"LIGHTING (AND SHADING) THE PATH TOWARD CONSERVATION"

GOAL:

TO HIGHLIGHT IN-SITU CONSERVATION EFFORTS, RESEARCH PROJECTS AND PROGRAMS

THAT ENCOURAGE VISITORS TO PROTECT WILDLIFE AND WILD PLACES:

ABSTRACT:

Light and light cycles are a key aspect of virtually every animal's environment. Breeding, foraging, biological growth and species interactions often occur through the nourishment and signals provided by changing patterns of natural light across the days, months and years. This may be very obvious to animal keepers, but often it is very difficult to create a luminous environment on a par with an animals indigenous habitat. Supplementation through UVb emitting lamps represents one familiar strategy as is the restriction of 'blue' light at night for hormone regulation in mammals and the proportioning of near and far infrared lamps to create understory conditions in rainforest species. It is also vital to provide a full range of cyclical lighting conditions within enclosures and exhibits, including darkened periods free from the intrusion of stray light. Animal welfare and enrichment depends on attention to lighting detail.

This paper does not simply summarize contemporary thinking in animal care, but also argues that lighting research in zoos and aquariums offers an invaluable resource to support wildlife conservation through dark-sky initiatives taking hold in communities across the globe. We present and discuss the procedures for certifying zoo and aquarium landscape/exhibit lighting as ecologically-sensitive, and methods for creating community awareness in nocturnal habitat preservation.

Lighting provides a direct link between welfare and conservation, and AAZK keepers can effectively double current efforts in biodiversity maintenance by emphasizing the importance of their work in this regard.

Sincerely yours,

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LIGHT: Resource and Environment

Light and light cycles are a key aspect of virtually every animal's environment. Breeding, foraging, biological growth and species interactions often occur through the nourishment and signals provided by changing patterns of natural light qualities across the days, months and years.

Our mandate in exotic animal husbandry is twofold. First, we need to provide proper lighting conditions for the animals under our care. Secondly, we need to relate these conditions to conditions found within indigenous environments, conditions which are all too rapidly disappearing due to artificial light and other factors. The dual challenge may be very obvious to animal keepers, but it is sometimes difficult to relate these aspects of luminous husbandry care to the financial backers we answer to.

This paper examines the role of light in animal husbandry, first attempting to sketch out a relevant definition of light useful for managed care, and then exploring the relationships within luminous husbandry specific to exhibition and conservation mandates of the institutions we find ourselves within.

Light and the luminous environment are not simple subjects. Light demands that one pay attention to questions of readership, because how light is considered will very much inform what can be done with it. The luminous environment is no less complex when we start to think about photo-biology and photo-ecology. Light can be thought of either as a resource or as a cyclical environment in this context, amongst other things and it is often the case that relationships are inverted from common sense. We will return to this point later, as wildlife depends very clearly in many instances on the *absence* of light rather than its presence.

Although as humans we often consider that light solely as a resource, something available and demanded constantly and at any time, organic life is different. It always entails cyclical fluctuations, in a dance with the nights, months, seasons and years. Organic life always oscillates. As this is not true of human desire, as we are beings of the drive that strive incessantly for objects to satisfy aims, it is important right away to mark the thing we are calling 'light' in exotic animal husbandry as a condition rather than quantifiable object to be supplied. 'Light' is better thought of as an environmental state of being for our purposes.

A natural place to develop these thoughts is in reference to the indigenous luminous environment, in other words how light functions at a macro-ecological substratum for life to evolve within. This will enable us to return to the question of how intervention in the natural luminous environment transforms the ecologies which animals originate from, though it demands attention to properties more familiar to artists than scientists.

Light might be said to have FORM, QUALITIES and PERIODICITY.

FORM refers to the 'shape' of light. QUALITIES refer to the frequencies (wavelengths), polarization and rendition (material interactions) of light. PERIODICITY refers to the cycling of form and qualities; that is to say the repetition and dynamic patterning of light that marks time; the hours, days, seasons and years. Biomes evolve, and have done so according to largely regular patterns from the beginning. The form, qualities and periodicity of an indigenous luminous environment structure the behavior and biology of ecologies and the species within them, and so are very important to explore in turn.

Let's begin with the 'FORM' of light. Within the natural sciences, the wave-particle duality sits within a very definite constant: light has speed and as such it always has direction. Even if we think of light as a particle, it can in no way be thought of as an 'object' but rather always as a 'vector'. Light has, for lack of a better term, a 'shape' with potential. Thinking of light in this way may seem odd, perhaps theatrical, but it demands that one rethink simplified supplementation strategies in managed care. Just as nutrients alone do not satisfy the full range of activities built around eating (i.e. foraging, breeding etc...), nor will the provision of one specific frequency or another serve the well being of an animal in managed care. Form matters.

The FORM of light may be categorized by three separate terms: Line, Plane and Point. Many already know these terms well from the art criticism of Wassily Kandinsky, but they are useful here too. For our purposes we might give an analogy of sun, sky and reflection. Light from the sun comes in virtually parallel rays, and provides direction, timing and shapes perception within a visual (i.e. sensory) ecology. Light from the sky creates an atmosphere for events to occur, a ‘setting’. Finally reflections produce signaling events within atmospheric conditions, prosaic moments in animal life related to everyday functions.

A more complete accounting of these formal properties would consider a broader range of phenomena, such as moon/stars, atmosphere/canopy and bioluminescence/patterning (signaling), and each is very important. Sun, sky and reflection offer an easy mnemonic though. Light FORM is primary to an environment, indigenous or ex situ, and is eminently measurable and translatable to exhibit modification.

To determine relevant lines in an indigenous environment, we might first consider the solar path in a given latitude. Alternately, we might look at the cycling of the moon or the shifting positions of the stars in time. These are to be found in published charts or now, within mobile apps such as TPE.

In looking at the environment in managed care, one could ask several relevant questions. In what direction at a given time of year, in its indigenous environment, does the animal’s native sun or moon rise or set? At what angle does the sun warm the earth at prime basking times? Does Polaris matter to the species, relevant to the magnetic field? Are key directions accessible to the species, so that significant cued events are possible? Lines form a topology, and ought to be thought of as the clockworks of the luminous environment.

Planes are somewhat different. To determine relevant planar components, we might first look to solar radiation data for an indigenous zone. Often, the contribution of the sky to local illumination far outstrips that of the direct sun. For understory environments, the challenge is much more than shading or patterns of shade and shadow that might be relevant. Leaves absorb near and far infrared lightwaves at different rates, and this leads to a significantly different environment. The effect of this environment on plants is well known, and horticulturalists will use this to change growth patterns. Planar form comprises the wash of light in an environment, as something experienced from within.

In actuality, planes consist in points. Points create gradients, and in a practical sense will consist in other animals, nesting materials, prey or food signals, reflections on water, lek objects or other significant features. If planes provide the setting, points provide those aspects of life that an animal is habituated to. In trying to establish relevant points in an exhibit, it is important to remember that sensory ecologies are always relational. Points always have a background that establishes the potential of the gradient they produce. When we think of sensory ecologies, the specifics of visual attraction/repulsion or indeed any locomotion challenges related to vision, we are firmly in the realm of the point insofar as conglomeration of points build the plane.

These environmental formal descriptors will always be very difficult to address in managed care, but are crucial to an understanding of natural light and the effects and affect of artificial modifications to natural light in the environment. Initial considerations such as these in exhibit enrichment would improve the care of many species in the same way that other enrichment schemes do, by enabling a wider expression of the behaviors that make an animal what it is.

The idea of line, plane and point translates well into standard physical measures. They translate easily into the familiar terms of radiance (line), scalar irradiance (plane) and vector irradiance (point). Each of these must be accounted for to give a complete picture of an animal’s environment, and we will return to them later. For now, suffice it to say that radiance gives pure direction and is conserved over distances, scalar irradiance counts the energy or number of photons available at a given point regardless of direction and vector irradiance enables for the judgement of distance through the measurement of gradients.

Now, light is more than just form, and it is more than what it is to human ocular perception. Light has quality in addition to dynamic shape. The FORM of light creates possibilities and the potential for behavioral expression, but would be meaningless without reference to the QUALITIES impregnated within.

QUALITIES of light are relationships struck within light FORM.

Measurement is always crucial. Our eyes are flexible and incredibly subjective in all senses of the term, and as such are not a good measuring stick for photobiology, photo-ecology or sensory ecology. The picture we have of an animals health related to mere observation, will almost always need to be corrected. Relevant optical qualities (useful whether measurements are taken in photons/sec or watts/sec are wavelength, frequency, intensity and polarization.

Light is not an easy subject, and how to measure it is challenging due to the many confusing approaches taken to it over the centuries. It has been identified in terms of salvation and human perception, none of which are relevant to the photobiology of animals (though they might be useful in other types of discussions). If there is an alternative to photo-biology, it might be within so-called 'sensory' ecology although, we must tread carefully in that field and will leave it to one side for now. To conclude the paper, we will comment upon ways to measure and induce changes in the luminous environment of an animal. The following summary is based upon Sönke Johnsen's The Optics of Life, which we highly, highly recommend.

It is important to measure radiance (line), scalar irradiance (plane) and vector irradiance (point) to understand the relevant FORM of light, and the qualities it possesses. Measuring these three properties is best accomplished with a spectro-radiometer, either a scanning or a multi-channel device. These are essentially digital cameras, recording the wavelength/frequencies of light within set intensity ranges. Most research has been recorded in frequencies rather than wavelengths (though converting is not difficult), and ought to record photons/sec rather than wattage/sec, though it depends upon the goal of the study (heat is generally measured in watts, for example).

Spectro-radiometers (or spectrometers, for short) must be connected via fibers to sampling optics suited to the type of measurement sought (think of this as a 'lens'). There are a variety of choices within each of these three elements (spectrometer, fiber, sampling optics) which Johnsen covers exhaustively. For our part, we refer the reader to his excellent summary and highlight the relevant measures for husbandry purposes. Each of these measurements ought to be thought of as a relative measure to parameters found in indigenous environments.

Radiance (which requires a Gershun tube as the sampling optic...as simple as a cardboard tube), is useful for determining actual sun or moon penetration into a particular space or site. Taken in combination with a solar path measurement, this will indicate threshold cues for example, and the actual contribution of timing cues at the times when these bodies are visible. It is also useful in determining the glare of added light sources, by contrasting readings of say an exposed filament to a darkened ceiling that surrounds it. In humans, permissible ratios end at about 10 to 1.

Scalar irradiance is useful to provide a picture of the directionless amount of light, and the quantitative distribution of frequencies/wavelength in an exhibit. This allows one to determine the general atmosphere of an exhibit, and of how variations in this atmosphere change from morning to afternoon, twilight to dawn. Specialized sampling optics, in the form of a sphere are available here, with the caveat that aligning the connecting wire with the darkest direction will produce the smallest error in the reading.

Vector irradiance is the more common measure in photo-biology research, and it allows one to determine gradients of light and accordingly, the directional profile of a space. This is important for a number of reasons, including knowing how unplanned lighting elements affect the luminous environment, such as lit graphics or signage, and how added light sources are functioning to provide light 'nutrition' and at what range. Taking readings to the four cardinal, four ordinal, eight supplemental and central (i.e. horizontal...looking 'up') directions may seem extreme, but it will produce a complete profile or light picture, of the space at a given moment. A cosine corrector or integrating sphere serves as the sampling optic here.

Taking measurements in these three areas at key moments is important to an overall assessment, at several key moments. Over the course of a year, a complete picture can be built by reading four key moments. Solstices and Equinoxes provide the extremes but, the completeness of such a picture depends on solar penetration indicated by a solar path analysis and sky access profile. Concern with lunar lighting would lead one to measure at new, half and full events. Daily measurements ought to occur at the key times of dawn, noon, twilight and midnight. These can be automated by putting the spectrometer on a timer.

Such measurements provide a complex picture of what is going on in a space, and the environment a managed animal exists within. Such a profile allows one to determine adjustments to photo-enrichment strategies, and is a necessary component of animal welfare strategies. When deciding what is 'as close as possible' to a natural lighting environment (ie. an indigenous one free of the impact of artificial lighting), such a profile is indispensable.

It is important to emphasize that within these measurements, it may very well be that the relative combinations of QUALITIES, and not the 'amount' of light, that is critical to understand. In horticulture, growers long ago

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recognized that near to far infrared ratios mattered a great deal to plant growth; with a direct relationship to indigenous environmental conditions beneath a forested canopy.

Another quality to attend to is the polarization of light due to materials within an enclosure. Many species are able to modulate their reception of light according to the degree of polarization (or angular consistency) made available in material reflections. Many insects for example, are attracted to light polarized by tarps. The natural sky is not smoothly polarized either, and several bird species use this patterning for navigation. These patterns likewise reflect off of 'shiny' and 'matte' surfaces differently (such as still water).

Polarized light is relevant to managed animals in terms of sky access, but also in looking at the materials of an enclosure and how this might relate to an indigenous habitat. The point here is not to demand fidelity to nature, but to increase understanding and relationships in controlled experimental situations rather than simply leaving the effects of our interventions to blind chance and obscurity.

PERIODICITY of light concerns patterns of variation in FORM and QUALITY, and it is clear that this periodicity is not simply the alternation of 'light' and 'dark', but rather an intricate yet repetitive movement combining all aspects of LINE, PLANE and POINT along the complex range of qualities inherent to the luminous environment.

PERIODICITY affects FORM and QUALITY. Any introductory book on photography will mention the golden and blue hours, when light fades into color, lengthening the shadows in a slower or faster transition to night or day. This last point is important within PERIODICITY, as one of my students pointed out to me last year. If you are managing equatorial animals, it would be very appropriate to switch lights on or off relatively quickly. For circumpolar animals, the reverse is true. Twilights and dawns vary considerably in length from equator to pole, as does the brightness of vertical surfaces, such as tree bark or cliffs.

One difficult challenge to tackle, is to gain and apply a subtle understanding of the nocturnal environment to health and activity. Although it might seem strange to think in these terms, the night is not dark as such but only appears this way to modern humans used to seeing the world artificially lit all of the time. The range of light levels in the night is outstanding, varying in fact more orders of magnitude than occurs in the daytime. Humans simply cannot perceive this without measuring instruments, and research has not developed to account for the nocturnal luminous environment. No more than the bogie man, light does not simply go away at night because we shut our eyes.

Strategies to enrich a managed animal's environment can take many forms, all based on the realization that something is missing. Two relevant examples are worthwhile to summarize, one of basking reptiles and the other of mammalian hormone cycling. The first is key because it relates a light cycle to welfare in a way that is now standard practice, and the second because it represents the next step in care with direct environmental consequences.

The UVGuide out of the UK summarizes the importance of light quality to basking reptile life most succinctly. For basking reptiles, best practice suggests that it is necessary to provide both UVb and red/infrared energies for hormone regulation. Skin cells manufacture protovitamin D, a cholesterol (7-dehydrocholesterol, 7DHC). UVb frequency light (described as 297nm) quickly transforms this protovitamin D into previtamin D3. Over a long period of time, warmth provided by basking under red/infrared light transforms this previtamin D3 within the skin to vitamin D3. Though studies are lacking as to the optimal balance of near and far red here, which has a parallel in horticulture and is a key aspect of microclimate variation in the luminous environment, the absorption of low frequency/long wavelength light in basking is the culminating point in the process.

Vitamin D3 is taken up into the plasma, and carries into the bloodstream to the liver. The liver then hydroxylates vitamin D3 into calcediol, 25-hydroxy-vitamin D3. Calecdiol then circulates through the bloodstream, converted to the hormone calcetriol in the kidneys. Calcetriol is important as it regulates the absorption of calcium, necessary for bone growth, cardiovascular health, cancer mitigation and the immune system in general.

For our purposes, it is crucial that basking marks a complex interaction that regulates the organism as a whole, and this includes behavioral responses. For example, it is possible and even quite likely, to see overdose concentrations of synthetic Vitamin D3. Such an overdose is not possible via the light induced process. Interestingly, the biological mechanisms for 'shutting down' are also light dependent.

Just as protoD3(7DHC) is sensitive to UV, preD3 is also sensitive to it, though up to 325nm (which touches into the UVa range). As red/infrared converts preD3 slowly to D3, incident UV also converts a portion of preD3 into lumisterol3 and tachysterol3. These also accumulate in the skin, in effect diverting some of the energy from preD3 production whist also becoming a resource for protoD3 and preD3 production (the conversion is reversible, effectively producing an inert store for times when there is not enough UVb to convert protoD3 into PreD3. It is important to suggest that darkened periods, devoid of UV altogether, are also important, to prevent build up of lumeristerol and tachysterol. The second regulatory biological mechanism removes any excess vitamin D3 present in the skin. UVb not only converts protoD3 to PreD3, it also break down excess D3 in the skin. Whatever the plasma does not absorb, is effectively broken down into other substances.

Basking reptiles also have behavioral responses tied to hormone regulation. With adequate D3 in their bloodstream, they stop basking (if an environment permits it of course...). Being able to move in and out of a complex lighting environment is absolutely crucial. Reptiles, as well as any other organism, will suffer burns if exposed to too much UVa or UVb. Biological organisms require rest. Some do this in the daytime, under the blinding light of the sun, and others sleep at night. While it is true that light energies stimulate organisms, without rest from these energies all organic systems will burn out and die. This is as true at the cellular level as it is at those of the organism, ecosystem or planet.

Indeed, the contribution of UVb to D3 synthesis occurs relatively rapidly. This is not surprising, as the energy of high frequency Uvb is rather intense. In most cases, the biological relationship to the luminous environment is the obverse. In terms of behavior, for many animals the subtle variations in form and quality of the night are more crucial than those of the day. A majority of animals are nocturnal of course, but all animals evolved and spend half their time in nocturnal habitat whether they are active at night or no. This is important, as it means that all animals in our care would benefit from actively managed light cycles acknowledging this other half of all habitat.

For brevity, an example with reference to human and mammalian ‘circadian’ rhythms is appropriate.

A living mammal derives energy from the environment by eating food. All human food is ultimately derived from compounds created by plant from the soil through photosynthesis. Ultimately, wildlife is dependent upon the soil and plants and of course, the ability of the soil and plants to manipulate the sun’s energy. Just as we saw with basking reptiles, the mechanisms in place are cyclical and regulatory. Of key importance are the hormones serotonin, and melatonin.

A key food substance is tryptophan, an amino acid essential for the production of serotonin within animal bodies. In the human body, serotonin is produced mainly (90%) in the alimentary canal but a fraction is also produced in the brain stem, by neurons of the raphe nuclei. “Axons of neurons in the higher raphe nuclei terminate in 1) subcortical nuclei including the centrally located thalami; the surrounding corpus striata including the nucleus accumbens; the hypothalamus, hippocampus, and amygdala, 2) the cingulate cortex, including the cingulum, a tract of association fibers connecting the corpus callosum with the hippocampus, and 3) the neocortex.” Serotonin plays a role in the regulation of intestinal movements, but also in a great many other functions as it relays impulses between nerve synapses. It is a growth hormone, also known alternately as the happiness or pain hormone as it elevates the senses and functioning. Serotonin is a key vehicle for the sensory system, and in addition to its digestive function it affects sleep, mood, memory, wound-healing and cognition. Too much serotonin in the system leads to depression, cancerous growth and impotence. For our purposes, serotonin is interesting not simply in itself, but because it is converted under darkened conditions by the pineal gland to melatonin.

Though the majority of melatonin is also produced in the alimentary canal, it is the small amount produced by the pineal gland that is vital. A brief summary of melatonin production is warranted, though we refer readers to the existing (and quite substantial) literature on the subject. In mammals, neural signaling and hormone production are intertwined. We might describe the process this way. Light of 450nm-480nm impacts photosensitive ganglion cells in the retina and signals the hypothalamus. The hypothalamus in turn connects through the spinal cord to the superior cervical ganglia, and from there to post-ganglionic neurons to the pineal gland. Under this stimulation, the pineal gland is restricted from deriving melatonin from serotonin. Under natural conditions, melatonin is secreted at night, and the duration of secretion varies occurs in inverse relation to day length.

Indeed, it is not ‘day-length’ that is important, but ‘night-length’. In a manner of speaking, photoperiod information is “encoded” in the melatonin signal sent from the pineal gland to various targets in the organism. The melatonin ‘signal’ regulates a variety of seasonal responses, mainly surrounding reproduction behaviors but also those attendant to it, such as hibernation and foraging. Night length, and the qualitative variations within it nocturnal luminous environments, serve as the key factor in melatonin informed behaviors. This is also why, even brief periods of disruptions to a darkened period are problematic. A light that goes on in holding, or in any nocturnal habitat, will effectively sever the necessary darkened period.

Another way that melatonin has been described has been to characterize it as an anti-gonadotropin. This means essentially that it functions as a damper the effects of serotonin. Melatonin is produced ONLY when signaling from the hypothalamus stops. The ‘darkness’ hormone, as it is often called, chiefly functions as an inhibitor. It is necessary, for without it an organism would ‘burn out’, so to speak. It functions chiefly in ecological systems as a regulator and preparatory substance for breeding seasons, and as a counter-effect to the stimulation of serotonin which is, for the most part, light independent. This means that although we must provide enrichment for lacking elements of natural daylight conditions, more attention needs to be paid to the nocturnal environment than typically is done for both nocturnal and diurnal species alike.

Small changes in the quality and timing of luminous stimulation make a great deal of difference. For practical purposes, this means that though we might ‘darken’ a space for animal care, it is important to provide appropriate variation within this darkness. There are several ways to do this, the easiest to provide dimming switches and lighting elements capable of minute variation. The most important factor is strict measurement of the space in question, as previously alluded to.

ANIMAL WELFARE, ENRICHMENT AND LUMINOUS CONSERVATION

In thinking about how to light a managed collection, the very first criteria that has to come to mind is the purpose of the collection itself. Different purposes will entail different challenges in lighting, if we are to think of light in its environmental aspects beyond the notion of simple supplementation. A diet of vitamins is not nutrition, so to speak, and light is more than a simple vitamin added to an otherwise independent environment. This section relates photobiology to nocturnal habitat conservation, and the importance of relating the two in managed care.

When a facility puts an animal on display, there is a need to light the entire exhibit scene so that it has greatest impact. Despite this, there is also an ethical dimension to providing enrichment and striving for the highest animal welfare possible. This should relate to animals immediately present in managed care, but also animals in the wild that are represented thereby. It is no secret that artificial night lighting is degrading nocturnal habitat significantly across the globe and, as we try to replicate indigenous luminous conditions in managed care we must in fact, address and understand this ever increasing challenge. Artificial night lighting degrades habitat drastically, and in order to understand welfare challenges within a facility it is important to recognize them beyond the gates.

Artificial night lighting affects wildlife, and the ecosystems dependent upon it, in several distinct ways.

Longcore and Rich’s ‘Ecological Consequences of Artificial Night Lighting’ provides a valuable overview on the subject, and we reference observations in the work in order to stress the impact that artificial light has upon wildlife when it is not well considered, and the ecological challenges it causes.

Following ECANL’s summation of existing research and literature, artificial night lighting may disrupt the physiology, behavior and ecological interactions and functions across taxonomic groups. Mammals, birds, reptiles, amphibians, fish and invertebrates all exhibit significant changes in their well being when natural lighting cycles are halted by man-made light.

We have already seen that for mammals, nocturnally produced melatonin is critical as a regulator for most activities including reproduction and the suppression of growth based tumors. Hormone cycling directly affects the physiological well-being of mammals in many ways, and it is light-level dependent.

However, there are other photo-ecology concerns as well. All mammals have a dual visual system, and in effect two separate sensory ecologies that they live within; one of the night and the other for the day. Night vision tends to be better at discriminating motion, whilst day adapted vision excels at color discrimination and clarity. Although primates tend to be diurnal, most mammals are adapted primarily to nocturnal activity through increased fitness within specific and highly timed nocturnal conditions. Changing the night into a static secondary day changes the sensory ecology considerably, essentially making evolved perceptual mechanisms, and perhaps entire organisms, vestigial.

Some mammals are positively phototactic, attracted to light, and others are negatively phototactic, repulsed by it. Artificial light effectively redistributes mammals, grouping those with similar tolerances from the former and more diverse luminous ecology. An example can be found within lunar patterns of behavior. In the absence of artificial light a bright and full moonlight can drive many species into forested canopies or similar shelter, changing available resources in a naturally food depleted environment and leading to complex behavioral responses, such as the territorial (or sympathetic) howling of coyotes under the full moon when prey rodents become scarce. Artificial lighting changes these relationships, in essence redistributing resources leading to other relationships learned in new environments (scavenging from human settlement, in the case of coyotes, is the first thing that comes to mind).

Changes in mammalian sensory ecologies also leads to other types of risks as well. Mammals disorientation under streetlights, as well as the bright glow of headlights, are at greater risk of becoming roadkill. Dark adaptation typically takes much longer than light adaptation, and so even motion sensitive security lighting poses a problem.

For birds, artificial night lighting also affects physiology directly through dark dependent hormone cycling. Night length is crucial for birds, informing growth, metabolism, skeletal development, sexual development, courtship and mating rituals, reproductive cycles, migration and molting. The effects of artificial night lighting on bird physiology are significant, highlighted in husbandry practices, the poultry industry and in field studies.

Disruption of sensory ecology is a challenging problem for birds. Differences imperceptible to unaided human observation cue significant events such as migration and breeding and impact navigation. Orientation depends upon the FORM and QUALITY of light in its various cycles, in certain cases with sensitivity to stellar rotation, solar positioning and the geo-magnetic field. Light induces phototactic behavior in many birds, drawing some species to urban areas and creating inescapable light 'traps'. Glass near such areas adds a survival challenge. Glass strikes kill nearly a quarter of US populations bird yearly, contributing to an ecological disaster of incredible proportions for endangered and common species alike. Light and glass are a fatal combination, and not just for birds but for all ecologies that depend upon them.

Threats of nocturnal habitat degradation go beyond these most important ones as well. Avian eyes are also sensitive to UV light. This means that any added but unintentional UV light in nocturnal habitat (say from fluorescent tubes, metal halide or plasma sources) will shift the perceptual potential of nocturnal habitat. UV is emitted in small amounts by many artificial light sources, and never present at night naturally. It represents an 'unseen' modification to the luminous environment that requires measurement for its effects to be understood. Subtle changes in the luminous environment are important to birds. Many birds will change singing patterns and timing in the presence of artificial light. This is significant, as singing is related to a host of ecologically necessary functions and what impacts one taxonomic group will impact others. It is important to place birds within context, as they are so critical to humanity for seed dispersal, pollination, pest control and soil fertilization.

Reptiles too are not immune to disruptions of nocturnal lighting regimes. Though D3 synthesis dominates luminous husbandry concerns for the group, the disruption of nesting choice by female sea turtles and hatchling orientation is just as well known. Sky glow degrades habitat, and points to the necessity of tackling nocturnal habitat conservation as an urban problem. Reptiles are disappearing at an incredible rate, and any degradation of reptile habitat needs to be taken quite seriously, more so than it has been.

Reptiles, as a class, are incredibly diverse in their exploitation of the luminous environment. They can be nocturnally or diurnally active, and either positively phototactic or negatively so. Many reptiles will also exploit artificial night lighting 'niches', following insects to artificial lights. This reaps short-term benefits for individuals, but changes overall ecological relationships in favor of biodiversity reduction.

Amphibians face similar challenges, but suffer additionally due to their relative lack of mobility, complex life cycles and overall sensitivity to light.

As in mammalian systems, the primary physiological challenges for amphibians. In some species, extended photoperiod significantly retards the development of larvae. Longer, undisturbed nights leads to larger and more developed physiques more rapidly than occurs under artificial lighting. While research is lacking as to the effect of variations within nocturnal habitat limitations, it is clear that extended periods in nocturnal states play a direct role on growth. Changes to photo-phase also affects foraging, growth and fat accrual. It is important to note that hormone cycling upon tadpoles of many species are entirely light dependent. Normal rhythms of color change are destroyed by alterations to daily light cycles.

The sensory ecology of amphibians is also remarkable, with many nocturnal species functioning quite well even in dim starlight. This makes them especially sensitive to artificial night lighting, even for brief periods. A brief flash of light can blind an animal for hours, effectively destroying a night's work. Losing such the starlight environment completely due to artificial night lighting effectively destroys the niche for nocturnal frogs, attendantly effecting prey populations adversely by reducing the fitness of predators to hunt.

On the other hand, a wide variety of species of frogs and toads are positively and extremely phototactic. They will forage under streetlights, placing them at greater risk from automobiles. Also, within the constant illumination of streetlights dark adaptation never occurs, affecting mate choice, territorial interactions and predator avoidance. Responses to various wavelengths/frequencies change depending on whether or not animals are day or night adapted, though most frogs will exhibit a preference for 'blue' light when dark adapted. Street lights but the problem for many species is not simply their own phototactic responses, but those of their prey. Insects attracted to street lighting are no longer in forested environments, and thus cannot serve as food for amphibians.

When we think of the familiar attraction of insects to light, it is often in the context of food chain effects and this is a significant aspect of the phenomena. Insect biodiversity is vital, but it is reduced through the effects associated with artificial night lighting. These effects impact rare species as well as common ones. In addition to local mortality challenges, artificial lighting affects the migration and emergence patterns of insects such as many species of moths and butterflies.

Artificial night lighting affects insect physiology at all stages of growth, from egg to adult. Melatonin, dependent on nocturnal photo-periods, also plays key roles in insect physiology, behavior and reproduction. This has recently been related to pheromone sensory ecologies and signaling, affecting both inter and intra species interaction. Insect sensory ecologies also accommodate day and night patterns. As with other classes, insects transition far more quickly to a day adapted state than nocturnal state, on the order of seconds to a half hour. So too, the challenge of UV lighting is present for insects in artificial light, from for example a mercury vapor source. This has the affect of extending daytime opportunity into the night, and changing the functional ecology of an environment.

Perhaps the most significant arena affected by artificial lighting are aquatic systems, particularly coastal regions. Fish display phototactic behaviors, and here the affects of artificial lighting are particularly important as light, along with temperature, essentially structures the aquatic habitat. Stasis in the variability of light alters fish communities, through variability in physiology, sensory ecologies and population distribution, as it does for other groups mentioned. Aquatic systems though are more susceptible to artificial light, whether this comes from ships, shore or platform lighting. As the role of light in structuring aquatic communities is well studies, further research into the effects of altering these environments is crucial in order to address the ecological challenges faced in general.

Research in luminous husbandry is necessary to inform design practices. A homogenized luminous environment reduces biodiversity, through the sole provision of one, universally unsuitable, condition. Surviving animals become little more than 'weeds', dependent upon very artificial and contingent conditions created within human development. 'Weeds', though we often seek to destroy them, are more subject to disease and less beneficial overall than the same animal or plant set in a complex system where it benefits from many interactions.

There is thus a direct connection between knowledge and practices developed in luminous husbandry to conservation initiatives. Knowing how and why animals respond to various lighting conditions in managed care allows us to also understand how they are impacted ex situ. Photo-biology research is in fact, a wildlife conservation requirement.

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ADDENDA: MEASURING AND MODIFYING LIGHT IN HUSBANDRY CARE

Lighting technology is a hot button topic in animal husbandry care, and probably the driving factor for interest in the subject. The question is usually posed as ‘What ‘kind’ of light is best for ‘my’ animals?’. It is a good question, but not an easy one particularly given the dynamism of the luminous environment and complex ways in which animals manipulate light in their existence.
As a general strategy, ethical welfare sensitive lighting design in managed care has a simple pattern. Consider potential sun- and moon-light penetration first, then sky access (comparing the in situ environment to ex situ conditions), then the optical qualities of materials and surfaces within the holding and exhibit areas, then light sheltering or shading devices and finally, artificial light supplementation. Supplementation will almost always be necessary when moving animals from one location to another, and so it is important to end on a few general comments.

Again, as it is best practice to address any lack in form, quality and periodicity as far as possible. This means that there will be the need to supplement during the day and shelter during the night. One word of caution though, is that artificial light sources cannot behave as the sun does (they are point sources with a gradient, located at best only a few meters away from the animals. This creates the risk of burns, and of the inclusion of inappropriate frequencies which need to be filtered out. Before determining what light to use, ask what it is at a certain moment of the day, month or year that is different in the managed lighting environment (either lacking, too abundant or simply misplaced), rather than what is missing in general. This will allow for more exacting and environmental husbandry.

The most important thing to remember is that light is always well, light. There is no ‘different’ light that comes from one source or another, although not all sources will give the same distribution. The benefits and drawbacks of sources are significant though, and the challenge is in using the appropriate technology to establish necessary relationships and proportions.

Different lighting technologies have qualities that differ significantly from the others. We can take these somewhat chronologically, but remember that simply because a technology is newer doesn’t mean it is inherently ‘better’. The way in which lighting produces light is important, because it has implications for what an animal keeper can do with that light. Briefly, three types of lighting technologies are relevant for husbandry; incandescent, discharge and LEDs.

Incandescent bulbs pass an electric current through a tungsten filament, heating it to incandescence, meaning it will glow. These lamps provide light energy over the entire visible spectrum, but generally weighted to the lower frequency wavelengths (the reds and infrareds). Much of the electrical energy is converted to light that is invisible to us, i.e. infrared, and perceived as heat rather than light for humans. Because ‘lumens’ are a measure that is weighted to the human eye, and because efficiency is rated as lumens per input watt, incandescent lights are generally felt to be inefficient for visible tasks (about 8-24 lumens per watt). Generally, an incandescent lamp will last from 750-2000 hours, slightly linger if they are put on a dimmer switch. Tungsten-halogen lamps last slightly longer, by redepositing tungsten back onto the internal filament (thus giving it a second life), but dimming these actually decreases brightness significantly and won’t gain anything. Incandescents are very useful for night lighting in animal areas, especially if fitted with filters restricting the flow of light with wavelength shorter than 555nm.

Fluorescent, metal halide and sodium lamps produce light differently. These use a cathode to create an electrical current through one type of gas or another. The current excites an enclosed gas, giving off photons of discrete wavelengths depending on the materials used.

In a fluorescent tube (whether compact or no), the photons emitted by mercury-vapor gas have a frequency in the UV range. These ‘invisible’ waves interact with phosphors of various types coated on the inside of the glass enclosure, which then produce visible light. It is this light that we see, though phosphors are available that emit light in the UVa and UVb range as well. Induction lighting is a special, and more durable, form of fluorescent that places the cathode on the outside of the tube. This extends lamp life significantly.

Notice that there is ‘mercury-vapor’ in fluorescent tubes. Without being alarmist, it would be negligent to say that this wasn’t a problem. There is mercury used in the production of incandescent lights too...much more actually. The only solution I can see to reduce mercury is to maximize daylight delivery. Even LEDs, which are best in this regard, are actually rife with heavy metals which will take their own environmental toll. Reduce, even in exotic

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animal husbandry, has to be the first environmental watchword long before we talk about the energy 'efficiency' of the technology itself.

The frequencies/wavelengths emitted by a fluorescent tube depend upon the phosphors used. The resulting light pattern emitted will always be in discrete wavelengths. Because these phosphors have been well selected over the years, they are again tailored to the human visual system and so have efficiencies of 50 to 69 lumens per watt. Rated lifetimes are also very good, lasting for the most part for more than than 10,000 and up to 20,000 hours. However, fluorescent lamps will decrease output by about 20 - 30% over their lifetime, and so often the strategy is to over-specify in the beginning and allow for the 'half-life' to bear the weight of the minimum required for a certain task. This isn't a problem in general, but it is for sensitive animals that don't take to increasing light the way that humans do. What we would suggest is to provide a filter for the early stages of a fluorescent light, and measure at regular intervals. Fluorescent lights require a ballast to regulate current. Special ballasts are necessary for dimming. This is something to consider in using these for animal husbandry operations, as it will affect the timing of transitions.

For very large spaces, low and high pressure sodium (HPS) lamps are useful. These discharge an electric arc through a concentrated sodium vapor. This vapor itself glows, producing light spikes across the entire visible spectrum (low pressure sodium produces a very narrow spike which looks quite yellow to the human eye). These tend to be very yellow/orange, and they do not render colors for the human eye quite as well as fluorescents or incandescent/halogen. They have the longest rated life of all the lamps discussed at about 24,000 hours but do require a ballast and cannot be dimmed. The key issue with HPS lamps is that they require a warm up time of between 5 and 15 minutes, which means that after a power outage, backup lighting may be necessary until full illumination has been achieved again. These lamps have been used successfully in poultry facilities, mostly in breeder houses and turkey facilities, with peaked roofs so that light distribution is more easily controlled (Andrews and Zimmerman, 1990).

Metal Halide lamps can be very useful in daytime supplementation or aquarium lighting, as the light emitted tends to emphasize the short end of the spectrum. They have efficiencies of about 80 to 100 lumens per watt and are rated at about 10,000 to 20,000 hours of life. MH lamps require a ballast, and cannot be dimmed. Because the very small amount of metal halide used to produce these lamps, it is very necessary to measure output carefully. Individual lamps tend to vary from each other, and even in response to temperature differences (say due to airflow). Metal halide lamps can have very high wattages, and so will provide a great amount of light with the associated risk of glare and burns.

Plasma lights have been marketed recently, as matching daylight quality and intensity. Whilst these are very useful products for certain applications, such as casting light deep into a feature aquarium tank, they should never be used in an exterior application sensitive to wildlife and with caution at night in general. Though it is fashionable to suggest that 'daylight' quality lamps are both possible and healthy, research suggests that the nocturnal condition is far more important as we have discussed. An added risk in plasma lighting is actually the small size of the capsule used in producing light, as it increases the potential for glare when placed in comparison to any unlit surface surrounding it (such as a ceiling or open sky).

LEDs represent the easiest technology available now to adapt to wildlife sensitive technologies, at least in the sense of a complete package. There are two types of LED lamps that we ought to be concerned with, but each begins in the same way. LED lamps produce light by passing current through a semi-conductor made of one material or another. Emitted light is generally restricted to a very narrow range of wavelengths, appearing very saturated to the human eye. For general applications, manufacturers have gotten around this by either combining primaries, or by using UV emitting diodes to ignite phosphors. These in turn produce visible light, in a range comparable to fluorescent tubes. Such light can be very bright, and is typically weighted to the blue end of the spectrum.

Individual LED components use less energy than comparable alternatives, and it is possible to compose highly controllable combinations of diodes to deliver precise supplementation. These can be easily controlled via computer, and so integrated into proper timing patterns at the lower light levels necessary for nocturnal variation. Several companies now manufacture grow-lights for agriculture which enable switching from vegetative to blooming phases of growth, and it is possible to adapt these for animal husbandry uses.

Regardless of the technology used to enrich an enclosure, the crucial requirement for exemplary care is measurement and control, actively maintained through a dedicated luminous enrichment program.

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