ALPINE ECOSYSTEM RESPONSES TO RISING TEMPERATURE AND ATMOSPHERIC CO$_2$
A number of people are concerned that Earth's temperature will rise so high and so fast in response to CO₂-induced global warming that many alpine plant and animal species will soon be mere memories, because of the assumption that after being forced to migrate to the tops of the mountains upon which they now reside at lower levels, there will be nowhere else for them to go in a vertical direction but to the sorry state of extinction.

Such has long been the siren call of James Hansen, former Director of NASA's Goddard Institute for Space Studies, who in testimony given to the Select Committee of Energy Independence and Global Warming of the United States House of Representatives in 2008, declared -- in no uncertain terms -- that “climate is nearing dangerous tipping points," that if CO₂ emissions follow a business-as-usual scenario, "alpine species will be pushed off the planet," and that "we have used up all slack in the schedule for actions needed to defuse the global warming time bomb," adding that his conclusions "have a certainty exceeding 99 percent."

But is this really so? Are rising temperatures and atmospheric CO₂ concentrations driving alpine species toward extinction? In a word, no; as shown in the paragraphs below, multiple studies refute Hansen's extinction claims, revealing in many instances that just the opposite is occurring among alpine species.

Most of the research on this topic has been conducted using one of the following four investigative methods: (1) model-based analyses, (2) laboratory or field CO₂ enrichment studies, (3) laboratory or field temperature studies, or (4) field studies documenting the historic effects of one or both of these parameters on alpine plants and/or animals. With respect to the first of these methods, Riedo et al. (2001) examined the consequences of simultaneous increases in surface air temperature and atmospheric CO₂ concentration for a Swiss Alps pasture via a simulation model forced by a stochastic weather generator. They found that a 2°C temperature rise increased ecosystem evapotranspiration, but that a doubling the air's CO₂ content reduced this impact while simultaneously enhancing ecosystem net primary production. The net result of the two environmental changes was a rise in ecosystem water-use efficiency and a 10% increase in soil carbon content, which projections run contrary to the alpine extinction hypothesis.

In another model-based study also focusing on the Swiss Alps, Rammig et al. (2010) acknowledged that "alpine shrub- and grasslands are shaped by extreme climatic conditions such as a long-lasting snow cover and a short vegetation period," adding that "such ecosystems are

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2 http://www.co2science.org/articles/V13/N35/B3.php
expected to be highly sensitive to global environmental change." In a unique experiment, which they described as "the first quantitative and spatially explicit estimates of climate change impacts on future growing season length and the respective productivity of alpine plant communities in the Swiss Alps," Rammig et al. monitored climatic conditions and plant growth for nearly a decade at seventeen "snow meteorological stations" in different alpine regions throughout the mountainous parts of Switzerland. Such efforts revealed "highly significant correlations between mean air temperature in May/June and snow melt out, onset of plant growth, and plant height." And using these correlations to project plant growth under future climatic conditions based on the gridded output of a set of regional climate models, they determined that (1) "melt out and onset of growth were projected to occur on average seventeen days earlier by the end of the century than in the control period from 1971-2000," and that in response to these changes (2) "plant height and biomass production were expected to increase by 77% and 45%, respectively," while in some cases, they report that (3) "projections of biomass production over a season resulted in changes of up to two-fold." Thus, future warming -- if it occurs -- will likely benefit lands at the margins, where low temperatures, snow-cover and permafrost have typically limited their ability to grow to their full potential.

Investigating the extinction hypothesis in a CO₂ enrichment study, Schappi and Korner (1997)³ observed increases in the carbon/nitrogen ratios of the growing leaves of four different species of alpine plants, but no changes in the chemical composition of their leaves by the time they naturally senesced and fell to the ground. Hirschel et al. (1997)⁴ likewise found no compositional differences in the naturally-senesced leaf litter of an alpine grassland; but they observed that litter from high alpine sedges produced under elevated concentrations of atmospheric CO₂ decomposed significantly slower than litter from similar plants produced under ambient conditions. Both of these phenomena tend to enhance soil carbon sequestration; and the finding of Arnone (1999)⁵ -- that the symbiotic nitrogen-fixing Trifolium alpinum was not stimulated in any way by atmospheric CO₂ enrichment -- does not alter this conclusion.

Price and Waser (2000)⁶ examined the topic in a temperature-based study. Prefacing their work, they note that ecosystems at high elevations "may be especially sensitive to global warming, because productivity is limited to a snow-free growing season, and warming is expected to cause earlier snowmelt." To explore this widely-held assumption, they designed an experiment in which they suspended electric heaters above half of ten replicate plots on the slope of a small glacial

³ http://www.co2science.org/articles/V2/N22/C5.php
⁴ http://www.co2science.org/articles/V2/N22/C3.php
⁵ http://www.co2science.org/articles/V2/N19/B2.php
Contrary to expectations, the experimental warming did not extend the duration of plant reproduction, nor did it change the composition of the ecosystem. Price and Waser report, for example, that the warming "did not induce shifts in abundance of short-lived species, graminoids, forbs, shrubs, or in total vegetation cover." Neither did it affect species richness or species distributions along the elevation gradient of the moraine. In fact, they could not identify a single negative consequence of the additional warmth.

In another study, Kudernatsch et al. (2008)7 carried out a warming experiment on species-rich Carex sempervirens (CS) and species-poor Carex firma (CF) calcareous grasslands in the Berchtesgaden National Park of Southeast Germany by installing several open-top chambers on them in each of three successive years just after snowmelt was complete in the spring and by removing them just before snowfall commenced in the autumn, which operation led to snow-free-season increases in mean daily air temperature 0.7°C in the CS grasslands and 1.4°C in the CF grasslands, along with corresponding mean daily soil temperature increases of 0.2 and 0.8°C. In doing so, the team of researchers report that "growth and/or reproduction of 12 of the 14 studied species were significantly stimulated by warming," that "only two species showed no response," and that "none of the species experienced decreases in growth or reproduction." They also found that dwarf shrubs and graminoids showed stronger responses than herbaceous perennials, and that "a significant effect of warming on nutrient availability could not be detected," leading them to conclude that "the observed response of vegetation is therefore mainly caused by direct and not by indirect temperature effects."

Commenting on their findings, Kudernatsch et al. stated they found what most other studies of warming effects on alpine plants have found -- "positive effects on growth and reproduction of the species" -- in support of which statement they cited eleven different scientific papers, additionally noting that "the non-appearance of an effect or even a negative response is rather an exception." Hence, they wrote that "obviously -- as in our study -- a large number of alpine plant species benefit from temperature enhancement," so much so, in fact, that they were able to report that increases in species richness in high-mountain ecosystems have been documented for the Alps as well as for Scandinavia, citing five additional scientific papers in support of this statement.

Perhaps the most common method of evaluating the extinction hypothesis, however, is to examine the response of alpine species to historic changes in temperature and CO₂ out in the real world. And many scientists have done just that, especially for the period of time covering the past

century, when temperatures and atmospheric CO₂ concentrations rose to levels described by some as unprecedented in at least the past millennia or more.

In one such study that covers a temporal view of the subject that is much longer than most, DeChaine and Martin (2005)⁸ "inferred the phylogeography of the alpine butterfly Colias meadii Edwards (Pieridae) and compared its genetic structure with that of another high elevation, co-distributed butterfly, Parnassius smithei Doubleday (Papilionidae), to test if the two Rocky Mountain butterflies responded similarly to the palaeoclimatic cycles of the Quaternary," i.e., to the recurring cycles of glacial and interglacial climates, in the hope of "establishing a baseline for predicting the effects of future climate change." Their research showed, among several other things, that the two butterfly species "experienced similar cycles of expansion and contraction," suggesting that "populations persisted across the geographic range throughout the climate cycles, experiencing isolation on 'sky islands' during interglacial periods and becoming connected as they migrated down-slope during cool, wet climates." 

In discussing their findings, the authors state "inferences from our study suggest that the general response of alpine taxa in the Rocky Mountains to palaeoclimatic oscillations of the Quaternary fits an expanding-contracting archipelago model," whereby "populations persisted across the latitudinal range of the Rockies throughout the climate cycles by expanding down-slope during glacial periods, and contracting upslope into a fragmented archipelago of sky islands during warm interglacials." This (or something very close to it) being the case, it may be inferred that all species currently inhabiting the Rocky Mountains are likely immune to the extinctions climate alarmists claim will occur in response to IPCC-predicted global warming; for all indigenous species found throughout the Rocky Mountains today had to have survived the high temperatures of all prior interglacials, the last four of which were more than 2°C warmer, in the mean, than the abnormally cool interglacial in which we currently live (Petit et al., 1999). 

Working in Montana, USA, Klasner and Fagre (2002)⁹ evaluated summer temperatures and spring snowpack over the period 1927-1991 in the McDonald Creek drainage basin of Glacier National Park. Despite periodic claims of impending warming-induced disaster in this region, the authors' data revealed no net change in spring snowpack from the beginning to the end of the record. Likewise, there was no net change in summer minimum temperature; and there was an actual drop of approximately 0.7°C in summer maximum temperature. Hence, as would be expected on the basis of these observations, there were no altitudinal changes in the location of the alpine treeline, although there was a 3.4% increase in the area of tree coverage from 1945 to 1991, perhaps partially in response to the historical rise in the air's CO₂ content over that period. 

Capers and Stone (2011)¹⁰ also chose trees as the subject of their analysis. Writing as background for their work, they state that "woody species are predicted to increase in tundra ecosystems as a result of global climate change (Chapin et al., 1996; Epstein et al., 2000)," and, in fact, it has been found that in response to rising air temperatures, "trees have established where they did not previously occur, both in alpine areas (Wardle and Coleman, 1992; Peterson, 1994; Kullman, 2001, 2002), and in arctic tundra (Lescop-Sinclair and Payette, 1995; Danby and Hik, 2007)," while

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⁸ http://www.co2science.org/articles/V9/N2/B2.php
¹⁰ http://www.co2science.org/articles/V15/N20/C3.php
"increasing shrub abundance also has been reported in alpine (Klanderud and Birks, 2003) and arctic locations (Sturm et al., 2001; Tape et al., 2006; Wilson and Nilsson, 2009)."

In an attempt to learn more about this phenomenon, Capers and Stone "studied a community in western Maine, comparing the frequency and abundance of alpine plants in 2009 with frequency and abundance recorded in 1976," while noting that "the 2009 survey was designed to provide a fair comparison with that of 1976," which was conducted and described by Stone (1980). In doing so, the two researchers found that the 2009 survey "provided evidence of the increasing importance of woody plants -- both trees and shrubs -- in the alpine community," commenting that "the most widespread tree species increased dramatically." In addition, they say they "recorded an increase in total species richness of the community with the addition of four lower montane species that had not been recorded previously." And in another important positive finding, they say they "found no evidence that species with high-arctic distributions had declined more than other species."

Capers and Stone say the changes they recorded "are consistent with those reported in tundra communities around the world." And although there is some concern that the observed increase in species richness could ultimately turn out to be temporary if alpine species were to disappear because of competition from the new species appearing on the scene, they state that "species losses resulting from competition have not typically been found with rising richness in high alpine areas, possibly because newly arriving species occupy different microhabitats," citing the work of Walther et al. (2005).

Another researcher who has long studied alpine regions is Leif Kullman, and he has published several research papers evaluating the extinction claims of Hansen and others. In a 2010 review,
Kullman (2010a) presented what he called "an integrative review of results from long-term monitoring of subalpine/alpine vegetation in the [mountainous] Swedish Scandes," from which he derived "tentative projections of landscape transformations in a potentially warmer future," which are based on "actual observations and paleoecological data (Kullman and Kjallgren, 2006; Kullman 2006)."

Among his list of findings, the professor of physical geography at Sweden's Umea University writes that post-Little Ice Age warming has, at long last, broken the back of "a multi-millennial trend of plant cover retrogression" and "floristic and faunal impoverishment, all imposed by progressive and deterministic neoglacial climate cooling," reporting that the "upper range margin rise of trees and low-altitude (boreal) plant species, expansion of alpine grasslands and dwarf-shrub heaths are the modal biotic adjustments during the past few decades, after a century of substantial climate warming." Currently, therefore, the situation was found to be one where "alpine plant life is proliferating, biodiversity is on the rise and the mountain world appears more productive and inviting than ever." And he made it very clear that "in contrast to model predictions, no single alpine plant species has become extinct, neither in Scandinavia nor in any other part of the world in response to climate warming over the past century," citing, in addition to his own studies, the work of Pauli et al. (2001, 2007), Theurillat and Guisan (2001), and Birks (2008).

With respect to how and why such warming-induced benefits occurred, Kullman writes that "many alpine species are extremely tolerant of high temperatures per se," citing Dahl (1998) and Birks (2008), as indicated "by their prospering and spread along roadsides far below the treeline, where emerging trees and shrubs are regularly mechanically exterminated (Kullman, 2006; Westerstrom, 2008)." And he notes that "another argument against the much-discussed option of pending mass-extinction of alpine species in a warmer future is that some alpine and arctic plant species contain a variety of ecotypes, pre-adapted to quite variable microclimatic and edaphic conditions, which could buffer against extinction in a possibly warmer future (Crawford, 2008)." In addition, he writes that this view is supported "by the fact that in the early Holocene, alpine plants survived, reproduced and spread in accordance with higher and more rapidly rising temperatures than those projected for the future by climate models (Oldfield, 2005; Birks, 2008)."

With respect to the value of the great and good ecological transformation that Kullman and others are documenting, he indicates that "extended ranges of many flowering species and

11 http://www.co2science.org/articles/V14/N10/B2.php
increasing plant species richness and habitat diversity imply a highly variable and aesthetically appealing mountain landscape, which should be positive from a nature conservation point of view (Jurasisinski and Kreyling, 2007)." In fact, he says that "such a course of landscape evolution adds to physical and ecological stability, functional efficiency, resilience and assures against 'system failure,'" citing McCann (2000), Korner (2002) and McLaren (2006).

Consequently, given all of the above, Kullman concludes that "continued modest warming over the present century will likely be beneficial to alpine biodiversity, geological stability, resilience, sustainable reindeer husbandry and aesthetic landscape qualities."

In another paper published that same year, Kullman (2010c) reports in the Nordic Journal of Botany the results he obtained from recent species inventories he conducted on the uppermost 20 meters of four high-mountain summits in the Swedish Scandes (Kullman 2007a,b), the results of which he compared with the findings of "historical species inventories from the early 1950s, executed by a highly competent and experienced botanist (Kilander, 1955)," which endeavor, in his words, "can be seen as an evaluation of a full-scale 'natural experiment' (cf. Grabherr et al., 2001)." In doing so, Kullman found that the species pools at the tops of the studied mountains have (1) "increased by 60-170% since the 1950s," that (2) "some of the invading species are new to the alpine tundra, with more silvine and thermophilic properties than the extant alpine flora," and (3) "not a single species of the original flora has disappeared from any of the summits." Given such findings, Kullman writes "the alpine flora appears to be more adaptive and responsive to climate change than generally believed," and that "overall, a richer, greener and more productive alpine world has emerged in the wake of the recent climate warming episode (Kullman, 2010a, 2010b)."

Three years later, Kullman (2014) prefaced his latest contribution to the subject by noting "many studies display upshifts of trees, shrubs and ground-cover species in supposed response to a widespread episode of rising temperatures since the late 20th century and culminating around the millennium shift," citing fourteen different publications; and he goes on to state that "a coupling of alpine floristic dynamics to climate variability would be more convincing, and the results more useful for dynamic modeling, if it were demonstrated that alpine plant species richness declined in response to decadal trends of climate cooling," while noting that as far as he knows, "no such study exists."

In an effort to fill this void, Kullman analyzed plant species richness on several alpine summits in the southern Swedish Scandes between 2004/2006 and 2012, which period, in his words, "experienced consistent summer and winter cooling and finalized with a cold and snow rich summer 2012." As a result of his efforts, the Swedish scientist discovered that (1) "plant species richness on high alpine summits decreased by 25-46% between 2004/2006 and 2012," that (2) "most of the lost species have their main distribution in subalpine forest and the low-alpine region," but that (3) they "advanced upslope and colonized the summit areas in response to warmer climate between the 1950s and early 2000s," that (4) "despite the reduction in species numbers, the summit floras are still richer than in the 1950s," and that (5) "substantial and consistent climate cooling (summer and winter) during a decade preceded the recent floristic

12 http://www.co2science.org/articles/V14/N11/EDIT.php
13 http://www.co2science.org/articles/V17/oct/a17.php
demise." Consequently, Kullman states his results "highlight a large capability of certain alpine plant species to track their ecological niches as climate fluctuates on annual to decadal scales."

Finally, Windmaisser and Reisch (2013) analyzed vegetation surveys from 99 non-permanent plots located in the southern part of the high valley of Hochmossferner, near Greitspitze (47°03'18"N, 11°11'48" E) in the Central Alps that were performed at approximate 2-year intervals between 1980 and 2012. Mean temperatures obtained from a location situated near the study site revealed an increase of approximately 1.2°C over this period, which led the pair of German botanists to postulate they would find "shifts in the cover of the grassland species and increasing species richness due to immigration of species from lower altitudes."

A total of 59 species were identified in the plot surveys, yet according to Windmaisser and Reisch neither plant species richness, evenness, nor diversity decreased or increased over the period of study such that they "observed almost no changes in the composition of the analyzed alpine grassland." With respect to the observed temperature increase since 1980, the authors add that any influence of this warming "could not be detected in [their vegetation survey] data set." As a result of their work, Windmaisser and Reisch state that their findings "amend the conclusion of previous studies (de Witte et al., 2012) that not only long-lived alpine plant species but also plant communities can persist in alpine ecosystems despite considerable climatic change." In other words, their work demonstrates that alpine flora have a much greater ability to adapt to rising temperatures than climate models generally project, which indicates that predictions of their widespread decline and extinction are highly unlikely and exaggerated.

Taken together, the several studies highlighted above demonstrate that in response to whatever environmental changes may be occurring in alpine ecosystems around the world, there appear to be few, if any, negative biological consequences. In fact, alpine species in many locations are responding in a positive manner to increasing temperature and atmospheric CO₂ concentrations. Such observations, therefore, reveal they are less likely, not more likely, to suffer warming-induced extinctions.

REFERENCES


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