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An Integrative Ecosystem Approach To A More Sustainable Urban Ecology: Heat Island Mitigation, Urban Forestry, and Landscape Management Can Reduce the Ecological Footprint of Our Cities

Ashwani Vasishth
Assistant Professor,
Department of Urban Studies and Planning,
California State University, Northridge
vasishth@csun.edu
(818) 677-6137

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Conventional planning often under-represents, and at times even misrepresents, situations because it is overly biased towards physically tangible and humanly perceivable entities and events, while systematically undervaluing the less tangible, but formatively more significant, processes and functions that underwrite ecological realities. While we can only act in the world by manipulating the structural and morphological elements that mark its shapes, we cannot afford to ignore the often insensate processes and functions that constitute our world. I have argued that an ecological planning, based on an ecosystem approach to making descriptions, would be more effective in constructing instrumental representations in support of planning interventions. Such an approach recognizes the perspectival bias inherent in all attempts to describe a complex, and hence multiply occurring, reality. It also explicates the making of contingent boundaries, is self-conscious about the scales that are chosen to depict the elements of concern, and is predicated upon a statement of the purpose for which each particular description is being made.

My thesis, that such an ecosystem approach to making descriptions based on processes and functions results in more effective and relevant instrumental depictions, is usefully illustrated by the case of an urban ecology that incorporates heat island mitigations, urban forestry, and landscape management (taken both as the introduction of native vegetation and the insertion of increased proportions of pervious paving), all considered within the framework of an integrative ecosystem approach to land use planning. Taken apart, and in each case, the benefits of urban heat island mitigation, urban forestry, and impervious surface management measures may appear marginal, at best. But, taken cumulatively, the pay-off becomes substantial, thus illustrating the value and the necessity of an integrative systems approach. More importantly, such an approach to urban ecology is useful because, as a mode of intervention, it rests on—indeed, requires—an acknowledgement in environmental planning of the often amorphous and usually only indirectly sensible atmospheric, biogeochemical and hydrological processes and functions.

Managing Ecological Processes and Functions As A Way of Reintegrating Cities with Nature

Dark, heat-absorbing, impervious surfaces—roofs, roads, and parking lots—are the quintessential hallmark of urbanization. Such surfaces, often unmitigated, have a range of significant and cumulative effects on the ecological and bio-geo-chemical processes and functions that underwrite our cities, and so shape our inhabited world. Conventional building practices result in increased ambient temperatures[1] due to the proliferation of heat-absorbing surfaces, increased urban stormwater runoff, reduced groundwater recharge, disruptions of local landscape ecologies, fragmentation of natural habitats, increased air pollution, increased water pollution, increased biological and mechanical heat stress, and the more unequivocal separation of humans from nature.

This diverse range of changes to processes and functions can partly be captured by the concepts of urban heat islands, urban forestry, and, in the case of warm and arid Southern California, Xeriscape. We can dramatically change how our cities work, and how they sit in nature, by paying conscious attention to these ecological phenomena in land use planning. Although these various

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[1] Analysis shows that rural-urban differences in temperature correlate strongly with population increases in the case of changes in minimum temperatures, although in a stepped or episodic manner (showings abrupt increases followed by extended periods of no change, perhaps linked to concentrated growth spurts in urbanization). Maximum temperatures, being recorded in the daytime, fluctuate much more due to highly localized changes in meteorology and increased air turbulence, and so clear trends are more difficult to determine. [Brazel et al., 2000]

effects, as well as the measures which can effectively mitigate against them, have been known for some time, the ways in which we choose to plan and build have just barely begun to take these factors into account—perhaps because we continue to treat the world as mechanical, rather than embracing its ecological basis.

Such dark, under-shaded surfaces absorb in-coming solar radiation and then re-radiate this heat into the lower atmosphere, raising localized temperatures, often by five to ten degrees Fahrenheit. This increase in ambient temperatures usually results in greater expenditures of energy for cooling the structures we inhabit, particularly in the mid- to low-latitudes and in the summer afternoons, when energy demand is often at its highest. Mitigation measures—the use of lighter colored and heat reflecting surfaces for roofs and paving, as well as the increased plantation of ecologically suitable species of trees and vegetation[2]—are capable of reducing ambient temperatures by four to eight degrees Fahrenheit. This reduction is achieved partly by physically altering the heat-absorbing properties of surfaces, partly by increasing localized cooling

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[2] Trees are not all equal, and can themselves be a source of volatile organic compounds in the form of biogenic emissions. See, for instance, Benjamin & Winer [1998]; Benjamin et al., [1996]; Beckett et al., [2000]. In addition, non-native tree species are often not adapted to localized conditions, and so may require substantially greater investment, in terms of care and maintenance. Choosing from a palette of native species, and using criteria based on the particular location of each planting, we can increase the effectiveness of such ecological interventions by managing for biogenic emissions, for habitat suitability, and for maintainablity.

due to evaporative transpiration from plant and soil systems,[3] and partly by morphologically inserting shade into the urban landscape, thus reducing energy consumption in the summer and in the afternoons when energy demand is highest.[4]

Taken together, these mitigation measures have a number of other quite substantial benefits as well. Tropospheric ozone formation is a temperature sensitive photochemical reaction, in which precursor gases (volatile organic compounds and oxides of nitrogen) react in the presence of sunlight to form smog. This reaction is temperature-sensitive. Thus, reductions in urban ambient temperatures carry the potential of reducing smog-formation, without physically reducing the volume of precursor gases exhausted into the lower atmosphere.

The extensive plantation of ecologically suitable species of trees and shrubbery, besides increasing morphological shading and enhancing the locally cooling processes of evaporative transpiration in soil-plant systems, also greatly

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[3] See, for instance, Meier [1991]; Sailor [1998]; and Dimoudi & Nikolopoulou [2003].

[4] There is a converse “winter penalty” that is incurred, in some cases, by the wide-spread application of these heat island mitigation measures, in that the cost of heating buildings in the winter would be increased somewhat. But Rosenfeld et al. [1998:54] find that this is a small penalty, and the cumulative summer-time benefits of reducing air conditioning costs by 24% far outweigh the winter penalty, which increased heating costs by about 7% in the case of Southern California. Elsewhere, Rosenfeld et al. [1997:57] note that this net energy saving applies as far north as New York City, explaining that, in all mid-latitude locations, winter sun is lower in the sky, and thus the ratio of sunlight striking the roof to the walls is also smaller. In addition, winter days are shorter, and so the summer benefits of lighter colored roofs substantially outweigh their winter penalty.

increase the surfaces available to capture ambient particulate matter (dust) generated by traffic and by urban activity, thus potentially benefiting respiratory health. In addition, the vegetation of the urban landscape increases the proportion of pervious to impervious surfaces, which, in turn, reduces storm-water run-off even as it increases ground-water recharge. A variety of habitat-enhancing ecological and community effects can also be ascribed to the increased native vegetation resulting from such measures. Not incidentally, these reductions in temperatures also reduce the often considerable thermal stress on roofing and paving materials, substantially increasing their effective life span and reducing maintenance costs [Taha & Akbari, 2003:1].

We have known about these processes and phenomena for some time now, but the shape of how we plan and build has only just begun to take these factors into account in transformative ways. No doubt this lag in adoptive action is shaped most by disciplinary fragmentation in research, and by the professional segmentation of environmental planning into functional typologies such as land use planning, air quality planning, water quality planning, stormwater management, urban forestry, and so on. But it may as well be the case that conventional descriptions of the world are traditionally biased toward the morphological—in that, it is easier to mobilize action against pollution processes that are directly sensible to us, based on sight and smell, and harder to do so against pollution processes that can only be indirectly measured, using instruments and models.

Albedo Modification, Vegetation and Urban Forestry As Heat Island Mitigation

Impervious surfaces are the hallmark of urbanization. Vitousek [1994] argues that land use and land cover change, taken together, are one of the three most significant global change processes that ecologists must take into account. From within an ecological perspective, roofs, roads and paving are perhaps the single most critical factor that set cities apart from the countryside [Arnold & Gibbons, 1996; Pielke et al., 2002 Brabec et al., 2002; Berke et al., 2003; De Fries et al., 2004; Stone, Jr., 2004; Jin et al., 2005]. The consequences of such a concentration of impervious surfaces, usually in the form of dark asphalt and roofing materials, extend to influencing the local climate and the local hydrology in varying degrees and depending upon the particulars of locational and ecological context. Taha [1997a:99] notes that “northern hemisphere urban areas annually have an average of 12% less solar radiation, 8% more clouds, 14% more rainfall, 10% more snowfall, and 15% more thunderstorms than their rural counterparts.”

However, urban heat islands, like most ecological phenomena, are not a singularity. In general, urban areas are four to 10 degrees Fahrenheit warmer than their surrounding countryside. Depending upon latitudinal location, the surrounding ecology, and meso-scale climate, a heat island effect may show itself most either in the summer or in the winter, during the day or at night, and causing increases in heating, smog formation or rainfall. In the higher latitudes, urban heat islands may most markedly increase temperatures in the winter, thus reducing building heating costs. In lower latitudes, the effect may be most pronounced in the summer months, resulting in higher air-conditioning costs and increased smog formation. In coastal arid climates such as Los Angeles, the heat island effect may be most relevant in the afternoons, causing increased smog formation and energy consumption. Along the more humid Atlantic seaboard, heat islands may generate increased rainfall and thunderstorms [Dixon & Mote 2003, Shepherd et al., 2002; Rozoff et al., 2003a, 2003b]. While in desert locations, and with depressed topographies such as Phoenix, the effect may most show itself most at night, keeping the urban core hotter for hours after the sun has set [Brazel et al., 2005; Kullman, 2005] and thus increasing energy consumption long into the otherwise-cooler nights.

In Southern California, in the case of the urbanization in the region surrounding Los Angeles, the Mediterranean climate is influenced by its coastal location, juxtaposed with an inland desert ecology, and capped by a tropospheric inversion layer that tends to trap smog-forming precursor gases—namely, volatile organic compounds and oxides of nitrogen. In such a case, and broadly speaking, the urban heat island effect is most markedly manifest at about 2 PM in the afternoon, when increased ambient temperatures most severely affect peak demands for electricity, and when the temperature-sensitive photochemical smog-forming reactions most manifest their pollution effects.

Here, three sorts of strategies are available to mitigate the heat island effect. We can physically increase the albedo, or heat reflecting properties, of sunward oriented surfaces such as roofs, roads and paving, by using lighter colored or otherwise more heat-reflecting materials.[5] We can increase the proportion of vegetation and shrubbery to hard landscapes, and even promoting the adoption of roof-top gardens or green roofs, thus increasing opportunities for plant- and soil-based processes of evapo-transpirative cooling. And we can use urban forestry programs to extensively plant strategically sited and ecologically-suitable tree species throughout the urbanized area, increasing both evapo-transpiration and physical shading.[6]

Rosenfeld et al. [1998] describe a “cool communities” strategy for the inland urbanized Los Angeles area, in which they assess the energy conservation and tropospheric ozone (smog) air pollution reduction benefits of a two-pronged strategy that focuses on increasing the albedo of roofing and paving

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[5] Albedo is the heat-reflecting property of a surface, the proportion of incoming electro-magnetic radiation that is reflected by surfaces directly exposed to solar energy. The ratio is usually represented as a fraction between 0 and 1, where 0 represents a theoretical condition where all of the incoming solar radiation is absorbed by a surface, and 1 represents a theoretical condition under which all the incoming solar radiation is reflected by a surface. Typically, fresh tarmac asphalt has an albedo of something like 0.05, aged asphalt has an albedo of about 0.10, most urban surfaces have an albedo between 0.10 and 0.20 [Taha, 1997:100], highly reflective roof surfaces can have an albedo of about 0.65, and fresh white paint may have an albedo of up to 0.90.

[6] In addition, health benefits such as due to the amelioration of ultra-violet-B radiation, which has been linked strongly to certain forms of skin cancers. Research indicates that “…where many large street tree crowns block much of the sky, substantial protection from UVB is afforded for pedestrians,, even in spots with direct sunlight. The result argues for the maintenance of large-crowned trees in areas frequented by people, especially children.” [Heisler & Grant, 2000b:27] Interestingly, Heisler and Grant [2000a: 217] find that even trees with bare branches and twigs (such as in winter conditions) can substantially reduce UV-B irradiation, while actual shade does not always correlate with lower levers of UV-B [2000a: 214].

materials by an average of 0.30, and on the strategic plantation of 11 million trees in the more densely inhabited parts of the region. Their analysis shows a 12% reduction in the number of days per year on which tropospheric ozone exceeds the National Ambient Air Quality Standards, and a 10% reduction in air-conditioning loads during peak early afternoon demand. They found that, at peak temperatures, around 2 PM, an approximately five to six degrees Fahrenheit reduction in ambient temperatures would be effected by their "cool communities" strategy.

Their research concludes that the proposed albedo modification component and the tree planting component of their "cool communities" strategy generate roughly equal amounts of ambient cooling in the lower atmosphere of the Los Angeles urbanized area. That is to say, if about one-third of the rooftops within the region, and if the paved surfaces concentrated within 25% of the inland urbanized area, were treated so as to increase the albedo of treated roofs by about 0.35 and the albedo of modified paving by about 0.25, this would generate an average increase in the albedo of sunward oriented surfaces in the order of about 0.30. And if, in addition, about 11 million ecologically suitable species of trees were to be planted strategically across the region, then about half the cooling in ambient temperatures would be attributable to each of these two strategies. "The cooling for 'albedo only' turns out to be equal to that of 'trees only,' and is additive" [Rosenfeld et al., 1998: 53].

Estimating smog reduction benefits on the basis of the reduction in the number of days in the year that smog concentrations exceed the California ambient air quality standard of 90 parts per billion by volume (ppbv), their simulation shows that the combined benefits of the tree planting and albedo modification strategies result in a 12% reduction in the number of days in a year on which the air quality standards for tropospheric ozone are exceeded. "In apportioning how much of the benefits we calculated could be attributed to the three separate strategies (trees, roofs, and pavements), we found 50% of the temperature decrease (and thus 50% of the smog reduction) arises from tree planting. The remaining 50% was proportionally attributed to albedo changes resulting from light-colored roofs (0.35) and pavements (0.25), which translates to 29% of the benefits from light-colored roofs and 21% from light-colored pavements" [Rosenfeld et al., 1998: 53-54].

Smog, or tropospheric ozone, is not a directly emitted pollutant, but rather is the product of a complex reaction involving two sets of precursor gases—oxides of Nitrogen and volatile organic compounds (VOC)—in the presence of sunlight. The photochemical reaction may be either NOx-constrained or VOC-constrained, depending on the relative proportion of the gases present in the troposphere. In the case of Southern California, Rosenfeld et al. take the reaction to be NOx-constrained. In assessing the smog-reduction benefits of their proposed heat island mitigation measures of shade tree plantation and a change to lighter colored paving and roof surfaces, they consider two components in the reduction of NOx gases—the direct reductions in NOx emissions by power plants, due to reductions in peak-time electric power consumption, and the effective or “equivalent” reductions in NOx, due to reductions in ambient temperatures.[7]

In the base case for Southern California, they assume that 1,350 tons of NOx and 1,500 tons of volatile organic compounds (VOC) are present and available to the photochemical smog-formation reaction by the early afternoon peak reaction time. They find that the reductions in electricity consumption result in a small reduction in NOx emissions by power plants, in the order of 7 tons, or a direct reduction of 0.5% in NOx. However, as they point out, “(r)educing smog by citywide cooling can be considered equivalent to reducing the formation of smog precursors at constant temperatures.” Relying on research by Taha [1996; 1997b], Rosenfeld et al. conclude that the two strategies of shade trees and lighter colored or higher albedo surfaces, together result in a 10% reduction in smog. Applying research by Milford et al. [1989], they conclude that this 10% reduction in smog is equivalent to a 25% reduction in precursor gases, with the tropospheric system behaving as though there had been a 350 ton reduction in NOx emissions within the air basin.

Albedo modification strategies, cool roofs and cool paving interventions that cumulatively increase regional albedo from 0.25 to 0.40, have been modeled to effectively reduce localized ambient temperatures by as much as seven

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[7] Since the smog forming reaction is temperature-sensitive, a reduction in ambient temperatures is equivalent to a reduction in NOx, with the tropospheric system behaving as though there were lower quantities of precursor gases present.

degrees Fahrenheit in Southern California's mid-latitude climate [Taha, 1997a:101]. Taha concludes, "temperature decreases of this magnitude could reduce the electricity load from air conditioning by 10% and smog (ozone concentrations) by up to 20% during hot summer days." Elsewhere, Taha [1997b:1668] has found that the average albedo for sunward oriented land surfaces in Southern California is 0.14, and has concluded that the theoretical "maximum increase in albedo will probably never exceed 0.30," and that this should be established as the extreme upper bound for modeling purposes, while an albedo increase of 0.15 for sunward oriented surfaces is a reasonable moderate increase.

The results of his simulation of such changes in albedo, for a clear and warm day in August, at 3 PM, indicate that the urban core might see a decrease in temperature of about three to four degrees Fahrenheit in the case of moderate (0.15) increase in albedo, and up to eight degrees Fahrenheit in the case of an extreme (0.30) increase in albedo, with outlying areas showing a more modest decrease of about two and four degrees Fahrenheit [Taha, 1997b:1670]. The estimated effect of such a temperature reduction on tropospheric ozone formation was considered to account for "(1) a decrease in some photochemical reaction rates, (2) a decrease in temperature-dependent biogenic hydrocarbon emissions,[8] (3) a decrease in evaporative losses of organic compounds from

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[8] Trees and vegetation are natural sources of hydrocarbon, which are precursor gases in tropospheric ozone formation [Benjamin & Winer, 1997], and

mobile and stationary sources, and (4) a decreased need for cooling energy, generating capacity, and, thus, emissions from power plants" [Taha, 1997b:1667].

Sensitivity simulations in the Southern California Air Basin (SCAB) have shown a net decrease in tropospheric ozone concentrations of about 12%, for a domain-wide average reduction in temperature of three degrees Fahrenheit. While "decreasing the SoCAB's temperature alone always resulted in decreasing ozone concentrations," Taha points out that this decrease is a net effect, as there is likely to be a slight increase in ozone concentrations in some sub-areas and at some mixing heights, due to changes in atmospheric densities and a potential slowing down of sea breezes at some heights [Taha, 1997b:1672]. Of course, preventing the formation of tropospheric ozone in some part of the air basin, by reducing local ambient temperatures, does not preclude the subsequent transportation of those same precursor gases to some other parts of the air basin with relatively higher temperatures, where the smog formation earlier avoided may now take place. These various factors, taken together, have been shown to result in both increases and decreases in ozone formation at the sub-regional level, but the complex processes resulting from decreases in ambient temperature always result in a net decrease in smog formation in Southern California.

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this is an important factor to keep in mind when selecting the species of trees and shrubs to be used in heat island mitigation schemes of this sort.

Changing the Albedo of Roofing and Paving Materials

Vernacular architecture, in a cross-cultural context, is defined as the traditional, native, locally prevalent mode of building, using locally available materials and construction techniques, and based on a traditional and historically tested knowledge-base. Many "traditional," and hence by implication "primitive," modes of knowing may actually be more effective than modern-day beliefs and practices. Take, for instance, the traditional architectures of places that fall within desert climates. In most cases, structures in such places are regularly white-washed, including rooftops. For instance, "building owners in hot cities like Haifa and Tel Aviv are required to whitewash their roofs each spring, after the rains stop" [Rosenfeld et al.,1997:55]. Modern day building practices are driven far more by the contemporary economics of air conditioning, which routinely fail to internalize many of the costs of not using such traditional building techniques. An ecological approach to building would require attention to such knowledge processes.

One key insight from process-function ecology is that direct human sensory perception is at best a limited means of "getting at" the processes and functions that actually shape our world. Conventional empiricism, being based on a reliance on our senses of sight, smell, hearing, taste and touch, has only limited value in an ecosystem approach. Processes and functions outside the scope of our senses drive many of the phenomena that matter most to us. Albedo is one such phenomenon. In general, and very incompletely, the gradient from light to dark colors does approximate the gradient from high to low albedo—that is to say, from highly heat reflecting properties to highly heat absorbing properties. But a substantial part of the heating that occurs due to incoming solar radiation is in the near-infrared range of the spectrum, and so hidden from our direct sensory abilities. This explains why, for instance, "dark" terracotta roofing tiles may be measurably cooler than "white" asphalt-fiberglass shingles [Rosenfeld et al., 1997:57], and why old "white" shingles may be more heat reflective (by up to 20 degrees Fahrenheit) than modern "white" shingles, which use one-sixth the thickness of white pigment as they did in 1960 [Rosenfeld et al., 1997:55].

What this means, of course, is that we are not strictly constrained to the aesthetic of "white," in our urban landscapes. The use of, for instance, titanium dioxide (TiO2) as an additive to paints used to coat roof surfaces, allows us to apply a range of pastel shades which still have the high albedo properties in which we are most interested. Recent developments in building materials, particularly some very interesting contemporary research about the dirt-repelling properties of TiO2-coated materials, for instance, raises interesting prospects for longer-lasting albedo-increasing effects in a variety of building materials [Benedix et al., 2000; Frazer, 2001].[9]

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[9] Besides increasing the albedo of paints in which TiO2 is used as a pigment additive, this material has shown some additionally intriguing properties, such as the repelling of dirt from a variety of materials (glass, fabric, etc.), the reduction of nitrogen oxides [Mitsubishi Materials Corporation, undated Sales Brochure] and of volatile organic compounds [Turchi et al., 1995], in the presence of ultraviolet

Another facet of such an albedo-modification approach would focus on roads and pavements, where direct experiments show substantial heat reduction benefits as well.

Tree Planting and Vegetation Change As Integrative Regional Environmental Interventions

Landscape level land use change is one of the most significant ways in which we shape, and by which we can reshape, our lived environments. The displacement of native vegetative cover, first by small-scale agriculture, then by the more extensive irrigated agricultural systems that mark our recent industrializing history, resulted in a host of ecological changes upon the land. Just as one example, Southern California saw a significant decreasing trend in ambient temperatures as large-scale agriculture and orchard cultivation took hold at the turn of the previous century, with yearly high temperatures dropping almost as low as 95 degrees Fahrenheit by about 1930. Then, urbanization became the ecologically dominant force in land cover and land use change, and the yearly

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light. So, for instance, a semi-open multilevel parking structure of the sort commonly found in most U.S. urban settings, and a local hotspot for both nitrogen oxides and volatile organic compounds, could very easily and quite cheaply have its ceilings, walls, columns and floors painted with TiO_2-based paint materials, which, in the presence of some suitable artificial lighting system that radiates in the ultra-violet range, would then proceed to deconstruct the exhaust gases emitted by vehicles as they travel in to and out of these structures. The turbulence generated by moving vehicles would additionally bring these exhaust gases more effectively into contact with the TiO_2-treated surfaces.

high temperatures began a fairly steady increase, which has continued into the present [Rosenfeld et al., 1997:56].

The insertion of ecologically appropriate species of trees and vegetative cover into the urban fabric can be at least as powerful a transformation of the ecosystem processes and functions that support the city, as was their displacement by impervious surfaces. In the particular context of urban heat island mitigation, the most obvious way in which trees help is by physically interjecting shade into our built landscape, thus reducing the heat loads on the walls and immediate surroundings of our urban environment. Shade alone may provide a significant reduction in heat flux, reducing the amount of heat transferred through walls and roofs into the interior spaces by as much as 40 to 50 degrees Fahrenheit, and thus directly reducing the amount of cooling work needed to be done by our air-conditioning systems.

Soil-Vegetation Evaporation and Transpiration As Cooling Processes

But there is a subtler, though at least as effective, process of cooling that is a by-product of tree and plant growth. Vegetation draws up water from the soil below, through its root structures, and some of this water is released in the form of moisture by the foliage (transpiration) and by the soil itself (evaporation), so cooling the lower atmosphere. The soil-vegetation complex acts to enhance this natural process of evaporative transpiration, or evapo-transpiration. This process can be a major influence in micro-climate cooling, as walking under a broad, leafy tree on any hot, dry summer afternoon will directly demonstrate. Evapo-transpiration processes can generate estimated reductions in local ambient temperatures of 10 to 15 degrees Fahrenheit, on a typical summer afternoon [Meier, 1991; Sailor, 1998; Dimoudi & Nikolopoulou, 2003]. This cooling effect is more pronounced in dry, semi-arid climates such as Southern California.

Green Roofs for Heat Insulation and Stormwater Retention

A different, but equally effective and promising, strategy is the widespread introduction of what are coming to be called "green roofs," or roof-top gardens. Both through extensive experimentation and through materials innovation, green roofs are now poised to significantly help restore nature and natural processes back into the built urban environment. Broadly speaking, there are two sorts of green roofs—extensive and intensive. Extensive green roofs are usually thin layers of vegetative growing media, typically six inches or less, spread over large expanses of roofing, with some suitably durable and hardy species of ground cover, such as one of the many varieties of sedum. "The challenge in designing extensive green roofs is to replicate many of the benefits of green open space, while keeping them light in weight and affordable. Thus, the new generation of green roofs relies on a marriage of the sciences of horticulture, waterproofing, and engineering" [Miller, undated].

Green roofs have evolved, in recent years, from being thought of as an additional burden to be placed on roof structures to being seen now as an additional protective covering that helps shield the waterproofing membranes of conventional flat or very low slope roofs from heat stress. Experimental tests seem to indicate that well-designed and properly constructed extensive green roofs may help extend the life of the waterproofing membrane and of the roof structure itself, even as they insulate the enclosed spaces from the worst ravages of the summer sun [Taha &Akbari, 2003].

As a heat island mitigation strategy, green roofs are different from albedo modification and urban forestry in that their primary functional action is to physically insulate the roof membrane. Certainly the albedo of such green roofs is likely to be higher than that of conventional (particularly normal asphalt) shingles. But, when compared to the albedo of most materials normally used for their heat-reflective properties (titanium-dioxide treated white shingles or some of the more contemporary membrane materials), the benefits are likely to be nominal. There is certainly an evapo-transpirative effect, but since it plays out in the rather narrow zone immediately above the ground cover, its heat-reducing actions, either locally or regionally, are again likely to be nominal at best.

However, extensive green roofs do have one additional advantage, in that they can be designed to deliver, at little increase in cost and performance, virtually any desired level of stormwater retention. A 50% reduction in runoff is almost the default setting, and additional gains are easily made. German designers have worked with green roofs very extensively, and case studies are said to be available across a very wide range of siting conditions and using different technologies, making comparative analysis possible. Most researchers who have worked with green roof technologies seem to be clear that these technologies, with some little care and attention in execution, are consistently reliable and do, indeed, deliver the range of benefits that theoretical calculations suggest.

Urban Forestry and Landscape Ecology In Air Pollution Mitigation

Heat island mitigation measures that include strategic and intensive tree planting can cumulatively reduce local ambient temperatures by between four to eight degrees Fahrenheit. As discussed earlier, this reduction in local temperatures can potentially reduce the formation of tropospheric ozone (smog) by up to 20%. This result occurs because smog formation is a photo-chemical reaction that is sensitive to temperature. The same volumes of precursor gases (volatile organic compounds and nitrogen oxides) will produce lower volumes of tropospheric ozone at lower temperatures, providing a significant benefit in air quality. Rosenfeld et al. [1998] suggest that the massive plantation of something like 11 million trees in the Southern California region, when coupled with the strategic treatment of one-third of the residential rooftops within about 25% of the urbanized portion of the region, along with the treatment of road surfaces within this same sub-region, would result in a 12% reduction in the number of days on which air quality in the South Coast Air Basin exceeds the National Ambient Air Quality Standards. This is equivalent to a 350 ton decrease in precursor gases, as discussed earlier.

An additional and not insignificant benefit to urban ecology derives in the case of Southern California, from the implementation of tree planting ordinances for downtown surface parking lots and car dealerships. This is particularly salient in the case of Los Angeles County, where little effort is currently made to implement or enforce any such minimum tree cover measure, and acres of cars can be seen sitting baking in the sun all day. A 50% tree cover ordinance would go a long way to mitigating the range of adverse environmental impacts from these typically treeless expanses of impervious surfaces [McPherson et al., 2001; Scott et al., 1999a; Scott et al., 1999b; Geiger, 2002; Wolf, 2004]. Not only are there measurable benefits to be realized from the reductions in evaporative emissions from such parked vehicles, but substantial stormwater and ground water benefits would accrue as well, both in terms of stormwater mitigation and in terms of ground water recharge. This is especially true if tree planting ordinances are combined with landscape management techniques such as the encouraged use of porous pavement and pervious concrete, implemented in appropriate ways [Cahill, 1994; Booth & Leavitt, 1999; Brabec et al., 2002; Huffman, 2005].

These reductions in local ambient temperature have the additional benefit of decreasing the need for air conditioning during peak demand periods—that is to say, in the summer and in the mid-afternoon. This decrease reduces the region’s need for cooling energy, particularly in the residential context, as Rosenfeld et al. [1998] and Taha [1997b] point out, in turn reducing the demand for electricity generating capacity, and so indirectly reducing emissions from power plants. Of course, power plants supplying electricity to a particular region, such as Southern California, may or may not be located in that region. And nuclear power plants are also an exception to this case. But, in most instances, some air pollution benefits can be expected to accrue from this reduced demand for air conditioning energy. Beside toxic ozone-precursor emission reductions, a substantial abatement of greenhouse gas emissions can also be attributed to such heat island and urban forestry sorts of interventions.

An additional and related air pollution control benefit accruing directly from increased use of ecologically appropriate species of trees and vegetation is the capture and sequestration of carbon dioxide (CO2), a significant greenhouse gas, through the natural process of photosynthesis. Rosenfeld et al. [1998:57] suggest that urban trees may provide three times the carbon dioxide reduction benefits than the same trees planted in forests or in non-urban areas. This reduction occurs because, in urban environments and besides the direct sequestration of carbon into the biomass through photosynthesis (which might be in the order of about 5 kilograms of carbon), these urban trees may as well reduce energy consumption for air conditioning if they are appropriately sited so as to provide direct shading to buildings, by as much as 15 kilograms each year. Nowak & Crane [2002:387] estimate that urban trees, through a combination of direct carbon sequestration and carbon dioxide emission avoidance, may provide four times the GHG reduction benefits of the same tree planted in a forest stand. As such, projects that seek to implement tree planting as carbon sequestration should consider prioritizing the planting of trees in urban environments, particularly in cases where these trees might directly and indirectly shade air conditioned buildings, as their return on investment will be much higher than if they were to fund similar projects in forest or rural areas.

Besides direct local shading and local cooling through evapo-transpiration, another local air quality benefit accrues from the ability of leafy trees to trap fine and ultra-fine particulate matter onto their leaf surfaces. The dense plantation of otherwise low-biogenic emission tree species [Benjamin & Winer, 1998; Benjamin et al., 1996; Beckett et al., 2000] downwind of dust pollution sources such as traffic corridors with high volumes of, for instance, truck traffic, would substantially reduce human and ecological exposures to toxic exhaust gases in strategically identified “hot spots,” generating substantial environmental health benefits.

Impervious Surface Management and Landscape Ecology for Stormwater Retention and Groundwater Recharge

The extent to which our cities are marked by the spread of impervious surfaces is a powerful indicator of our ecological footprint, and of the heaviness of our tread upon the land. A variety of strategies are available to us to mitigate the ecological impacts of roofs, roads and paving. We can insert trees and vegetation into our urban landscapes far more copiously than is our current practice, taking care to choose species of trees, shrubs and ground cover vegetation that are well adapted to local ecosystem conditions. We can advocate strongly for the conversion of conventional urban and suburban lawns, which intensively use irrigation and chemicals, to Xeriscape sorts of plants and vegetation. We can begin to popularize the use of green roofs, which will do quite well in Southern California with thoughtful design and appropriate selection of species of cover, such as sedum, which are able to thrive with little on-going maintenance.

A variety of porous materials are also available for parking lots and for paving, which, when combined with rainwater harvesting technologies, can substantially increase groundwater recharge even as they dramatically reduce stormwater run-off [Cahill, 1994; Booth & Leavitt, 1999; Brabec et al., 2002; Huffman, 2005].

Letting Nature Back Into Our Cities, Using Ecological Processes, Functions and Landscape Management

Conventional building practices result in increased ambient temperatures due to the proliferation of heat-absorbing surfaces, reduced groundwater recharge and increased urban stormwater runoff. Constructing tree-less parking lots, placing non-native vegetation in ornamental gardens and synthetically maintained lawns, results in a patchwork appropriation of land uses, increased air and water pollution more biological and material heat stress, and, ultimately, the deepening separation of humans from nature.

Rather than using locally appropriate building materials and climatically adapted dwelling types, we choose instead to capitalize on what seem, in the short term and in some narrowly defined way, like the clear economic benefits of mass-production mass-culture. Of course, we must then compensate for the ecological consequences of such narrowly constructed choices through the increased use of air conditioning and heating, single-occupancy automotive transportation, and the ever-greater importation of water and electricity. By denying ecology, we come to live more heavily upon the land.

Fortunately, it need not be so. We can let nature back into our cities, using intelligence and trees and native vegetation to lighten our tread. These three strategies from urban ecology can, together, provide many of the infrastructure benefits our contemporary society needs. Heat island mitigations, urban forestry, and impervious surface management can drastically reduce air and water pollution, significantly increase our natural water supply, substantially strengthen the connectivity of the rich and diverse habitats within which we dwell, and at the same time considerably mitigate that massive transfer of below-ground carbon into the atmosphere due to our civilization's reliance on fossil fuels.

Heat island mitigation measures use lighter colored and heat reflecting building and paving materials for sunward oriented surfaces, to reduce peak afternoon loads on our electricity supply infrastructure, and to substantially extend the life of the building materials themselves, by reducing heat stress. Urban forestry uses ecologically appropriate species of trees and shrubs strategically planted to shade our buildings, to cool the air through the entirely natural processes of evaporative transpiration, to capture dust particles upon their copious leaf surfaces, to capture and store rainwater, and penetrate the soils to increase groundwater recharge. Impervious surface management would use innovative and by now well-tested materials technologies to make our downtown parking lots more porous, while deploying drought-resistant Xeriscape plants which naturally need less water to grow across our lawns and gardens. Together, and cumulatively, these green infrastructure measures would reduce our ecological footprint, and, at the same time, increase the effective carrying capacity of our land.

The key elements to such an ecosystem approach to ecological planning require: that we give due consideration to the sometimes intangible processes and functions that drive occurrence in reality; that we conceptualize complex systems as being organized into nested levels; that we give attention to the power of multiple spatial, temporal and organizational scales to reveal different relevant aspects of reality; and that we properly select multiple depictive boundaries that simultaneously respect the ecological elements of structure, pattern and process.

Pulling It All together: Humans As Components of Ecosystems

Integrating our cities and urban regions back into nature is an objective we should take seriously, both because it reduces adverse environmental impacts, thus reducing pollution treatment and remediation costs. Such a strategy, if based on contemporary ecosystem ecological, landscape ecological, and urban ecological research-based knowledge, would significantly reduce the ecological footprint of human habitation, thus effectively increasing planetary carrying capacity. Together, these potential benefits provide a sound and savvy science-based approach to contemporary regional sustainability planning.

Urbanizing habitat conservation planning, by percolating ecologically appropriate landscape elements back into the city, would move regions such as Southern California, with their high incidence of pressured, at-risk, threatened and endangered species, away from a reactive “crisis management” approach to a more sustainable, nurturing and proactive approach to integrating our cities back into nature.[10]

The approach advocating for the adoption of albedo-modifying heat island mitigation measures, when combined with urban forestry, impervious surface management, and, in the case of Southern California, Xeriscape sorts of ecologically appropriate vegetation, illustrate one example of innovative connections that wait to be made across conventionally disparate and insular myriad sub-disciplines that make up the planning structures of regional governance. [Vasishth, 2006]

Taking a landscape ecology approach to regional land cover management in urbanizing areas would, in itself, strengthen habitat integrity, reduce pressures on nature conservation planning, reduce energy consumption, improve air quality, reduce stormwater runoff, reduce urban runoff pollution, enhance groundwater recharge, enhance community livability, allow the inculcation of a

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[10] One crucial confounder in conventional planning is the imperative to economic efficiency, when it is too narrowly or unthinkingly defined. The idea of choosing the “least costly” option from among a range of potential alternative actions is usually approached without a consideration of time scales. An option can be cheaper in the present while simultaneously being more expensive in the future. But planning has not yet learned to think sophisticatedly in multiple temporal scales.

cultural connectivity with ecological processes and functions, and so, quite directly, with nature. Arguably, acting reflectively and self-consciously to take account of such usually ignored processes and functions would also strengthen the robustness of the way everyday planning and decision making happens at the community and city level.

And, at the very least, such an integrative approach to regional planning would foster synergistic support across conventional planning disciplines, with transportation planners, air quality planners, water quality and supply planners, urban foresters, land use planners, habitat conservation planners, community development planners, natural resource planners, energy planners, and so on, both providing support to, and receiving support from, one another.

I have sought to show that a quite specific sort of ecosystem approach based on nested scale hierarchic or process-function ecosystem ecology does, in very pragmatic ways, provide us with the tools to create richly informative descriptions of otherwise complex spaces. The “dilemmas in a general theory of planning” posited by Rittel and Webber in their classic characterization of complex systems as “wicked problems,” are indeed amenable to planning. But only if we are astute enough to recognize their assertion that the tools from “tame” problem planning cannot be applied, in and of themselves, to complex systems. And then we need to see that there are indeed ways in which we can engage these complex systems in meaningful conversations that generate outcomes more desirable to the greater good and across levels of organization. We need to grow from a merely reactive and mechanistic problem-solving approach that attempts to singularize issues to make them easier for us to wrap our heads around, toward a planning that embraces the adoption of an adaptive management-based ecosystem approach. This approach needs also to be grounded firmly in techniques for making rich descriptions that allow us to get a better handle on complexity. Respect for, and especially a deep appreciation of, complexity is necessary. But we have the means for constructive engagement as well.

Synthesis: Hallmarks of An Ecosystem Approach to Making Rich Descriptions Under Complexity

Attention to context and consequence are the hallmarks of an ecosystem approach to planning, under conditions of complexity. Nested scale-hierarchic process-function ecosystem ecology offers some very useful tools for generating pragmatic descriptions in environmental planning. To summarize, and as prelude to demonstrating an application of such an ecosystem approach to regional urban planning in the particular case of Southern California, three key points need to be underscored:

1. System connectivity counts—the ecological consequences of specific actions cut across spatial, temporal and functional scales, and must be traced across *levels of organization*.
2. *Processes and functions* may matter more than morphological entities and events—occurrant actuality may trump perceived reality in coming to know ecological consequences.

3. *Boundaries and scales* must be chosen multiply and deliberatively, and across levels of organization, using functionally appropriate and diverse spatial, temporal and organizational scales, to richly capture ecological context.

Put differently, the core elements of an ecosystem approach to decision making under conditions of complexity consist of the self-conscious and reflective use of a multi-perspective, multi-criteria, multi-scale, multi-boundary approach to making operational descriptions, using the levels-of-organization concept to structure the planning domain under consideration, and paying particular attention to the processes and functions that may or may not be directly evident to human sensory perception.

Planning, as the craft of societal deliberative decision making, has already begun the work of integrating the instrumental dimensions of the sustainability imperative. Two of the keys to the sustainability puzzle are embodied in: a) the recognition of the need for a multi-factor, multi-criteria, multi-perspective approach to describing the contextual characteristics of decision phenomena, and b) the need for an inter-temporal, inter-generational perspective in tracing consequence. The next step in the realization of a genuinely ecological approach—that is to say, taking on complexity fearlessly, while getting beyond the metaphoric imagery and the jargon of holism, the everything-is-connected-to-everything-else sorts of stuff—is an expansion of this view of sustainability in two directions.

First, we must broaden our ideas of system formation to accept ecological processes and functions as the real and proper “objects of concern” for regional environmental planning. This requires that we train ourselves in the sophisticated choosing of multiple functionally relevant boundaries. And also that we expand our ideas of scale beyond our current recognition of spatial and temporal dimensions, by integrating organizational and functional scales as well.

On the second front, and perhaps more urgently, we need to train ourselves in the inter-disciplinary application of knowledge, both across other disciplines and within our own. We must learn to speak in tongues, becoming comfortable in diverse disciplinary cultures. Much of this work has already been done, as a survey of topics covered at almost any planning conference, or the interests of almost any cohort of planning students will demonstrate. We just need to get more systematic about this. And we need to reach across the divides that fragment our own discipline as well. Air quality planners should seek out habitat conservation planners, who should talk on a regular basis with water quality planners, who should be working closely with land use planners, who should be talking with the urban forestry folks, who should be working side-by-side with the community economic development planners, and so on.

Of course, none of this is really new. Calls to multi-disciplinary holism stretch back as far as lived memory can see. What *has* changed is the ecological frame—evolutionary scale hierarchic ecosystem ecology—within which we can now situate planning practice. We have seen complexity in all its richness, and blinking doesn’t make it disappear. We can move away and move back, and still see reasonable approximations of what we were looking at earlier. It is our conceptual imagination that has expanded—not displacing old ways of knowing, but incorporating them into an overarching ecosystem approach. And with the advent of new technologies in computer networking and the internet, we can begin to becomes savvy in decentralized and democratic information management, so as to lower the information costs of taking a truly adaptive, response-sensitive management-based approach to engaging the complex sorts of problems with which we most need to deal.

Living as we do in our four-dimensional world, the craft of planning practice requires us to broaden our scope so as to integrate across sub-disciplines. We need to extend our conception of how the world actually works so that we can give due consideration to processes and functions as the building blocks of nature. We need to extend our descriptions of phenomena inward and outward across levels of organization so as to better take account of context. And we need to reach across event-time horizons so as to better appreciate consequence.

By accepting the premise—that reality is better described as exhibiting nested structures, which are shaped in their actuality by processes and functions, and requiring the use of multiple perspectives, boundaries and scales in their telling—we come to a place where we can begin the business of incorporating the constraints and principles articulated by Rittel and Webber [1973]. The strategic and systematic breaching of the constructed, but now deeply entrenched, boundaries our technologies have allowed us to create between the “human” and the “natural,” by integrating within and across levels of organization, and again by expanding our world-view to incorporate processes and functions as the stuff the world is actually made up of, allows us to both embrace the contextual richness illustrated by Holling and Goldberg [1971] and to realize what some ecologists have already begun to see—that humans, properly, are indeed components of ecosystems [McDonnell & Pickett, 1993]. Then we can get down to the business of getting humans back into nature, and thus of placing our cities back into their ecological context.

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