# Global Climate Change and California Oaks

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For nearly 20 years, the authors have monitored, planted, and cared for native oaks (*Quercus agrifolia, Q. douglasii, and Q. lobata*) on more than a thousand semi-rural acres on the San Francisco Peninsula. By guarding oaks against unsustainable grazing, urban sprawl, and firewood cutting, and by suppressing competing exotic vegetation, we have conserved the habitat—and perhaps increased the vigor—of many thousands of trees. By planting and nurturing acorns and seedlings among populations that appeared to be failing to regenerate naturally, we have established more than 2,000 new saplings. Despite these gains, we are concerned that our actions may prove inadequate to our objective: self-sustaining oak populations on the land we steward. We perceive that ongoing anthropogenic global climate change is a challenge of a new genre, destined possibly to reverse our own and others' oak protection achievements to date, and perhaps even to inflict additional losses far greater than any previously endured.

We undertook a review of literature on global change and its implications for plants in general and oaks in particular. These studies ranged from assessments of known atmospheric changes, to probable effects on climate, to possible effects on California oaks, moving further into indeterminacy with each narrowing of focus. Thus, this paper is less an effort to predict in detail the consequences of climate change for California oaks than an argument that we already have sufficient information to warrant responding vigorously to this threat. To frame the issue, we begin with a summary of recent and projected human alterations to the gaseous composition of the atmosphere, and with an overview of appraisals of resultant effects on climate, and on ecosystem elements like soils and water. Next we review some of the literature examining possible impacts of sudden climate change on oaks and other biota. Then we discuss how we are adapting our own research, advocacy, and field work to the accumulating evidence of human-driven global climate change, noting obstacles that we have encountered and offering our thoughts about their underpinnings and ways to surmount them. Finally we suggest how people may husband oaks through what appears likely to be at least a difficult transitional period, and how we may reduce human threats to their longer-term well-being.

### Human Impacts on Atmospheric Composition & Climate

The gaseous composition of Earth's atmosphere was relatively stable from the end of the last ice age, about 10,000 years ago, until the 1800s. Over the past century or so, people have substantially altered this long-standing balance (Vitousek, 1994). By burning fossil fuels, clearing forests, increasing domesticated livestock populations, and processing industrial materials, we have added to the amounts of carbon dioxide, nitrous oxide, and methane in the air. In addition, we have released artificial chemicals heretofore absent from the ecosphere, such as chlorofluorocarbons (CFCs), which alter atmospheric composition both by their presence, and by their diminution of other components (e.g. stratospheric ozone) (Mitchell, 1989; Rowland, 1989).

These changes are already measurably affecting temperature, precipitation, insolation, and wind. The Intergovernmental Panel on Climate Change (IPCC) recently concluded that human disturbance of the atmosphere will likely cause global average temperatures to rise at an accelerating rate, producing overall warming of 0.9-3.5 degrees C by the end of the 21st century. During the last ice age, the Earth was only about 5 degrees C cooler than it is today (Goudie, 1992).

In California, because of maritime influences and variations in topography, local results of warming will vary. For example, a strengthened California current—one possible effect of overall warming—may yield increased fog with resultant cooling of the coast during summer. Alternatively, global warming may weaken the California current. Even if this occurs, higher overall temperatures may make coastal California cooler and wetter by inducing greater and more frequent inland movement of the marine layer (Knox, 1991, Botkin et al. 1991).

Warming is projected to increase precipitation globally by 10 percent, and may significantly alter its form, timing, intensity, and distribution (Knox, 1991). Seasonal shifts are possible, and wider fluctuations from norms are likely (Vaux, 1991). An overall increase in California precipitation is expected, but changes for particular locales fall in the range of ±20 percent (Vaux, 1991). More certain is that rain will replace snow over 100-150 m of elevation for each 1 degree C of warming (Gleick, 1987). By reducing upper atmosphere concentrations of ozone, humans have allowed more biologically damaging high-frequency UVb to reach Earth's surface (de Gruijl, 1994). In 1991, UVb within California was estimated to be 10-20 percent above levels of mid-20th century (Knox, 1991). UVb is generally thought to be increasing about 2 percent for each 1 percent decrease in ozone, suggesting that it may peak at 20-40 percent above historic levels (Madronich et al. 1994). At the same time, some researchers expect that warming will increase cloud cover locally and seasonally, reducing the duration and intensity of sunlight, and further altering the proportions of solar energy of various frequencies which reach the Earth's surface (Westman and Malanson, 1992).

As additional heat energy is absorbed by the atmosphere, storm winds may increase in strength and frequency. Though much uncertainty remains, meteorologists are accumulating evidence for such a trend. For example, in 1995, the United States had the most active Atlantic hurricane season since the 1930s (Flavin, 1996; Botkin et al. 1991). Many parts of

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California are already regularly subjected to powerful winds. If the California current is strengthened by global warming, onshore winds will probably increase. In addition, overall warming may shift storm tracks northward, subjecting California to greater risk from high velocity wind (Knox, 1991).

**Effects of Climate Change on Surface Features**

Stream and river flows, lake levels and flushing, ocean levels, aquifer recharge, wetland functioning, and soil depth, texture, and nutrient content are all dependent upon climate and are being affected by the changes underway (Vaux, 1991; Botkin, 1991).

Increased precipitation, especially where peak hourly or daily rainfall is higher than it had been, may result in flooding (Watson et al. 1996). Evidence from the geological record of the past 7,000 years shows that changes in mean annual global temperatures of only 1-2 degrees C and increases in mean annual precipitation of only 10-20 percent can bring frequent floods of a magnitude that previously occurred only once every 500 years (Knox, 1993).

With a 2-4 degree C warming, California snowlines are expected to rise by 200-600 m vertically, and the snowpack will probably melt earlier (Gleick, 1987; Vaux, 1991). If this occurs, runoff will increase during winter and early spring, and decrease during late spring and summer. These changes may bring more frequent and extensive winter and spring floods; and they may also lessen the summer and autumn availability of surface water. The amount of water stored in snowpack is projected to drop 33 percent statewide in an average year, with Sacramento Basin losses projected to be at least 40 percent, and San Joaquin Basin losses about 25 percent (Knox, 1991; Vaux, 1991).

One researcher suggests that a 4 degree C rise in temperature will increase evaporative losses from lakes, rivers, streams, and soils enough to reduce overall annual run-off in northern California by 10 percent, with summer reductions as high as 62 percent (Gleick, 1988).

Groundwater drawdown and recharge may well be markedly different as a result both of climate change and of human action to compensate for it, and overall drop of groundwater levels is likely (Vaux, 1991).

Sediment burdens may increase as heavier storms augment runoff, as soils previously subjected primarily to snow are scoured by rain, and as those once protected by vegetative cover are left bare by the death of heat- and drought-stressed plants. Accumulation of water-borne sediment in artificial reservoirs and natural lakes and estuaries may further exacerbate flooding during peak flows (Vaux, 1991; Botkin et al. 1991).

Oceans have risen 10-25 cm in this century as warming seawater has expanded and polar ice has melted. If warming continues as projected, cumulative worldwide mean increases in sea levels by the end of the 21st century are predicted by the IPCC to be about 50 cm, with much local variation (Houghton et al. 1996). In 1989, the National Research Council estimated sea level rises during the next 50 years along California shores on the order of 0.2-1 meter. Intrusion of brackish water into coastal aquifers and surface waters, particularly in the San Joaquin/Sacramento delta, and flooding of low-lying areas around San Francisco Bay and in the Central Valley are likely (Vaux, 1991).

Increased temperatures, greater evapotranspirative losses, more severe storms and runoff, increased flooding, and higher winds will probably accelerate weathering and erosion, and may significantly alter soil moisture, aeration, nutrient levels, organic content, and soil organism populations. Loss of plant cover may reinforce these trends, and soil depth may be altered in many places (Botkin et al. 1991).

### Impacts of Climate Change on California Oaks

As we have discussed alterations of atmospheric composition, climatological consequences, and impacts on soil and water, we have become progressively less certain of our predictions. In assessing how oaks will be affected by global climate change, we take a further step into indeterminacy. Researchers have widely differing views about the degrees to which oaks will expand beyond, persist in, or disappear from their current ranges. Though accumulating evidence will confirm some forecasts and strengthen our confidence in others, complexity of the ecosystem and limitations of our modeling ensure that much about impacts of anthropogenic global climate change on oaks will remain unknowable even after they occur. Our purpose here is to alert readers to possibilities of which many may have yet to become aware, and to stimulate consideration of costs and benefits of actions by which we may make various outcomes more or less likely.

Like all living things, oaks persist by maintaining a match between their internal information and the qualities of their environment. Raven and Axelrod (1978) assert that the pattern of Mediterranean climate characteristic of current California oak habitat—cool, wet winters and warm, dry summers—emerged in the Quaternary (1 my bp). California vegetation types with substantial oak components—including oak woodland, blue oak-gray pine woodland, inland prairie, and chaparral—are tightly coupled to both temperature and precipitation, and because the ecosystems in which California oaks grow are typically semi-arid, they may be particularly sensitive to warming (Watson et al. 1996). Human-induced global climate changes are now proceeding at a scale and speed that is unprecedented in oaks' history and will pose a challenge to their ability to adapt.

### Mechanisms for Climatic Impact on Oaks

Oak species differ in sensitivity to $CO_2$, temperature, water, light, soil, and presence or absence of other species. Their response to each of these may fluctuate with stages in their life cycles, and will vary also with limiting factors at boundaries of particular habitats. Climate change may affect reproductive success, vigor, and mortality at many ages (Botkin et al. 1991).

Higher $CO_2$ levels may accelerate growth and improve efficiency of water use during photosynthesis. This is potentially an advantage to oak species that are metabolically active during summer (Woodward, 1992).

Untimely or excessive heat, cold, rain, or drought may impede flower development, pollination, acorn numbers and viability, and seedling establishment. Warmth may stimulate growth, but excessive heat decreases it, and if prolonged or intense enough can be fatal. Low temperatures may suppress insects and other organisms which can damage or kill oaks, but they also limit growing season. Even short periods of extreme heat or cold during critical times may injure or kill. Because temperatures are expected to become more volatile, damage arising from unseasonable or extreme heat and cold will likely become more common.

Reductions in snowpack and late-season runoff may diminish availability of water during the warmest months with the longest days, and may also bring saltwater intrusion into low-

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lying areas. Both types of change might prove devastating to oaks (Lewis et al. 1991; Botkin et al. 1991).

Increases or decreases in cloudiness and in stratospheric transparency to UVb will alter light energy available, possibly affecting photosynthesis and evapotranspiration. Ultraviolet radiation can damage many important biologically active molecules, including DNA. Current and expected UV levels are beyond anything oaks and many of their symbionts have previously endured (de Gruijl, 1994). Already ozone depletion and resultant rise in UVb have been implicated in damage to populations as disparate as ocean corals (Vitousek, 1993) and human beings (de Gruijl, 1994).

Die-off of understory plants may result in disruption of beneficial symbioses, reduced percolation—further limiting water availability, and heating of exposed soils to levels fatal to oak seedlings and damaging to mature trees. Colonization by invasive species may pose added obstacles to regeneration. Woodward (1992) has observed an 8% increase in plant family diversity for every 10 degree C increase in minimum temperatures. Warming is likely to lead to at least temporary increases in biodiversity, with persistence of oaks and their historical symbionts in their current ranges depending upon successful competition with new challengers in unfamiliar conditions.

Stressed oaks and other species may become more vulnerable to pests of all kinds. Standing dead biomass may fuel more frequent, more prolonged, and hotter fires, which kill additional seedlings or even mature trees (Botkin et al. 1991).

On the slopes of the Sierra foothills and the coastal ranges, erosion from the combined effects of understory species lossing to drought, fire, and increasingly violent storms may accelerate decline in older trees and make reseeding and seedling survival in situ, as well as migration to other areas, less likely (Botkin et al. 1991).

Once the fabric of life is rent, a cascade of unforeseen—or even difficult to imagine—effects may ensue. For example, extensive loss of northern and temperate boreal forests during the next few decades may release tens of billions of tons of additional carbon into the atmosphere. Warming of tundra, with attendant decay of long-frozen organic detritus, may generate immense quantities of methane and $CO_2$ (Woodwell and Mackenzie, 1995). Both of these processes may further accelerate warming and intensify resulting impacts on oaks and oak habitat.

### Migration as an Adaptation to Climate Change

Obstacles to oaks' migration are many. Unsuitability of contiguous or proximate soils and slopes, momentum in existing plant communities, and competition by weedy species well-adapted to disturbance all pose challenges. Moreover, oaks themselves are in several important ways ill-equipped for rapid migration. They require several years to produce their first seed, and decades to reach reproductive maturity. Their seed production is modest by contrast to that of many plants, and often intermittent, and dispersal is limited by the sheer size of acorns (McBride and Mossadegh, 1990; Westman and Malanson, 1992; Woodward, 1992).

Although some may imagine oaks moving northward or upslope in response to warming, California's diverse physiography often bars such migration. For example, there are no geographic equivalents of the Salinas Valley or the Napa Valley anywhere between Santa Rosa and Washington State (Lewis et al. 1991). In addition, humans have fragmented oak populations and habitat, and have blocked many potential migration corridors with urban settlements and agricultural uses.

If warming stops within the limits of current projections, existing and potential future ranges of particular oak species may indeed overlap, and surviving populations may eventually be able to migrate into newly-available zones of favorable climate. Under transitional conditions, squirrels, jays, and other acorn-planting rodents and birds may increase their numbers, and become even more effective seed dispersers. In any event, oaks' genetic variability may afford them some advantage in competing (McBride and Mossadegh, 1990).

If warming continues beyond what is currently predicted, however, there may be no overlap between existing and future habitats. With each increment of distance, successful migration becomes less likely. Colonization of outlier patches is difficult in a landscape as topographically and geographically complex, and as thoroughly fragmented by humans, as California's.

Even where contiguous potential habitat allows for migration, we have posed an unprecedented challenge by the speed of the changes we have set in motion. During the last period of glacial retreat, sustained, globally-averaged warming of a few degrees occurred over thousands of years. We are projected to generate a shift of this magnitude in mere decades. With mid-latitude temperatures varying ~1degree C per 100 kilometers of north-south travel, a 2-4 degrees C warming corresponds to a 200-400 km poleward shift of thermal zones (Roberts, 1989). If such a warming occurs in a century, it will entail movement of kilometers each year, a rate which appears well beyond the capability of oaks, given the time they require to reach reproductive maturity, their seed dispersal ranges, and observed patterns of ecological succession.

Margaret Davis and Catherine Zabinski (1992) studied plant migration in response to warming at the end of the last ice age and concluded that individual species moved at different rates and even in different directions. Such migration can result in new, "no-analog" habitats depauperate in pollinators, dispersal agents, or other critical-link species (Schneider, 1997a).

## Observed and Predicted Effects

California oaks may already be waning as a result of climate change. In recent decades, blue oak (*Q. douglasii*), the dominant native low-elevation tree in the state, has been failing to regenerate. While researchers typically attribute blue oaks' decline to grazing, to increases in populations of rodents resulting from extirpation of their predators, or to inability to compete with non-native annual grasses for limited water, Lewis et al. (1992) note that "the only [blue] oaks standing today are those that germinated during periods of 2 or 3 consecutive wet years. The last such period occurred about 60 years ago. A drier environment caused by global warming could conceivably bring about the elimination of the blue oak in California." Others have noted local disappearance of valley oak, and conjecture that this might be attributable to falling water tables (Schoenherr, 1992). This may partially be a result of prolonged drought linked to increased climate volatility.

Regardless of whether climate-induced changes have begun, and of how great they will ultimately prove, initial effects will probably be subtle, and most evident at the margins. Increases and decreases in seed production and seedling survival may be early indicators of climatological impacts where populations of mature trees appear little changed (Davis and

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Zabinski, 1992). If late-season stream flows diminish as projected, riparian habitat edges may contract inward and downstream. Also, streamside habitat may narrow if higher-volume winter and early spring flows accelerate bank erosion, or if floods prove directly fatal, or deposit intolerable sediment over root zones or crowns. Where saltwater intrusion currently limits oak survival, as it may in low-lying areas adjoining San Francisco Bay, rising ocean levels and wind-borne salt spray may further restrict their range (Botkin et al. 1991).

Oaks may benefit from some aspects of climate change. Increased warmth, and in some areas greater precipitation, may enable them to become more securely established or to expand their range where lack of heat or water are now constraints. McBride and Mossadegh (1990) assessed responses of California oaks to climate change using models developed at the Goddard Institute for Space Studies (GISS), Geophysical Fluid Dynamics Laboratory (GFDL), and Oregon State University (OSU). They concluded that because greater precipitation will offset higher temperatures in northern California, and because more efficient use of water resulting from elevated $CO_2$ and existing adaptations to drought will enable oaks to persist in the San Joaquin drainage, "distributions of arboreal species of oaks will not be significantly impacted."

Research by others suggests that where oak populations are at the threshold of their tolerance for dry conditions, the hotter, drier climate which may accompany global warming over parts of California may eliminate them. When Westman & Malanson (1992) applied the GISS and GFDL models, they found that expected alterations in temperature and precipitation were likely to lead to expansion of chaparral at the expense of southern oak woodland and blue oak-gray pine woodland. Neilson (1993) asserts that under most models, greater evapotranspiration more than offsets benefits from increases in precipitation and water use efficiency. Woodward (1992) notes that because gases besides $CO_2$ contribute to global warming, actual $CO_2$ will only be about 1.5 times historical levels when temperatures reach the level predicted for "doubled $CO_2$," and that as a result, models of plant response to a doubling of $CO_2$ and studies performed at these concentrations underestimate moisture stress.

T. Webb (1986) has proposed that the ratio of plant taxa response time (the time it takes to respond significantly to a given climate change by changing local abundance and/or geographic range) to the rate of climate change is a guide in assessing the likelihood of successful adaptation. If the ratio is small (e.g. 200 years/20,000 years) dynamic equilibrium can prevail. If it is larger (e.g. 200 years/200 years) then disequilibrium may exist. Response times for tree taxa are yet to be determined conclusively, but minimums on the order of 50-200 years have been estimated. These are fast enough for tree taxa to stay in equilibria with most major past climate changes, but are similar in length to the predicted time scale for current human-mediated climate change, and imply disequilibria. (Westman and Malanson, 1992)

S. P. Hamburg and C. V. Cogbill (1988) describe an example of disequilibrium for conifers when they report that as growing season has lengthened over the last 180 years in mixed boreal conifer and deciduous broadleaved forest of the eastern U.S. Canopy dominance by conifers has been gradually decreasing, and red spruce (Picea rubens) has been virtually extinguished.

Joseph Knox, Director of the National Institute for Global Environmental Change at UC Davis, and editor of Global Climate Change and California, described his group's work as "plausible estimates ... which have been made as consistent as possible with the current consensus understanding of the greenhouse effect." He reported that, "The panel estimates that 20-50 percent of the area occupied by natural ecosystems will no longer be suitable for the communities that exist there now ..." and concluded bluntly that, "Diebacks ... and loss of species could well prevail ..." (Knox, 1991).

McBride and Mossadegh (1990) cited a study conducted a decade ago to predict the impacts of global climate change on oaks. This study by Woodman and Furiness (1988) evaluated the effects of potential climatic change on the major commercial conifer species in California, and concluded that the state was "unlikely to experience significant large-scale reductions ... in the next century." Yet four of the 10 largest California wildfires of the past 60 years occurred between 1987 and 1996 (California Department of Forestry and Fire Protection, 1997). Exceptional heat and drought, and insect infestation of stressed trees were factors in these fires. A link to global climate change remains unproven, yet we may fairly ask whether this threat was accurately assessed.

EPA researchers have warned that, "[G]reenhouse warming will spell doom for many forests across the United States. ... [Total forested area in the West could be dramatically reduced. ... [Some species would go locally extinct." Even where they deemed dominant trees possibly able to adapt, they characterized chances of survival for many understory plants as "disappearingly small" (Roberts, 1989).

Though there are many grounds to assert that oaks will survive the next century, there is mounting evidence that they will be sorely tested by human-generated climate change.

**Evolving Our Response to Global Climate Change**

Nearly 20 years ago the authors observed that California native oaks on Stanford University lands were dying without successors. We began planting acorns in hopes of contributing to more stable oak populations. Our results were disappointing, so we sought advice from Stanford and UC Berkeley faculty, and from UC Extension and California Division of Forestry staff. From them we learned that oaks in many parts of California were apparently failing to regenerate, and with their guidance, we began a series of trials. When Stanford planners retained a forester and a landscape architect to prepare a vegetation management plan with special emphasis upon oak preservation and regeneration, we were contracted to implement it.

Both our own early activities and the vegetation management plan were founded on an assumption that proper local resource management was sufficient for oak regeneration. Our tools were prohibition of tree-cutting and of downed wood removal, modified grazing regimes, a moratorium on additional road and building construction, rodent suppression and exclusion, limited vehicular access, eradication of exotics, planting of natives, fire management, and regulation of recreational use.

Despite these interventions, we noted continuing adverse change on lands we stewarded. Erosion seemed to be accelerating, with gullies and slumps proliferating. Fox and coyote became rarer. Rodent populations burgeoned. Stands of exotics like mustard became denser and more extensive. Most oaks produced few or no acorns, and seedling recruitment was far from sufficient to maintain existing populations.

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Observers elsewhere noted similar departures from past patterns. Fire devastated forests across the western United States. Species ranging from Monterey Bay snails (Barry, 1995) to Edith's checkerspot butterflies (Parmesan, 1994) disappeared from habitats where they had long flourished. Record heat, cold, rain, drought, winds, and floods struck around the globe (Flavin, 1996). Scientists in diverse disciplines published a growing number of papers suggesting that these and other ecosystem disruptions were human-driven, and that remedying any of them successfully was likely to require addressing all of them.

As we have become more aware of possible linkages between oaks and global phenomena, our attitudes and strategies have evolved. We are now far less confident that our tree planting and care will have lasting or significant direct impacts on the landscape. We have supplanted promises about "restoring" nature, with which we once motivated ourselves and others, with cautions against such hubris. We have tempered dreams of returning to admire our handiwork in forty or fifty years with questions about what more we will do if oaks are to persist.

When we introduce new volunteers and community audiences to our project, we increasingly emphasize oaks' dependence upon integrity of a global ecosystem, and we outline unprecedented ways in which humans are disturbing that system. What once was primarily an oak project is now much more a people project. Metaphorically, at least, we now see oaks growing as much in human hearts and minds as in any other medium. To create suitable "habitat" there, we are becoming more attentive to—and teaching others about—laws of nature, consequences of human choices, and necessity for deeply and persistently questioning what we want, how we can get it, and above all, how we arrive at our conclusions about these things.

Why are so many only slowly acknowledging and rising to the challenge of anthropogenic climate change, which scientists worldwide have identified as one of the greatest threats to our own and our descendants well-being? We offer a few ideas, aware that they are but a partial explanation. For centuries, Europeans and North Americans have led the way in using the leverage of fossil fuel burning to realize a vision of progress based upon accelerating conversion of nature to artifact. As we have gained the equivalent of slave labor in the form of fossil fuel energy—and capital plant and equipment converted from it—we have also transformed political economy from a consciously communal enterprise to one much more readily imagined to be individualistic, and we have coerced people around the world to follow suit. Now belief, law, and custom are everywhere increasingly uniform, and reflect centuries of apparent success in improving upon nature by manipulating it, and in defining self-interest narrowly.

To adapt successfully in both near and longer term, we will become more cautious about imagining that we can manipulate what lies around us to good effect, and we will more fully appreciate benefits of cooperating to secure our common future. Substantially lessening our impacts on climate entails gross reductions in fossil fuel burning, deforestation, CFC releases, and other activities which are central to many of our lives. To reverse current trends towards devil-take-the-hindmost and move instead towards greater civility, some will lead in accepting very evident personal costs of addressing climate change, even though we lack guarantee of future reward for ourselves or anyone else. Our success will depend at once upon reducing our own direct impacts on climate, and upon convincingly demonstrating the advantages of such action to others.

As "winners" in the current order, many of us want it to continue and are eager to believe that it can and will. Even people who recognize an end to recent trends to be inevitable, and who see benefit in that occurring sooner rather than later, face obstacles to voicing or acting upon such views. In governmental agencies, private enterprises, non-profit organizations, and informal groups, we encounter many who are determined to carry on with business as usual—implicitly or explicitly denying past failures to accurately foresee consequences of our acts. Jobs, pay, authority, promotion, publication, and their collateral rewards are withheld from those who suggest that we are accumulating a vast ecological debt that will burden us and our heirs far into the future. Yet multinational agreements; local, state, and national government policies; and corporate and nonprofit organization operations all reflect and depend upon individual choices for their success. Each of us can lead.

**Recommendations**

Long-term welfare of oaks depends to a great extent upon short-term success in developing and implementing resource management policies that protect existing and potential oak habitats and that conserve and regenerate oak populations. Recommendations which follow are intended to complement rather than replace such activities, by securing their benefits against loss due to climate disruption and similar phenomena.

Each of us can reconsider in light of evidence for global climate instability our ideas about what we want and how to obtain it. These are our values, from which we generate our lives. With the fruits of introspection and study, we may reshape our behaviors to better reflect limits of the possible and our preferences within them. Though we have been conditioned to view our professional roles as those in which we exercise greatest influence, important changes requisite to slow or halt climate disruption lie outside this realm. We can effect greater change by modeling these as well.

We may encourage others to reflect upon their own ends and means, and to adjust their behaviors to match emerging realities. We may bring discourse about climate change and its connection to human values into community and professional forums. We may lobby for adoption and rigorous enforcement of local, state, national, and international policies to lessen human impacts on climate in particular and ecosystem stability in general. Specific ends we might pursue include decreasing release of greenhouse gases, balancing carbon budgets, and enforcing a ban on CFCs and other particularly potent greenhouse chemicals (e.g. methyl bromide). To avoid replacing current maladaptive behaviors with others similarly destructive, we will also find more fundamental ways to redistribute responsibility and privilege, so that we encourage behavior conducive to ecosystem integrity. Among the most critical issues are: setting limits upon reproduction, narrowing disparities in distribution of wealth, and establishing comprehensive limits, both qualitative and quantitative, on human-mediated matter-energy conversion.

In our field work with oaks we may study existing habitat with an eye to which portions may prove enduring; assess potential future habitat; lay plans to establish and/or sustain oaks where they appear more likely to survive a century or more of instability; collect, store, and plant seed from oaks in many locales to preserve genetic diversity and to learn which trees may be better suited to emerging conditions; more fully map biotic interactions to

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gain a better understanding of symbiotic and parasitic relationships sensitive to climate shifts; and conserve water and increase local surface storage and percolation.

Readers may find these recommendations somehow unsatisfying. Issues raised here are complex, broad, and deeply embedded in a host of others, and determining how to resolve them in advantageous ways is an evolutionary process in which all of us are engaged. The era of illusion about "simple things we can do to save the Earth" is drawing to a close.

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