MBCA

morongo basin conservation association

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Subject: DRECP Alternative Scenarios of July 25, 2012, Docket No. 09-RENEW EO-01

Thank you for this opportunity to comment on the July 25th 2012 renewable energy development alternatives of the DRECP. Specifically we will comment on Alternatives 3 and 5, and urge you to consider a scenario that does not develop renewable energy in the high-desert, tourism based communities.

The Morongo Basin Conservation Association (MBCA) is a 501(c) 4, community-based, California Nonprofit Corporation, incorporated in 1969 and dedicated to preserving the economic and environmental welfare of the Morongo Basin. MBCA was formed by residents in 1969 to stop the building of an electrical transmission corridor through the center of the Morongo Basin that would have changed our wild desert character forever. Members fought for 11 years---and won!

Alternatives 3 and 5 contain more or less of the East of Big Bear Polygon 11(page 71), which is considered a high conflict area. On the Industry Proposals map (page 9) the area is labeled CalWEA Wind Boundary (phase 1) with 62,634 acres for the generation of 1,726 MW of wind energy. New lines of transmission will be required along Hwy 247.

AESTHETICS AND ECONOMY

ALTERNATIVE 3 AND 5, POLYGON 11, EAST OF BIG BEAR

The area includes parts of the Morongo Basin and BLM lands next to Joshua Tree National Park (JTNP) and in undeveloped backcountry surrounding the Big Morongo Canyon Preserve, Pioneertown Mountain Preserve, and Bighorn Mountain Wilderness. Nestled amongst these public lands and private conservancy preserves are high-desert small towns and communities whose residents have contributed their own funds over the years to purchase private lands for protection and gifted them to the National Park System and the BLM. They also contribute thousands of person hours toward clean up and restoration before gifting the land. They perform these environmental stewardship activities in their own self interest because it ensures their quality-of-life and the economic stability of the region. A University of Idaho study identified five reasons why 1.4 million people visit Joshua Tree National Park annually – the same reasons why people choose to live here.

Views without development	90%
Clean air	89%
Natural quiet, sounds of nature	87%
Desert Plants/wildflowers	82%
Native wildlife	81%

An analysis by Daniel Stynes, Ph.D. (professor emeritus of the Department of Community, Agriculture, Recreation & Resources at Michigan State University) measures visitor spending from visits to JTNP. He estimates that the surrounding region (30 mile radius) receives total direct spending effects of $48 million and secondary effects of $16 million, for a total effect of over $64 million. Destruction of the visual resources degrades the recreational experience -- a direct hit on the economy of the region.

A landscape industrialized for wind energy will substantially damage the scenic vistas of the preserved public and private lands. Highway 62 and 247 are the main arteries connecting these lands with the Joshua Tree Gateway Communities. Although not yet officially designated, these highways are eligible for State Scenic Highway status (CALTRANS) and designation efforts are currently underway by the Homestead Valley Community Association for Highway 247. Highway 247 is not an appropriate location for new transmission lines.

The industrialization of the ridgelines and slopes will also substantially damage the visual and biological resources which draw people to the area to recreate and live. The destruction would include hundreds of miles of graded dirt roads scarifying the currently pristine desert slopes. Every mile will be edged with skirts of debris spilling over and smothering the natural vegetation and critters. Besides the dust generated during construction and maintenance (area is currently out of PM10 compliance) weedy species, such as Sahara mustard and fountain grass, can take up residence on the disturbed soils. Add miles of turbines breaking the smooth contours of the ridgelines and you have an irretrievable loss of visual resources. The biological resources take an additional hit with predicted deaths of golden eagles, condor (there have been two good sightings in the Morongo Basin) and bats.

The industrialization also compromises personal investment by lowering the property values of the community residents, especially those living within 1-2km of turbines. Residents with health responses to the low frequency sound vibrations (including ultrasound), shadow flicker or strobing, or the electromagnetic pollution, will want to move. This can be a significant hardship when land values plummet. Who would buy a home in a location where the thrumming generated by the rotors causes sleep problems, headaches, dizziness, exhaustion, and tinnitus and the strobing can precipitate seizures? [1]The median household income for residents is only 68% of the state median and this loss of investment will cause economic hardship.

BIOLOGICAL RESOURCES- CONNECTIVITY

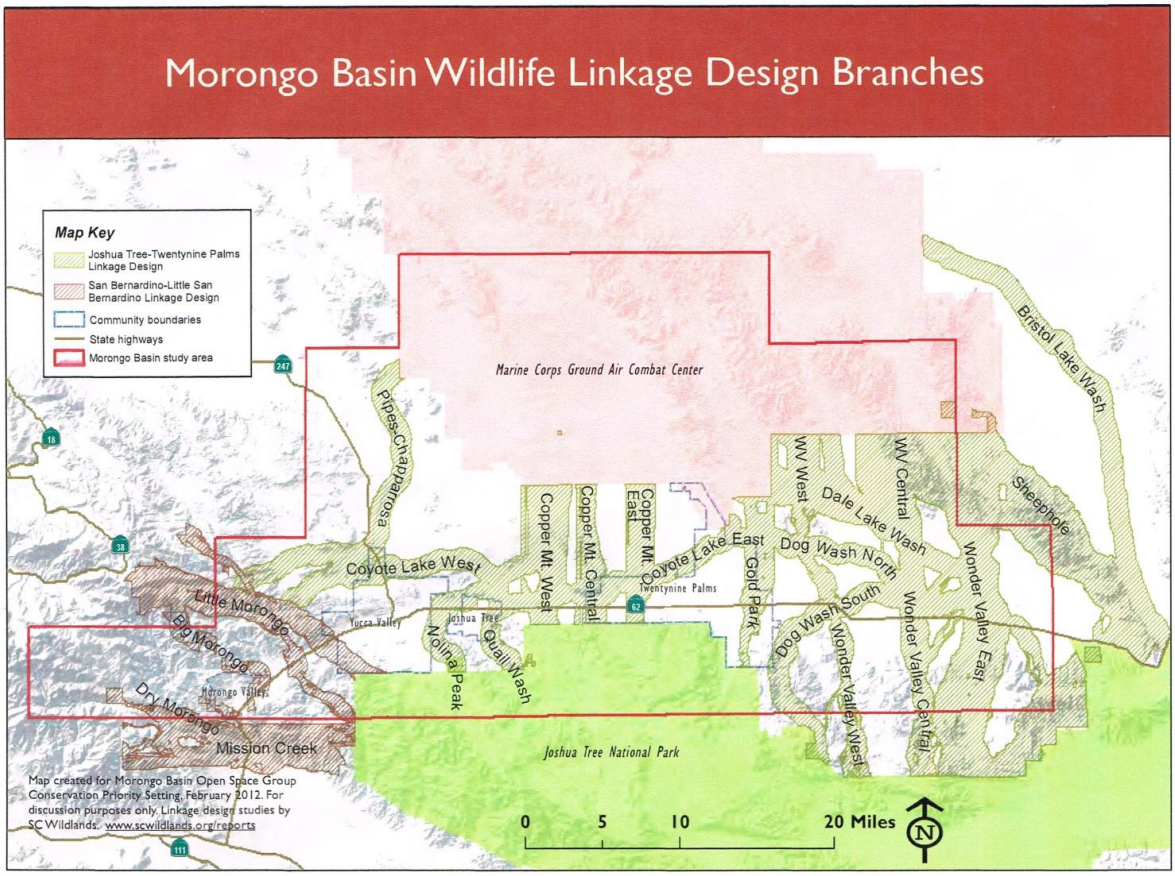
ALTERNATIVE 3 AND 5, POLYGON 11, EAST OF BIG BEAR

This area is within two Linkage Designs: The San Bernardino-Little San Bernardino (SB-LSB) and Joshua Tree-Twentynine Palms (JT-29P) Connections. Although Highway 62 is the abrupt dividing line between the San Bernardino and Little San Bernardino Mountain ranges, the gradient going from mountains to desert is more gradual. Both plant and animal species occupy a relatively broad ecotone considering topography, soil types, and weather. However, the DRECP Planning Area Boundary bisects the linkage designs from north to south (possibly at Hwy 62 – difficult to tell on the map). Under 'potential biological conflicts' (page 71) only the 21,587 acres of desert linkages is listed, leading to speculation that the mountain sections of the designs are not evaluated.

- Are both linkage design connections (see map) considered in their entirety; or, are only those parts of the connections within the desert areas (east of Hwy 62) considered? Is the SB-LSB Connection considered at all?
- The total number of modeled DRECP species for this polygon is 23. Are these species included in the 23 focal species of the SB-LSB and the 25 focal species for the JT-29P connections? The focal species were chosen based on the diversity of their movement needs and living requirements. Are these criteria factored into the DRECP modeled species?
- To conserve biodiversity between the three wildland blocks: San Bernardino Mountains, Joshua Tree National Park, and Twentynine Palms Newberry-Rodman ACEC, the two linkage designs must be maintained over time. How does the DRECP plan to achieve this?

[1] Wind Turbines – Wind Farms © Alasdair and Jean Phillips (attached)

- The multiplier for wind ranges from 3 to 5 times the actual ground area disturbance; i.e. 21,587 acres x 4 = 86,348 acres of disturbance. The nature of the disturbance – thousands of turbine pads with cleared areas and hundreds of miles of hillsides scarified by access roads – will fragment habitats across this topographically diverse landscape. Similar to industrial solar development, it is prudent to assume that it is unknown how this fragmentation will affect the biological values and linkage function across this large area. [2] Therefore, the loss of biological values and linkage function is unmitigatible.
- The SB-LSB and JT-29P were developed prior to *A Linkage Network for the California Desert* (LNCD). A feature of the LNCD is the addition of land facet corridors *to more likely serve species under novel climate conditions. These land facet corridors provide connectivity for land facets, which are the*



enduring features (topographic elements such as sunny lowland flats, or steep north-facing slopes) that will interact with future climate to support future biotic communities. (page 37*)* Conservation of the land facets is critical to preserving the connective value of the corridors in an uncertain climate future. However, land facets have not been mapped for the SB-LSB and JT-29P Connections. To properly evaluate the massive, highly fragmenting land disturbances caused by the construction of wind turbines over tens of thousands of acres, land facets for these connections should be mapped. [3]

ALTERNATIVE 5, POLYGON 27, NORTH 29 PALMS

This solar area is identified as a high conflict area (page 73) and you list 24,485 acres of desert linkage. This polygon is also included in the PEIS. We urge you to eliminate it from consideration because of its size (28,177 acres) and location. It completely blocks the land facets connecting the Mojave National Preserve-

[2] Lovich, Jeffery E. and Joshua R. Ennen. 2011. Wildlife Conservation and Solar Development in the Desert Southwest, United States. BioScience. Vol. 61 No. 12. Article attached

[3] Beier, Paul and Brian Brost. 2010. Use of Land Facets to Plan for Climate Change: Conserving the Arenas, Not the Actors. Conservation Biology. Contributed Paper. Article attached.

Twentynine Palms and Newberry Rodman landscape blocks. There is no similar connective landscape for mitigation.

WILDLAND FIRE HAZARD

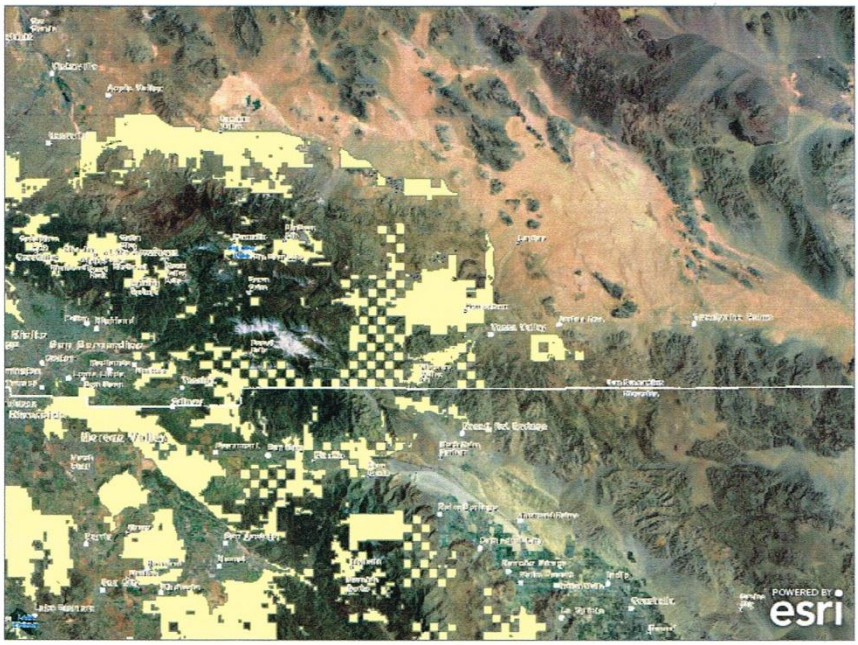
ALTERNATIVE 3 AND 5, POLYGON 11, EAST OF BIG BEAR

The DFAs within Scenarios 3 and 5 are within the CA State Responsibility Areas (SRA). Wildland fires in this area of windy narrow canyons exposes people and structures to a significant risk of loss, injury or death – even when defensible space practices are followed.

8/3/12 ArcGIS - Yellow areas = CA State Responsibility Areas (SRA) ~ No color = Non-SRA

Yellow areas = CA State Responsibility Areas (SRA) ~ No color = Non-SRA

CAL FIRE has a legal responsibility under PRC 4102 to provide fire protection on all State Responsibility Area lands (depicted in yellow on this map).



Source: Esri, i-cubed, USDA, USGS, AEX, GeoEye, Getmapping, Aerogrid, IGN, IGP, and the GIS User Community | Copyright:© 2012 Esri, DeLorme, NAVTEQ, TomTom

Although wind developers have recently claimed that clearance around turbines, coupled with improved technology, make prospects of fire slim, this is not borne out by incidents worldwide.[4] Just recently, two local turbine fires: one in the Tehachapi area (July 27, 2012) and another in the Whitewater area (June 17, 2012Riverside County) that became a 367 acre wildland fire, forcing the evacuation of homes, and required 100 fire fighters to put out, made the news. A search of the web for "turbine fires" shows a growing awareness of this danger worldwide. The turbines are a recognized liability. Fires, in areas of strong wind, where residents are intermixed with wildlands, are a serious risk.

From a summary of turbine accident data we learn that "fire is the second most common accident cause in the incidents found. Fire can arise from a number of sources – and some turbine types seem more prone to fire than others. A total of 190 fire incidents were found. (from 1990s to 2012) the biggest problem with turbine fires is that, because of the turbine height, the fire brigade can do little but watch it burn itself out. While this may be acceptable in reasonably still conditions, in a storm it means burning debris being scattered over a wide area, with obvious consequences. In dry weather there is obviously a wider-area fire risk, especially for those constructed in or close to forest areas and/or close to housing."[5] Since Industry assurances can be self fulfilling it is prudent to consult third party evaluations of fire dangers in the SRA.

PUBLIC SERVICES - WILDLAND FIRE RESPONSE

ALTERNATIVE 3 AND 5, POLYGON 11, EAST OF BIG BEAR

The opening of 62,634 acres to wind development in the SRA comes with the increased need for a quick response. Suppression of local wildland fires depends on the mutual aid system for fast response. This response is in jeopardy as the quote below indicates.

"Assembly Bill 29 now imposes a new annual fee of $150 for fire prevention services in SRAs. People must pay this fee even if they are within an existing fire district. According to the Fire Districts Association of

[4] Summary of Wind Farm Accident Data to 30 June 2012. Report attached

[5] Ibid

California (FDAC) "The local fire districts are placed in the unenviable position of shouldering the day to day expenses of providing services, while onerous fees are imposed on their constituents without any direct benefit to the jurisdictions." California's Master Mutual Aid System, in which districts cooperate to send aid when and where it's needed is a model for the rest of the nation. But according to the FDAC, "This model of cooperation is now in jeopardy as agencies evaluate their willingness and ability to participate in this valuable program." http://www.eastcountymagazine.org/node/10593 (article attached)

Although not a satisfactory answer because the risk continues, wind energy companies should be required to post a bond sufficient to cover the expenses of wildland fires caused through failure of their technology. Local residents and fire districts should not incur the expenses for fire response and property damages related to turbines malfunction.

LESSONS LEARNED

Wind energy technology is not new; both it's up and down sides are known and many countries are developing protocols to diminish the negative effects on local residents, wildlife, and wildlands. The cumulative effects on small communities when massive projects are superimposed on 'their' landscape can be surprisingly far reaching.[6] There are consequences not only to the biological resources, economy and public services, but also deep into the value systems of individuals who are forced into questioning not only their current quality-of-life but also their future. A lesson learned long ago by international organizations is that the individual communities closely associated with ecologically valuable resource areas are the real conservators (See UNESCO Man and Biosphere Program). If the DRECP (and PEIS) do not value community needs, than conservation priorities may suffer from this neglect. Residents who once contributed their own funds to purchase private lands for protection and then spent hours restoring that land may find other uses for their energy, time, and money. The DRECP should become aware of the lessons learned by countries that started industrial scale wind and solar development long before we did, and apply them as they evaluate the alternatives. While at it, reach out to communities: involve the community members that will live with the results of your decisions. In this way you become familiar with the local economy, and the land use, conservation, and open space elements in General Plans. This outreach will help to ensure that the DRECP is a conservation plan.

In conclusion, as one of the oldest collective voices in this area, we support a scenario that does not develop renewable energy in the high-desert, tourism based communities. Although we do not support utility scale solar and wind development in the Morongo Basin we do support renewable energy and have not opposed small scale renewable energy projects. We encourage the adoption of Alternative 1 after first deleting the variance lands or the adoption of Alternative 2.

Thank you for your thoughtful consideration of our concerns.

Sincerely,

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ATTACHMENTS

- Wind Turbines – Wind Farms © Alasdair and Jean Phillips
- Beier, Paul and Brian Brost. 2010. Use of Land Facets to Plan for Climate Change: Conserving the Arenas, Not the Actors. Conservation Biology. Contributed Paper. Pdf
- Lovich, Jeffery E. and Joshua R. Ennen. 2011. Wildlife Conservation and Solar Development in the Desert Southwest, United States. BioScience. Vol. 61 No. 12

[6] Ibid

- Summary of Wind Farm Accident Data to 30 June 2012
- East county magazine article on new fees in SRAs.

Wind Turbines – Wind Farms

There are increasing numbers of wind farms being erected across the countryside to provide a more sustainable source of energy to replace our historical dependence on fossil fuels. As well as large wind farms a number of small windmills are being erected on buildings to provide a local power generation source to reduce expenditure on energy and to contribute to the overall production of more sustainable energy.

Discussed below are the different concerns that have been raised, and at the bottom a more general evaluation of wind turbine energy production. The figures available are for a large wind farms rather than isolated small windmills.

As always, nothing is simple and straightforward. The major reported problems are the sound (especially extremely low frequency -"infra"- sound from the turbines, which not everybody can hear, but is very troublesome to those who can, as well as the aesthetic question. Some people seem more accepting of the visual appearance than others. A study by Pedersen & Persson Waye (2007) concluded *"There is a need to take the unique environment into account when planning a new wind farm so that adverse health effects are avoided."* They stated that perception and annoyance were greater in rural rather than suburban settings , and that complex ground (hilly or rocky terrain) increased the risk of perception and annoyance than flat ground.

There are also concerns with regard to the efficiency and longevity of the turbines and infrastructure.

There is also the thorny issue regarding individual small turbines and the way they feed electricity into the grid. The Grid has not been developed to accept small *ad hoc* inputs. The problems with electricity supply are likely to grow as these new sources are added in a random fashion to the national system.

EMF problems

Are there any EMF problems associated with wind turbines?

Dr Hugo Schooneveld of the Dutch EHS foundation measured the magnetic fields from a turbine *in situ.* To his surprise, at a distance of a few metres and against the steel wall of the bases only a few nanotesla AC field could be detected. At 10 metres no field could be measured at all. He came to the conclusion that the electric circuits had been well-designed, and that no EMF dangers were to be expected from the machines.

However, a Russian article (Kireeva 2009) suggests precaution due to possible risk factors from windmill electric generating plants. The authors recommend a 400 metre control area, on the basis of calculated acoustic and electromagnetic pollution possibilities.

Professor Magda Havas from Trent University in Canada, says that wind turbines generate dirty power as the electricity is converted from DC to AC and this can get onto wires coming into people's homes.

Sound

Low frequency sound vibrations (including ultrasound) generated by the rotors can make people feel ill. Dr Nina Pierpont (MD, PhD) has coined the term "Wind Turbine Syndrome", also known as vibroacoustic disease (VAD). She has provided expert testimony before the New York State Legislature Energy Committee.

Dr Pierpont's research claims that any or all of the following symptoms can occur as the result of a person living too closely to a wind turbine.

1. Sleep problems: noise or physical sensations of pulsation or pressure make it hard to go to sleep and cause frequent awakening.
2. Headaches which are increased in frequency or severity.
3. Dizziness, unsteadiness, and nausea.
4. Exhaustion, anxiety, anger, irritability, and depression.
5. Problems with concentration and learning.
6. Tinnitus (ringing in the ears).

According to Pierpont, eight of the 10 families in her study moved out of their homes.

Professor Mariana Alves-Pereira (an acoustical engineer) and Dr Nuno Castelo Branco (a surgical pathologist) have taken numerous noise/vibration measurements within a Portuguese home surrounded by 4 industrial wind turbines. The closest turbine is nearly 300 metres from the affected home. Their report concluded: *"These results irrefutably demonstrate that windmills in the proximity of residential areas produce acoustical environments that can lead to the development of VAD in the nearby home-dwellers."*

British physician Amanda Harry, in a February 2007 article titled *Wind Turbines, Noise and Health*, wrote of 39 people, including residents of New Zealand and Australia, who suffered from the sounds emitted by wind turbines.

This article by Harry, Frey & Hadden (2007) concluded that a safe buffer zone of at least 2 kilometres should exist between family dwellings and industrial wind turbines of up to 2MW installed capacity, with greater separation for a wind turbine greater than 2MW installed capacity.

The report said that the health responses in those living nearby included sleep deprivation, headaches, migraines, nausea, dizziness, palpitations, tinnitus, stress, anxiety and depression. These symptoms had a knock-on effect in the residents' daily lives, causing poor concentration, irritability and an inability to cope. The injuries were considered in the context of human rights, where it is contended that the environmental noise pollution destroys a person's effective enjoyment of right to respect for home and private life, a violation of Article 8 of the European Court of Human Rights Act.

An investigation by the Ddass (Direction Départementale des Affaires Sanitaires et Sociales) found sound levels occasionally exceeded allowable limits at 1 kilometre away.

Flicker and Strobing

There are two distinct types of flicker associated with wind turbines. Shadow flicker arises as the shadow of the moving turbine blades moves across the ground. This type of flicker is most common when the sun is at a low angle in the sky, such as mornings and evenings in the summer and just about any time in the winter. The second type of flicker that can arise from wind turbines is strobing. Strobing occurs when turbine blades catch the sun and reflect it back towards the viewer. Since a turbine blade will be in the position where this reflection takes place up to 60 times per minute, the effect is like a strobe light. Strobing can occur at any time of day and can happen anywhere the turbines can be seen – especially from the south, east and west. Small windmills situated on top of buildings have created a strobe effect as the sun was seen behind the revolving blades.

The most severe, though by no means the only, health risk associated with shadow flicker and strobing is seizure. Other risks include headache, loss of balance, nausea and disorientation.

Nina Pierpoint said *"Dizziness (specifically vertigo) and anxiety are neurologically linked phenomena. Hence the anxiety and depression seen in association with other symptoms near wind installations are not*

a neurotic response to symptoms, but rather a neurologically linked response to the balance disturbances people experience from shadow flicker or low-frequency noise. Those living within ½ mile should be apprised that they are likely to experience very bothersome levels of noise and flicker, which continue (though to a lesser degree) to a mile or more from the turbines."

Wind turbine data

Positioning of wind turbines

The power available from the wind is a function of the *cube* of the wind speed. Therefore if the wind blows at twice the speed, its energy content will increase eight fold. In practice, turbines at a site where the wind speed averages eight meters per second will produce around 80% more electricity than those where the average wind speed is six meters per second.

The Ministry of Defense have objected to the positioning of certain wind turbines as they interfere with primary and secondary radar, and with low flying. Tracking aircraft flying over a wind farm is extremely difficult.

Meanwhile, the University of Aberdeen has found that directing a radar beam at bat foraging sites reduces the number of bats colliding with turbine blades, as the sound of the radar disturbs them and the heat can make them uncomfortable so they avoid it. It is unclear whether this is only usable in areas where the MoD do not fly. It may also add to environmental RF problems for those sensitive to radar transmissions.

Wind Turbine design, costs and lifetime

Some of the information below is taken from sources which are promoting the development of wind farms and this should be borne in mind.

Wind turbine design has improved so that modern ones are designed to work for some 120,000 hours of operation throughout their design lifetime of 20 years. http://www.windpower.org/en/tour/econ/oandm.htm. Danish experience shows that maintenance costs are generally very low while the turbines are brand new, but they increase somewhat as the turbine ages. The actual lifetime of a wind turbine depends both on the quality of the turbine and the local climatic conditions, e.g. the amount of turbulence at the site

According to http://www.bwea.com/ref/econ.html, the wind turbine structure represents 64% of the cost of the project. The balance of the cost comes from civil works, electrical infrastructure, grid connection, etc. Onshore wind energy is competitive with new coal fired plant, and cheaper than new nuclear power.

http://www.woodlawnwind.com.au/_PDF/_Sections/19.pdf A Danish paper *The Energy Balance of Modern Wind Turbines* (Wind Power 1997) records the results of a detailed calculation of the energy balance, based on energy use associated with manufacture, installation, operations and decommissioning of a 600 kW Danish turbine.

A 2006 summary of all the reports and studies to date was compiled by Cutler Cleveland at Boston University. Cleveland's analysis was posted on the Oil Drum October 19, 2006.

Cleveland found that the average Energy Return on Investment (EROI)for wind turbines of the studies he evaluated varied depending upon whether the study assumed how the wind turbine would perform or whether it used actual field experience. For studies that estimated performance, the average EROI was 24.6, for those that used field experience the average EROI was 18.1. If wind turbines can be expected to operate for 20 years, then the average energy payback for those studies estimating performance is 9.8 months, for those studies using field experience the average energy payback is 13 months. While substantially longer than the paybacks determined by the early studies cited here, Cleveland's work confirms that wind turbines typically pay for their energy content within the first year of operation.

There are a variety of good primary sources with claims of energy balance being achieved after 13 months. 13 months is the point at which balance is achieved for the measured data as opposed to the estimated data which is unsurprisingly lower.
See http://www.theoildrum.com/story/2006/10/17/18478/085#more

The results can be summarized as follows:

- The turbine would recover all the energy spent in its manufacture, maintenance and decommissioning/disposal after about 13 months of its commissioning. This figure is based on measured, rather than theoretical results many of which quote shorter periods of time
- With a standard 20-year design lifetime, the wind turbine would supply at least 80 times the energy spent in its manufacture, installation, operation, maintenance and decommissioning/disposal
- The decommissioning of the turbine would require energy, but recycling would "save" slightly more energy in being able to recycle most materials, especially metals, than the energy required for the disposal process.

It looks as if the overall energy payback period has been decreasing from a few years to one year more or less for land-based wind farms. Sea-based ones will have significantly longer energy balance periods.

Jobs

To date, over 4,000 jobs are sustained by companies working in the wind sector, and this is projected to increase as the industry grows.

References

Kireeva IS et al 2009 – *The location of wind-mill electric generating plants: hygienic aspects* Gig Sanit Sep-Oct;(5):23-5

Pedersen E & K Persson Waye 2007 – *Wind turbine noise, annoyance and self-reported health and well-being in different living environments* Occup Environ Med 64(7):480-6

This article is available to download, free of charge, from www.powerwatch.org.uk

DOI: 10.1111/j.1523-1739.2009.01422.x

Contributed Paper

Use of Land Facets to Plan for Climate Change: Conserving the Arenas, Not the Actors

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Abstract: *Even under the most optimistic scenarios, during the next century human-caused climate change will threaten many wild populations and species. The most useful conservation response is to enlarge and link protected areas to support range shifts by plants and animals. To prioritize land for reserves and linkages, some scientists attempt to chain together four highly uncertain models (emission scenarios, global air–ocean circulation, regional circulation, and biotic response). This approach has high risk of error propagation and compounding and produces outputs at a coarser scale than conservation decisions. Instead, we advocate identifying land facets—recurring landscape units with uniform topographic and soil attributes—and designing reserves and linkages for diversity and interspersion of these units. This coarse-filter approach would conserve the arenas of biological activity, rather than the temporary occupants of those arenas. Integrative, context-sensitive variables, such as insolation and topographic wetness, are useful for defining land facets. Classification procedures such as k-means or fuzzy clustering are a good way to define land facets because they can analyze millions of pixels and are insensitive to case order. In regions lacking useful soil maps, river systems or riparian plants can indicate important facets. Conservation planners should set higher representation targets for rare and distinctive facets. High interspersion of land facets can promote ecological processes, evolutionary interaction, and range shift. Relevant studies suggest land-facet diversity is a good surrogate for today's biodiversity, but fails to conserve some species. To minimize such failures, a reserve design based on land facets should complement, rather than replace, other approaches. Designs based on land facets are not biased toward data-rich areas and can be applied where no maps of land cover exist.*

Keywords: adaptation, climate change, coarse-filter approach, conservation planning, ecological process, land facets, soil, topography

DOI: 10.1111/j.1523-1739.2009.01422.x

Introduction

Human-caused climate change will have profound impacts on biodiversity. Reversing human-caused emissions of carbon dioxide and other greenhouse gasses is critically necessary to halt and reverse climate change and its consequences. Nevertheless, even under the most optimistic scenarios of emissions and carbon sequestration programs, past emissions will drive temperature and precipitation changes for at least 50 years (IPCC 2001). These changes, interacting with habitat loss, habitat fragmentation, and invasive species, will cause range shifts by plants and animals and reassembly of biotic communities and threaten many wild populations and species with extinction (Lovejoy & Hannah 2005).

Given the inevitability of human-caused climate change, conservation biologists are beginning to develop strategies to help ecosystems cope with environmental change. Efforts to increase ecosystem resistance and resilience to climate change may be futile attempts to "paddle upstream" (Millar et al. 2007), so most strategies try to improve the ability of organisms to respond to change in three ways. First, conserving or increasing genetic diversity can help species adapt evolutionarily to new temperature and precipitation regimes (Millar et al. 2007; Skelly et al. 2007). Second, managers can translocate species to areas expected to have suitable future climate (Hunter 2007; McLachlan et al. 2007). Third, managers can support range shifts by enlarging protected areas or linking them with corridors (Hannah et al. 2002). The last-mentioned strategy avoids over-reliance on evolutionary response or the artificiality of assisted colonization. It is also consistent with paleoecological evidence that extensive shifts in "species' geographical ranges have been the most important response of biota to past large, rapid climatic changes" (Huntley 2005:121).

Some efforts to design reserves and linkages for climate change involve complex analyses in which emission scenarios drive linked global and regional circulation models to predict future climate. Climate envelope models are then used to produce dynamic maps of the expected future distribution of biomes or species to develop coarse-filter or fine-filter plans, respectively (Cramer et al. 2001; Hannah & Hansen 2005; Hannah et al. 2007). Unfortunately, each step has an enormous uncertainty. For example, emission scenarios over the next 100 years vary by a factor of six (Fig. 1). For a single emission scenario, the seven air–ocean global circulation models (AOGCMs) produce markedly different climate projections (Raper & Giorgi 2005; IPCC 2001), and climate-envelope models may perform no better than chance (Beale et al. 2008). Because these sophisticated models have not been able to simulate the large shifts that paleoecologists have documented during the last 100,000 years of glacial oscillations, Overpeck et al. (2005:99) conclude the "lesson for conservationists is not to put too much faith in simulations of future regional climate change" in designing robust conservation strategies. In addition, the resolution

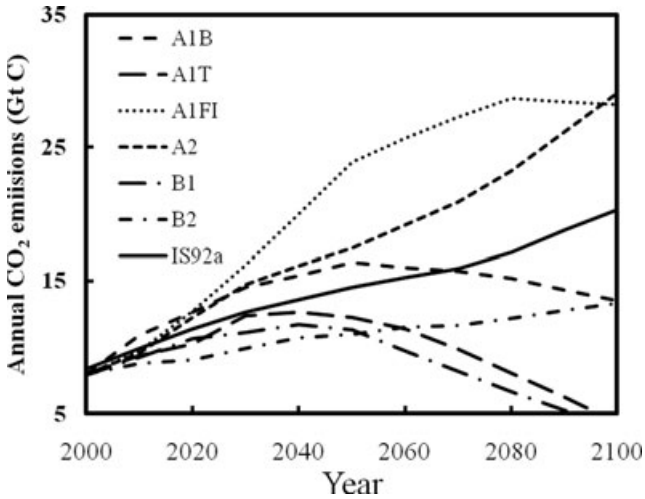

Figure 1. Seven emission scenarios developed by the Intergovernmental Panel on Climate Change (2001) for 2000–2100. The IS92a scenario (solid line) is "business as usual"; world population grows to 11.3 billion by 2100, economic growth continues at 2.3–2.9% per year, and no active steps are taken to reduce emissions. Most emissions are from fossil fuel and industrial sources. Depending on scenario and year, up to 24% of emissions are due to deforestation and land use. Actual emissions during 2000–2004 were higher than any of these scenarios (Raupach et al. 2007).

DOI: 10.1111/j.1523-1739.2009.01422.x

Table 1. Studies and conservation plans that used landscape units based on topography and soils as a surrogate for vegetation communities, species, or other elements of biodiversity.

Citation	*Number of landscape units*	*Name of landscape unit*	*used to define landscape units*[a]	*Feature landscape units are intended to represent*	*Procedure used to define landscape units*	*Size of study area (km^2)*	*Pixel size or map scale*[b]
Mackey et al. 1988	12–23	bioenvironment	E, G_S, I, P, T	geomorphic region	numerical classification	2750	~0.13 km^2
Belbin 1993	3	environmental partition	G_S, I, P, R, T	environmental region	numerical classification	3599	~1 km^2
Kirkpatrick & Brown 1994	68	environmental domain	E, G_S, I, P, T	variation in the physical environment	numerical classification	7140	10 km^2
Wessels et al. 1999	8	land facet	G_P, G_S, S, H	unit of uniform slope, parent material, soil, and hydrological conditions	air photo interpretation and geological survey	350	1:10000–1:50000
Fairbanks & Benn 2000	97	landscape	E, L, P, T	landscape	ordination	92100	1 km^2
Burrough et al. 2001	6	topo-climatic class	C, E, H, I, S	land-cover class	numerical classification	10000	100 m^2
Reyers et al. 2002	676	land type	G_S, L, P, T	unit of uniform terrain, soil, and climate	spatial intersection of factor levels	122305	1:250000
Carlson et al. 2004	126	landscape diversity unit	E, G_P, L	natural community type	spatial intersection of factor levels	84	30 m^2

[a]*Abbreviations: E, elevation; L, landform or topographic position; C, landscape curvature; F, suitability for farming; G_P, geology of parent material or bedrock; G_S, geology at land surface or soil type; H, hydrologic conditions; I, insolation; P, precipitation; R, ruggedness; S, slope; T, temperature.*

[b]*Minimum detectable size of a unit on a map is approximated by dividing the denominator in the map scale by 1000 (Tobler 1988) (e.g., the minimum detectable unit on a map with scale 1:250000 is 250 m^2).*

Figure 2. Illustration of the geographic distribution of land facets, defined on the basis of elevation, slope, insolation, and topographic position, draped over a hillshade map. For clarity, not all land facets in the landscape are shown.

of the final maps (square kilometers) is coarser than the typical scale at which lands are targeted for conservation.

Hunter et al. (1988) suggest an alternative coarse-filter conservation strategy to address climate change, namely to protect areas with a high diversity of physical landscape units defined by topography and soils. Several other researchers subsequently used some combination of topographic and soil variables to define landscape units for use as surrogates in conservation planning (Table 1). Following Wessels et al. (1999), we call these units *land facets*, defined as recurring areas of relatively uniform topographic and soil attributes (e.g., Fig. 2). Somewhat surprisingly, these authors (Table 1) used physical landscape units as surrogates only for current diversity of communities and species. None of them adopted the strategy of Hunter et al. (1988) and explicitly focused on the utility of physical landscape units as surrogates for ecological and evolutionary processes during the impending period of rapid climate change.

Cowling et al. (1999, 2003), Rouget et al. (2006), Pressey et al. (2007), and Klein et al. (2009) used physical features (e.g., upland–lowland gradients) as surrogates to conserve ecological and evolutionary processes, including biotic response to climate change, in a reserve design for the Cape Floristic Region. Nevertheless, their procedures did not include a formal, quantitative landscape classification based on physical attributes.

The purpose of this paper is to promote the utility of land facets for coarse-filter conservation planning in the face of climate change. We argue that this strategy is less subject to uncertainty than other modeling approaches, can enhance planning of both reserves and corridors, and

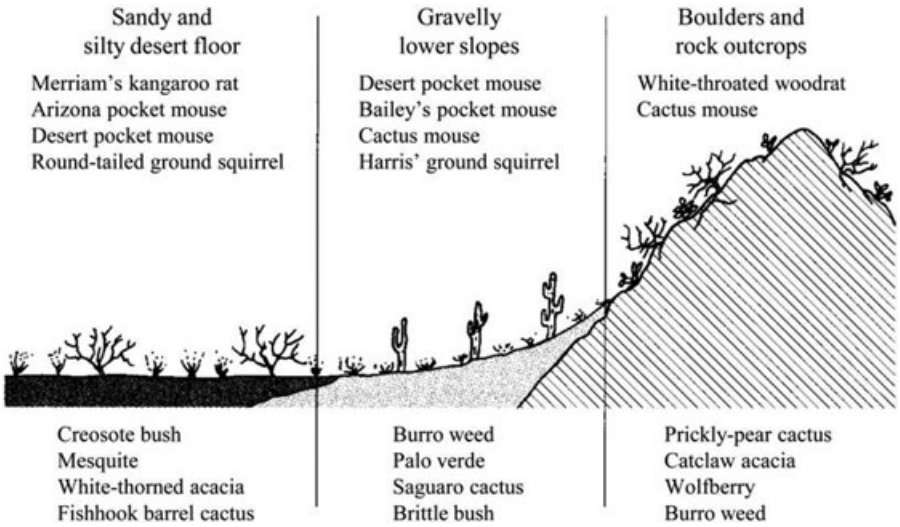

Figure 3. Influence of topography and soils on distribution of plants and animals in North American deserts (from Hugget 2004).

can be readily applied even in parts of the world where no maps of land cover exist. We discuss variables and procedures that can be used to define land facets and suggest strategies for using land facets in concert with other coarse-filter and fine-filter approaches to design reserves and linkages.

Land Facets as Surrogates for Future Biodiversity and Ecological Processes

Since the life zone concept was introduced by Merriam (1890), ecologists have recognized the influence of topography and geology on plant and animal communities (Fig. 3). These influences are obvious on aerial photographs (Fig. 4). More recent research shows that most modern plant communities are <8000 years old and are not highly organized units, but rather are transitory co-occurrences of plant taxa (Hunter et al. 1988; Huntley 2005). Because they are ephemeral, communities are not appropriate units for coarse-filter conservation planning. Accordingly, Hunter et al. (1988:380) "advocate basing the coarse-filter approach on physical environments as ''arenas'' of biological activity, rather than on communities, the temporary occupants of those arenas."

The species present at any given site are a function of climate, other organisms present in or adjacent to the site, disturbance regime, topography, the underlying geological material, and time (Jenny 1941; Amundson & Jenny 1997). Land facets reflect the more stable factors, namely topography, geology, and time (geology and time represented by a single soil-related variable). Topography also governs local (i.e., within the geographic extent of a typical conservation plan) variation in precipitation and temperature. Thus, reserves and linkages that capture diverse land facets should also support biodiversity under any future climate regime (Hunter et al. 1988).

Conserving diverse physical environments may also ensure persistence of the ecological and evolutionary processes that maintain and generate biodiversity. For example, protecting environmental gradients helps conserve intraspecific genetic diversity necessary for adaptive evolution and speciation (Noss 2001; Moritz 2002; Rouget et al. 2003). Protecting upland–lowland interfaces and soil interfaces can conserve ecological processes such as nutrient cycling and disturbance regimes (Rouget et al. 2003, 2006; Pressey et al. 2003).

Figure 4. Aerial photograph of eastern Tehama County, California (U.S.A.), shows bands of vegetation corresponding to geological strata and elevation contours intersected by heavily vegetated drainages.

Hunter et al. (1988), and most of the papers listed in Table 1, note another advantage of land facets, namely that topography and soils are relatively easy to inventory and map. In contrast, species diversity can be assessed only by long-term inventories (Cowling et al. 2009).

Several studies describe the correspondence between land facets and the current distribution of land-cover types or species. For instance, six of eight land facets identified by Wessels et al. (1999) supported distinctive communities of birds and dung beetles. Similarly, Burrough et al. (2001), Kintsch and Urban (2002), and Carlson et al. (2004) found that land facets were correlated with vegetation types in a statistically significant way, but the strengths of the associations varied among vegetation types and were low for some types. Modest correlations may be a consequence of a nonequilibrium between modern vegetation and land facets due to recent and ongoing climate change, biotic interactions (e.g., competition, seed rain, mutualists), past disturbance, and other historical legacies. Thus, land facets may not correspond well to modern land cover despite being a major driver. The moderate level of correspondence is of limited relevance, though, because the land-facet approach does not depend on a 1:1 mapping of land cover or species on land facets. Rather, the central idea is that a reserve or linkage designed to encompass the full diversity of dominant land facets at multiple spatial scales will encompass the full diversity of land-cover types and species, today and in the future, and will conserve ecological and evolutionary processes.

Several studies address whether the full diversity of land facets is a good surrogate for today's biodiversity. Kirkpatrick and Brown (1994) found a statistically significant correspondence between grid squares selected on the basis of land facets and those selected on the basis of forest types, endemic species, rare or vulnerable species, and poorly reserved plant communities. Nevertheless, the proposed reserve network based on land facets failed to capture known occurrences of some of the rarest species and communities. Similarly, Cowling et al. (1999) report that a hypothetical reserve network designed to conserve ecological processes (including biotic response to climate change) conserved 37% fewer rare species than a similar-sized hypothetical reserve designed to maximize representation of those species. The unrepresented species tended to be those that were rare, required specialized habitat, or had distributions determined by historical factors (Lombard et al. 2003). Reyers et al. (2002) found that an extensive reserve design (60% of the landscape) based on land facets (676 land types) represented most species, including rare and endemic species. The results of these studies suggest that although a land-facet approach should help conserve ecological processes, including range shifts of many species in the face of climate change, it remains a coarse-filter approach that will not conserve all species.

Selecting Useful Topographic and Soil Variables

Conservation strategies based on land facets can be applied worldwide because digital elevation models (DEM) are available for all continents at 30-m resolution (http://www.gdem.aster.ersdac.or.jp/), and 10-m resolution is available for some areas. Topographic attributes derived from a DEM include elevation, slope, aspect, topographic position, solar insolation, profile curvature (down-slope curvature), planiform curvature (horizontal, or cross-slope curvature), ruggedness, and topographic wetness index (Moore et al. 1991; Franklin 1995). Topographic position is usually characterized into several classes such as ridgetop, steep slope, gentle slope, or canyon bottom on the basis of elevation of the focal pixel relative to neighboring pixels (Jenness Enterprises 2006). Topographic wetness index is a proxy for soil water content; it is a function of slope and the area of the catchment that drains into a focal pixel (Moore et al. 1991).

Many researchers report a strong correlation between the distribution of plant and animal species and topographic variables such as elevation, insolation, slope, aspect, landform, curvature, and ruggedness (DeVelice et al. 1988; Davis & Goetz 1990; Forman 1995; Parker 1995; Pinder et al. 1997; Bolstad et al. 1998; Gottfried et al. 1998; Guissan et al. 1999; Franklin et al. 2000; Pfeffer et al. 2003; Dickson & Beier 2006). Nevertheless, the relative importance of a variable depends on spatial scale, species, and location of the study (Pfeffer et al. 2003; Deng et al. 2007).

The European Digital Archive of Soil Maps (EuDASM 2009) offers soil maps for every inhabited continent, typically at a scale of 1:200,000 (minimum mapping unit approximately 600 ha) to 1:2,000,000. Attributes of each soil map polygon may include soil order (e.g., mollisol, aridisol), the two dominant particle size classes, mineral composition class for the dominant particle size classes, cation exchange activity class (typically four classes), and soil-depth class (typically shallow or not shallow). Unfortunately, soil maps have many limitations (Sanchez et al. 2009). For instance, accuracy and sampling methods are rarely described. Furthermore, some polygons may lack values for a certain attribute or contain several states of that attribute, indicating the presence of unmapped heterogeneity. All soil maps are of low resolution and often fail to depict local conditions. In nonagricultural parts of the western United States, we found that soil maps consist of large, heterogeneous polygons from which inferences about relevant traits, such as moisture, texture, depth, or soil nutrients, cannot be made. Maps of bedrock type are especially problematic because soil properties may differ greatly within a bedrock type due to weathering, age, and alluvium or till that formed from a source different than the local bedrock (Carlson et al. 2004).

Where available soil maps are not helpful, conservation planners can use presence of streams, standing water, or riparian plants to map important soils. In the arid southwestern United States, for example, typically only one or two of several watersheds in a potential reserve or linkage area support perennial stream flows. Thus, even without a good soil map, conservation planners can prioritize the impervious soils associated with these watersheds. Similarly, vernal pools and karst lakes are features related to soil and geology that are relevant to biodiversity and identifiable without a soil map. In the long term better soil maps are needed to ensure rigorous mapping of land facets across the entire planning region.

Defining Land Facets in a Landscape

We recommend using explicit and repeatable procedures to derive a land-facet taxonomy from topographic and soil variables. Nevertheless, explicit and repeatable procedures are not entirely "objective" because the analyst subjectively chooses the topographic and soil attributes that will define facets and decides how many land facets to recognize (Mackey et al. 1988).

We suggest limiting the number of topographic and soil factors used to define land facets because a large number of explanatory factors can yield hundreds of land facets, many of which defy interpretation (Mackey et al. 1988; Pressey et al. 2000). If the resulting classification scheme and conservation maps cannot be explained to stakeholders and implementers, their value is diminished. Also, if an analysis includes three highly correlated variables (e.g., general curvature, planiform curvature, and profile curvature), these variables can "gang up" in many statistical procedures to swamp the importance of a single variable related to, say, soil depth (Mackey et al. 1988; B.B. & P.B., unpublished data).

The number of variables can be reduced by choosing those that are highly interpretable or ecologically most influential (DeVelice et al. 1988; Fairbanks et al. 2001) or by choosing a variable that integrates several other variables in a biologically meaningful way. For instance, solar insolation integrates many important influences of latitude, aspect, and slope on plants and animals.

Once topographic and soil variables have been selected, several rule-based or statistical procedures can identify land facets (Table 1). Various numerical classification procedures such as principle components analysis, k-means cluster analysis, and fuzzy-clustering algorithms can define land facets in a repeatable, transparent way. Procedures that require a pairwise distance matrix between all pixels (e.g., hierarchical cluster analysis and nonmetric multidimensional scaling) are limited to data sets smaller than typical DEM data sets. Procedures sensitive to case order (i.e., the order in which pixels are listed in the input file), such as two-step cluster analysis (SPSS, Chicago, Illinois) should also be avoided.

Various metrics—many of them specific to a particular clustering procedure—can help identify the number of classes that corresponds to the natural multivariate "lumpiness" in the topographic and soil attributes. In our experience, these metrics often disagree on the best number of classes, and they differ trivially among the two or three best options. Selecting the largest number of classes among the best options reduces the risk of failing to recognize and conserve a distinctive facet (Ferrier 2002). Mackey et al. (1988) provide a good example of evaluating different alternative classification schemes. They used interpretability of classes, color maps to reflect multivariate similarity of facets, maps of facet polygons draped over a topographic hillshade, plots of facet centroids in multivariate space, and hierarchic dendrograms to evaluate alternative schemes. Ground-truthing and inspection of the map by someone familiar with the landscape will reveal whether the scheme corresponds to natural units or imposes artificially discrete categories on a continuous landscape.

Land Facets in Reserve Design for a Changing Climate

Once land facets have been defined, planners can apply the same tools and criteria used in other coarse-filter approaches to reserve design. Selection algorithms such as simulated annealing (Margules & Pressey 2000) can ensure that targets for each land facet are achieved in an efficient area. Targets are typically expressed as minimum area or percent of each land facet to be captured in a reserve.

Deciding how much is enough will be subjective, just as it is for conservation plans based on today's communities or species. Setting targets is useful nonetheless because it makes goals explicit and encourages thoughtful discussion (Margules & Pressey 2000). Following Pressey et al. (2003), we advocate setting higher targets for distinctive and rare land facets, such as those likely to concentrate soil moisture (rivers, karst lakes, vernal pools) or support unique plant communities (e.g., serpentine soils, other resource-limited soils). Conserving a higher proportion of a rare class is important because a small fraction of a small area is less likely to support its associated populations and ecological processes. The proposed reserve should include at least one large polygon of each facet type to support disturbance regimes, seral stages of future communities, and species that will not survive on the same total area distributed among several small polygons of that land facet.

Setting targets for juxtaposition of land facets will be even more difficult than setting goals for minimum areas. Highly interspersed land facets can allow relatively immobile plants and invertebrates to quickly move to a land

facet with more favorable conditions (e.g., to a higher-elevation site or a site with a more poleward aspect). High interspersion also promotes various alternative combinations of species and future communities and thus is more likely to sustain ecological processes and evolutionary opportunities (McKenzie et al. 1989; Cowling et al. 1999; Fairbanks et al. 2001). To increase interspersion and conserve processes, Pressey et al. (2003) advocates setting targets for edaphic interfaces and upland–lowland interfaces. A map of land facets could provide a more rigorous basis for identifying and prioritizing these interfaces. Fairbanks et al. (2001) provide procedures to prioritize areas with high beta diversity (negative spatial autocorrelation) in species assemblages; the same procedures readily apply to land facets. Ferrier (2002) and Ferrier et al. (2007) describe how to model species dissimilarity between locations (i.e., beta and gamma diversity) as a function of environmental dissimilarity. They advocate using this relationship to prioritize locations on the basis of their contribution to the beta and gamma diversity of a proposed reserve system.

The need for minimum areas and interspersion should be considered at more than one spatial scale. For instance, when the planning area includes several major geophysical regions (e.g., coastal lowlands, foothills, major mountains, and interior basin and range), we suggest conducting separate analyses for each major geophysical region and assembling these into an overall reserve design. This would reduce the risk that a mechanical procedure might achieve the targets by selecting land facets only within a single geophysical region and would maximize conservation of evolutionary potential (Rouget et al. 2006).

Rivers and ephemeral drainages span elevational gradients in a way that increases interspersion (e.g., Fig. 4) and promotes ecological processes and flows, such as movement of animals, sediment, water, and nutrients. Because mechanical geospatial algorithms may fail to identify important riverine connections that are obvious to a human expert, we recommend manual inclusion of riverine elements if necessary (e.g., Cowling et al. 1999, 2003).

Land Facets in Linkage Design for a Changing Climat e

During the impending period of climate change, species will have to shift their ranges in ways that are more complex than simply moving to higher elevation and toward the poles (Halpin 1997; Peterson et al. 2005). We found only three studies that designed corridors specifically to support range shifts in a changing climate. Rouget et al. (2006) used an approach that maximized continuity along elevation gradients, and Williams et al. (2005) and Phillips et al. (2008) used models of emissions, global

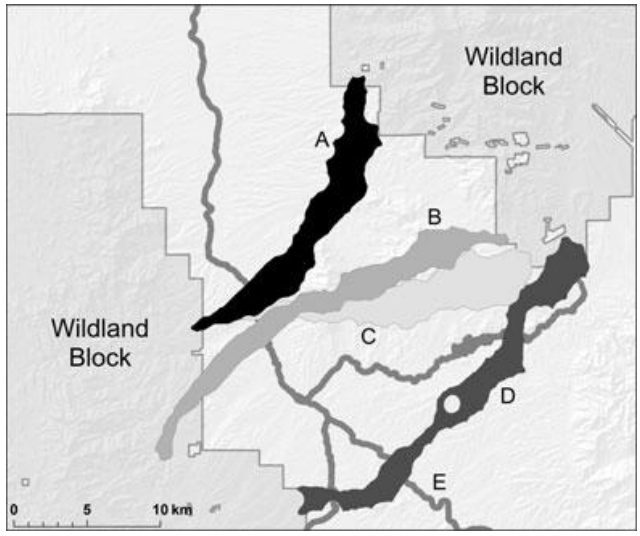

Figure 5. A multistranded linkage of land facets designed to allow species to shift their range in response to climate change and to support movement during periods of quasi equilibrium. Area A optimizes continuity for high local diversity of land facets. Other areas provide the best continuity of high-insolation, steep slopes (area B), low-elevation, gentle canyons (area C), and low-elevation, gentle ridges (area D). Area E encompasses the region's main river and its only perennial tributaries from each wildland block.

and regional atmospheric circulation, and bioclimatic envelopes to design movement corridors.

When designing corridors on the basis of land facets, we recommend giving top priority to the land facets that are dominant in the natural landscape blocks to be connected. Some facets that occur only in the matrix may also be considered, but the linkage should focus most fundamentally on the larger areas to be linked.

Like linkages designed for multiple focal species (Beier et al. 2008), linkages for diversity of land facets should contain multiple strands. The linkage design should include at least one strand intended to maximize continuity of each land facet (Fig. 5). Each such strand is intended to support occupancy and between-block movement by species associated with that land facet in periods of climate quasi equilibrium. The linkage design should also contain at least one strand with high beta diversity (i.e., high local interspersion of facets; Fig. 5) to support range shift, species turnover, and other underlying processes (Cowling et al. 1999; Fairbanks et al. 2001; Rouget et al. 2006).

Least-cost modeling (Beier et al. 2008) or circuit theory (McRae et al. 2008) can be used to identify optimal strands for individual land facets. Both these tools rely on an underlying map of resistance, wherein each pixel's resistance represents its dissimilarity to the focal facet

type. We recommend multivariate measures of dissimilarity such as Mahalanobis distance or Bray-Curtis percentage dissimilarity. Useful variables include elevation, insolation, slope, and density of the focal land facet within the pixel's neighborhood.

The linkage design should always include the major riverine or riparian connections between landscape blocks. As with land facets in reserve design, rivers can efficiently be included by having a local expert draw by hand the riverine system (Fig. 5).

Prior to corridor design, we recommend masking highly degraded, unrestorable areas, such as urban areas that are unlikely to support species movements (Knight et al. 2006; Rouget et al. 2006). We caution against wholesale exclusion of agricultural areas, especially if they can be restored to natural vegetation or occupy a large portion of the most productive land facets (those with gentle slopes and high soil moisture).

Conclusions

We advocate the use of land facets as a tool to prioritize land for conservation in the face of climate change. Compared with climate-modeling approaches, an approach based on land facets does not depend on emission scenarios or climate predictions. Compared with approaches based on mapped species occurrences, land-facet maps are not biased toward data-rich areas. Indeed, because digital elevation models are available everywhere, an approach based on land facets can be used even in areas lacking maps of current land cover and species distributions. We believe designs based on land facets should conserve ecological and evolutionary processes.

Relevant studies (see "Land Facets as Surrogates") suggest that a reserve or network based on land facets may include half or more of the landscape. Although this is an ambitious goal, any credible reserve design, including designs based on distributions of current species, will require a large fraction of the landscape (Soulé & Sanjayan 1998).

Although this approach will not conserve every species, conserving the stage for ecological and evolutionary processes should be an overarching goal for conservation biologists. Climate change and other human impacts will drive some species to extinction, but new biodiversity can be generated in large, diverse, well-connected systems of land facets. It does little good to conserve each species in a small patch of land if the stage on which those species evolve is not conserved. To minimize loss of individual species, we advocate using land facets to complement, rather than replace, fine-filter approaches (e.g., critical habitat for endangered species, maps of rare species occurrences) and coarse-filter approaches based on modern distribution of plant communities, biodiversity hotspots, and focal species. Conservation is too complicated and too important for any single approach.

There are several ways to combine land facets with other approaches. The most obvious is to create a thoughtful union of reserve designs produced by land facets, other coarse-filter approaches, and fine-filter approaches (e.g., Noss 1987). One complementary coarse-filter strategy is to identify and conserve refugia that remained stable during previous periods of rapid climate change (e.g., Eeley et al. 1999; Hewitt 2000; Noss 2001). Similarly, Klein et al. (2009) propose high conservation priority for drought refugia, defined as areas of high gross primary productivity in a time series of satellite images.

Another fruitful step would be to learn from the mismatch between locations prioritized by different approaches. An area with high species diversity, or large genetic and phenotypic variability within a species, apparently has ecological conditions that generate or maintain diversity. Conservation biologists should investigate areas of high diversity outside a land facet reserve to identify important physical factors missing from the current land facet classification. This will improve the way land facets are defined and used.

Systematic conservation planning has been slow to develop tools to address dynamic threats, such as the threat posed by ongoing climate change (Pressey et al. 2007). We acknowledge a mismatch between static maps of land facets and the dynamic nature of climate change, and the dynamic ecological and evolutionary processes we seek to conserve. Nonetheless, we believe that using land facets to help design reserves and linkages can be a simple and effective conservation strategy. A more dynamic strategy might be temporary or moveable conservation areas (Hannah & Hansen 2005; Pressey et al. 2007). Another dynamic strategy would be to reduce the uncertainty in the complex chained models we disparage in our Introduction.

Regardless of the types of strategies used, landholders and other interest groups should be involved throughout the design process (Cowling et al. 1999; Knight et al. 2006; Beier 2008). Analysts should engage stakeholders and generate several scenarios (alternative maps with accompanying recommendations) for achieving targets and collectively decide which of several similarly effective options should be implemented.

Finally, we caution against using this approach, or any other adaptation strategy, as an excuse to avoid addressing the root causes of climate change, namely human burning of fossil fuels and release of carbon from destruction of natural landscapes. Conservation biologists must persuade governments, corporations, and individuals to reduce energy use, halt conversion of natural land cover, transition from energy sources that produce greenhouse gasses to nonpolluting alternatives, and sequester CO_2 in naturally evolving ecosystems.

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Summary of Wind Turbine Accident data to 30 June 2012

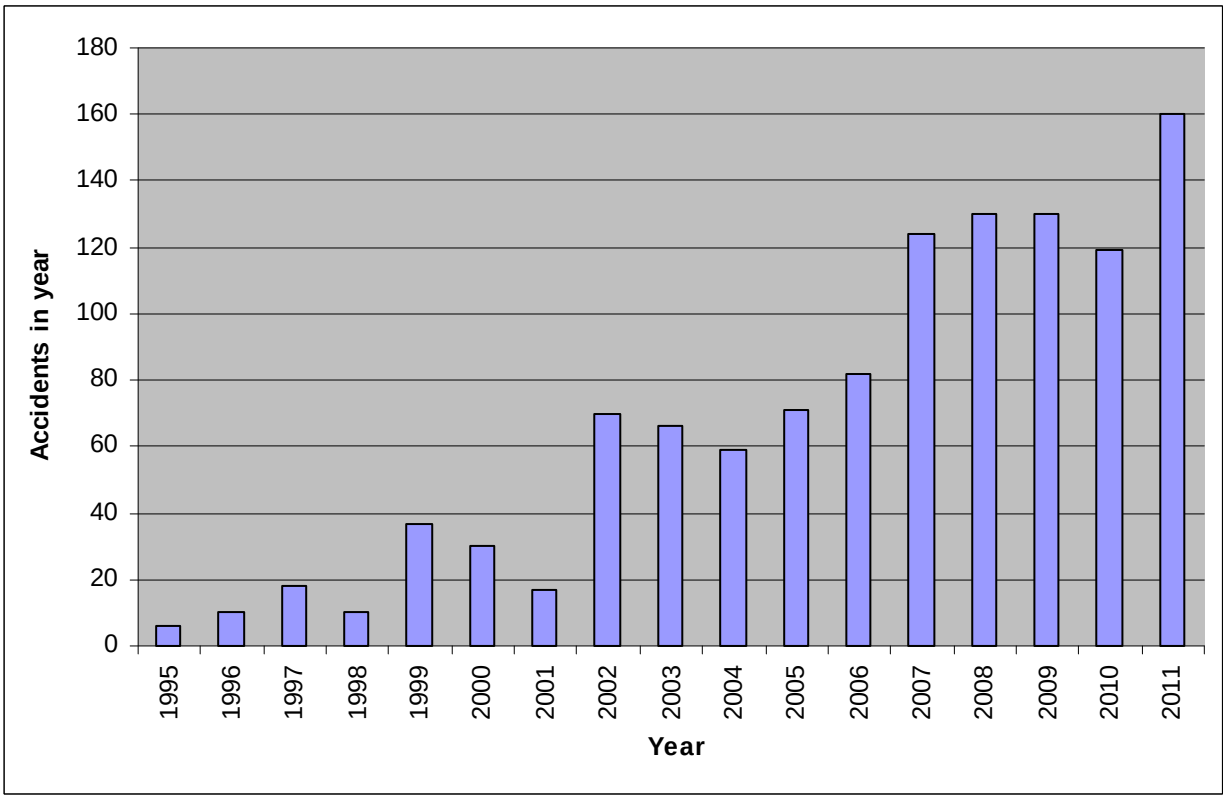
*These accident statistics are copyright Caithness Windfarm Information Forum 2012. The data may be used or referred to by groups or individuals, provided that the source (Caithness Windfarm Information Forum) is acknowledged and our URL **www.caithnesswindfarms.co.uk** quoted at the same time but please do not link to **this file** on your website as it will cease to be current. Caithness Windfarm Information Forum is not responsible for the accuracy of Third Party material or references.*

The accompanying detailed table includes all documented cases of wind turbine related accidents which could be found and confirmed through press reports or official information releases up to 30 June 2012. CWIF believe that this compendium of accident information may be the most comprehensive available anywhere.

Data in the detailed table is by no means fully comprehensive – CWIF believe that it is only the "tip of the iceberg" in terms of numbers of accidents and their frequency. Indeed on 11 December 2011 the Daily Telegraph reported that RenewableUK confirmed that there had been 1500 wind turbine accidents and incidents in the UK alone in the past 5 years. Data here reports only 142 UK accidents from 2006-2010 and so the figures here may only represent 9% of actual accidents.

The data does however give an excellent cross-section of the types of accidents which can and do occur, and their consequences. With few exceptions, before about 1997 only data on fatal accidents has been found.

The trend is as expected – as more turbines are built, more accidents occur. Numbers of recorded accidents reflect this, with an average of 6 accidents per year from 1992-96 inclusive; 22 accidents per year from 1997-2001 inclusive; 70 accidents per year from 2002-06 inclusive, and 133 accidents per year from 2007-11 inclusive.



This general trend upward in accident numbers is predicted to continue to escalate unless HSE make some significant changes – in particular to protect the public by declaring a minimum safe distance between new turbine developments and occupied housing and buildings.

Some countries are finally accepting that industrial wind turbines can pose a significant public safety risk. In New Zealand, the government is set to change planning rules to give residents the right to veto wind turbines from being built within 2km of their homes. In Australia, the Victorian government has set guidelines forbidding wind turbine construction closer than 2km to houses. In Scotland, a 2km guideline is also in place between large wind farm developments and communities, though the guideline is disgracefully ignored by the Scottish government planners. And in Canada, the Ontario Government has declared a moratorium on offshore wind projects and has proposed a reduction of noise from wind turbines from 40dB to 30-32dB, which would effectively extend the setback distance from homes.

Detailed data is presented chronologically. It can be broken down as follows:

Number of accidents

Total number of accidents: 1258

By year:

Year	70s	80s	90s	00	01	02	03	04	05	06	07	08	09	10	11	12*
No.	1	9	98	30	17	70	66	59	71	82	124	130	130	119	160	92

** To 30 June 2012 only*

Fatal accidents

Number of fatal accidents: 94

By year:

Year	70s	80s	90s	00	01	02	03	04	05	06	07	08	09	10	11	12*
No.	1	8	15	3		1	4	4	4	5	5	10	7	7	13	7

** To 30 June 2012 only*

Please note: **There are more fatalities than accidents as some accidents have caused multiple fatalities.**

Of the 123 fatalities:

- 74 were wind industry and direct support workers (divers, construction, maintenance, engineers, etc), or small turbine owner /operators.
- 49 were public fatalities, including workers not directly dependent on the wind industry (e.g. transport workers). 17 bus passengers were killed in one single incident in Brazil in March 2012.

Human injury

107 accidents regarding human injury are documented.

By year:

Year	70s	80s	90s	00	01	02	03	04	05	06	07	08	09	10	11	12*
No.			5	4	1	2	2	2	6	10	16	16	9	14	12	8

** To 30 June 2012 only*

89 accidents involved wind industry or construction/maintenance workers, and a further 18 involved members of the public or workers not directly dependent on the wind industry (e.g. fire fighters, transport workers). Six of these injuries to members of the public were in the UK.

Blade failure

By far the biggest number of incidents found was due to blade failure. "Blade failure" can arise from a number of possible sources, and results in either whole blades or pieces of blade being thrown from the turbine. A total of 244 separate incidences were found:

By year:

Year	70s	80s	90s	00	01	02	03	04	05	06	07	08	09	10	11	12*
No.			35	4	6	15	13	15	12	16	22	20	26	20	19	21

** To 30 June 2012 only*

Pieces of blade are documented as travelling up to one mile. In Germany, blade pieces have gone through the roofs and walls of nearby buildings. This is why CWIF believe that there should be a minimum distance of at least 2km between turbines and occupied housing, in order to adequately address public safety and other issues including noise and shadow flicker.

Fire

Fire is the second most common accident cause in incidents found. Fire can arise from a number of sources – and some turbine types seem more prone to fire than others. A total of 190 fire incidents were found:

By year:

Year	70s	80s	90s	00	01	02	03	04	05	06	07	08	09	10	11	12*
No.			6	3	2	24	17	15	14	12	21	17	17	13	20	9

** To 30 June 2012 only*

The biggest problem with turbine fires is that, because of the turbine height, the fire brigade can do little but watch it burn itself out. While this may be acceptable in reasonably still conditions, in a storm it means burning debris being scattered over a wide area, with obvious consequences. In dry weather there is obviously a wider-area fire risk, especially for those constructed in or close to forest areas and/or close to housing. Three fire accidents have badly burned wind industry workers.

Structural failure

From the data obtained, this is the third most common accident cause, with 129 instances found. "Structural failure" is assumed to be major component failure under conditions which components should be designed to withstand. This mainly concerns storm damage to turbines and tower collapse. However, poor quality control, lack of maintenance and component failure can also be responsible.

By year:

Year	70s	80s	90s	00	01	02	03	04	05	06	07	08	09	10	11	12*
No.		1	14	9	3	9	7	4	7	9	13	9	16	9	11	8

** To 30 June 2012 only*

While structural failure is far more damaging (and more expensive) than blade failure, the accident consequences and risks to human health are most likely lower, as risks are confined to within a relatively short distance from the turbine. However, as smaller turbines are now being placed on and around buildings including schools, the accident frequency is expected to rise.

Ice throw

34 incidences of ice throw were found. Some are multiple incidents. These are listed here unless they have caused human injury, in which case they are included under "human injury" above.

By year:

Year	70s	80s	90s	00	01	02	03	04	05	06	07	08	09	10	11	12*
No.			9			2	2	4	4	3		3	4	1	1	1

** To 30 June 2012 only*

Ice throw has been reported to 140m. Some Canadian turbine sites have warning signs posted asking people to stay at least 305m from turbines during icy conditions.

These are indeed only a very small fraction of actual incidences – a report* published in 2003 reported 880 icing events between 1990 and 2003 in Germany alone. 33% of these were in the lowlands and on the coastline.

** ("A Statistical Evaluation of Icing Failures in Germany's '250 MW Wind' Programme – Update 2003, M Durstwitz, BOREAS VI 9-11 April 2003 Pyhätunturi, Finland.)*

Additionally one report listed for 2005 includes 94 separate incidences of ice throw and two reports from 2006 include a further 27 such incidences.

Transport

There have been 103 reported accidents – including a 45m turbine section ramming through a house while being transported, a transporter knocking a utility pole through a restaurant, and a turbine section falling off in a tunnel. Transport fatalities and human injuries are included separately. Most accidents involve turbine sections falling from transporters, though turbine sections have also been lost at sea, along with a £50M barge. Transport is the single biggest cause of public fatalities.

By year:

Year	70s	80s	90s	00	01	02	03	04	05	06	07	08	09	10	11	12*
No.						4		3	6	6	19	10	11	11	24	9

** To 30 June 2012 only*

Environmental damage (including bird deaths)

110 cases of environmental damage have been reported – the majority since 2007. This is perhaps due to a change in legislation or new reporting requirement. All involved damage to the site itself, or reported damage to or death of wildlife. 46 instances reported here include confirmed deaths of protected species of bird. Deaths, however, are known to be far higher. At the Altamont Pass windfarm alone, 2400 protected golden eagles have been killed in 20 years, and about 10,000 protected raptors (Dr Smallwood, 2004). In Germany, 32 protected white tailed eagles were found dead, killed by wind turbines (Brandenburg State records). In Australia, 22 critically endangered Tasmanian eagles were killed by a single windfarm (Woolnorth). Further detailed information can be found at: www.iberica2000.org/Es/Articulo.asp?Id=3071
and at: www.iberica2000.org/Es/Articulo.asp?Id=1875

By year:

Year	70s	80s	90s	00	01	02	03	04	05	06	07	08	09	10	11	12*
No.			1		1	1	8	1	6	5	10	21	13	19	17	7

** To 30 June 2012 only*

Other (miscellaneous)

247 miscellaneous accidents are also present in the data. Component failure has been reported here if there has been no consequential structural damage. Also included are lack of maintenance, electrical failure (not led to fire or electrocution), etc. Construction and construction support accidents are also included, also lightning strikes when a strike has not resulted in blade damage or fire. A separate 1996 report** quotes 393 reports of lightning strikes from 1992 to 1995 in Germany alone,
124 of those direct to the turbine, the rest are to electrical distribution network.
*** (Data from WMEP database: taken from report "External Conditions for Wind Turbine Operation – Results from the German '250 MW Wind' Programme", M Durstewitz, et al, European Union Wind Energy Conference, Goeteborg, May 20-24, 1996)*
From 2012, human impact will also be included under miscellaneous – for example, reports of shadow flicker, noise investigations and breaches, etc.

By year:

Year	70s	80s	90s	00	01	02	03	04	05	06	07	08	09	10	11	12*
No.			13	7	4	12	13	11	12	16	18	24	27	25	43	22

** To 30 June 2012 only*

Caithness Windfarm Information Forum
30 June 2012

East County Magazine

FIRE FEES JEOPARDIZE MUTUAL AID, FIRE DISTRICTS ASSOCIATION WARNS

By Miriam Raftery

August 1, 2012 (Sacramento)—The Fire Districts Association of California has sent a letter to its members advising that the State is preparing to notify

property owners within State Responsbility Areas (SRA) of the new
$150 annual fee for fire prevention services under Assembly Bill 29—even if people are within an existing fire district.

"The local fire districts are placed in the unenviable position of shouldering the day to day expenses of providing services, while onerous fees are imposed on their constituents without any direct benefit to the jurisdictions," states the FDAC, which opposed the bill and warns that the measure could imperial public safety.

California's Master Mutual Aid System, in which districts cooperate to send aid when and where it's needed is a model for the rest of the nation. But according to the FDAC, "This model of cooperation is now in jeopardy as agencies evaluate their willingness and ability to participate in this valuable program." That negative impact will continue for years to come unless the measure is repealed, the FDAC maintains.

The organization has recommended that fire district boards engage their constituents about each district's opposition to the fees and to let residents know that the fees are being charged by the state—not the districts, which do not receive any of the revenues generated by the new SRA fees. A sample resolution for boards to oppose the SRA fees was also included.

The SRA fees have drawn bitter responses and, at times, sarcasm locally.

"To cover us from SDGE started fires," Alpine Community Planning Group member Lou Russo sniped in an email blasting the fees. In an email to Supervisor Jacob, he alluded to fire mitigation grant funds that the utility company has been promoting. "Maybe SDGE can pick this up for us," he said of the fire fees assessed on residents who feel twice burned. "They appear to have plenty of money to spread around."

Wildlife Conservation and Solar Energy Development in the Desert Southwest, United States

Jeffrey e. Lovich and Joshua r. ennen

Large areas of public land are currently being permitted or evaluated for utility-scale solar energy development (USSED) in the southwestern United States, including areas with high biodiversity and protected species. However, peer-reviewed studies of the effects of USSED on wildlife are lacking. The potential effects of the construction and the eventual decommissioning of solar energy facilities include the direct mortality of wildlife; environmental impacts of fugitive dust and dust suppressants; destruction and modification of habitat, including the impacts of roads; and off-site impacts related to construction material acquisition, processing, and transportation. The potential effects of the operation and maintenance of the facilities include habitat fragmentation and barriers to gene flow, increased noise, electromagnetic field generation, microclimate alteration, pollution, water consumption, and

fire. Facility design effects, the efficacy of site-selection criteria, and the cumulative effects of USSED on regional wildlife populations are unknown. Currently available peer-reviewed data are insufficient to allow a rigorous assessment of the impact of USSED on wildlife.

Keywords: solar energy development, Mojave Desert, Sonoran Desert, wildlife, desert tortoises

The United States is poised to develop new renewable energy facilities at an unprecedented rate, including in potentially large areas of public land in the Southwest. This quantum leap is driven by escalating costs and demand for traditional energy sources from fossil fuels and by concerns over global climate change. Attention is focused largely on renewable forms of energy, especially solar energy. The potential for utility-scale solar energy development (USSED) and operation (USSEDO) is particularly high in the southwestern United States, where solar energy potential is high (USDOI and USDOE 2011a) and is already being harnessed in some areas. However, the potential for USSEDO conflicts with natural resources, especially wildlife, is also high, given the exceptional biodiversity (Mittermeier et al. 2002) and sensitivity (Lovich and Bainbridge 1999) of arid Southwest ecosystems, especially the Mojave (Randall et al. 2010) and Sonoran Deserts, which are already stressed by climate and human changes (CBI 2010). In addition, the desert Southwest is identified as a "hotspot" for threatened and endangered species in the United States (Flather et al. 1998). For these reasons, planning efforts should consider ways to minimize USSEDO impacts on wildlife (CBI 2010). Paradoxically, the implementation of large-scale solar energy development as an "environmentally friendly" alternative to conventional energy sources may actually increase environmental degradation on a local and on a regional scale (Bezdek 1993, Abbasi and Abbasi 2000) with concomitant negative effects on wildlife.

A logical first step in evaluating the effects of USSEDO on wildlife is to assess the existing scientific knowledge. As renewable energy development proceeds rapidly worldwide, information is slowly accumulating on the effects of USSEDO on the environment (for reviews, see Harte and Jassby 1978, Pimentel et al. 1994, Abbasi and Abbasi 2000). Gill (2005) noted that although the number of peer-reviewed publications on renewable energy has increased dramatically since 1991, only 7.6% of all publications on the topic covered environmental impacts, only 4.0% included discussions of ecological implications, and less than 1.0% contained information on environmental risks. A great deal of information on USSEDO exists in environmental compliance documents and other unpublished, non-peer-reviewed "gray" literature sources. Published scientific information on the effects on wildlife of any form of renewable energy development, including that of wind energy, is scant (Kuvlesky et al. 2007). The vast majority of the published research on wildlife and renewable energy development has been focused on the effects of wind energy development on birds (Drewitt and Langston 2006) and bats (Kunz et al. 2007) because of their sensitivity to aerial impacts. In contrast, almost no information is available on the effects of solar energy development on wildlife.

From a conservation standpoint, one of the most important species in the desert Southwest is Agassiz's desert

BioScience 61: 982–992. ISSN 0006-3568, electronic ISSN 1525-3244. © 2011 by American Institute of Biological Sciences. All rights reserved. Request permission to photocopy or reproduce article content at the University of California Press's Rights and Permissions Web site at *www.ucpressjournals.com/reprintinfo.asp*. doi:10.1525/bio.2011.61.12.8

tortoise (*Gopherus agassizii*; figure 1). Distributed north and west of the Colorado River, the species was listed as *threatened* under the US Endangered Species Act in 1990. Because of its protected status, Agassiz's desert tortoise acts as an "umbrella species," extending protection to other plants and animals within its range (Tracy and Brussard, 1994). The newly described Morafka's desert tortoise (*Gopherus morafkai*; Murphy et al. 2011) is another species of significant conservation concern in the desert Southwest, found east of the Colorado River. Both tortoises are important as ecological engineers who construct burrows that provide shelter to many other animal species, which allows them to escape the temperature extremes of the desert (Ernst and Lovich 2009). The importance of these tortoises is thus greatly disproportionate to their intrinsic value as species. By virtue of their protected status, Agassiz's desert tortoises have a significant impact on regulatory issues in the listed portion of their range, yet little is known about the effects of USSEDO on the species, even a quarter century after the recognition of that deficiency (Pearson 1986). Large areas of habitat occupied by Agassiz's desert tortoise in particular have potential for development of USSED (figure 2).

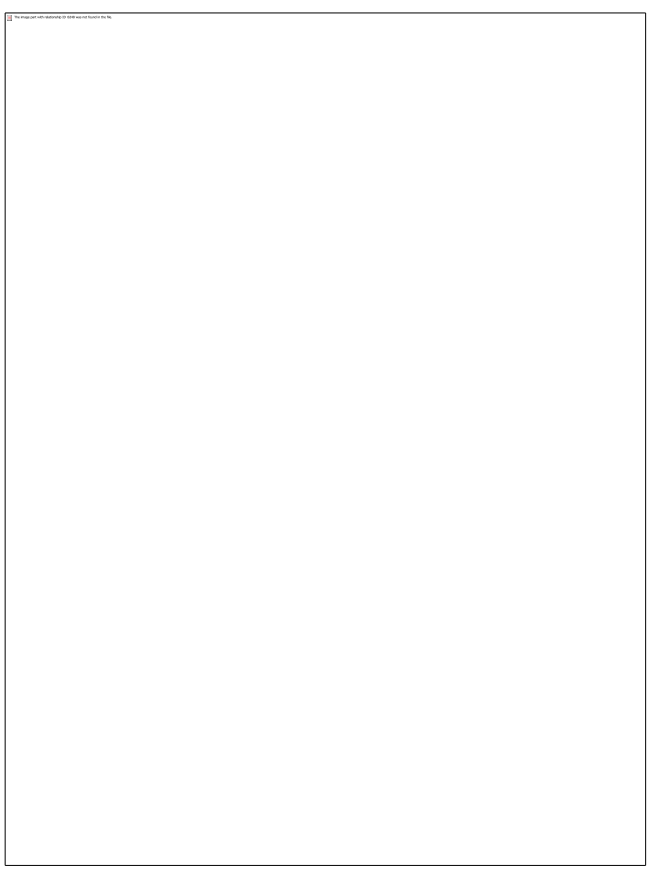


Figure 1. Agassiz's desert tortoise (*Gopherus agassizii*). Large areas of desert tortoise habitat are developed or being evaluated for renewable energy development, including for wind and solar energy. Photograph: Jeffrey E. Lovich.

In this article, we review the state of knowledge about the known and potential effects, both direct and indirect, of USSEDO on wildlife (table 1). Our review is based on information published primarily in peer-reviewed scientific journals for both energy and wildlife professionals. Agassiz's desert tortoise is periodically highlighted in our review because of its protected status, wide distribution in areas considered for USSEDO in the desert Southwest, and well-studied status (Ernst and Lovich 2009). In addition, we identify gaps in our understanding of the effects of USSEDO on wildlife and suggest questions that will guide future research toward a goal of mitigating or minimizing the negative effects on wildlife.

Background on proposed energy-development potential in the southwestern United States

The blueprint for evaluating and permitting the development of solar energy on public land in the region, as is required under the US National Environmental Policy Act (USEPA 2010), began in a draft environmental impact statement (EIS) prepared by two federal agencies (USDOI and USDOE 2011a). The purpose of the EIS is to "develop a new Solar Energy Program to further support utility-scale solar energy development on BLM [US Bureau of Land

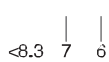


Figure 2. Concentrating solar energy potential (in kilowatt-hours per square meter per day [kWh/m²/day]) of the United States. The map shows the annual average direct normal solar resource data based on a 10-kilometer satellite-modeled data set for the period from 1998 to 2005. Refer to NREL (2011) for additional details and data sources. The white outline defines the approximate composite ranges of Agassiz's (west of the Colorado River) and Morafka's (east of the Colorado River) desert tortoises (Murphy et al. 2011) in the United States, both species of significant conservation concern. This figure was prepared by the National Renewable Energy Laboratory for the US Department of Energy (NREL 2011). The image was authored by an employee of the Alliance for Sustainable Energy, LLC, under Contract no. DE-AC36-08GO28308 with the US Department of Energy. Reprinted with permission from NREL 2011.

Table 1. List of known and potential impacts of utility-scale solar energy development on wildlife in the desert Southwest.

Impacts due to facility construction and decommissioning	Impacts due to facility presence, operation, and maintenance
Destruction and modification of wildlife habitat	Habitat fragmentation and barriers to movement and gene flow
Direct mortality of wildlife	Noise effects
Dust and dust-suppression effects	Electromagnetic field effects
Road effects	Microclimate effects
Off-site impacts	Pollution effects from spills
Destruction and modification of wildlife habitat	Water consumption effects
	Fire effects
	Light pollution effects, including polarized light
	Habitat fragmentation and barriers to movement and gene flow
	Noise effects

Management] -administered lands… and to ensure consistent application of measures to avoid, minimize, or mitigate the adverse impacts of such development" (p. ES-2). As of February 2010, the BLM had 127 active applications for solar facilities on lands that the BLM administers. According to USDOI and USDOE (2011a), all of the BLM-administered land in six states (California, Arizona, Utah, Nevada, New Mexico, and Colorado) was considered initially, for a total of 178 million hectares (ha). Not all of that land is compatible with solar energy development, so three alternative configurations are listed by USDOI and USDOI (2011a) for consideration, ranging from 274,244 to 39,972,558 ha. The larger figure is listed under the *no action alternative* where BLM would continue to use existing policy and guidance to evaluate applications. Of the area being considered under the two action alternatives, approximately 9 million ha meet the criteria established under the BLM's preferred action alternative to support solar development. Twenty-five criteria were used to exclude certain areas of public land from solar development and include environmental, social, and economic factors. The preferred alternative also included the identification of proposed *solar energy zones* (SEZs), defined as "area[s] with few impediments to utility-scale production of solar energy" (USDOI and USDOE 2011a, p. ES-7). By themselves, these SEZs constitute the nonpreferred action alternative of 274,244 ha listed above. Maps of SEZs are available at *http://solareis.anl.gov/documents/dpeis/index.cfm*.

Several sensitive, threatened, or endangered species are being considered within the EIS, but Agassiz's desert tortoise is one of only four species noted whose very presence at a site may be sufficient to exclude USSED in special cases (see table ES.2-2 in USDOI and USDOE 2011a). The potential effects of USSEDO are not trivial for tortoises or other wildlife species. Within the area covered in the draft EIS by USDOI and USDOE (2011a), it is estimated that approximately 161,943 ha of Agassiz's desert tortoise habitat will be directly affected. However, when including direct and indirect impacts on habitat (excluding transmission lines and roads that would add additional impacts; see Lovich and Bainbridge 1999, Kristan and Boarman 2007), it is estimated that approximately 769,230 ha will be affected. Some SEZs are adjacent to critical habitat designated for the recovery of Agassiz's desert tortoise, and this proximity is considered part of the indirect impacts.

On 28 October 2011, while this paper was in press, the BLM and US Department of Energy released a supplement to the EIS (USDOI and USDOE 2011b, 2011c) after receiving more than 80,500 comments. The no action alternative remains the same as in the EIS. The new preferred alternative (slightly reduced to 8,225,179 ha as the modified program alternative) eliminates or adjusts SEZs (now reduced to 115,335 ha in 17 zones as the modified SEZ alternative) to ensure that they are not in high-conflict areas and provides incentives for their use. The new plan also proposes a process to accommodate additional solar energy development outside of SEZs and to revisit ongoing state-based planning efforts to allow consideration of additional SEZs in the future.

The impacts of USSED on wildlife: Effects due to construction and decommissioning

The construction and eventual decommissioning of solar energy facilities will have impacts on wildlife, including rare and endangered species, and on their habitats in the desert (Harte and Jassby 1978). These activities involve significant ground disturbance and direct (e.g., mortality) and indirect (e.g., habitat loss, degradation, modification) impacts on wildlife and their habitat (Kuvlesky et al. 2007). Solar energy facilities require large land areas to harness sunlight and convert it to electrical energy. According to Wilshire and colleagues (2008), photovoltaic panels with a 10% conversion efficiency would need to cover an area of about 32,000 square kilometers, or an area a little smaller than the state of Maryland, to meet the current electricity demands of the United States. Many of the areas being considered for the development of solar energy in the Mojave and Sonoran Deserts are, at present, relatively undisturbed (USDOI and USDOE 2011a).

The extent of surface disturbance of USSED is related to the cooling technology used. Because of the scarcity of water in the desert Southwest region, dry-cooling systems, which consume 90%–95% less water than wet-cooling systems (EPRI 2002), are becoming a more viable option for concentrating solar facilities. Although wet-cooling systems are more economical and efficient, they consume larger amounts of water per kilowatt-hour (Torcellini et al. 2003). Unlike wet-cooling systems, dry-cooling systems use ambient air, instead of water, to cool the exhaust steam from the turbines. However, to achieve a heat-rejection efficiency similar to that in a wet-cooling system, Khalil and colleagues (2006) estimated that a direct dry-cooling system will require a larger footprint and would thus affect more wildlife habitat.

Although we found no information in the scientific literature about the direct effects of USSED on wildlife, the ground-disturbance impacts are expected to be similar to those caused by other human activities in the desert (Lovich and Bainbridge 1999).

Dust and dust suppressants. USSED transforms the landscape substantially through site preparation, including the construction of roads and other infrastructure. In addition, many solar facilities require vegetation removal and grading. These construction activities produce dust emissions, especially in arid environments (Munson et al. 2011), which already have the potential for natural dust emission. Dust can have dramatic effects on ecological processes at all scales (reviewed by Field et al. 2010). At the smallest scale, wind erosion, which powers dust emission, can alter the fertility and water-retention capabilities of the soil. Physiologically, dust can adversely influence the gas exchange, photosynthesis, and water usage of Mojave Desert shrubs (Sharifi et al. 1997). Depending on particle size, wind speed, and other factors, dust emission can physically damage plant species through root exposure, burial, and abrasions to their leaves and stems. The physiological and physical damage to plant species inflicted by dust emissions could ultimately reduce the plants' primary production and could indirectly affect wildlife food plants and habitat quality.

From an operational perspective, dust particles reduce mirror and panel efficiency in converting solar energy into heat or electricity. To combat dust, solar energy facilities apply various dust suppressants to surfaces with exposed soil (e.g., graded areas, areas with vegetation removed, roads). There are eight categories of common dust suppressants used for industrial applications: water, salts and brines, organic nonpetroleum products, synthetic polymers, organic petroleum, electrochemical substances, clay additives, and mulch and fiber mixtures (reviewed in Piechota et al. 2004). In a study conducted in the Mojave Desert in which the hydrological impacts of dust suppressants were compared, Singh and colleagues (2003) reported that changes did occur in the volume, rate, and timing of runoff when dust suppressants were used. In particular, petroleum-based and acrylic-polymer dust suppressants drastically influenced the hydrology of disturbed areas by increasing runoff volume and changing its timing. When it is applied to disturbed desert soils, magnesium chloride ($MgCl_2$), a commonly used salt-based dust depressant, does not increase runoff volume but does, however, increase the total suspended solids loads in runoff (Singh et al. 2003).

Others have highlighted the fact that there is a dearth of scientific research and literature on the effects of dust suppressants on wildlife, including the most commonly used category of dust depressant: brines and salts (Piechota et al. 2004, Goodrich et al. 2008). However, the application of $MgCl_2$ to roads was correlated with a higher frequency of plant damage (Goodrich et al. 2008). Because chloride salts, including $MgCl_2$, are not confined to the point of application but have the ability to be transported in runoff (White and Broadly 2001), the potential exists for a loss of primary production associated with plant damage in the habitats surrounding a solar facility, which could directly affect wildlife habitat.

Mortality of wildlife. We are not aware of any published studies documenting the direct effects of USSED on the survival of wildlife. However, subterranean animals can be affected by USSED, including species that hibernate underground. In the Sonoran Desert portion of California, Cowles (1941) observed that most reptiles in the Coachella Valley hibernated at depths of less than 33 centimeters (cm), with many at considerably shallower depths. Included in his observations were flat-tailed horned lizards (*Phrynosoma mcallii*)—a species of special concern in the region because of solar energy development (USDOI and USDOE 2011a)—and the federally protected Coachella Valley fringe-toed lizard (*Uma inornata*). Even lightweight vehicles like motorcycles are capable of causing greatly increased soil density (soil compaction) at a depth of 30–60 cm as their tires pass over the surface (Webb 1983). These observations suggest that vehicular activities in the desert have the potential to kill or entrap large numbers of subterranean animals (Stebbins 1995) through compressive forces or burrow collapse. Similar or greater impacts would be expected from the heavy equipment associated with the construction activities at an energy facility.

Destruction and modification of wildlife habitat. Despite the absence of published, peer-reviewed information on the effects of USSED on wildlife and their habitats, a considerable body of literature exists on the effects of other ground-disturbing activities on both ecological patterns and processes that are broadly comparable. Ground-disturbing activities affect a variety of processes in the desert, including soil density, water infiltration rate, vulnerability to erosion, secondary plant succession, invasion by exotic plant species, and stability of cryptobiotic soil crusts (for reviews, see Lovich and Bainbridge 1999, Webb et al. 2009). All of these processes have the ability—individually and together—to alter habitat quality, often to the detriment of wildlife. Any disturbance and alteration to the desert landscape, including the construction and decommissioning of utility-scale solar energy facilities, has the potential to increase soil erosion. Erosion can physically and physiologically affect plant species and can thus adversely influence primary production (Sharifi et al. 1997, Field et al. 2010) and food availability for wildlife.

Solar energy facilities require substantial site preparation (including the removal of vegetation) that alters topography and, thus, drainage patterns to divert the surface flow associated with rainfall away from facility infrastructure (Abbasi and Abbasi 2000). Channeling runoff away from plant communities can have dramatic negative effects on water availability and habitat quality in the desert, as was shown by Schlesinger and colleagues (1989). Areas deprived

of runoff from sheet flow support less biomass of perennial and annual plants relative to adjacent areas with uninterrupted water-flow patterns.

The impacts of roads. Roads are required in order to provide access to solar energy infrastructure. Both paved and unpaved roads have well-documented negative effects on wildlife (Forman and Alexander 1998), and similar effects are expected in utility-scale solar energy facilities. Although road mortality is most easily detected on the actual roadway, the effects of roads extend far beyond their physical surface. In a study of the effects of roads on Agassiz's desert tortoise populations in southern Nevada, von Seckendorff Hoff and Marlow (2002) examined transects along roads with traffic volumes varying from 25 to 5000 vehicles per day. Tortoises and tortoise sign (e.g., burrows, shells, scat) decreased with their proximity to a road. On roads with high traffic volumes, tortoises and tortoise sign were reduced as far as 4000 meters from the roadside. Roads with lower traffic volumes had fewer far-reaching effects.

Another effect of roads in the desert is the edge enhancement of plants and arthropod herbivores (Lightfoot and Whitford 1991). Perennial plants along the roadside are often larger than those farther away, and annual plant germination is often greatest along the shoulders of roads. It is possible that increased runoff due to impervious pavement or compacted soil contributes to this heterogeneity of vegetation in relationship to a road. Agassiz's desert tortoises may select locations for burrow construction that are close to roads, perhaps because of this increased productivity of food plants (Lovich and Daniels 2000). Although this situation suggests potentially beneficial impacts for herbivorous species of wildlife, such as tortoises, it increases their chance of being killed by vehicle strikes, as was shown by von Seckendorff Hoff and Marlow (2002).

Off-site impacts. Direct impacts on wildlife and habitat can occur well outside the actual footprint of the energy facility. Extraction of large amounts of raw materials for the construction of solar energy facilities (e.g., aggregate, cement, steel, glass); transportation and processing of those materials; the need for large amounts of water for cooling some installations; and the potential for the production of toxic wastes, including coolants, antifreeze, rust inhibitors, and heavy metals, can affect wildlife adjacent to or far from the location of the facility (Abbasi and Abbasi 2000). Abbasi and Abbasi (2000) summarized data suggesting that the material requirements for large-scale solar facilities exceed those for conventional fossil-fuel plants on a cost-per-unit-of-energy basis. In addition, water used for steam production at one solar energy facility in the Mojave Desert of California contained selenium, and the wastewater was pumped into evaporation ponds that attracted birds that fed on invertebrates. Although selenium toxicity was not considered a threat on the basis of the results of one study, the possibility exists for harmful bioaccumulation of this toxic micronutrient (Herbst 2006). In recognition of the hazard, Pimentel and colleagues (1994) suggested that fencing should be used to keep wildlife away from these toxic ponds.

The impacts of USSED on wildlife: Effects due to operation and maintenance

This category includes the effects related to the presence and operation of the solar facility, not the physical construction and decommissioning of the same. Some of the effects (e.g., mortality of wildlife and impacts caused by roads) are similar to those discussed previously for construction and decommissioning and are not discussed further.

Habitat fragmentation. Until relatively recently, the desert Southwest was characterized by large blocks of continuous and interconnected habitat. Roads and urban development continue to contribute to habitat fragmentation in this landscape. Large-scale energy development has the potential to add to and exacerbate the situation, presenting potential barriers to movement and genetic exchange in wildlife populations, including those of bighorn sheep (*Ovis canadensis*), deer (*Odocoileus* spp.), tortoises, and other species of concern and social significance. Research conducted on the effects of oil and gas exploration and development (OGED) on wildlife in the Intermountain West provides a possible analog to USSEDO, since comparable data are not available for the desert Southwest. The potential effects on mule deer (*Odocoileus hemionus*) and other wildlife species include impediments to free movement, the creation of migration bottlenecks, and a reduction in effective winter range size. Mule deer responded immediately to OGED by moving away from disturbances, with no sign of acclimation during the three years of study by Sawyer and colleagues (2009). Some deer avoidance resulted in their use of less-preferred and presumably less-suitable habitats.

Despite a lack of data on the direct contributions of USSEDO to habitat fragmentation, USSEDO has the potential to be an impediment to gene flow for some species. Although the extent of this impact is, as yet, largely unquantified in the desert, compelling evidence for the effects of human-caused habitat fragmentation on diverse wildlife species has already been demonstrated in the adjacent coastal region of southern California (Delaney et al. 2010).

Noise effects. Industrial noise can have impacts on wildlife, including changes to their habitat use and activity patterns, increases in stress, weakened immune systems, reduced reproductive success, altered foraging behavior, increased predation risk, degraded communication with conspecifics, and damaged hearing (Barber et al. 2009, Pater et al. 2009). Changes in sound level of only a few decibels can elicit substantial animal responses. Most noise associated with USSEDO is likely to be generated during the construction phase (Suter 2002), but noise can also be produced during operation and maintenance activities. Brattstrom and Bondello (1983) documented the effects of noise on Mojave

Desert wildlife on the basis of experiments involving off-highway vehicles. Noise from some of these vehicles can reach 110 decibels—near the threshold of human pain and certainly within the range expected for various construction, operation, and maintenance activities (Suter 2002) associated with USSEDO. This level of noise caused hearing loss in animals, such as kangaroo rats (*Dipodomys* spp.), desert iguanas (*Dipsosaurus dorsalis*), and fringe-toed lizards (*Uma* spp.). In addition, it interfered with the ability of kangaroo rats to detect predators, such as rattlesnakes (*Crotalus* spp.), and caused an unnatural emergence of aestivating spadefoot toads (*Scaphiopus* spp.), which would most likely result in their deaths. Because of impacts on wildlife, Brattstrom and Bondello (1983) recommended that "all undisturbed desert habitats, critical habitats, and all ranges of threatened, endangered, or otherwise protected desert species" (p. 204) should be protected from loud noise.

Although many consider solar energy production a "quiet" endeavor, noise is associated with their operation. For example, facilities at which wet-cooling systems are used will have noises generated by fans and pumps. As for facilities with dry-cooling systems, only noise from fans will be produced during operation (EPRI 2002). Because of the larger size requirements of dry-cooling systems, there will be more noise production associated with an increase in the number of fans.

Electromagnetic field generation. When electricity is passed through cables, it generates electric and magnetic fields. USSEDO requires a large distribution system of buried and overhead cables to transmit energy from the point of production to the end user. Electromagnetic fields (EMFs) produced as energy flows through system cables are a concern from the standpoint of both human and wildlife health, yet little information is available to assess the potential impact of the EMFs associated with USSEDO on wildlife. Concerns about EMFs have persisted for a long time, in part because of controversy over whether they're the actual cause of problems and disagreement about the underlying mechanisms for possible effects. For example, there is presently a lack of widely accepted agreement about the biological mechanisms that can explain the consistent associations between extremely low-frequency EMF exposure from overhead power lines and childhood leukemia, although there is no shortage of theories (Gee 2009).

Some conclude that the effects of EMFs on wildlife will be minor because of reviews of the often conflicting and inconclusive literature on the topic (Petersen and Malm 2006). Others suggest that EMFs are a possible source of harm for diverse species of wildlife and contribute to the decline of some mammal populations. Balmori (2010) listed possible impacts of chronic exposure to athermal electromagnetic radiation, which included damage to the nervous system, disruption of circadian rhythm, changes in heart function, impairment of immunity and fertility, and genetic and developmental problems. He concluded that enough evidence exists to confirm harm to wildlife but suggested that further study is urgently needed. Other authors suggest that the generally inconsistent epidemiological evidence in support of the effects of EMFs should not be cause for inaction. Instead, they argue that the precautionary principle should be applied in order to prevent a recurrence of the "late lessons from early warnings" scenario that has been repeated throughout history (Gee 2009).

Magnetic information is used for orientation by diverse species, from insects (Sharma and Kumar 2010) to reptiles (Perry A et al. 1985). Despite recognition of this phenomenon, the direct effects of USSEDO-produced EMFs on wildlife orientation remains unknown.

Microclimate effects. The alteration of a landscape through the removal of vegetation and the construction of structures by humans not only has the potential of increasing animal mortality but also changes the characteristics of the environment in a way that affects wildlife. The potential for microclimate effects unique to solar facilities was discussed by Pimentel and colleagues (1994) and by Harte and Jassby (1978). It has been estimated that a concentrating solar facility can increase the albedo of a desert environment by 30%–56%, which could influence local temperature and precipitation patterns through changes in wind speed and evapotranspiration. Depending on their design, large concentrating solar facilities may also have the ability to produce significant amounts of unused heat that could be carried downwind into adjacent wildlife habitat with the potential to create localized drought conditions. The heat produced by central-tower solar facilities can burn or incinerate birds and flying insects as they pass through the concentrated beams of reflected light (McCrary et al. 1986, Pimentel et al. 1994, Tsoutsos et al. 2005, Wilshire et al. 2008).

A dry-cooled solar facility—in particular, one with a concentrating-trough system—could reject heated air from the cooling process with temperatures 25–35 degrees Fahrenheit higher than the ambient temperature (EPRI 2002). This could affect the microclimate on site or those in adjacent habitats. To our knowledge, no research is available to assess the effects of USSEDO on temperature or that of any other climatic variable on wildlife. However, organisms whose sex is determined by incubation temperatures, such as both species of desert tortoises, may be especially sensitive to temperature changes, because small temperature changes have the potential to alter hatchling sex ratios (Hulin et al. 2009).

Pollutants from spills. USSEDO, especially at wet-cooled solar facilities, has a potential risk for hazardous chemical spills on site, associated with the toxicants used in cooling systems, antifreeze agents, rust inhibitors, herbicides, and heavy metals (Abbasi and Abbasi 2000, Tsoutsos et al. 2005). Wet-cooling solar systems must use treatment chemicals (e.g., chlorine, bromine, selenium) and acids and bases (e.g., sulfuric acid, sodium hydroxide, hydrated lime) for the prevention of fouling and scaling and for pH control of the water used in their recirculating systems (EPRI 2002).

Solar facilities at which a recirculating system is used also have treatment and disposal issues associated with water discharge, known as *blowdown*, which is water with a high concentration of dissolved and suspended materials created by the numerous evaporation cycles in the closed system (EPRI 2002). These discharges may contain chemicals used to prevent fouling and scaling. The potentially tainted water is usually stored in evaporative ponds, which further concentrates the toxicants (Herbst 2006). Because water is an attraction for desert wildlife, numerous species could be adversely affected. The adverse effects of the aforementioned substances and similar ones on wildlife are well documented in the literature, and a full review is outside the scope of this article. However, with the decreased likelihood of wet-cooling systems for solar facilities in the desert, the risk of hazardous spills and discharges on site will be less in the future, because dry-cooling systems eliminate most of the associated water-treatment processes (EPRI 2002). However, there are still risks of spills associated with a dry-cooling system. More research is needed on the adverse effects of chemical spills and tainted-water discharges specifically related to USSEDO on wildlife.

Water consumption (wet-cooled solar). The southwestern United States is a water-poor region, and water use is highly regulated throughout the area. Because of this water limitation, the type of cooling systems installed at solar facilities is limited as well. For example, a once-through cooling system—a form of wet cooling—is generally not feasible in arid environments, because there are few permanent bodies of water (i.e., rivers, oceans, and lakes) from which to draw cool water and then into which to release hot water. Likewise, other wet-cooling options, such as recirculating systems and hybrid systems, are becoming less popular because of water shortage issues in the arid region. Therefore, the popularity of the less-efficient and less-economical dry-cooling systems is increasing on public lands. Water will also be needed at solar facilities to periodically wash dust from the mirrors or panels. Although there are numerous reports in which the costs and benefits were compared both environmentally and economically (EPRI 2002, Khalil et al. 2006) between wet- and dry-cooled solar facilities, to our knowledge no one has actually quantified the effects of water use and consumption on desert wildlife in relation to the operation of these facilities.

Fire risks. Any system that produces electricity and heat has a potential risk of fire, and renewable energy facilities are no exception. Concentrating solar energy facilities harness the sun's energy to heat oils, gases, or liquid sodium, depending on the system design (e.g., heliostat power, trough, dish). With temperatures reaching more than 300 degrees Celsius in most concentrated solar systems, spills and leaks from the coolant system increase the risk of fires (Tsoutsos et al. 2005). Even though all vegetation is usually removed from the site during construction, which reduces the risk of a fire propagating on and off site, the increase of human activity in a desert region increases the potential for fire, especially along major highways and in the densely populated western Mojave Desert (Brooks and Matchett 2006).

The Southwest deserts are not fire-adapted ecosystems: fire was historically uncommon in these regions (Brooks and Esque 2002). However, with the establishment of numerous flammable invasive annual plants in the desert Southwest (Brown and Minnich 1986), coupled with an increase in anthropogenic ignitions, fire has become more common in the deserts, which adversely affects wildlife (Esque et al. 2003). For Agassiz's desert tortoise, fire can translate into direct mortality at renewable energy facilities (Lovich and Daniels 2000) and can cause reductions in food and habitat quality. To our knowledge, however, there is no scientific literature related to the effects of USSEDO-caused fire on wildlife.

Light pollution. Two types of light pollution could be produced by solar energy facilities: ecological light pollution (ELP; Longcore and Rich 2004) and polarized light pollution (PLP; Horváth et al. 2009). The latter, PLP, could be produced at high levels at facilities using photovoltaic solar panels, because dark surfaces polarize light. ELP can also be produced at solar facilities in the form of reflected light. The reflected light from USSEDO has been suggested as a possible hazard to eyesight (Abbasi and Abbasi 2000). ELP could adversely affect the physiology, behavior, and population ecology of wildlife, which could include the alteration of predation, competition, and reproduction (for reviews, see Longcore and Rich 2004, Perry G et al. 2008). For example, the foraging behavior of some species can be adversely affected by light pollution (for a review, see Longcore and Rich 2004). The literature is limited regarding the impact of artificial lighting on amphibians and reptiles (Perry G et al. 2008), and, to our knowledge, there are no published studies in which the impacts on wildlife of light pollution produced by USSEDO have been assessed. However, light pollution is considered by G. Perry and colleagues (2008) to be a serious threat to reptiles, amphibians, and entire ecological communities that requires consideration during project planning. G. Perry and colleagues (2008) further recommended the removal of unnecessary lighting so that the lighting conditions of nearby habitats would be as close as possible to their natural state.

Numerous anthropogenic products—usually those that are dark in color (e.g., oil spills, glass panes, automobiles, plastics, paints, asphalt roads)—can unnaturally polarize light, which can have adverse effects on wildlife (for a review, see Horváth et al. 2009). For example, numerous animal species use polarized light for orientation and navigation purposes (Horváth and Varjú 2004). Therefore, the potential exists for PLP to disrupt the orientation and migration abilities of desert wildlife, including those of sensitive species. In the review by Horváth and colleagues (2009), which was focused mostly on insects but included a few avian references, they highlighted the fact that anthropogenic products that produce PLP can appear to be water bodies to wildlife and can become ecological traps for insects and, to a lesser degree, avian species. Therefore,

utility-scale solar energy facilities at which photovoltaic technology is used in the desert Southwest could create a direct effect on insects (i.e., ecological trap), which could have profound but unquantified effects on the ecological community surrounding the solar facility. In addition, there may be indirect effects on wildlife through the limitation of plant food resources, especially if pollinators are negatively affected. As was stated by Horváth and colleagues (2009), the population- and community-level effects of PLP can only be speculated on because of the paucity of data.

Unanswered questions and research needs

In our review of the peer-reviewed scientific literature, we found only one peer-reviewed publication on the specific effects of utility-scale solar energy facility operation on wildlife (McCrary et al. 1986) and none on utility-scale solar energy facility construction or decommissioning. Although it is possible that we missed other peer-reviewed publications, our preliminary assessment demonstrates that very little critically reviewed information is available on this topic. The dearth of published, peer-reviewed scientific information provides an opportunity to identify the fundamental research questions for which resource managers need answers. Without those answers, resource managers will be unable to effectively minimize the negative effects of USSEDO on wildlife, especially before permitting widespread development of this technology on relatively undisturbed public land.

Before-and-after studies. Carefully controlled studies are required in order to tease out the direct and indirect effects of USSEDO on wildlife. Pre- and postconstruction evaluations are necessary to identify the effects of renewable energy facilities and to compare results across studies (Kunz et al. 2007). In their review of wind energy development and wildlife, with an emphasis on birds, Kuvlesky and colleagues (2007) noted that experimental designs and data-collection standards were typically inconsistent among studies. This fact alone contributes measurably to the reported variability among studies or renders comparisons difficult, if not impossible. Additional studies should emphasize the need for carefully controlled before-after-control-impact (BACI) studies (Kuvlesky et al. 2007) with replication (if possible) and a detailed description of site conditions. The potential payoff for supporting BACI studies now could be significant: They could provide answers for how to mitigate the negative impacts on wildlife in a cost-effective and timely manner.

What are the cumulative effects of large numbers of dispersed or concentrated energy facilities? Large portions of the desert Southwest have the potential for solar energy development. Although certain areas are targeted for large facilities because of resource availability and engineering requirements (e.g., their proximity to existing transmission corridors), other areas may receive smaller, more widely scattered facilities. A major unanswered question is what the cumulative impacts of these facilities on wildlife are. Would it be better for wildlife if development is concentrated or if it is scattered in smaller, dispersed facilities? Modeling based on existing data would be highly suspect because of the deficiency of detailed site-level published information identified in our analysis. Except for those on habitat destruction and alteration related to other human endeavors, there are no published articles on the population genetic consequences of habitat fragmentation related to USSED, which makes this a high priority for future research.

What density or design of development maximizes energy benefits while minimizing negative effects on wildlife? We are not aware of any published peer-reviewed studies in which the impacts on wildlife of different USSED densities or designs have been assessed. For example, would it benefit wildlife to leave strips of undisturbed habitat between rows of concentrating solar arrays? Research projects in which various densities, arrays, or designs of energy-development infrastructure are considered would be extremely valuable. BACI studies would be very useful for addressing this deficiency.

What are the best sites for energy farms with respect to the needs of wildlife? The large areas of public land available for renewable energy development in the desert Southwest encompass a wide variety of habitats. Although this provides a large number of choices for USSED, not all areas have the same energy potential because of resource availability and the limitations associated with engineering requirements, as was noted above. Detailed information on wildlife distribution and habitat requirements are crucially needed for proper site location and for the design of renewable energy developments (Tsoutsos et al. 2005). Public-resource-management agencies have access to rich geospatial data sets based on many years of inventories and resource-management planning. These data could be used to identify areas of high value for both energy development and wildlife. Areas with overlapping high values could be carefully studied through risk assessment when it appears that conflicts are likely. Previously degraded wildlife habitats, such as old mine sites, overgrazed pastures, and abandoned crop fields, may be good places to concentrate USSED to minimize its impacts on wildlife (CBI 2010).

Can the impacts of solar energy development on wildlife be mitigated? The construction of solar energy facilities can cause direct mortality of wildlife. In addition, building these facilities results in the destruction and fragmentation of wildlife habitat and may increase the possibility of fire, as was discussed above. Beyond these effects, essentially nothing is known about the operational effects of solar energy facilities on wildlife. Current mitigation strategies for desert tortoises and other protected species include few alternatives other than translocation of the animals from the footprint of the development into other areas. Although this strategy may be appealing at first glance, animal translocation has a checkered history of success, especially for reptiles and amphibians (Germano and Bishop 2008, CBI 2010). Translocation

has yet to be demonstrated as a viable long-term solution that would mitigate the destruction of Agassiz's desert tortoise habitat (Ernst and Lovich 2009, CBI 2010).

Conclusions

All energy production has associated social and environmental costs (Budnitz and Holdren 1976, Bezdek 1993). In their review of the adverse environmental effects of renewable energy development, Abbasi and Abbasi (2000) stated that "renewable energy sources are not the panacea they are popularly perceived to be; indeed, in some cases, their adverse environmental impacts can be as strongly negative as the impacts of conventional energy sources" (p. 121). Therefore, responsible, efficient energy production requires both the minimization of environmental costs and the maximization of benefits to society—factors that are not mutually exclusive. Stevens and colleagues (1991) and Martín-López and colleagues (2008) suggested that the analyses of costs and benefits should include both wildlife use and existence values. On the basis of our review of the existing peer-reviewed scientific literature, it appears that insufficient evidence is available to determine whether solar energy development, as it is envisioned for the desert Southwest, is compatible with wildlife conservation. This is especially true for threatened species such as Agassiz's desert tortoise. The many other unanswered questions that remain after reviewing the available evidence provide opportunities for future research, as was outlined above.

The shift toward renewable energy is widely perceived by the public as a "green movement" intended to reduce greenhouse-gas emissions and acid rain and to curb global climate change (Abbasi and Abbasi 2000). However, as was noted by Harte and Jassby (1978), just because an energy technology is simple, thermodynamically optimal, renewable, or inexpensive does not mean that it will be benign from an ecological perspective. The issue of wildlife impacts is much more complex than is widely appreciated, especially when the various scales of impact (e.g., local, regional, global) are considered. Our analysis shows that, on a local scale, so little is known about the effects USSEDO on wildlife that extrapolation to larger scales with any degree of confidence is currently limited by an inadequate amount of scientific data. Therefore, without additional research to fill the significant information void, accurate assessment of the potential impacts of solar energy development on wildlife is largely theoretical but needs to be empirical and well-founded on supporting science.

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