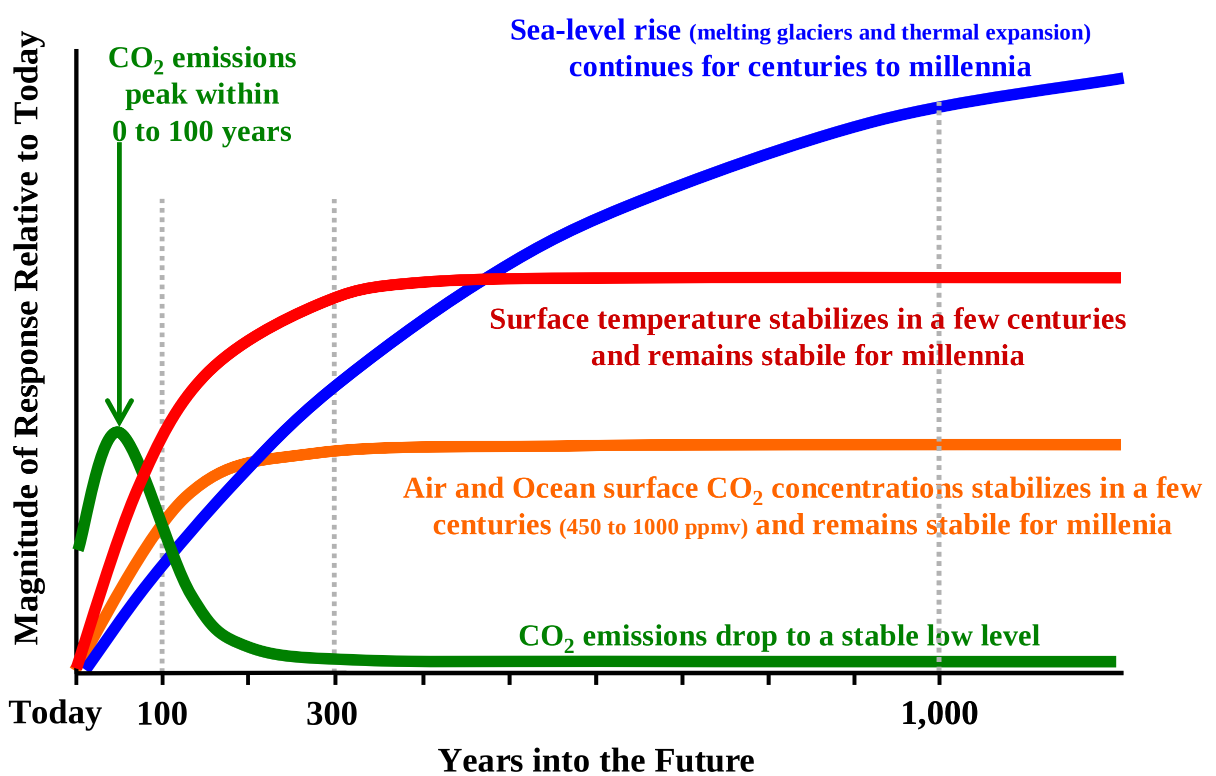
Figure 2. Past and Present Greenhouse Gasses



- In the past 400,000 years, maximum natural concentrations carbon dioxide and methane were almost half as much as the current levels (Figure 2). These two most important anthropogenic greenhouse gasses account for 86% of the global warming (radiative forcing) caused by human activity (IPCC 2007).

  - At the last glacial maximum the concentration of CO^2 was 265 ppm and methane was 680 ppb (Monnin *et al.*, 2001). At the start of the industrial revolution (1860), these levels were 280 ppm and 700 ppb, respectively.
  - The current level of CO^2 is 385 ppm and methane is 1,780 ppb; a 45% and a 65% increase over levels obtained during the last glacial maximum.
  - Currently, concentrations of CO_2 and CH_4 in the atmosphere continue to rise and there is no current significant effort to curtail their increases.
- Success in bring about a reduction in greenhouse gasses will greatly affect the nature of conservation, and therefore the nature of FWS activities, for several hundred years.
- This long-term effect on FWS activities follows directly from the manner in which anthropogenic greenhouse gasses affect the magnitude and duration of the climate change (IPCC 2001, 2007).
  - Atmospheric and ocean surface CO_2 concentrations and land and ocean surface temperatures will continue to rise for several hundred years (Figure 3).
  - Atmospheric and surface ocean CO_2 concentrations and land and ocean surface temperatures and they will remain at high levels long after greenhouse gas emissions are stabilized at very low levels.
- Reduction of greenhouse gasses can <u>only</u> significantly affect the maximum extent of the rise in temperature – will it get a little hotter or a lot hotter (IPCC 2001, 2007).
- The <u>duration of the effects of global warming</u> is a result of climate processes currently beyond the control or influence of human actions. For conservation, and the activities of FWS, this is a permanent change of state (IPCC 2001, 2007).

Figure 3. Anticipated duration of the effects of Global Warming (IPCC 2001)



2. Modeling Climate Change

   Note: the curve will likely remain high for the foreseeable future but should become more predictive as climate-model variances are reduced (Hartman *et al*, 2003).

- Give high priority to climate modeling focused at ecologically useful scales (regional or finer scale);
- Develop one or more regional models that best represent all aspects of regional climate;
- Develop a set of secondary models that address specific features such as hydrology, or specific landscapes.
- Agree upon standards for interpreting model outputs to assure consistency in their application to management and policy decisions.

3. Modeling Landscape, Habitat, and Species Responses to Climate Change

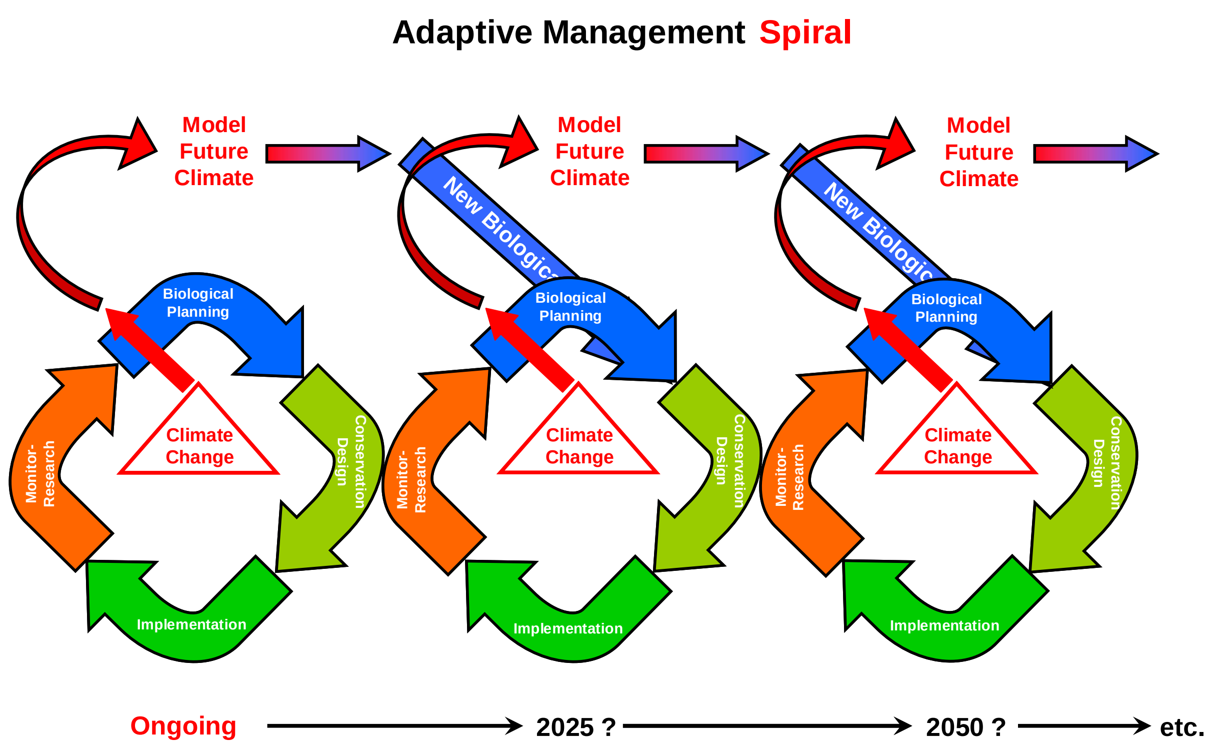
   Note: as with the climate modeling curve, the life-zone/bio-climate modeling curve will likely remain high for the foreseeable future but predictive information from these models should become more reliable in the future.

- These eco-climate models should evaluate likely ecological changes that will occur over time, under different climate-change scenarios.
- Give high priority to modeling the effects of climate change on life zones, bio-climates, species, habitats, food webs, ecosystems or landscape processes. As climate change progresses, changes in spatially explicit vegetation classification will be reflected in landscape metrics:
  - The distribution or area of current land-cover classes, patches, and habitats may shift.
    - Some land-cover classes better adapted to the new climate regime may increase in absolute and/or relative representation.
    - Some current land-cover classes and patches may decrease in size or be lost from the landscape.
  - New land-cover classes, patches, and habitats may appear on the target landscape.
    - Existing land-cover classes not currently represented in the landscape may appear on the landscape.
    - Entirely new land-cover classes may need to be defined for a given landscape.
  - Changes in land-cover classes, patches, and habitats will likely be paralleled by changes in the abundance and distribution of species associated with these land-cover classes, patches, and habitats.
    - Species currently on the landscape may decline in abundance and/or distribution, or be extirpated from the landscape.
    - Other species may adapt to the new climate regime and may increase in abundance and distribution. Some of these will likely be invasive species that will require management. Whereas in the past, invasive species have often been limited to habitat-scale effects, invasive species may become major landscape-scale indicators of climate change.

    - In some cases, SHC^{P} may become untenable for the selected focal species as climate change extirpates local and regional populations.
- Map these effects at multiple scales:
    - Ecoregional land cover or ecosystems (*e.g.*, Bailey's ecoregions);
    - Landscape: patches and corridors; biodiversity
    - Species' habitats – bioclimate envelopes
    - Populations – species ranges
- To guide policy and management decisions, use the models to identify critical points of transition (tipping points), along with levels of confidence in the model outputs.
    - Use the evaluations in choosing future conservation targets (focal species, habitats, landscapes, etc.).
    - Use the evaluations in deciding when to scale back (or stop) ongoing conservation actions for existing targets.
    - Use the evaluations in deciding when to shift conservation actions for existing targets from on-the-ground (viable in the field) to in-the-zoo (no longer viable in the field).

The potential for persistence and/or representation of conservation targets in the field will likely be affected by climate change. The Adaptive Management Cycle assumes a normal capacity for species to adapt to normal climate variability. Climate change will change the Adaptive Management Cycle to an Adaptive Management Spiral, as shown in Figure 4. Periodic, timely assessments of climate impacts will be needed in management is to keep pace with the future needs of conservation targets. An initial response (Reactive Adaptation) and a longer term response (Anticipatory Adaptation) need to be developed to address the continuing changes imposed on conservation target by global warming.

Figure 4: Adaptive Management and Climate Change



4. Reactive Adaptation

   Note: The Reactive Adaptation curve eventually declines as climate change overwhelms the ecological requirements of the conservation target. Reactive Adaptation does not mean maintaining conservation targets by attempting to resist long-term climate change or sea level rise, which would be futile.

   Reactive adaptation will, at first, strive to maintain conservation targets at currently managed sites, and subsequently, strive to maintain representation within the current know range of the conservation target (=managing for resilience). This should continue until ecological models of the effects of climate change indicate the potential for successful conservation has been reduced to a critical level where the conservation target is unlikely to persist into the future.

   - Increasing the spatial redundancy of the conservation target may enhance persistence, but the effects of climate change on the ecological requirements of the conservation target will ultimately determine the capacity for long term persistence within the historic range.
   - Reactive Adaptation should focus on managing critical ecosystem processes (e.g., water flow, fire frequency, sediment transport; etc.) as well as habitats and populations.
   - If the effects of climate change on the ecological requirements of the conservation target are low, reactive adaptation may be able to maintain the conservation target indefinitely.
   - When extreme conditions threaten to extirpate resident species, Reactive Adaptation should serve to provide source populations for translocation or captive breeding.

5. Anticipatory Adaptation

   Note: The Anticipatory Adaptation curve rises with improved modeling of climate change and its effects on future ecological conditions. The need to fully develop the field of Transition Ecology will increase as climate change increases the need for geospatial translocation of conservation targets.

   Anticipatory adaptation evaluates the potential effects of climate change on the conservation target and design conservation actions accordingly. Persistence of the conservation target will depend on the extent to which its ecological requirements are effected by climate change.

   - Identify and enhance areas that may be suitable habitat in the future (based on climate and species models);
   - Expand expertise and knowledge in transition ecology (= study and application of all ecological features that assist species in tracking suitable habitats across landscapes and maintaining themselves within changing species assemblages);
   - Using modeled transition points and field data, move species and manage habitats in “new” landscapes.
     - If the effects of climate change on the ecological requirements of the conservation target are moderate, then range shifts and assisted migration may be able to maintain long-term representation at new field sites outside of the historic range.

- If the effects of climate change on the ecological requirements of the conservation target are high, the conservation target may not be able to persist into the future.
- Anticipatory adaptation needs to become an explicit goal of conservation within FWS, especially with regard to:
  - The long-term value and purpose of existing conservation areas and the establishment of new conservation areas.
  - The long-term potential for conservation of current conservation targets.
  - The identification of future conservation targets.
  - Long term planning for future conservation policy and direction.

The Importance of Landscapes and Connectivity to Climate Change.

Landscape ecology and species' biology will likely dictate the urgency of transitional management. With regard to climate change, perhaps the single most important landscape feature is connectivity among patches and habitats. Connectivity affects the ability of species to successfully disperse across the landscape, thereby tracking changes in the distribution and quality of their habitats. Assisted colonization (or assisted migration) is needed when species can no long adjust their dispersal to effectively track changes in habitat. The anticipated rate of climate change may require a good deal more that simply assisting species in dispersal to new habitats. Where the effects of climate change overwhelm the abilities of species to move or disperse to more suitable geographic areas, entire habitats may need to be established in new location to accommodate the species of concern. This is much more complex that assisted colonization and is best referred to as Transition Ecology – the application of landscape and ecosystem ecology to the creation of suitable habitat for focal species.

Transition Ecology - need to develop commentary

Effects of climate change on marine ecosystems

Climate change will affect marine organisms in two ways: thermal stress due to rising sea surface temperature, and increased ocean acidification due to the absorption of CO_2 by ocean surface water.

- Marine Protected Areas (MPAs) may initially provide enhance resistance and resilience to coral bleaching due to thermal stress. Local environmental factors that are predictors of resistance and resilience to coral bleaching have partly been indentified but need field and laboratory verification. These predictors may help indentify source areas that will provide larval dispersal to surrounding sink or less suitable areas. Source areas should be designated as MPAs that are necessary for sustaining coral reef communities over the next 100 years. Longer term responses of coral reef communities will greatly depend on future sea surface temperature increases.

- Some coral species may have some resilience to the effects of short term increases in sea surface temperature (West and Salm 2003). However, resistance to long term (hundreds to several thousand years) elevated sea surface temperature has not been evaluated. More northern and southern geographic areas that are currently marginal or uninhabitable for coral reef communities may in the future attain more suitable sea surface temperatures for corals; these areas may serve as future marine refugia.

- Ocean acidification is a more pervasive and potentially debilitation consequence of global warming. Marine organism that rely on calcium carbonate skeletal structures (e.g., corals, snails, dinoflagellates, etc.)

Literature

Hartman, D.L., A K. Betts, G.B. Bonan, L.E. Branscome, A.J. Busalacchi, Jr., A. Lynch, S. Manabe, D.G. Martinson, R. Najjar, E.M. Rasmusson, A.R. Ravishankara, D.R. Sarewitz, D.J. Seidel, G.L. Stephens, L.D. Talley, J.M. Wallace, A.J. Weaver, S.C. Wofsy, and E.F. Wood. 2003. Understanding Climate Change Feedbacks. National Research Council, National Academy of Science. 166 pages.

Lindenmayer et al. 2008, A checklist for ecological management of landscapes for conservation. Ecological Letters 11:78-91.

Monnin, E., A. Indermühle, A.Dällenbach, J. Flückiger, B. Stauffer, T. Stocker, D. Raynaud, J.-M. Barnola. 2001. Atmospheric CO2 Concentrations over the Last Glacial Termination. Science Vol. 291: 112-114.